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High Gain 1x4 Slot Antenna Array for 5G 28GHz Networks

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A B S T R A C T

This work introduces a high-gain slot antenna designed for the latest 5G networks, specifically operating at a frequency of 28 GHz. The antenna features a rectangular slot design, and its gain is significantly enhanced using 1x2 and 1x4 antenna arrays, resulting in an approximate increase of 4.2 dBi. The antenna has been fabricated and thoroughly tested, demonstrating operation within the frequency range of 26 GHz to 29.6 GHz with an S11 value of ≤ -10 dB, and achieving a gain of about 5 dBi across this band. The 1x2 and 1x4 antenna arrays have shown a bandwidth with S11 ≤ -10 dB ranging from 25.6 GHz to 29.8 GHz and 26.4 GHz to 29.9 GHz, respectively, attaining gains of 7.4 dBi and 10.4 dBi at 28 GHz. The simulation and experimental results exhibit consistent patterns, confirming the proposed antenna's suitability for new 5G applications. All simulations were conducted using an EM simulator.

1. Introduction

Every decade, new generations of mobile technology are introduced, driven by increasing data volumes, variety, and the rapid evolution of data consumption types. The next generation, 5G, is already being rolled out and will eventually replace the 4G networks that began in 2010. Transitioning to millimeter-wave (MMW) will be in a progressive way, leveraging the benefits of increased capacity, lower system latency, larger bandwidth, and a vast available spectrum[1-2]. The lower band and the higher band are considered the two primary frequency bands for 5G technology [3-4]. The mm-wave range, including 28 GHz and 38 GHz, is recognized as a potential standard for future 5G applications[5-6],. Utilizing more spectrum enables higher transmission speeds and capacity, though the corresponding frequencies are influenced by atmospheric attenuation, like rain and fog. These absorption difficulties may be handled by utilizing high-gain, highly directional antennas[7-8].

Researchers have proposed several high-gain antenna designs, including antenna arrays with an artificial magnetic conductor (AMC) beneath the antenn[9-10], and the use of frequency selective surfaces (FSS)[11]. In [12], a dense dielectric patch with array configuration is investigated to be worked at 28 GHz. Dense dielectric patch antennas have higher radiation efficiency than standard metallic patch antennas, particularly at higher frequencies. A superstrate functions as a lens to enhance the antenna radiation which in turn improves the antenna gain is discussed in [13]. Ref [14] investigates a 28 GHz Yagi-Uda antenna to enhance the antenna gain of around 12.7. In [15], a 28 GHz linear array with 10 dBi gain is discussed. A high-gain dipole antenna with 12.5 dBi is discussed in [16]. In this present research, 1x2, and 1x4 slot antenna arrays are created for gain enhancement. Using the 1x2 and 1x4 antenna arrays increases the antenna gain by approximately 4.2 dB. The fabricated antenna was tested, showing good agreement between simulated and experimental results. The 1x2 and 1x4 antenna arrays achieved bandwidths with S_{11} ≤ -10 dB, ranging from 25.4 GHz to 29.8 GHz and from 26.4 GHz to 30 GHz, respectively, and realized gains of about 7.4 dB at 27.3 GHz and 11.15 dB at 27.8 GHz. The proposed antenna demonstrates a compact size and suitable gain. The paper is arranged as: the first part provides an introduction and overview of 5G antenna improvement strategies. The second part describes the single antenna structure design. The third part describes the 1x2 antenna array. The final section outlines the numerical outcomes of the suggested 1x4 antenna array setup. The final point was presented in the fifth section.

2. Single Antenna

Figure 1 shows the 2D perspective view of the slot antenna arrangement as well as the fabricated photo. A 50 Ω microstrip line is placed on a 4003 Rogers substrate, which has a dielectric constant of 3.35, a thickness of 0.203 mm, and tan δ = 0.0027. The feed line is on the top layer of the substrate, while the slotted rectangular is on the ground bottom layer. The design parameters include L=12 mm, a=3 mm, and b=2.6 mm, with the overall antenna dimensions being 12 mm x 12 mm. The feeding line leegnth has an important role in achieving good matching features. The end launcher connector is utilized in the simulation process as illustrated in Figure 1 to mimic the testing process. The proposed antenna has been investigated utilizing the EM simulator. The length of the microstrip line (denoted as d) is crucial for achieving optimal matching, as depicted in Figure 2. Any variation in microstrip length can influence the capacitance and inductance values of the transmission line, thereby affecting the antenna matching, as illustrated in Figure 2.

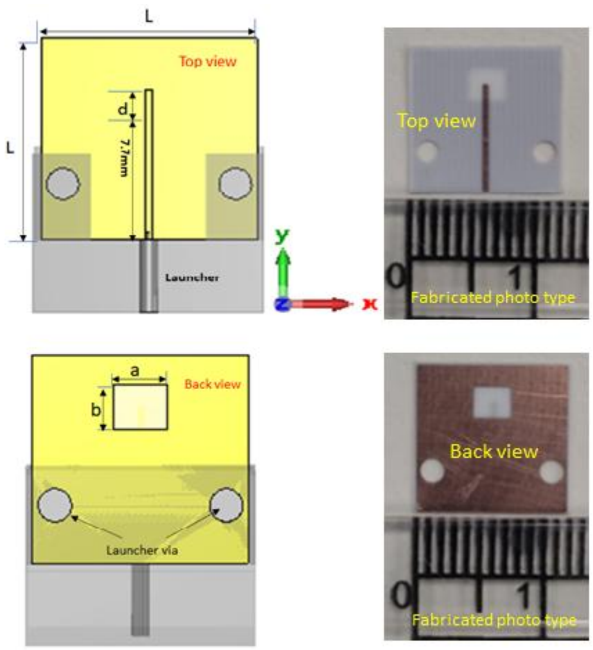

Figure 1: 2D design and an image of the fabricated slot antenna

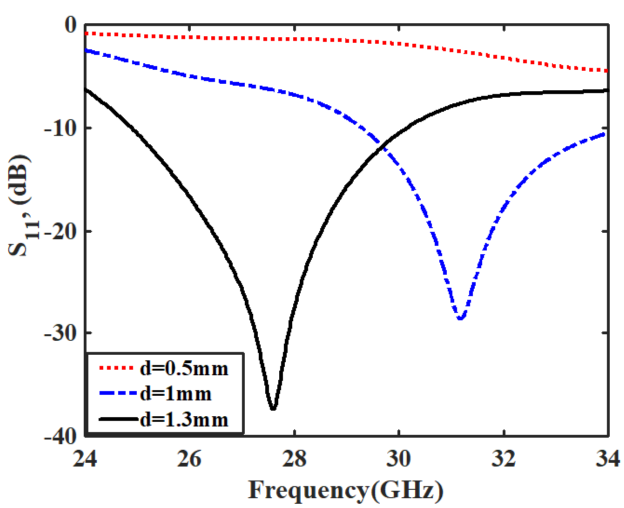

Figure 2: S11 with different values of (d)

The antenna matching changes significantly, as the microstrip length (d) moves between the two values 0.5 and 1.3 mm. At d = 0.5 mm, we lose the antenna matching within the frequency of interest, as displayed in Figure 2. While at d = 1 mm, the frequency band from 29.7 GHz - 34 GHz is obtained with a good level of antenna matching around -28 dB. Finally, at d = 1.3 mm, a frequency band of 26.5 GHz - 30 GHz is produced, with a matching level of less than -37 dB. Figure 3 shows a model of the present current spread at 28 GHz. It's observed that the current is gathered about the slot, ensuring that the antenna radiates effectively within the 28 GHz frequency range.

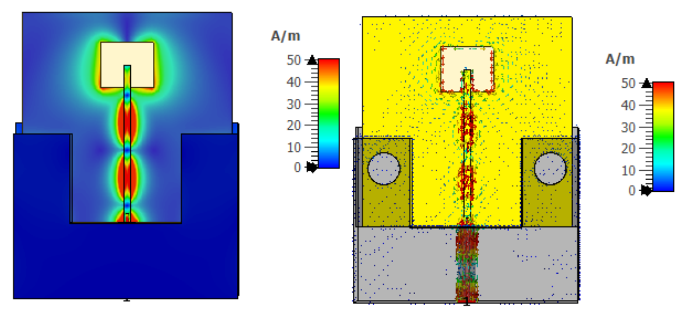

Figure 3: The slot antenna's current distribution

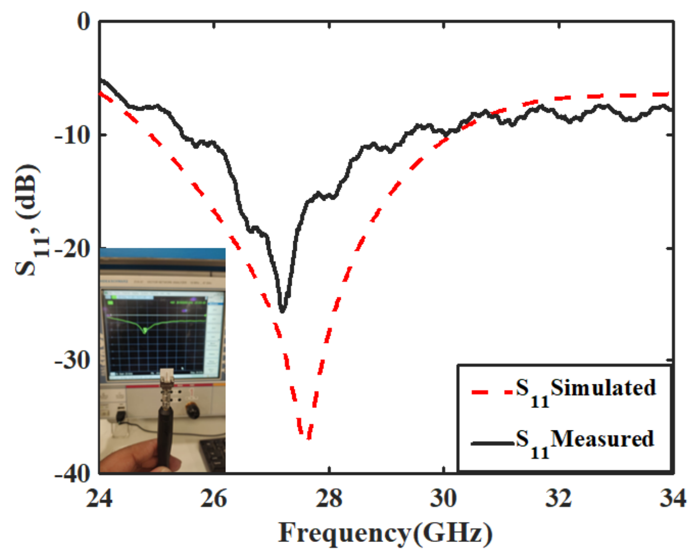

Figure 4: S11 Outcomes of the slot antenna

The VNA Rohde & Schwarz ZVA 67 is utilized to test the slot antenna through the end launcher, which produces the tested reflection coefficient data displayed in Figure 4. Figure 4 also shows the antenna's calculated frequency spectrum from 25.5 GHz - 30 GHz (4.5 GHz bandwidth), using S11 ≤ -10 dB. The tested results suggest a frequency band of 26 GHz - 29 GHz (3 GHz bandwidth) with S11 ≤ -10 dB. The simulated and measured results were consistent, as indicated in Figure 4. The measurement setup uses an anechoic chamber, with a slot antenna installed at the receiving end, maintaining a 65 cm distance to meet far-field criteria. A horn antenna, functioning within the range from 26 to forty GHz, is set up at the end where it sends signals. The experimental antenna is rotated in two directions while keeping a direct view connection with the other antenna, as shown in Figure 5. Figure 6 displays the actual gain achieved by the antenna. Within the frequency band, the simulation yields approximately 5 dBi, while the measured results show around 4.7 dBi. Figure 7 displays the radiation of the antenna operating at 28 GHz. The patterns are generated by The antenna that exhibits symmetrical behavior in both directions, showing a significant relationship between the two sets of findings.

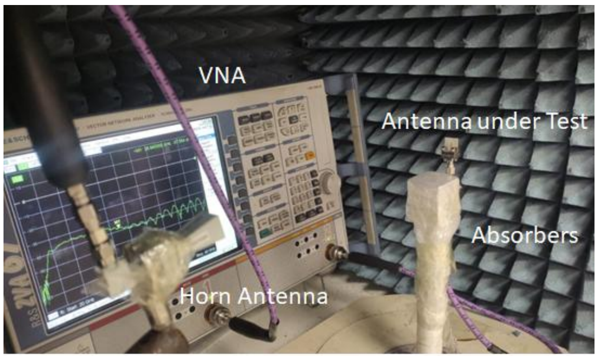

Figure 5: The radiation measuring mechanism of the antenna structure

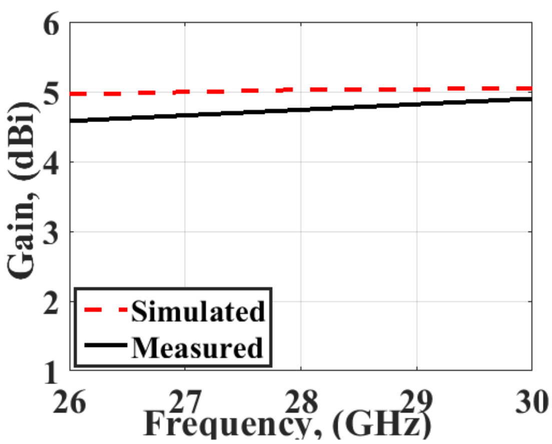

Figure 6: The gain of slot antenna

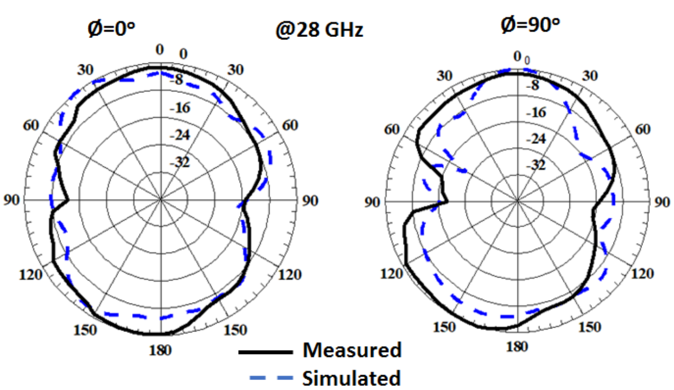

Figure7: The radiation pattern of the antenna

3. 1x2 Antenna Array

To enhance the gain performance compared to the previous antenna, a simple equal-phase feeding network is used to build 1 x 4 linear arrays. This Part covers 1x 2 sub-arrays; a complete 1 x 4 antenna array is provided in the following part. A basic T-power divider is used to distribute the array. As a Wilkinson energy divider, this kind of setup does not require an isolation resistor. Connecting two 50Ω lines in parallel creates an approximately 25Ω impedance transformer with a λ/4 ratio and an impedance of 35.35Ω is linked to the 50Ω input line. Figure 8 depicts the two views of the 1x2 antenna array in the 2D layout. The design parameters are lf=7, L1=1.9, L2=3, X1=0.4, X2=0.8, X3=4.8, and w=2.2 (all in millimeters). Figure 9 depicts the 1x2 antenna array reflection coefficient. The antenna is modeled using a frequency spectrum that ranges from 25.6 GHz to 29.8 GHz, with an S_{11} value not exceeding -10 dB. The actual measurements achieved a frequency spectrum from 25.8 GHz to 29.5 GHz. The simulated and actual outcomes show a high degree of consistency. A gain of 7.4 dBi at 28 GHz has been accomplished in this configuration.

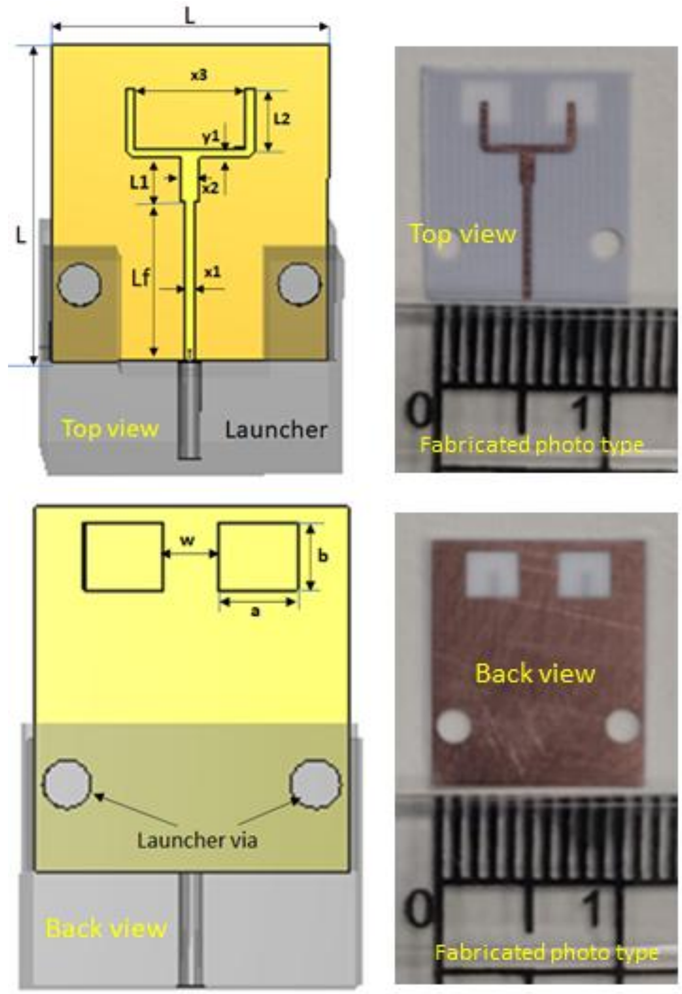

Figure 8: 2D design and an image of the fabricated 1x2 antenna array

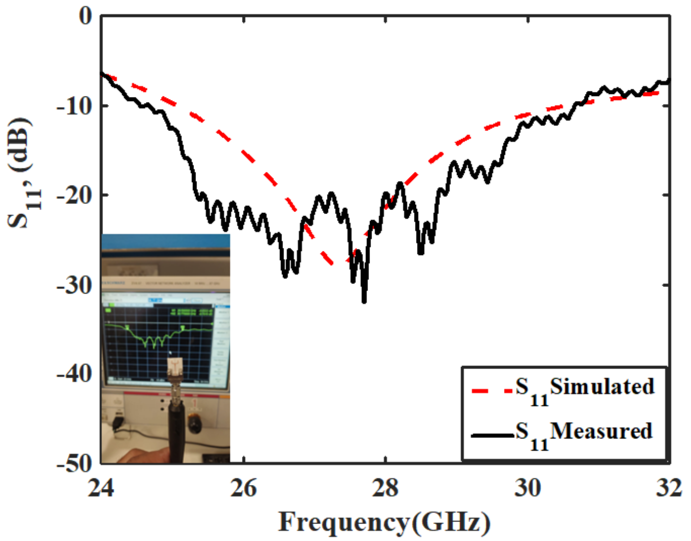

Figure 9: S11 outcomes of the 1x2 antenna array

4. 1x4 Antenna Array

By merging three T-power divider units into a 1x2 configuration, a 1x4 antenna array was created, which led to effective matching and appropriate gain properties. Optimization parameters for T-dividers are carried out to obtain good results. Figure 10 shows the geometry of the 2D arrangement and a produced photo of the 1x4 antenna array. The design parameters are: L3=1.5, L4=3, Y1=0.4, Y2=0.8, Y3=0.4, X1=10, X2=4.8, X3=4.8, C1=0.4, and C2=0.3 (all in millimeters). Figure 11 shows the reflection coefficients for a 1-by-4 antenna setup. During the testing phase, the Rohde and Schwarz ZVA 67 is employed. The simulated frequency spectrum of the antenna spans from 26.3 GHz to 30 GHz. The tested results obtained S11 ≤ -10 dB from 26.6 GHz - 29.8 GHz.

Figure 11 shows that the simulated and measured results have good accuracy, which can be attributed to the fabrication procedure. The measurement setup uses an anechoic chamber, with a 1×4 slot antenna installed at the receiving end, maintaining a 65 cm distance to meet far-field criteria. A horn antenna, functioning within the range from 26 to forty GHz, is set up at the end where it sends signals. The experimental antenna is rotated in two directions while keeping a direct view connection with the other antenna, as shown in Figure 12. The 1 x 4 array's gain vs frequency is shown in Figure 13. The calculated maximum gain of the array matches the actual measurements. The calculated gain at 28 GHz is 10.8dBi, and the actual gain is 10.4dBi. Figure 14 shows the 2D normal radiation pattern at 28 GHz. The 1 x 4 array forms a two-way pattern in two directions, creating a narrow beam, and showing the array's good directivity. This is due to the antenna array.

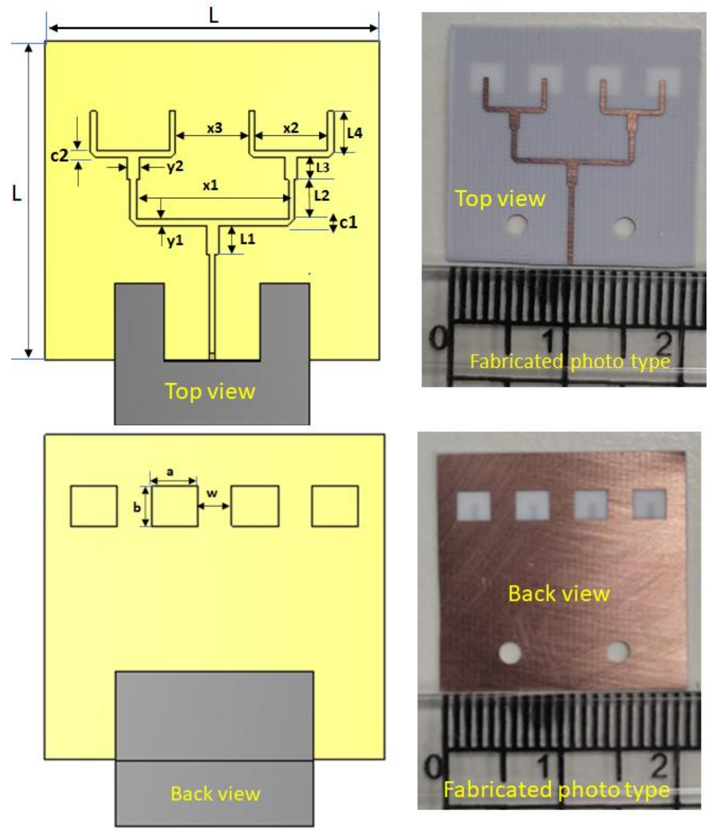

Figure 10: 2D design and an image of the fabricated 1x4 antenna array

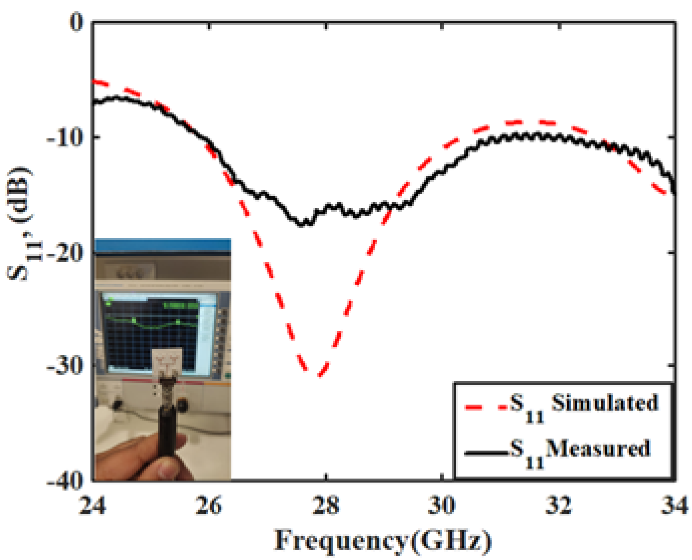

Figure 11: S11 Outcomes from Simulations and Measurements of the 1x4 Antenna Array

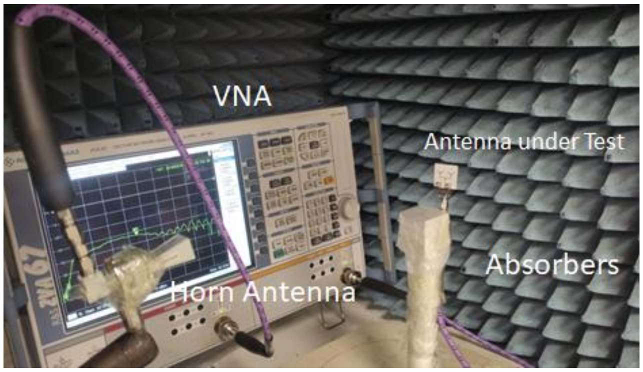

Figure 12: The radiation measuring mechanism of the 1x4 antenna structure

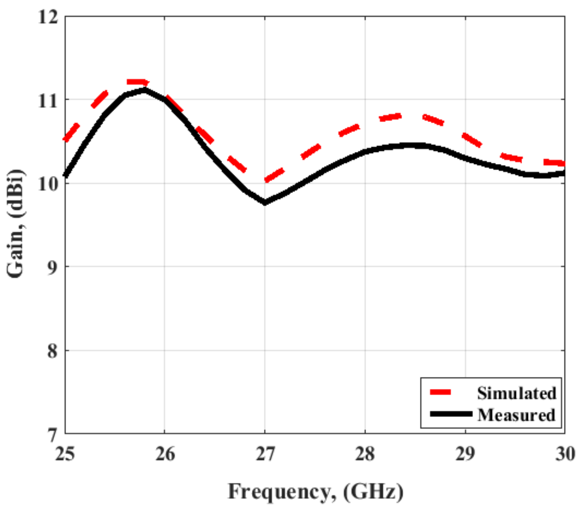

Figure 13: The 1x4 antenna array gain vs frequency

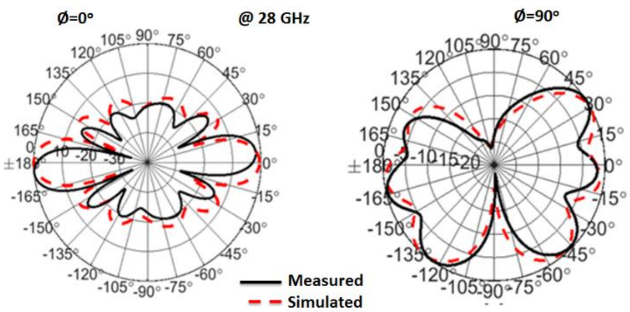

Figure 14: The radiation patterns of the 1x4 antenna

5. Conclusions

A design of slot antenna applicable for 5G networks, featuring improved gain, has been put forward. The desired gain enhancement was achieved using a 1x4 array. The proposed antenna measures a total of 12x12 mm. The antenna, lacking a 1x2 or 1x4 configuration, reached a frequency range of S11 = -10 dB between 26.5 GHz and 30 GHz, with a gain of 5 dBi. When using the 1x2 and 1x4 arrays, the bandwidths achieved with S11 = -10 dB were from 25.6 GHz - 29.8 GHz and from 26.4 GHz - 29.9 GHz, with realized gains of 7.4 dBi and 10.4 dB at 28 GHz, respectively. A good connection between measured and simulated data indicates that the suggested antenna is suitable for impending 5G networks.

Conflicts of Interest

The authors declare no conflict of interest.

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Abbreviation and symbols

MMW	**millimeter-wave**
AMC	**artificial magnetic conductor**
FSS	**frequency selective surfaces**