Linear Dual-Polarized Microstrip Patch Antenna with U-shaped Aperture

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***Abstract*—In this paper, a small size, high-gain, linear dual-polarized U-shaped aperture antenna for 5G communication systems is presented. The U-shaped aperture is used to increase impedance matching and coupling level, while allowing dual-polarization operation at the same time. This antenna is composed of two substrates separated by air gap. The square radiating element is positioned beneath the upper substrate and is fed by two orthogonal feed lines located beneath the lower substrate. The electromagnetic waves are connected to the radiating element through two U-shaped apertures cut in the ground plane, located above the lower substrate. According to the simulation results, the antenna's gain and directivity are 6.89dB and 7.09dBi, respectively, with excellent isolation between the two ports and a high radiating efficiency of more than 90%. The suggested antenna is designed using RO4003 substrate with a thickness of 0.813 and a dielectric constant of 3.5. The antenna is modeled and simulated using Finite Integration Technique (FIT).**

***Index Terms*—U-shape, aperture coupled antenna, microstrip antenna, dual-polarization, 5G.**

I. Introduction

Researchers have become more interested in microstrip antennas in recent years due to its low profile, low cost, ease of manufacturing, and wide range of applications.

Pozar proposed a new method for feeding microstrip antennas in 1985 [1], which has the benefit of increasing bandwidth and gain. This method is known as aperture coupled antenna, and it requires that the antenna is composed of at least two substrates, one containing the radiating element and the other containing the feed line, with no physical contact between them, and they are electromagnetically coupled through an aperture cut in the ground plane. Generally speaking, a material with a high dielectric constant is used for the lower substrate, while a thick material with a low dielectric constant is used for the upper substrate to optimize the patch radiation [2].

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Several architectures were proposed in the years that followed, with variations either in the shape of the aperture [3] [4] , or the shape of the radiating element [5], or in the form of the feed line [6] [7].

In [8], Anandkumar et al. have constructed and compared two antennas that were fed using two different feeding techniques: the inset and aperture techniques. The aperture technique yielded significantly better results than the inset technique. The bandwidth achieved using the aperture feeding technique is 15% higher, and the gain and the directivity have been enhanced by 5dB and 4.5dB, respectively. On the other hand, Wang et al. in [6] used a L-shaped feed line to feed the radiating element through three slots with the same length and different widths. But the gain obtained using this architecture is limited and it's less than 4.7dB.

Another advantage of employing microstrip antennas is the ease with which the dual polarization can be formed. In [3], a dual polarized antenna with dumbbell shaped aperture has been presented, with a significantly higher bandwidth but a gain of less than 6dB.

Finally, a 5G wireless communication system antenna with a simple short aperture vertical to feed line was presented in [9]. The antenna is very narrow band, with a bandwidth of 40MHz, but the gain and directivity are slightly enhanced, and they are equal to 6.4dB and 6.66dBi, respectively.

A low-profile, high-gain aperture antenna for 5G communication systems is presented. A U-shaped aperture was used to increase impedance matching and coupling level, while allowing dual-polarization operation at the same time. The suggested structure has a small size as it is made up of only two substrates and does not include any superfluous layers that would make the structure too complicated. Across the operating band, good performances were obtained in terms of gain, directivity, and efficiency, which makes this structure appropriate for the development of 5G MIMO array antenna.

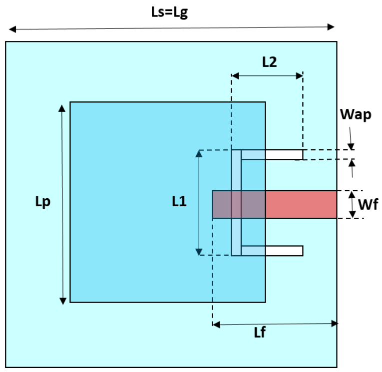

Fig. 1. Top view of the antenna with single feed line.

II. U-shaped aperture coupled antenna design

Figure 1 presents the proposed linearly polarized single U-shaped slot antenna's structure. It is composed of two layers of Rogers 4003 separated by air gap, a square patch, a single feed line, and a ground plane. The square radiating element of length Lp is situated underneath the upper substrate, while the second substrate is sandwiched between the ground plane and a simple micro-strip feed line of 50 Ohm. The electromagnetic waves are connected from the micro-strip feed line towards the square patch via the U-shape aperture created in the ground plane.

The simplicity with which dual-polarization antennas can be constructed is one of the advantages of coupled aperture antenna technology. Figure 2 depicts the proposed dual-polarized U-shaped aperture antenna. A second feeder with a U-shaped aperture is positioned perpendicular to the first one. With this design, good isolation can be achieved without offsetting the feed system from the center of the substrate. However, moving the feeder away from the center has almost no effect on the impedance matching but it can reduce the gain of the antenna. The position of the feed line in relation to the aperture, on the other hand, has a significant impact on the coupling level as well, thus, it should be positioned at a right angle to the slot's center for maximum coupling and efficiency.

The overall thickness of the structure is around 7mm, which is approximately $0.08\lambda_0$ (λ_0 represents free-space wavelength at 3.5GHz). The substrate used has a square geometry with length Ls, its thickness is 0.813mm, its dielectric constant is $\xi = 3.55$, and its dissipation factor is $tan\delta = 0.0027$. The design was done with manual calculation using the equations mentioned in [9], then these values are optimized by using electromagnetic simulation software. However, the optimized dimensions are represented in the table I.

TABLE I
Optimized Values for the Key Parameters of the Proposed Antenna

Parameters	Ls	Lp	Lf	wf	L1	L2	Wap	Ha
Value (mm)	36	27	11	1.75	11.25	7.7	1	5

When the port 1 is excited, the E-plane corresponds to $\varphi = 0°$, and the H-plane corresponds to $\varphi = 90°$, indicating that the proposed antenna's linear polarization is in $\varphi = 0°$. And when the port 2 is excited, the H-plane corresponds to $\varphi = 0°$, and E-plane corresponds to $\varphi = 90°$, indicating that the linear polarization is in $\varphi = 90°$.

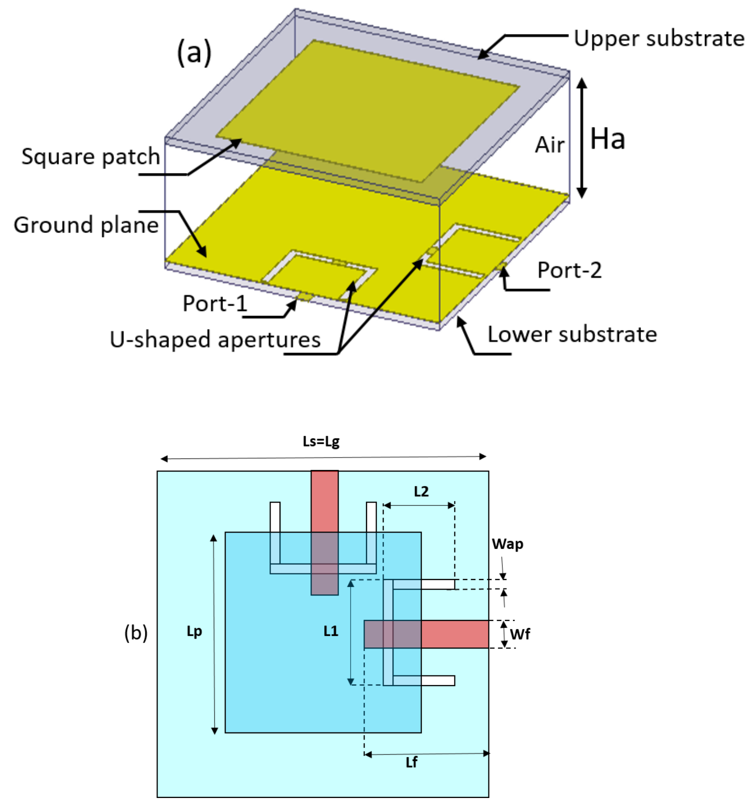

Fig. 2. Structure of the proposed dual-polarized aperture coupling antenna: (a) 3D view, (b) Top view.

III. Simulation Results

Figure 3 illustrates the isolation between the two ports as well as the reflection coefficients S11 and S22 of the proposed antenna. Thanks to the symmetry of the structure, S11 is identical to S22 and S21 is identical to S12. The isolation between the two ports is more than 20dB, indicating that the two ports are well isolated. The bandwidth for S11 and S22 less than -10dB can reach 140MHz.

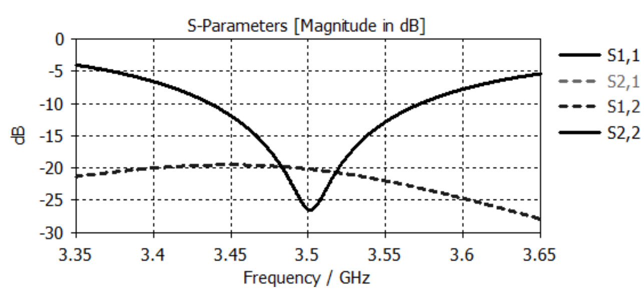

Fig. 3. S-parameters

The gain and directivity of the antenna are shown in figure 4 and 5 respectively. The gain is 6.89dB and the directivity is 7.09dBi at the central frequency. Regardless of whether port 1 or 2 is utilized to feed the antenna, the values of the gain and directivity remain the same.

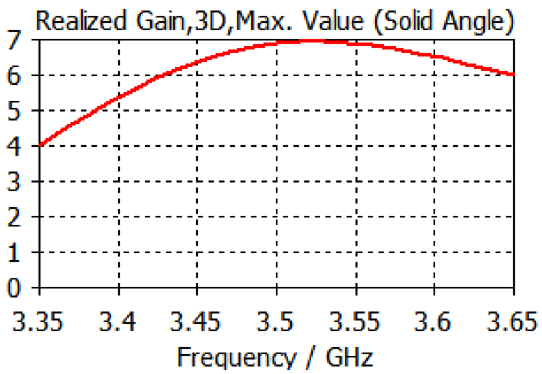

Fig. 4. The gain of the proposed antenna.

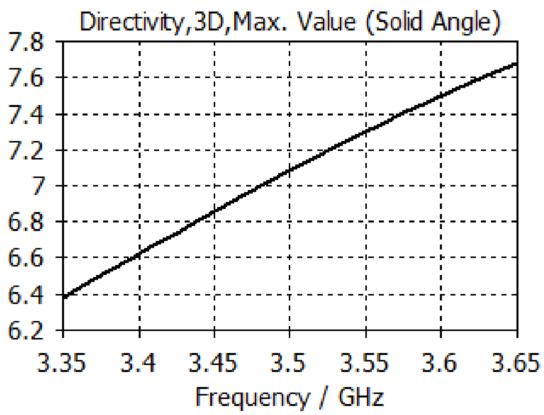

Fig. 5. Directivity of the proposed antenna.

An antenna's efficiency is defined as the ratio of its gain to its directivity. Figure 6 shows that the proposed antenna could achieve more than 90 percent of efficiency at 3.5GHz, indicating that the suggested U-shaped aperture antenna is very efficient due to minimal power loss and gain enhancement.

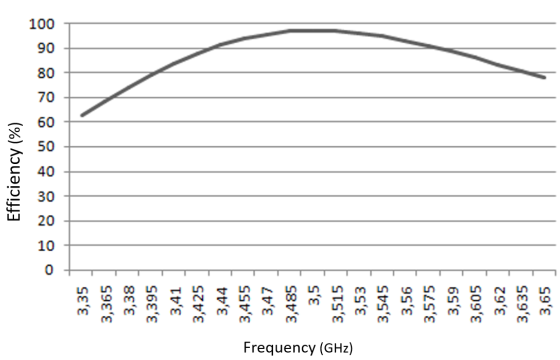

Fig. 6. Radiation efficiency of the antenna

Next two figures depict the proposed antenna's radiation pattern. Figure 7 shows the radiation pattern when the antenna is excited via port 1, and figure 8 shows the radiation pattern when the antenna is driven using port 2. The suggested antenna is nearly directional, as shown in the 3D view.

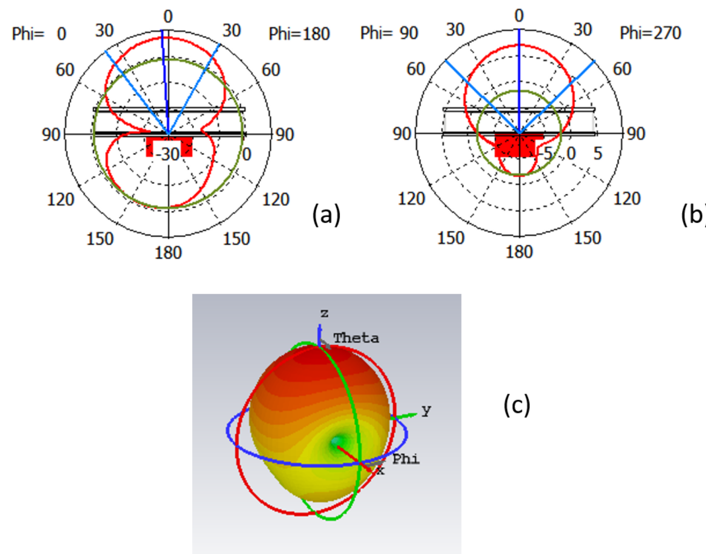

Fig. 7. Diagram pattern: (a) E-plane and (b) H-plane. (c) 3D diagram pattern.

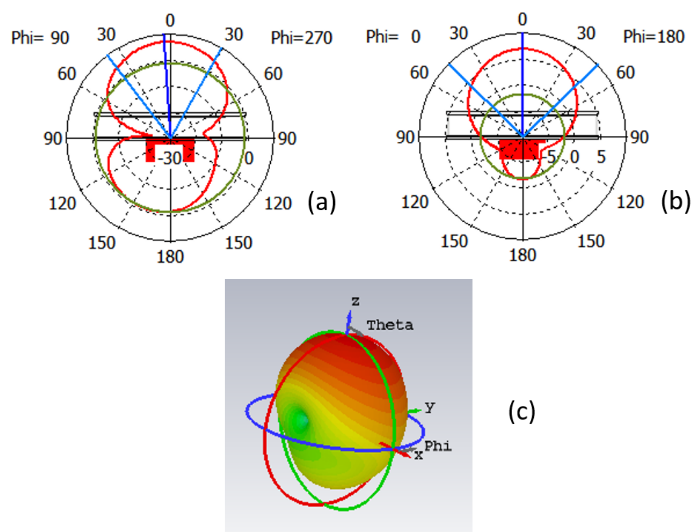

Fig. 8. Diagram pattern: (a) E-plane and (b) H-plane. (c) 3D diagram pattern.

IV. Conclusion

A high performance dual polarization U-shaped aperture coupled micro strip patch antenna is developed and simulated. According to the simulation results, the antenna has an enhanced gain of 6.89dB and directivity of 7.09dBi. The efficiency, on the other hand, has increased to more than 90% due to the reduced power losses thanks to the antenna's simple structure. This antenna operates at 3.5GHz frequency, which makes it suitable for 5G Wireless communication systems.

Because the bandwidth of this antenna is a bit limited, the next obvious step will be to try to increase the bandwidth by adjusting some structural parameters, such as the distance between the two substrates. The final version will then be used to develop a MIMO array antenna for future 5G communication systems.

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