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Wideband Radiation Inverted U-Slot Microstrip Patch Antenna Design for Multiband Applications

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ABSTRACT

This research presents the design, modeling, and characterization of an Inverted U-slot microstrip Patch Antenna (IUSMPA) that has been specifically designed for broadband communication applications operating within the frequency range of 4 GHz to 14 GHz. The development of contemporary communication systems, such as wireless communication, radar, and satellite communication, has led to an increase in the need for antennas that are capable of supporting a broad frequency range and have high levels of performance. To meet this requirement, the proposed IUSMPA has features that are favorable to meeting it. These qualities include attaining a small footprint while simultaneously assuring outstanding bandwidth and radiation performance. To improve bandwidth, the antenna design makes use of a slot in the form of an inverted U that has been carefully carved onto a microstrip patch. Simulation is performed using the CST software. Simulation results show improvement in bandwidth and gain.

Keywords

Antenna, Microstrip, Inverted, U-slot, CST, Bandwidth, Gain.

1. INTRODUCTION

In the realm of antennas that have improved performance characteristics, such as a wider bandwidth and smaller form factors, continues to be an important area of research attention in the field of wireless communication systems. A novel approach that addresses these issues is the Inverted U-Slot Microstrip Patch Antenna (IUSMPA). This antenna takes use of the beneficial characteristics of microstrip patch antennas by including an inverted U-shaped slot into its design.

Because of its low profile, lightweight, and easy integration with current communication systems, microstrip patch antennas have acquired an enormous amount of appeal in recent years. However, their intrinsic weakness resides in their inability to provide broad bandwidth, which is a necessity for modern communication applications such as high-speed data transmission, satellite communication, and radar systems. To improve the bandwidth of microstrip patch antennas, one method that has shown to be useful is the incorporation of slots or disturbances into the structure of the radiating patch. The Inverted U-slot microstrip Patch Antenna is a unique version that makes use of the capacitive coupling effect that is created by an inverted U-shaped slot that is etched into the radiating patch. Consequently, the antenna's operating bandwidth is greatly increased as a result of this particular design innovation, which offers an extra degree of freedom in adjusting the antenna's resonant frequency and impedance-matching properties.

The ability of the inverted U-slot design to overcome the inherent restrictions of typical microstrip patch antennas is one of the most significant benefits of this configuration. It provides a flexible platform that strikes a compromise between the size constraints that are common in communication systems and the desire for high-performance communication systems. This antenna design becomes especially essential in circumstances where a large frequency range is needed, such as in the development of broadband communication devices and systems that need to work across varied frequency bands.

The relevance of this antenna is highlighted by the issues that are now being faced in the field of communication as well as the changing landscape of wireless technology. In the following sections, it will go into the design concepts, simulation approaches, and performance assessment criteria that were used to evaluate the potential of this antenna in terms of obtaining increased bandwidth and resilient communication capabilities.

Creating a modified structure that deviates from normal microstrip topologies is the goal of the Inverted U-Slot Microstrip Patch Antenna's one-of-a-kind design, which entails carefully placing an inverted U-shaped slot on the radiating patch. In addition to improving the coupling effect between the patch and the ground plane, this slot has a second function. It disturbs the current distribution on the patch, which results in the introduction of extra capacitance and a modification of the antenna's resonant behavior. By taking advantage of this synergistic approach, it is possible to make a controlled modification to the electrical characteristics of the antenna, which paves the way for an increase in bandwidth.

2. LITERATURE REVIEW

R. Gupta et al.,[1] An integrated rectangular patch antenna array with two inverted U-slots has been presented. This antenna array has the potential to be used for S-band applications, such as radar applications, communication networks, and wireless networks. To enhance the bandwidth of the proposed antenna design, two inverted U slots have been included in the patch. This results in a bandwidth of 150 MHz and a gain of 4.08 dBi, with the antenna resonating at 3.3 GHz. In addition, a gain of 14.2 dBi is achieved by fabricating a 4 x 4 antenna array on a substrate manufactured from FR4 with a thickness of 1.6 millimeters and a dielectric constant of 4.4. For antenna modeling, Ansys HFSS is used, and a prototype is first manufactured and then tested.

Instead of functioning as a radiating element, the design that was proposed by S. A. Malakooti et al., [2] functions as a wideband bandpass filter. The fact that the active scattering parameters are of critical relevance for dual-port antennas that are supplied by in-phase and out-of-phase inputs is the root cause of the evident confusion that exists about the scattering performance.

The H-shaped stub that was reported by S. Radavaram et al., [3] was able to help the improvement of impedance matching thanks to the shorting vias that were placed on it. To improve the overall active reflection coefficients of both modes of operation, namely sum and difference modes, L-shaped probes are used to excite the antenna structure rather than SMA probes. This is done to maximize the overall active reflection coefficients. As part of the process of integrating the L-probes, the profile of the antenna has been enhanced from about 0.02λd to approximately 0.08λd. The dielectric wavelength at the center frequency of operation is denoted by λd.

It was shown by S. Radavaram et al., [4] that the slot and patch parameters are subjected to numerical analysis to obtain symmetric radiation patterns and a large bandwidth simultaneously. Because the null depth that is obtained in the Difference mode is much lower than -30 dB, the suggested antenna is an excellent choice for applications involving monopulse radar. The antenna has a frequency range that extends from 1.98 to 4 gigahertz. Fabrication and testing are performed on a prototype. It has been noted that the findings of the simulation and the measurements are in good agreement.

It was shown by A. K. Esnagari et al. [5] that a small meandering inverted-F multiple-input-multiple-output (MIMO) antenna that operates at two wireless local area network (WLAN) bands 2.4/5GHz has been designed, simulated, and built. It is made up of two symmetrical inverted-F antennas that are separated by a short distance from one another. On the top layer of a low-cost FR4 epoxy substrate with a thickness of 1.6mm, it is printed with an ε r value of 4.4 and a tanδ value of 0.02. By adding decoupling structures on the ground plane, such as T-slot and meander-line resonators, it is possible to achieve the requisite level of isolation at two different WLAN bands. To achieve a high impedance bandwidth, the individual antennas are supplied with a U-slot loaded 50-Ω microstrip line.

S. Tejeswee et al., [6] A broadband circularly polarized U slot antenna is the kind of antenna that is given in this study. For this work, the circularly polarized radiation is accomplished by dangling two separated rectangular strips from the inner edge of the ground and making use of an inverted L-shaped center feeding stub. An extensive notch is carved from the ground, which results in an increase of 51.35 percent in the ARBW as compared to a square-shaped ground that is simple. Every one of the outcomes has been correctly simulated.

An innovative design for a tiny UHF-RFID tag antenna that can be mounted on metallic objects was presented by W. Lan et al., [7]. This antenna was designed for the Chinese frequency band, which ranges from 920 to 925 MHz. A U-slot radiating patch, multiple shorting via holes, a coplanar waveguide feeding structure, and a metal ground plane are the components that make up the proposed tag antenna. This antenna is based on a construction known as a planar inverted-F antenna (PIFA). The antenna that is being suggested has a small construction, with the total dimensions being 48 mm by 46 mm by 2 mm. In the frequency range of 922.5MHz, the antenna has a maximum gain of 4.39 dBi.

S. B. Behera et al., [8] It has been suggested that an LTE/WiMAX application might benefit from a multi-dielectric microstrip slotted antenna that has a coaxial probe feed setup. The construction of the antenna is a conventional rectangular patch with an inverted U-slot positioned in the middle of the patch. Significantly, an SSR slot is inserted into the inverted U-slot, which is located on the inner edge of the socket. It is possible to operate at many frequencies, namely at 3.6 GHz and 5.4 GHz, thanks to its slotted design. Excitation of the suggested antenna patch is accomplished by the use of the probe feeding method. This approach results in enhanced impedance characteristics due to the optimized feed point.

According to the research conducted by I. K. Sokhi et al., [9], a tiny multiple-input-multiple-output (MIMO) antenna with dimensions of 36 × 40 mm 2 has been suggested. Each of the two planar-monopole (PM) antenna components is positioned perpendicular to the other to obtain a high level of isolation. The microstrip-fed antenna components are printed on one side of the substrate during the manufacturing process. The opposite side of the substrate is where two ground planes are joined to one another using a short ground strip. Additionally, two stubs in the form of an inverted U are added to the ground. An increase in impedance bandwidth is achieved by this configuration, which also offers superior isolation. Simulated findings are obtained by the use of High-Frequency Structure Simulator Software.

An innovative arrangement of a dual-band microstrip patch antenna was described by P. S. Kumar et al., [10] for use in applications requiring S-band (2GHz-4GHz) and C-band (4GHz-8GHz) frequencies. Due to its fast transmission rate and big data capacity, the dual-band antenna has emerged as an intriguing technology in recent years. With the help of this study, a rectangular microstrip antenna that has inverted E-slots and U-slots is presented. This antenna provides an enhanced gain while simultaneously operating on two different bands. The performance of the developed antenna is evaluated in comparison to the dual-band designs that are already in existence and documented in the literature. It has been proved that there is an improvement in gain in both operating frequencies.

S. Goswami et al., [11] presented a constructed and simulated system that used the inset feeding approach. An antenna consisting of a microstrip patch comprised of four elements. The array antenna is made up of four square patch antenna components that were constructed on a substrate made of RT/duroid 5880. A substrate with a relative permittivity of 2.2 RT/duroid5880 and a thickness of 0.25 mm, together with an inverted U slot, is used in the design of the suggested antenna. To enhance gain, and directivity, and improve radiation patterns, it undergoes a transformation from a 2×1 linear array to a 4×1 linear patch array where it is then subjected to analysis. A single band 4×1 linear patch array with a frequency of 28.5 GHz has been observed to have the frequencies that have been measured for a unique system.

A step-slot antenna that is small and has band-notched features was presented by W. Thaiwirot et al., [12] for use in ultra-wideband (UWB) transmission applications. When it comes to impedance matching for the higher frequency range of the UWB spectrum, the stepped slot that is etched on the ground plane plays a significant role. Through the incorporation of the inverted-U slot into the rectangular stub, the band-notched feature may be accomplished. The antenna that has been presented is characterized by its modest size, with dimensions of 20×26×1.6 mm3. It operates in the frequency range of 3.1-10.6 GHz, therefore avoiding interference with the WLAN band, which operates at 5.15-5.825 GHz. The suggested antenna's simulated findings are compared with the measured data, which shows that there is a good agreement between the two sets of results.

3. PROPOSED ANTENNA DESIGN AND METHODOLOGY

Design Steps of Inverted U-Slot Microstrip Patch Antenna

1. Substrate selection:

The selection of the substrate material is the first stage in the process of building an inverted U-slot microstrip patch antenna, better known as an IU-MPA. To reduce dielectric losses and optimize radiation efficiency, the substrate needs to possess a low dielectric constant (εr) and a low loss tangent (tan δ). FR-4 is one of the substrates that is often used for IU-MPAs.

2. Patch dimension calculation:

The intended operating frequency (f0) and the dielectric constant of the substrate are the two factors that define the size of the patch. When calculating the width (W) and length (L) of the patch, the following formulae may be used to accomplish the task:

$$W = c / [\ 2 * f0 * \mathrm{sqrt}(\varepsilon r)\ ]$$

$$L = W / [\ 2 * \mathrm{sqrt}(\varepsilon r + 1/2)\ ]$$

3. Slot design:

The inverted U-slot is meant to extend the antenna's bandwidth and create more resonant modes. This is accomplished via the slot's design. Additionally, the performance of the antenna is substantially impacted by the dimensions of the slot, which include its width, length, and location. Techniques of optimization are often used to ascertain the slot size that is most suitable for a certain set of criteria.

4. Feed line design:

The feed line communicates the radio frequency signal to the radiating patch. Several other methods of feeding may be used, including aperture coupling, microstrip line, and coaxial feed, among others. The choice of feed method is determined by several criteria, such as the amount of difficulty involved in manufacturing, the requirements for impedance matching, and the radiation pattern that is required.

5. Simulation and optimization:

Once the basic design has been finished, it is essential to model the antenna utilizing CST electromagnetic simulation software. This is done to optimize the antenna. This will be of use in determining whether or not the antenna is functioning properly and locating any possible issues. The performance of the antenna may be further improved by the use of optimization methods, such as those that increase the bandwidth, gain, and radiation pattern.

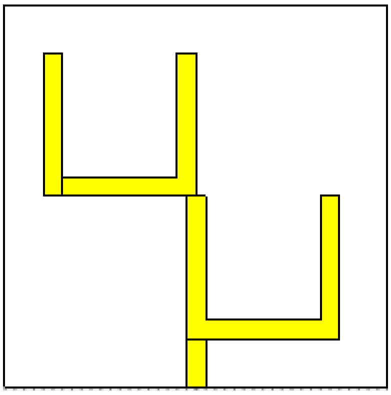


Figure 1: Front view

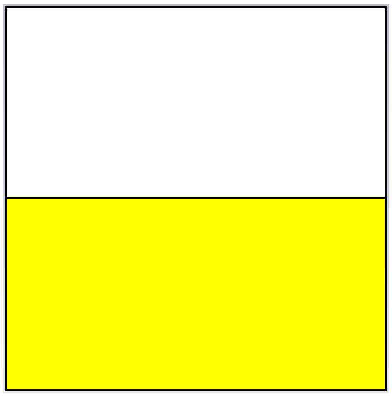


Figure 2: Back view

Figure 1 presents the front view of the proposed antenna, the dimension of length is 40 mm and width is also 40 mm, height is 1.64 mm. The dimension of the fee line are 2mm in width and 5mm in length. This antenna design is made using the CST simulation software. Copper material is used for the top and bottom design view and FR4 material is used for the substrate.

4. SIMULATION RESULTS

The simulation work is done in the computer simulation technology (CST) software.

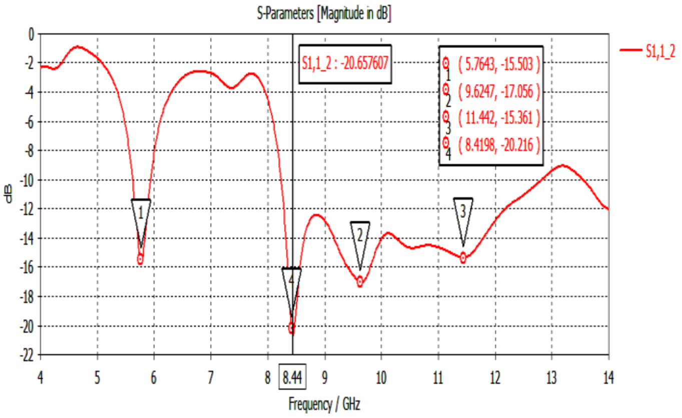
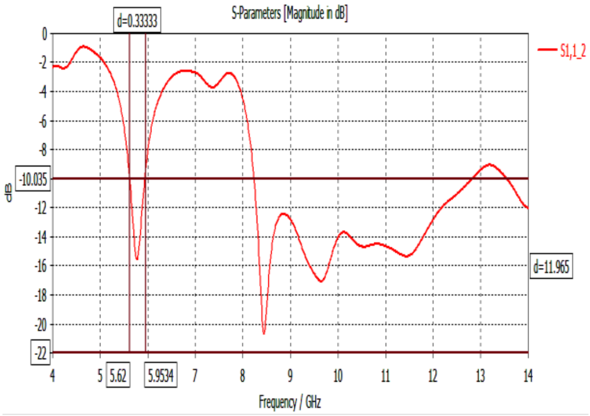
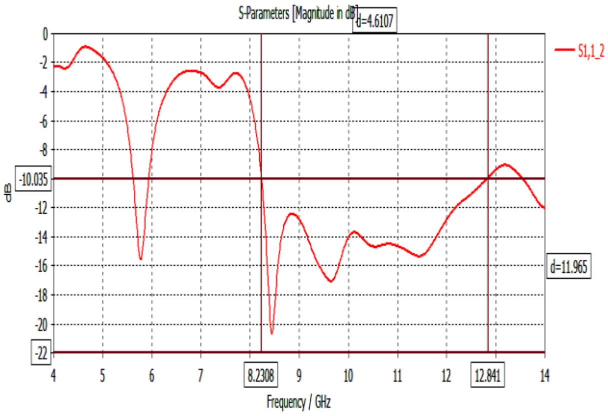


Figure 3: Return loss

Figure 3 presents the value of return loss, this antenna is resonant in 4 different frequency bands. The resonant frequency and optimized return loss are shown in the above figure, the minimum return loss is -20.21dB at 8.41GHZ.



(a)



(b)

Figure 4: Bandwidth

Figure 4 presents the bandwidth of the proposed antenna, this antenna design gives 4 different bands. The maximum bandwidth value is 4.61GHz.

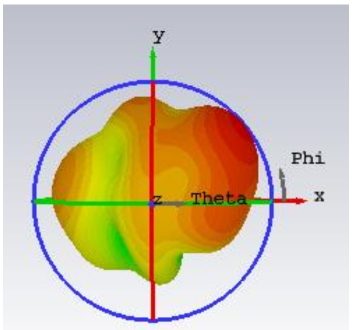


Figure 5: Radiation pattern

The 3D radiation pattern of an antenna is a graphical depiction of how the antenna transmits electromagnetic energy around it in three-dimensional space. This depiction is very helpful in gaining knowledge of the directional features of the antenna, which may have significant repercussions for its use in a variety of communication systems.

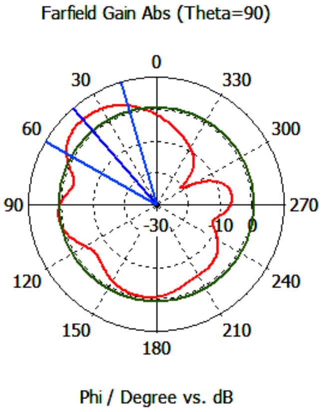


Figure 5: Polar plot gain

A polar plot of gain is a graphical depiction that depicts how the gain of an antenna changes with various azimuthal angles. This kind of plot is considered to be a polar plot of gain. When it comes to comprehending the directional features of an antenna on a two-dimensional plane, the polar plot is a very helpful tool.

Table 1: Simulation Results

Sr No	Parameter Name	Value
1	Return loss	-15.50dB, -20.21dB, -17.05dB, -15.36dB
2	Bandwidth	333MHz, 4.61GHz (694MHz, 1228MHz, 2699MHz)
3	Resonant frequency	5.76 GHz, 8.41 GHz, 9.62GHz, 11.44 GHz
4	VSWR	1.197
5	Directivity	7.023dBi
6	Gain	7.53dBi

Table 1: Results Comparison

Sr No	Parameter name	Existing work	Proposed work
1	Band	3	4
2	Bandwidth	415MHz, 645MHz, 120MHz	333MHz, 694MHz, 1228MHz, 2699MHz
3	Gain	6dBi	7.53dBi

Compared to the work that is already being done, the work that is being suggested has a greater gain and a broader bandwidth. On the other hand, it also functions in a higher frequency spectrum, which may be ideal for a variety of applications. Additional frequency bands, expanded bandwidth, and better gain are some of the developments that are suggested to be made by the work that is being presented. Because of these upgrades, the performance of the antenna may be improved, which will result in the antenna being more adaptable and able to meet a wider variety of communication needs.

5. CONCLUSION

The proposed work shows the increases in the antenna's capacity to function in an extra band, bringing the total number of bands it can operate in up to four from the current three bands. The antenna's adaptability and applicability over a larger range of frequencies might be improved as a result of this extension. The proposed antenna spans a greater frequency range (333MHz to 2699MHz) across all four bands than the work that has been done before compared to the current work. Applications that need communication across a wide range of frequencies may benefit from this increase in bandwidth since it allows them more flexibility. A gain of 7.53 dBi is shown by the work that is being presented, which is an increase over the previous study's gain of 6 dBi. When the gain is larger, it means that the capacity to concentrate the radiated energy in a certain direction is enhanced. This might be advantageous for applications that need precise directional applications or require communication over vast distances.

6. REFERENCES

[1] R. Gupta, S. Christopher and R. D. Koilpillai, "2-Inverted U-Slot Integrated Rectangular Patch Antenna Array for S-band Applications," 2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio

Science Meeting (AP-S/URSI), Denver, CO, USA, 2022, pp. 1834-1835, doi: 10.1109/AP-S/USNC-URSI47032.2022.9886846.

[2] S. A. Malakooti and C. Fumeaux, "Comments on “Wideband Radiation Reconfigurable Microstrip Patch Antenna Loaded With Two Inverted U-Slots”," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 2, pp. 1214-1215, Feb. 2020, doi: 10.1109/TAP.2019.2955200.

[3] S. Radavaram and M. Pour, "Reply to Comments on “Wideband Radiation Reconfigurable Microstrip Patch Antenna Loaded With Two Inverted U-Slots”," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 2, pp. 1216-1218, Feb. 2020, doi: 10.1109/TAP.2019.2955215.

[4] S. Radavaram and M. Pour, "Wideband Radiation Reconfigurable Microstrip Patch Antenna Loaded With Two Inverted U-Slots," in IEEE Transactions on Antennas and Propagation, vol. 67, no. 3, pp. 1501-1508, March 2019, doi: 10.1109/TAP.2018.2885433.

[5] A. K. Esnagari and B. Anantha, "A Compact Microstrip-Line Fed Meandered Inverted-F MIMO Antenna," 2018 IEEE Indian Conference on Antennas and Propogation (InCAP), Hyderabad, India, 2018, pp. 1-4, doi: 10.1109/INCAP.2018.8770918.

[6] S. Tejeswee and S. Verma, "Broadband Circularly Polarized U-Slot Antenna for Wireless Application," 2018 International Conference on Current Trends towards Converging Technologies (ICCTCT), Coimbatore, India, 2018, pp. 1-4, doi: 10.1109/ICCTCT.2018.8550866.

[7] W. Lan and Y. Jianguo, "A Novel UHF-RFID Tag Using a Planar Inverted-F Antenna Mountable on the Metallic Objects," 2018 IEEE International Conference on Computer and Communication Engineering Technology (CCET), Beijing, China, 2018, pp. 146-149, doi: 10.1109/CCET.2018.8542221.

[8] S. B. Behera, D. Barad and S. Behera, "Performance analysis of a stacked microstrip patch with SSR and inverted U-slot," 2018 4th International Conference on Recent Advances in Information Technology (RAIT), Dhanbad, India, 2018, pp. 1-4, doi: 10.1109/RAIT.2018.8389014.

[9] I. K. Sokhi, Ramesh R and Usha Kiran K, "Design of UWB-MIMO antenna for wireless applications," 2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Chennai, India, 2016, pp. 962-966, doi: 10.1109/WiSPNET.2016.7566277.

[10] P. S. Kumar and B. C. Mohan, "Dual-band microstrip patch antenna design with inverted-E slot and U-slot," 2016 11th International Conference on Industrial and Information Systems (ICIIS), Roorkee, India, 2016, pp. 128-132, doi: 10.1109/ICIINFS.2016.8262920.

[11] S. Goswami and D. Bhatia, "Design and Simulation a Novel 4×1 Micro Strip Patch Array for Satellite Applications," 2015 International Conference on Computational Intelligence and Communication Networks (CICN), Jabalpur, India, 2015, pp. 9-11, doi: 10.1109/CICN.2015.10.

[12] W. Thaiwirot, Y. Chareonsiri and P. Akkaraekthalin, "A compact band-notched step-slot antenna for UWB applications," 2015 IEEE Conference on Antenna Measurements & Applications (CAMA), Chiang Mai, Thailand, 2015, pp. 1-4, doi: 10.1109/CAMA.2015.7428174.