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Design of A 3.5 GHz Compact Size Microstrip Antenna of Two Folded U-Shaped Arms for 5G Applications

Asem Zahran[1], Ahmed I. A. Galal[2], Ahmed M. El-Sawy[2], Emmad Tammam[2,*]
[1] *Egyptian Electricity Transmission Company (EETC), Egypt*
[2] *Electrical Engineering Dep., Faculty of Engineering, Minia University, Minia, Egypt*
* *Corresponding author(s) E-mail:* emad.tammam@mu.edu.eg

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A B S T R A C T

This paper presents a compact printed antenna based on two folded U-shaped arms radiator for 5G wireless applications. The proposed antenna is intended to work at the 3.5 GHz frequency band. The two arms of the antenna's radiator are U-shaped to miniaturize the size, while the currents are maintained in the same direction during the folding process. Maintaining the current in the same direction over the surface of the antenna guarantees constructive electromagnetic coupling and improves the radiation characteristics of the antenna. The proposed antenna's radiator is printed on the top of an FR4 substrate with a complete ground plane on the bottom side. Dimensions of the antenna are optimized to satisfy the required electrical and radiation characteristics of 5G standards. The overall size of the antenna is $20 \times 29 \times 1.6$ mm^3. The proposed antenna is simulated using HFSS simulator, fabricated, and experimentally tested. The conducted measurements show a properly matched antenna over the frequency band 3.42 to 3.62 GHz with its peak resonance existing at 3.5 GHz. The measured S_{11} of the antenna is -30.5 dB at the resonance frequency. The antenna has directional radiation pattern with 2.1 dBi maximum gain at the 3.5 GHz frequency. Measurements of the antenna have proved its good characteristics which come in good agreement with the obtained simulation results. The characteristics of the proposed antenna qualify it to be a good choice for 5G applications.

1. Introduction

With the rapid evolution of wireless communications technologies and with the emergence of 5G systems, the need for advanced antenna that is able to meet the requirements of deployed and next generations of communications networks increases [1]. As the deployment of 5G technology begins, various frequency bands has become a focal point of research and development. The mid-band of 5G which is concentrated about the 3.5 GHz spectrum is one of the most important frequency bands allocated for 5G. This band is intended for delivering high-speed data, reduced latency, and improved connectivity. The design and optimization of antennas operating in this band are crucial for realizing the full potential of 5G communications systems. The 3.5 GHz frequency range, part of the mid-band spectrum, offers a balanced trade-off between coverage and capacity, making it a preferred choice for both urban and rural deployments. However, designing an efficient antenna for this frequency involves addressing several challenges, including size constraints, radiation patterns, and bandwidth requirements. In fact, the performance of an antenna in 5G systems significantly impacts overall network efficiency, data throughput, and coverage [2–4]. So that, antenna designed for 5G systems should take into account satisfying these requirements in addition to maintaining the size as small as possible. Many of antenna designs in the literature have been introduced to meet the requirements of 5G.

A microstrip patch antenna based on metamaterial is proposed in [5] to be used in 5G applications. This antenna works at 3.5 GHz and has electrical dimensions of ($0.94\lambda \times 0.694\lambda$). The antenna's bandwidth is 138 MHz, S_{11} is -22.71 dB, and the gain is 2.984 dBi. The main drawback of such an antenna lies in its narrow bandwidth in addition to its large size. In [6], a circular microstrip patch antenna for 5G with dimensions ($0.52\lambda \times 0.34\lambda$) is presented. This antenna resonates at 3.5 GHz with S_{11} of -40.28 dB and bandwidth of 200 MHz. This antenna has achieved substantial gain of 5.8 dB. A novel hook-shaped antenna appears in [7] to serve in 5G applications. The overall dimensions of the antenna are ($0.23\lambda \times 0.14\lambda$). This antenna is characterized by its compact size. It has achieved 1.9 dBi gain, 200 MHz bandwidth and S_{11} of -32 dB. In [9], an artificial dielectric open-ring designed to resonate at 3.5 GHz with S_{11} of -26.46 dB and bandwidth of 194.7 MHz. Substrate's dimensions is ($0.46\lambda \times 0.52\lambda$) and the gain is 6.391 dB. A C-Shaped antenna is designed in [10] for 5G applications with electrical dimensions of ($0.39\lambda \times 0.37\lambda$), 500 MHz bandwidth, 3.4 dB gain and S_{11} of -41.74 dB.

The 5G antenna can be designed as a reconfigurable structure as in the case of [11]. These structures can be strategically placed in the radio channel between a transmitter and receiver to control the way the signal reflects off a surface in its propagation path. Planar filtenna (filtering antenna is a structure that has filtering as well as radiation function on the same substrate) is used to serve in the 5G sub-6 GHz bands. The filtenna dimensions are (1.54λ × 1.62λ) and its bandwidth is 460 MHz with S_{11} of -25 dB. The gain of the antenna at 3.5 GHz frequency is 2.8 dBi. In addition to the single element form, antennas can be utilized as multiple—input multiple-output (MIMO) system. In [12], array of 12 antenna elements is presented for 5G mobile communications. This antenna works in the 3.4 – 3.6 GHz frequency band. Tri-polarization technique is utilized to improve the isolation between the antenna elements in the array. Massive MIMO antenna, while a large number of antenna elements can be utilized, is an effective candidate in 5G systems. In [13], a massive MIMO of eight antenna subarrays is designed to serve in the 5G base stations at 3.5 GHz. This massive MIMO system has satisfied 300 MHz bandwidth and 9.5 dB gain. Many other 5G antennas designs can be found in the literature.

In this paper, we present a simple compact size antenna that meets the requirements of the 5G systems, working in the mid-band (below 6 GHz) spectrum in the N78 band (3.3 GHz – 3.8 GHz) at 3.5 GHz. The proposed antenna is constructed as two microstrip arms fed by a microstrip line. Each microstrip arm is folded back and forward to form a U-shaped structure. Dimensions of the two U-shaped arms are optimized such that the current in each side of the U-shaped arm flows in the same direction. Folding of the microstrip arms results in significant reduction in the antenna size, while maintaining the current flow in the same direction results in constructive electromagnetic coupling, and consequently, good radiation characteristics.

Design and performance of the proposed antenna are investigated in the rest of the paper as follows: Section 2 presents the structural design of the antenna. Simulation, fabrication and measurements of the antenna come in Section 3. In Section 4, the obtained results are discussed. Finally, the main pints of the paper are concluded.

2. Antenna Structural Design

2.1. Proposed Antenna Configuration

The proposed antenna configuration, as shown in Figure 1, is a planar structure of two folded U-shaped arms radiator printed on a substrate of complete ground plane on the bottom side. The utilized substrate is FR4 with a thickness of 1.6 mm, dielectric constant of (ε_r = 4.4), and tangent loss of (tan δ = 0.002). The overall dimension of the antenna is 0.3372λ (29) × 0.232λ (20) mm^2. Detailed dimensions of the antenna are listed in Table 1.

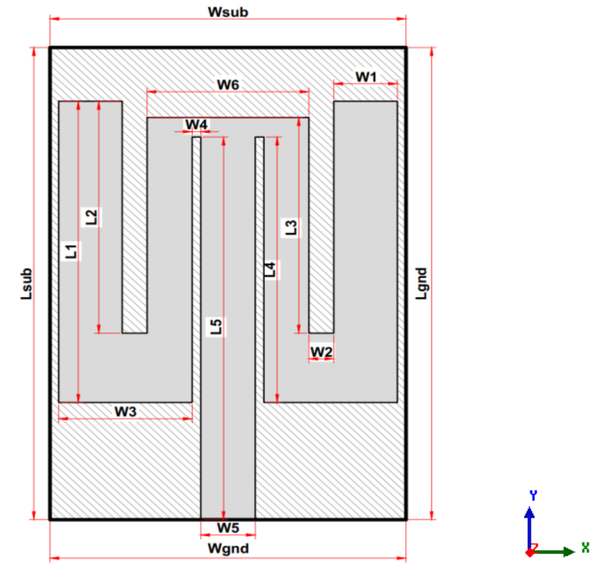


Figure 1: Configuration of the proposed antenna.

Table 1: Dimensions of the proposed antenna

Parameter	Dimension (mm)	Parameter	Dimension (mm)
Wsub	20	Lsub	29
W1	3.5	L1	18.5
W2	1.4	L2	14.2
W3	7.5	L3	13.2
W4	0.5	L4	16.3
W5	3	L5	23.5
W6	9	Lgnd	29
Wgnd	20		

2.2. Simulation of the Proposed Antenna

The antenna is designed and validated for operation at 3.5 GHz for the C band 5G. Ansys HFSS simulation software has been utilized throughout the design process. The main idea behind the antenna design is to provide a current path of electrical length equals to half wavelength or multiples to stimulate a resonance state. The wavelength, and consequently, the length of the antenna can be basically calculated using the following relation [14]:

$$\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}}}$$

where λ is the wavelength, f is the operating frequency, and ε_{eff} is the effective permittivity and can be calculated as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12h/w}}$$

where ε_r is the dielectric constant of the antenna's substrate, h is the substrate's thickness, and w is the microstrip width.

To achieve the compactness of the antenna, the two arms of the antenna are folded in U-shaped form in a manner that ensures the same direction of the current over the whole length of each arm. The current distribution on the surface of the antenna is depicted in Figure 2. Observing the direction of currents on the surface of antenna clarify that the current propagates on the most of the antenna's surface in the same direction. This is important for the high gain requirements of the antenna.

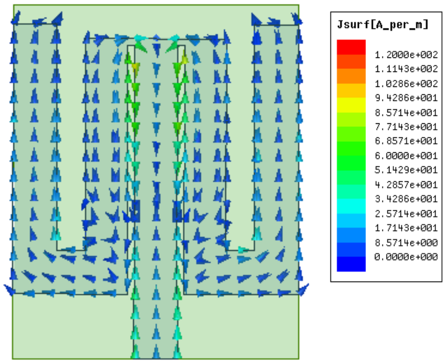


Figure 2: Current distribution on the surface of antenna at the resonance frequency, 3.5 GHz.

Simulated S11 of the antenna is shown in Figure 3. As shown in figure, the antenna has achieved good impedance matching at 3.5 GHz with simulated S11 of – 26 dB with a wide channel bandwidth of 200 MHz extended from 3.42 GHz to 3.62 GHz.

During the design steps of the antenna, some of dimensions were more effective in the behavior of the antenna. The length of the resonating arms is one of the most effective dimensions. Figure 3 shows the effect of the dimension L_1 variation. The length of the two arms of the antenna (L_1) is tested at the values L1 = 17, 18, 18.5, 19, and 20 mm. Changing the value of L_1 has shifted the resonance frequency of the antenna. The optimum value of L_1 that ensures the required performance of the antenna is L_1 = 18.5 mm. The antenna's resonance frequency at L_1 = 18.5 mm is 3.52 GHz and the bandwidth is 200 MHz as shown in figure.

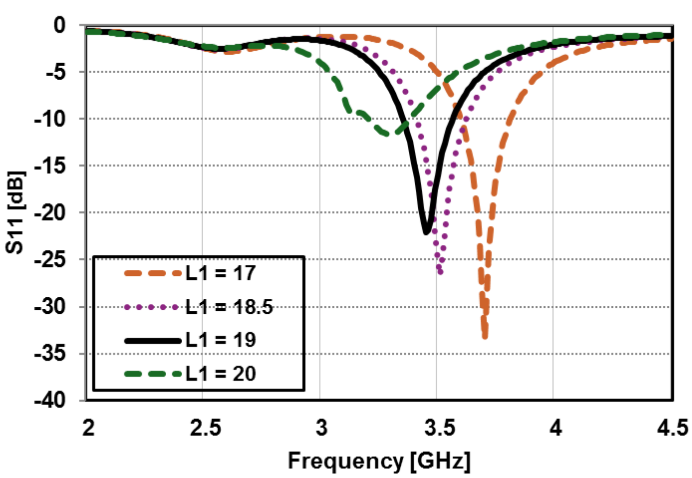
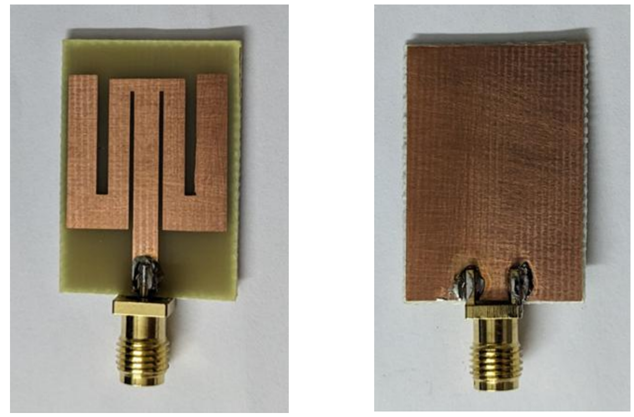


Figure 3: S11 of the antenna at different values of L_1.

3. Fabrication and Experimental Testing of the Proposed Antenna

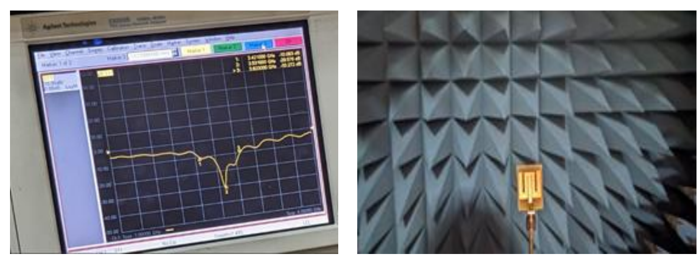
The proposed antenna is fabricated in the National Telecommunication Institute (NTI) with the dimensions 29 mm × 20 mm and is fed using SMA connector. Top and bottom sides of the fabricated antenna are shown in Figure 4. Performance of the fabricated antenna is measured in Science & Technology Center of Excellence.



(a) **(b)**

Figure 4: Fabricated antenna; (a) Top side, (b) Bottom side.

The measurements of S11 have been conducted using vector network analyzer as shown in Figure 5(a). The antenna is connected to a 50 Ω port while the impedance matching characteristics are tested over the frequency band 3 GHz to 4 GHz. The radiation characteristics of the antenna have been measured using Satimo Starlab 18 as shown in Figure 5(b). The radiation pattern of the antenna is measured in the E-plane and H-plane at three different frequencies within the matching band of the antenna, these are 3.42 GHz, 3.5 GHz, and 3.62 GHz.



(a) **(b)**

Figure 5: Measurements of the proposed antenna; (a) S11 measurement, (b) Radiation pattern measurement.

4. Results and Discussion

Measured S11 of the antenna is depicted together with the simulated one in Figure 6. It is clearly shown in the figure that there is a good agreement between the simulation and measurement results of S11 except for some ripples in the measured curve due to the measurement cables and surrounding conditions. The antenna is matched at 3.5 GHz with S11 of -30.5 dB and a bandwidth of 200 MHz extending over the frequency range 3.42 – 3.62 GHz.

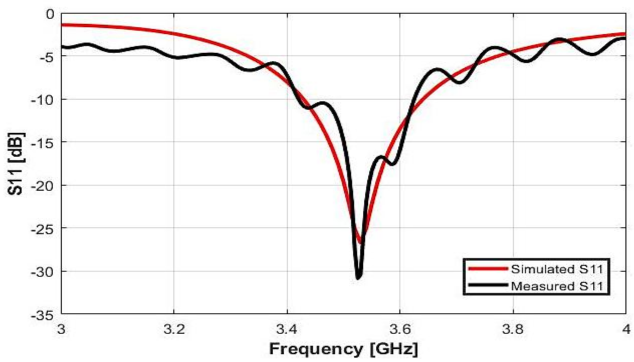


Figure 6: Measured and simulated S11 of the proposed antenna

Now we are going to discuss results of the antenna radiation pattern of the antenna. Radiation pattern of the antenna is measured at the center resonance frequency, i.e., 3.5 GHz, and at the borders of the matched frequency band, i.e., 3.42 GHz and 3.62 GHz. Figure 7 shows the radiation pattern of the antenna in the E-plane and H-plane at the three different frequencies. It is clearly shown in the figure that the radiation of the antenna is directed upwards in the z-direction. This is due to the complete ground plane in the backside of the antenna. However, a large portion of the radiated power is distributed over the backside of the antenna due to the small size of the ground plane. It can be observed from the figure that the radiation pattern in each plane takes, approximately, the same shape at the different frequencies. This emphasize that the antenna has a stable behavior along the whole bandwidth.

The following is a table of comparison that summarizes the performance parameters of the proposed antenna in this work and other antenna designs presented in the cited references. The comparison parameters include the size, the bandwidth, S11, and the gain of antenna. The proposed antenna design achieves a smaller size than all of the listed designs except for the design of reference [7] which is smaller in size but lower in the achievable gain. This table of comparison clarifies that the proposed antenna efficiently compromised between the size and the other design parameters.

Table 2: Performance comparison between the proposed antenna and other antennas in the cited references.

Reference	Size [mm^2] ($\lambda_o \times \lambda_o$)	Bandwidth [GHz]	S11 [dB]	Gain [dBi]
This Work	20 x 29 ($0.232\lambda_o \times 0.337\lambda_o$)	200	-30.85	2.1
[5]	59.7 x 80.9 ($0.694\lambda_o \times 0.94\lambda_o$)	138	-22.71	2.98
[6]	30 x 45 ($0.348\lambda_o \times 0.523\lambda_o$)	200	-40.28	5.8
[7]	20 x 12 ($0.232\lambda_o \times 0.139\lambda_o$)	200	-32	1.9
[8]	40 x 40 ($0.465\lambda_o \times 0.465\lambda_o$)	144.1	-30.61	6.05
[9]	40 x 45 ($0.465\lambda_o \times 0.523\lambda_o$)	194.7	-26.64	6.39
[10]	34 x 32 ($0.395\lambda_o \times 0.372\lambda_o$)	500	-41.74	3.4
[11]	133 x 140 ($1.546\lambda_o \times 1.627\lambda_o$)	460	-25	2.8
[12]	44 x 30 ($0.511\lambda_o \times 0.348\lambda_o$)	1026.5	-43.95	4.36

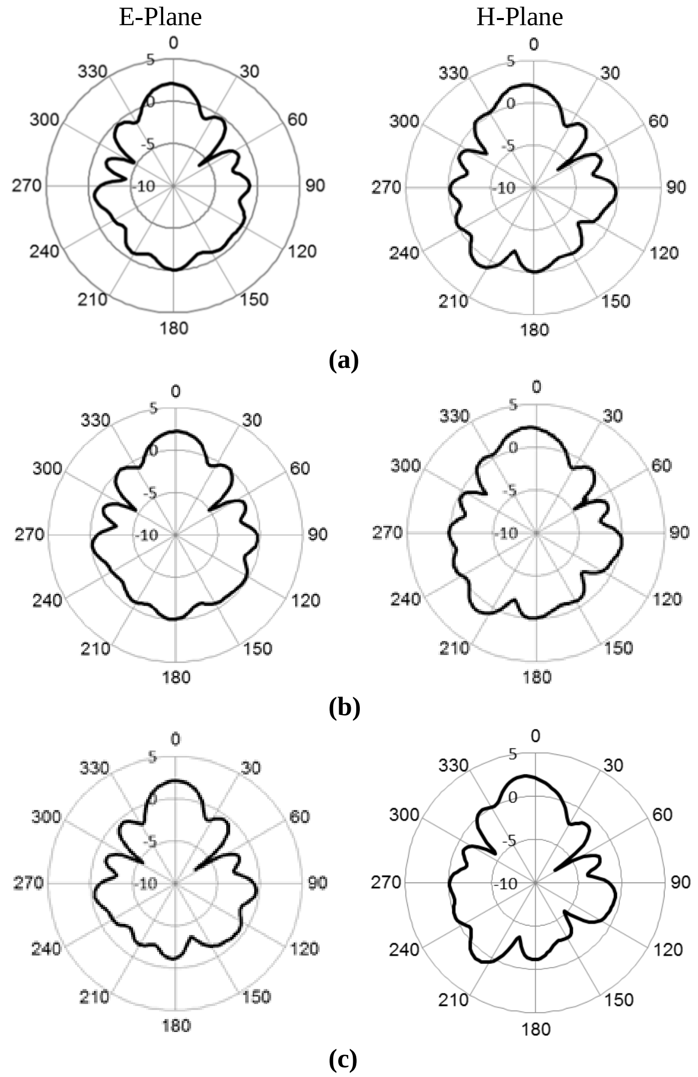


Figure 7: Radiation pattern of the antenna in the E-plane (Left Hand Side) and the H-plane (Right Hand Side) at three different frequencies; (a) 3.42 GHz, (b) 3.5 GHz, and (c) 3.62 GHz.

5. Conclusions

A 3.5 GHz compact size U-shaped microstrip antenna is presented in this paper. The antenna is designed to serve in the mid-band spectrum of 5G emerging technology. The compactness of the antenna size has been achieved by folding the two microstrip arms of the antenna in the U-shaped form. Meanwhile, the dimensions of the U-shaped arms are optimized such that the current flows in the same direction over each side of the U shape. The flow of antenna's current in the same direction ensures good radiation characteristics and high gain. The antenna has been simulated, fabricated and measured. The measured performance of the antenna has shown that the antenna is properly matched at 3.5 GHz with S11 of -30 dB. The antenna is matched over the frequency band 3.42 GHz to 3.62 GHz with 200 MHz impedance bandwidth. The measured gain of the antenna has recorded 2.1 dBi with stable behavior over the whole operating frequency band. The proposed antenna design combines the simplicity of design and compactness of size, all of these together with satisfactory electrical and radiation characteristics.

Conflict of Interest

The authors declare no conflict of interest.

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