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Parametrical Analysis of Symmetrical Double U-Slots Micro Strip Circular Patch Antenna for Wireless Communication Devices

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The advancement in telecommunication demands antennas having wide bandwidth, compact size, and high performance. On the other hand, the microstrip antenna has a narrow bandwidth and low radiation efficiency. Recently, a number of researches were made to improve the bandwidth of microstrip antenna. The proposed antenna is based on to studied parametrically the microstrip antenna and their effect has been analyzed in terms of return loss, radiation patterns, and current distribution on the surface of the patch. The parameters such as the radius of the patch, lengths and widths of the slots, and feed point location are changed to different values using CST Microwave Studio. In this article double U-slotted in circular patch microstrip antenna are designed. The circular patch of radius 18mm and thickness of 1mm, FR4 substrate of permittivity of 4.3, dimension of (40 X 50) mm2, the thickness of 3.6mm, and coaxial probe are used to design the proposed antenna. The designed antenna has resonance frequencies at 3.2GHz, 5.8GHz, and 6GHz and the simulated gains are 3.72dBi, 7.67dBi, and 8.02dBi respectively. The VSWR at the resonance frequencies 3.2GHz, 5.7GHz, 5.8GHz, 5.94GHz, 6GHz, and 6.14GHz are 1.50, 1.38, 1.42, 1.60, 1.34 and 1.61. The VSWR is less than 2 at all resonance frequencies which shows good impedance matching. The return loss at the resonance frequencies of 5.8GHz and 3.24GHz is -19.04dB and -16.38dB respectively. The antenna has a bandwidth of 0.68GHz ranging from 5.52GHz to 6.18GHz. The proposed antenna is suitable for many wireless applications such as WLAN (5.15 – 5.35 & 5.75 – 5.8) GHz, Wi-Fi (5.15 – 5.82) GHz, and RFID (5.725 – 5.875) GHz.

Keywords: Micro Strip Patch; Return Loss; Radiation Efficiency; WLAN; Wi-Fi; Multiband.

Introduction:

The Microstrip patch antenna is used widely in modern communication devices due to its lightweight, low profile, and ease of fabrication. Despite all these advantages, the microstrip patch antenna has shortcomings of narrow bandwidth and poor radiation patterns, which reduce their performance in many wireless communication applications. To address this limitation, researchers have explored various techniques to improve the bandwidth and enhance the radiation pattern of the microstrip antennas. Broadband characteristics of antenna are discussed in [1][2] which is the demand of modern communication devices. The microstrip patch antenna should be compact to fit inside modern communication systems. In [3][4][5] studies show that U-slot patch antennas are not only used for wideband applications but also for multiband configurations, supporting dual- and triple-band functions. Integrating multiple bands for wireless technologies like AWS (Advanced Wireless Services), GSM (Global System for Mobile Communications), and various WiMAX and WLAN bands across different frequency ranges is particularly challenging [6][7]. While bandwidth can be increased by enlarging the patch size, a multilayer dielectric substrate has been employed to enhance bandwidth without this trade-off [8][9]. This multilayer structure not only improves impedance bandwidth but also maintains consistent performance across the target frequency bands [10].

Techniques such as using multilayer microstrip antennas with low dielectric constant substrates improve both impedance bandwidth and operational frequency range [11][12]. Multilayer stacked patch antenna designs, as proposed in [13][14], provide the wide bandwidths required for broadband applications. Additionally, as air gap length increases, the two resonant frequencies converge, which can be understood as coupling between two resonating modes across the dielectric regions via the air gap [15][16]. In [17][18][19][20][21] the researches were made to design antennas that have a low profile and one-half wavelength of the transmission line. Over the past decade, numerous studies have been conducted to analyze the resonant frequency, bandwidth, and radiation efficiency of circular microstrip patch antennas. In [22][23], a study examined that circular patch antenna and its arrays with L-shaped slots are designed for broadband dual-frequency operation. In [24] an integrated U-shaped slot into an equilateral triangular microstrip antenna to create a broadband structure. The concepts of effective radius and dynamic dielectric constants, essential for calculating resonant frequency, were developed in [25][26] investigated the performance of a U-shaped circular patch antenna with L-probe feeding to enhance bandwidth and gain, while [27] reported on the performance of a circular U-slot patch with dielectric properties.

In the proposed antenna, air is used as a substrate which makes the antenna lighter and compact. The length of the antenna depends on the substrate thickness. If the thickness of the substrate decreases antenna length increase [28][29][30]. The proposed antenna is parametrically analyzed using a CST microwave simulator. The parameters such as the patch radius, and heights of bigger and smaller U-slots are changed to different values and their effects on the performance of the antenna are analyzed carefully. Finally, a compact-size broad-band antenna has been designed. The antenna has a bandwidth of 0.68GHz ranging from 5.52GHz to 6.18GHz. The proposed antenna is suitable for many wireless applications such as WLAN (5.15 – 5.35 & 5.75 – 5.8) GHz, Wi-Fi (5.15 – 5.82) GHz, and RFID (5.725 – 5.875) GHz.

Objectives:

- To design a lightweight and compact antenna using air as a substrate, optimizing its size by adjusting the substrate thickness.
- To perform a parametric analysis of the antenna's design, varying key parameters such as patch radius and U-slot dimensions, to evaluate their impact on antenna performance.
- To develop a broadband antenna with a frequency range of 5.52 GHz to 6.18 GHz, suitable for multiple wireless applications, including WLAN, Wi-Fi, and RFID.

Novelty Statement:

The proposed antenna utilizes air as a substrate, significantly reducing its weight and enabling a more compact design. Through systematic parametric analysis and optimization, the antenna achieves a broad operational bandwidth of 0.68 GHz, covering 5.52 GHz to 6.18 GHz. This design offers an efficient and versatile solution compatible with various wireless technologies, such as WLAN, Wi-Fi, and RFID, highlighting its applicability in modern wireless communication systems.

Material and Methods:

Figure 1, shows the proposed antenna designed using CST microwave studio using a circular patch having two U-slots in the patch surface. The patch has a radius of 18mm and thickness of 1mm and copper is used as the material of the patch for good radiation. The dimension of the substrate and ground are the same which is ($W_g \times L_g$) and (Ws x Ls) mm^2 is (40 x 50) $mm^2$and the thickness of substrate t_s is 3.6mm, and the thickness of ground t_g is 0.1mm. The FR4 substrate of relative permittivity 4.3 is used which is easily available and not so expensive that can increase the validity of the antenna during the fabrication process. The antenna is fed from the coaxial probe of the inner and outer radius of 0.6mm and 2mm respectively.

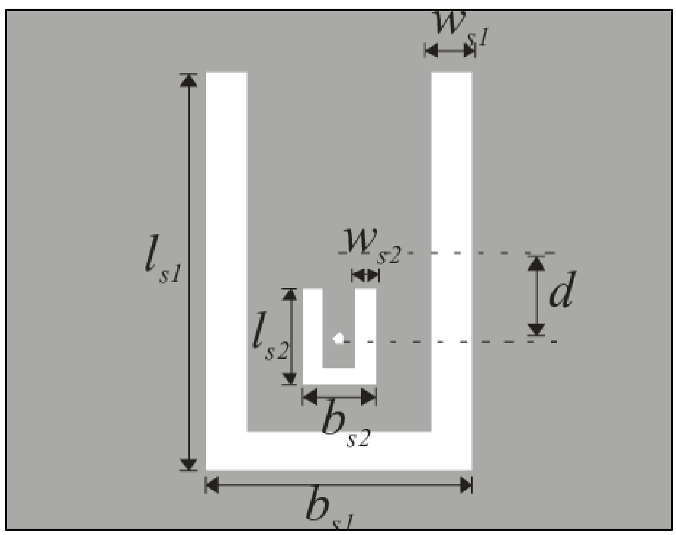

Figure 1. Geometrical representation of dual U-slot microstrip patch antenna [31].

The parameters of the antenna such as the radius of the patch, the lengths and widths of the legs of the inner and outer two U-slots, and the position of the feed point are changed to different values in order to achieve an improvement in radiation patterns, return loss, bandwidth, efficiency, and gain. The parameters of the designed antenna are mentioned in table 1

Table 1. Parameters of the proposed antenna.

Wg	40mm	LS	50mm	ts	3.6mm
Lg	50mm	Patch radius	18mm	tp	1mm
Ws	40mm	tg	0.1mm	substrate	FR4

Result and Discussion:

Figure 2 demonstrates the effect of changing the radius of the patch on return loss and radiation pattern. The return loss is a critical parameter that shows how well the antenna is matched with the transmission line. The batter impedance matching signifies how lower or more negative is the return loss in dB. The radius of the patch selected is 19mm the second resonance frequency is more negative which is -37dB. And at the radius of the patch being selected as 17mm the first resonance frequency has the return loss lower is -39dB. Secondly, the radius of the patch depends inversely on the resonant frequency shift. As the radius of the patch increases from 17mm to 19mm the resonant frequencies are shifting toward the right side of the graph.

The radius also affects the bandwidth of the antenna. The bandwidth of the antenna becomes narrow with increasing the radius of the patch as depicted in figure 2. The large radius of the patch supports high current distribution and effectively radiates so the gain and directivity increase. The large radius pronounced side lobes due to complex current distribution on the large physical aperture.

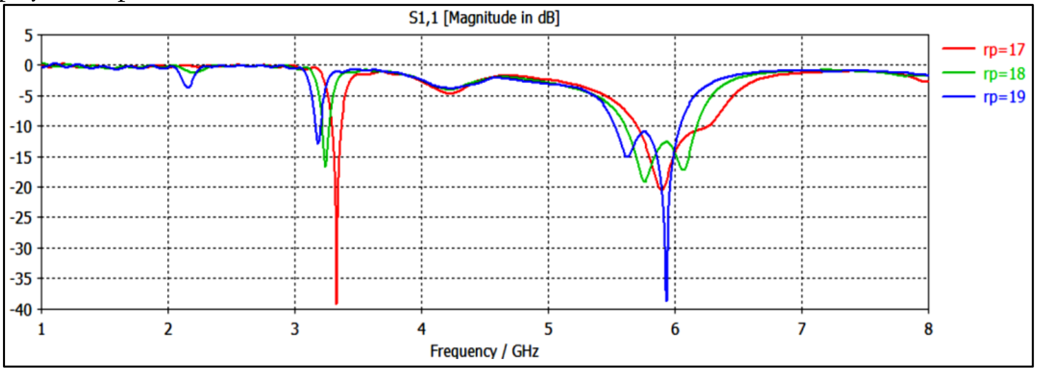

Figure 2. Effect of parameter radius 'rp' of the patch on antenna performance.

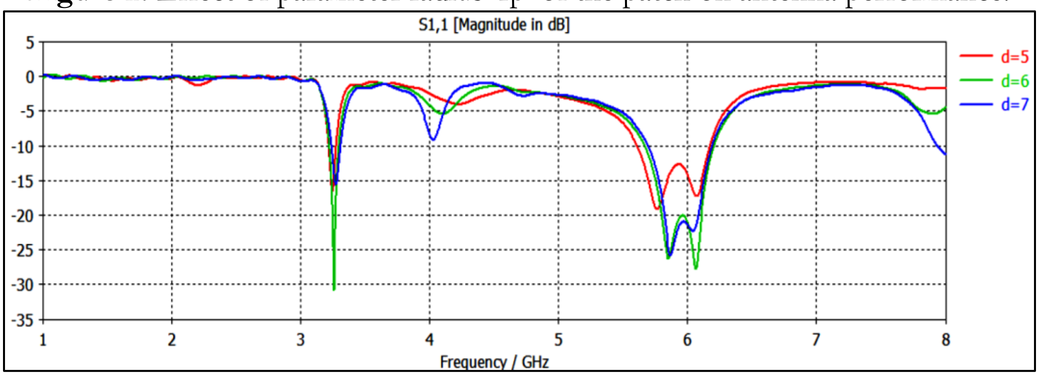

Figure 3. Effect of position of the supply 'd' on antenna performance.

The position of the feed is changed to 5mm, 6mm, and 7mm and their effect on resonant frequency, impedance matching, radiation pattern, and bandwidth of the antenna are analyzed. The VSWR is between 1 and 1.5 in Figure 7 illustrating that the antenna is well matched. The feed position affects the distribution of the current in the patch as shown in Figure 9 which affects the radiation pattern, directivity, and gain of the antenna. Correct feed location maximizes bandwidth while improper placement of feed can narrow bandwidth. Selecting different locations of the feed for optimizing resonance frequency, impedance matching, and bandwidth of the proposed antenna.

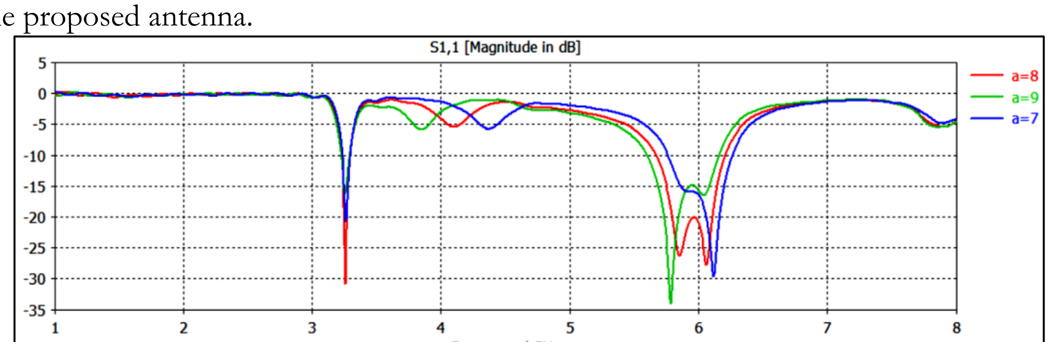

Figure 4. Effect of variation of length of small U-slot 'a' on antenna performance.

Figures 4 and 5 demonstrate the effect of changing the length of the small U-slot and large U-slot of the patch on the antenna performances. The length of the small U-slot is varied as 7mm, 8mm, and 9mm, and the large U-slot is changed to 18mm, 19mm, and 20mm which significantly affects its performance. The resonant frequencies are lower and rise with increasing and decreasing the size of the slots due to the increase and decrease in the effective length of the current path on the patch. The bandwidth can be broadened by larger slots to enhance the impedance bandwidth by altering the distribution of the current on the patch surface.

The slot size modifies the radiating currents which tend to radiate effectively. The directionality and shape of the side lobes and main lobes also effectively change. The gain is improved by enhancing the radiation efficiency. In the proposed antenna the slot size is adjusted to fine-tune the antenna for better matching with the transmission line. The slots are introduced which affect the antenna size and weight which is beneficial for compact integrated designs.

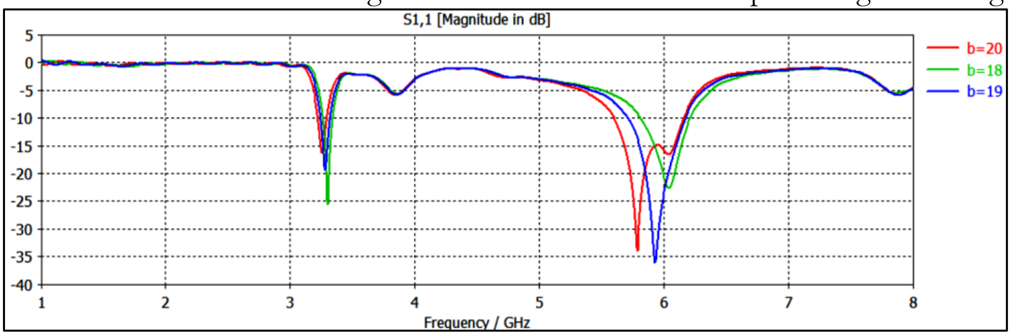

Figure 5. Effect of variation of length of largest U-slot 'b' on antenna performance.

At the resonance frequency 5.9GHz the return loss is -12.76dB and the return loss of -17.19dB is shown at the resonance frequency of 6.06GHz. The antenna is suitable for many wireless applications which are WLAN (5.15 – 5.35 & 5.75 – 5.8) GHz, Wi-Fi (5.15 – 5.82) GHz, RFID (5.725 – 5.875) GHz.

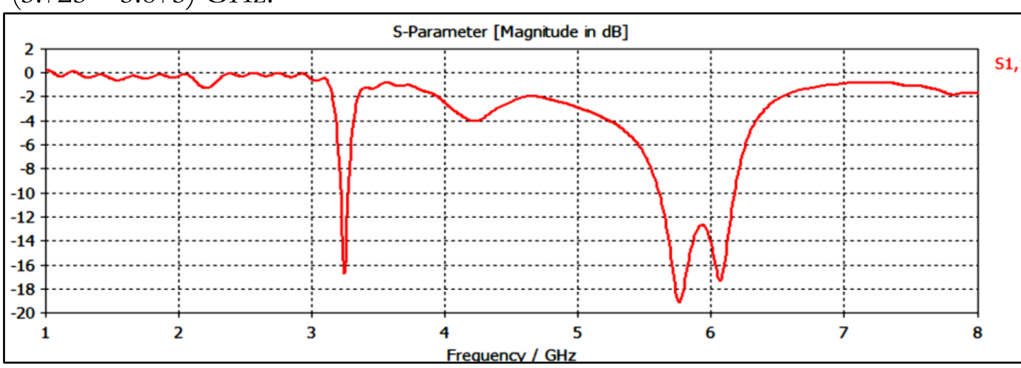

Figure 6. Reflection coefficient of dual U-Slot path antenna.

The VSWR of the antenna is shown in the figure 6.20. The VSWR at the resonance frequencies 3.2GHz, 5.7GHz, 5.8GHz, 5.94GHz, 6GHz, and 6.14GHz are 1.50, 1.38, 1.42, 1.60, 1.34 and 1.61. The VSWR is less than 2 at all resonance frequencies.

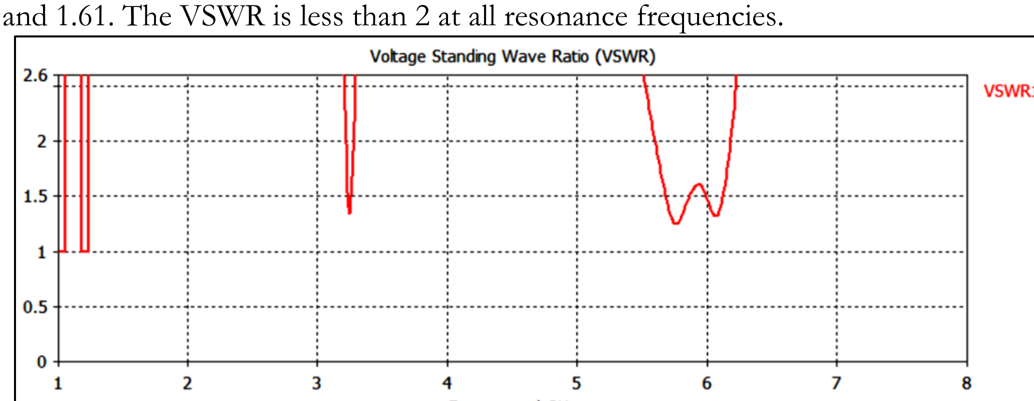

Figure 7. Voltage standing wave ratio of dual U-slot patch antenna.

Three-dimensional radiation patterns of the antenna are demonstrated in Figure 8. The gain and directivity of the antenna increase with increasing the resonance frequencies. The directivities of the antenna are 3.716dBi, 7.672dBi, and 8.02dBi at the central frequencies of 3.2GHz, 5.8GHz, and 6GHz respectively. At the resonance frequency 3.2GHz the main lobe magnitude and direction are 3.7dBi and 48°. The angular width is 258°. At the resonance frequency 5.8GHz the main lobe magnitude and direction are 7.7dBi and 50°. The angular width is 65.6°. At the resonance frequency 6GHz the main lobe magnitude and direction are 6dBi and 51° and the angular also known as 3dB width is 60.1°.

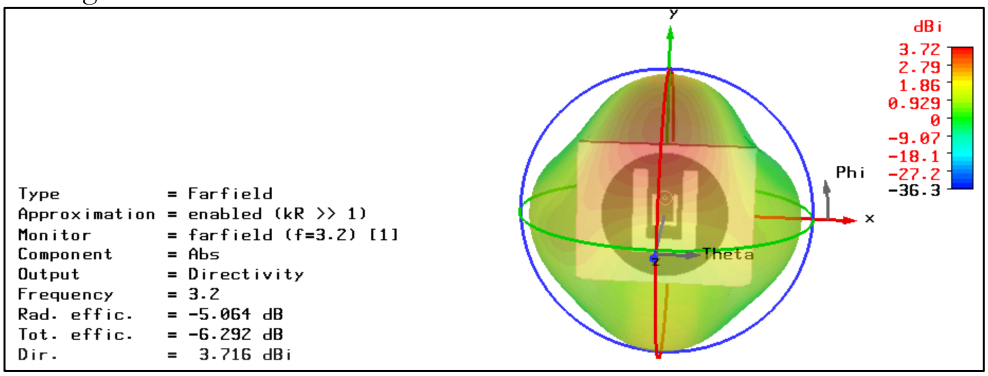

Figure 8a. The 3D radiation pattern of dual U-slot microstrip patch antenna at 3.2GHz.

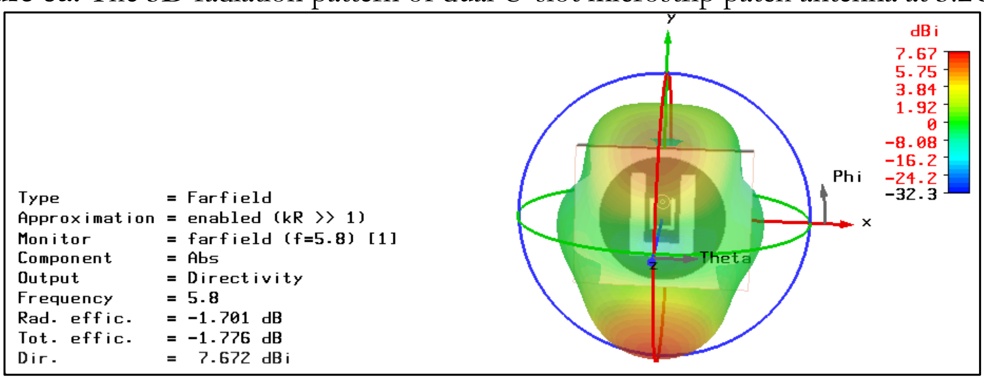

Figure 8b. The 3D radiation pattern of dual U-slot microstrip patch antenna at 5.8GHz.

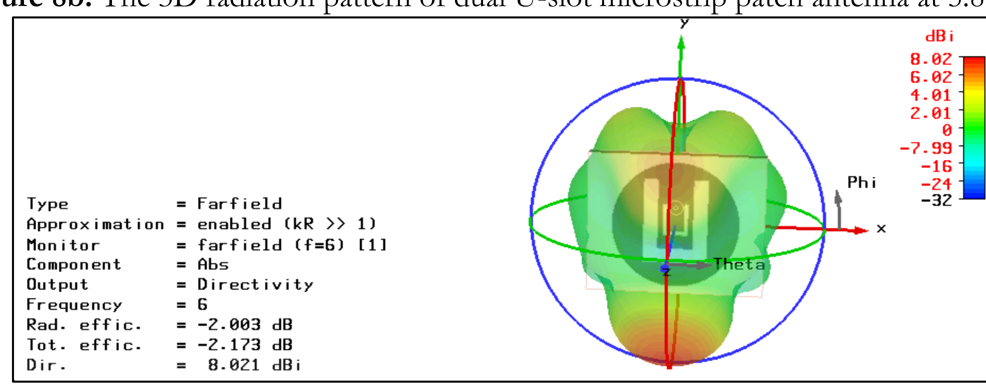

Figure 8c. The 3D radiation pattern of dual U-slot microstrip patch antenna at 6GHz.

The distribution of surface current in the antenna at the resonance frequencies of 6GHz is demonstrated in Figure 9. The current distribution at the lower frequencies is larger and a longer path is available for the flow of current which results in the lower resonance frequencies. The amount of surface current distribution at higher resonance frequencies is less and a shorter path is available for the current flow which results in upper resonance frequencies.

Comparative Analysis:

The results mentioned in Table 2, show the comparisons of our designed antenna with antennas designed in [31] and [32]. The proposed antenna has a compact, low profile, ease of fabrication, and is less costly. The gains at the particular resonance frequencies are higher and the bandwidth is large as compared to the other two antennas.

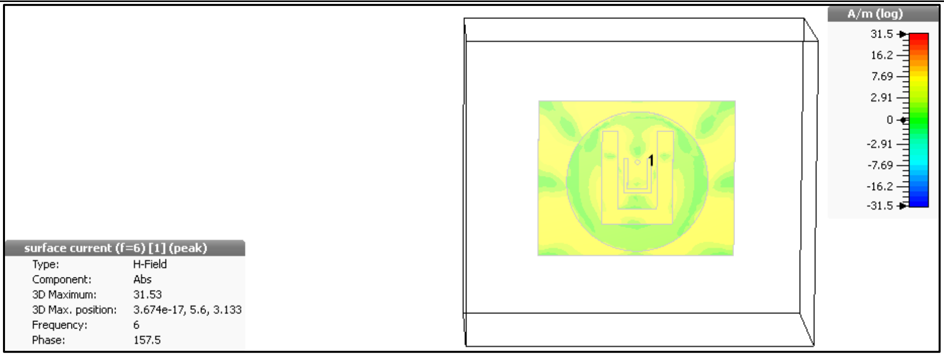

Figure 9. Distribution of surface current in dual U-slot microstrip patch antenna at 6GHz.

Table 2. Comparative Analysis of proposed antenna design with antennas designed in [31]and [32].

Parameters	Antenna designed in [31]	Antenna designed in [32]	Proposed Antenna
Dimension of patch	(LxW) mm2 = (71x52) mm2 = 3692 mm2	Diameter of patch =16.5 mm	Diameter of Patch = 18 mm
Thickness of Substrate	Three-layer internal structure = 9.1mm	5 mm	3.6 mm
Bandwidths of Dual bands	i. (1.7-2.2) GHz = 0.5 GHz. ii. (2.4 – 2.5) GHz = 0.1GHz.	i. (3.37 -2.2) GHz = 0.27GHz. ii. (5.15 – 5.62) GHz = 0.47 GHz.	i.(3.02 – 3.26) GHz = 0.24GHz (5.52 -6.18) GHz = 0.66 GHz
Gain of Antennas	Lower band gain is above 6 dBi and lower 6 dBi at higher band.	Gain of 8.77 dBi at 3.6 GHz, Gain of 9.47dBi at 5.2 GHz and Gain of 8.1 dBi at 5.8 GHz	Gain of 7.6 dBi at 5.8 GHz, Gain of 8 dBi at 6 GHz, and Gain of 3.72 dBi at 3.2 GHz
S11 at centered frequencies	S11 is below -6db at the above band and the cross-polarization level at the lower frequency range is below -15 dB.	S11 at the lower frequency range is -20dB and at the higher frequency range is above -20 dB.	S11 at a lower frequency range is -30dB and at a higher frequency range is above -25 dB.

Conclusion:

The proposed antenna is designed and studied parametrically using CST Microwave Studio. It reveals significant insights into its performance for wireless communication applications. The double U-slots are introduced which effectively enhance the bandwidth and improve impedance matching, which are critical for modern wireless communication systems. Key parameters such as slot dimensions, and radius of the patch were systematically varied to observe their effect on the antenna's return loss, bandwidth, and radiation patterns. Adjusting the length, and width of the U-slots significantly impacts the resonant frequency and bandwidth. Optimal dimensions of the slots lead to a wider bandwidth, making the antenna suitable for multiband and broadband applications. The symmetrical design ensures stable and omnidirectional radiation patterns, which are desirable for uniform coverage in wireless communication devices. The addition of U-slots did not significantly affect the radiation pattern, maintaining good directivity and gain. The enhanced bandwidth and stable radiation characteristics make it an excellent choice for applications requiring reliable, high-performance antennas in compact forms. Future work could explore further optimization of the slot geometry and the use of different substrate materials to enhance performance further.

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