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A Novel Cow-Head Shaped Multiple Input Multiple Output Antenna for 5G Sub:6 GHz N77/N78 & N79 Bands Applications

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Abstract—The present work proposes a novel cow-head shaped multiple input multiple output (MIMO) antenna for 5G sub:6 GHz applications, which include N77/N78 (3.3–4.2 GHz/3.3–3.8 GHz) and N79 (4.4–5.0 GHz) bands. The proposed work is designed and developed on a $30 \times 66\,\mathrm{mm}^2$ size FR4 substrate with a dielectric constant of 4.4 and loss of tangent of 0.002. The proposed design works in the region from 3.3 to 5 GHz, and an isolation above 18 dB is attained. The parametric analysis and surface current distribution are studied for the optimization of parameters, and the coupling between elements is analyzed respectively. The performance of the design is studied in terms of efficiency ($\geq 91.5\%$), peak gain (3.1–4.6 dBi), and radiation patterns (E & H fields). The diversity parameters (ECC, DG, TARC, CCL, & MEG) are calculated and checked, the same as measured results. Then all the measured results of the fabricated prototype are compared with simulated ones, and they are in good agreement.

1. INTRODUCTION

Multiple Input Multiple Output (MIMO) technique is playing a key role in present wireless communications due to its imminent features like high data rate, channel capacity, and good quality of service. It is an efficient technique to combat multipath fading in a free space environment [1, 2]. However, one of the main limiting factors in MIMO technology is mutual coupling. Mutual coupling is mainly due to the number of antenna elements connected in limited space in portable devices and element-to-element spacing. Due to the lower spacing between the antenna elements, the radiation and surface currents of individual elements may collide and flow to the other elements respectively. Till now, different methods used by authors are Defected Ground Structure (DGS), Electromagnetic Band Gap (EBG) structures, decoupling structures, metamaterials, neutralization techniques, and parasitic elements [3, 4]. The first generation (1G) communication is transmitting the voice signal only. Next, 2G, 3G, and 4G (LTE) communication technologies came into existence and play a vital role in wireless communication. However, these technologies are not capable of providing higher data rates and better channel capacity due to the limited channel bandwidth. Today we are living in an era of 5G communication technology with many improved and advanced features. The salient advantages of 5G communication are higher data rates with more channel capacity and effective transmission. The combination of MIMO with 5G communication is most desirable in current wireless technologies, particularly in mobile base station applications [5, 6].

The authors have proposed distinct MIMO antennas for the 5G sub:6 GHz applications. A simple planar patch antenna is designed for 5G NR 77/78 & 79 bands, and it also covers the UMTS & GSM bands. However, it is a single element structure [7]. A swastika slotted rectangular patch MIMO antenna is designed for 5G sub:6 GHz applications, and the isolation of 16.86 dB is attained [8]. A two element patch antenna developed for 5G sub:6 GHz wireless applications is presented [9]. A reconfigurable patch

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antenna mapped out for WLAN and sub:6 GHz applications is presented [10]. A cross dipole antenna designed for 4G and 5G applications at base stations is presented [11]. A transparent two element 5G antenna is designed for sub:6 GHz applications. Isolation of above 15 dB and good diversity performance are obtained with proper design parameters [12]. A dual element hybrid MIMO antenna is designed for sub:6 GHz and WLAN applications [13]. A triple band MIMO antenna is designed. Bands include WIFI, 5G, and WLAN applications [14]. A 4-element circular loop with a gap array antenna designed for sub:6 GHz applications is presented [15]. Two and eight element MIMO antenna arrays are designed and presented in [16], and the isolation of only 12 dB is obtained. An octagonal patch slotted hexagon-shaped MIMO antenna designed for wideband applications is presented [17]. A two element decoupling MIMO antenna is presented for 5G applications [18]. In the above-listed literature, most of the works are designed for 5G sub:6 GHz applications along with either WiFi or WLAN bands and in some cases, 4G applications. However, the present work is exclusively designed for 5G sub:6 GHz applications.

The proposed work is designed for 5G sub:6 GHz applications. It covers the bandwidth from 3.3 to 5.0 GHz, which includes N77/N78 & N79 bands. The proposed design is developed on a low-cost FR4 substrate with size $30 \times 66\,\mathrm{mm}^2$ and dielectric constant 4.4. The isolation of above 18 dB is attained in the entire working region. Radiation performance is checked with efficiency ($\geq 91.5\%$), gain (3.1–4.6 dBi), and patterns results. Stable and bore sight patterns are attained with a proper constructive design. The diversity metrics ECC, DG, TARC, CCL, & MEG values are calculated and checked with measured results.

2. ANTENNA DESIGN & ANALYSIS

2.1. Antenna Design & Process

The proposed cow-head-shaped single antenna with dimensional parameters is presented in Fig. 1, and parameter values are presented in Table 1. The proposed design is developed on a low-cost FR4 substrate having a height of 1.6 mm and a dielectric constant of 4.4. The proposed single antenna works in the band from 3.0 to 5.2 GHz, and the two element antenna operates in 3.3 to 5.0 GHz band region with an

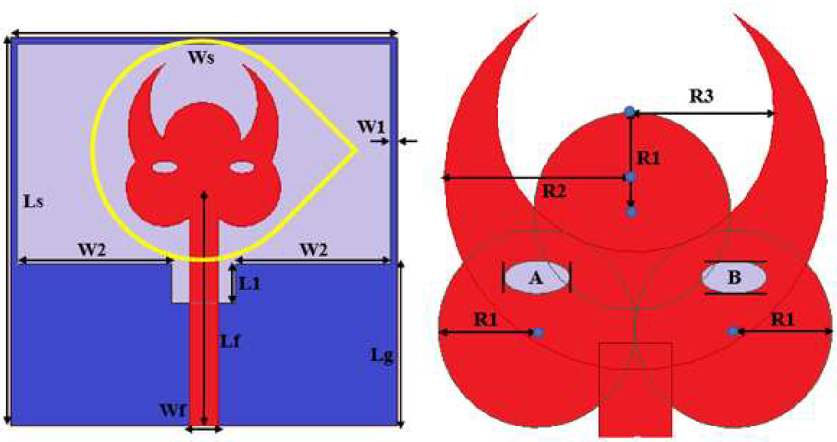

Figure 1. Proposed single antenna structure with dimensional parameters.

Table 1. Proposed antenna parameters with values.

Parameter	L_s	W_s	L_g	L_1	L_f	W_f	W_1
Value (mm)	30	30	12.5	3	15.5	2.2	0.5
Parameter	W_2	R_1	R_2	R_3	A	B	h
Value (mm)	12	4	5.8	4.3	2	1	1.6

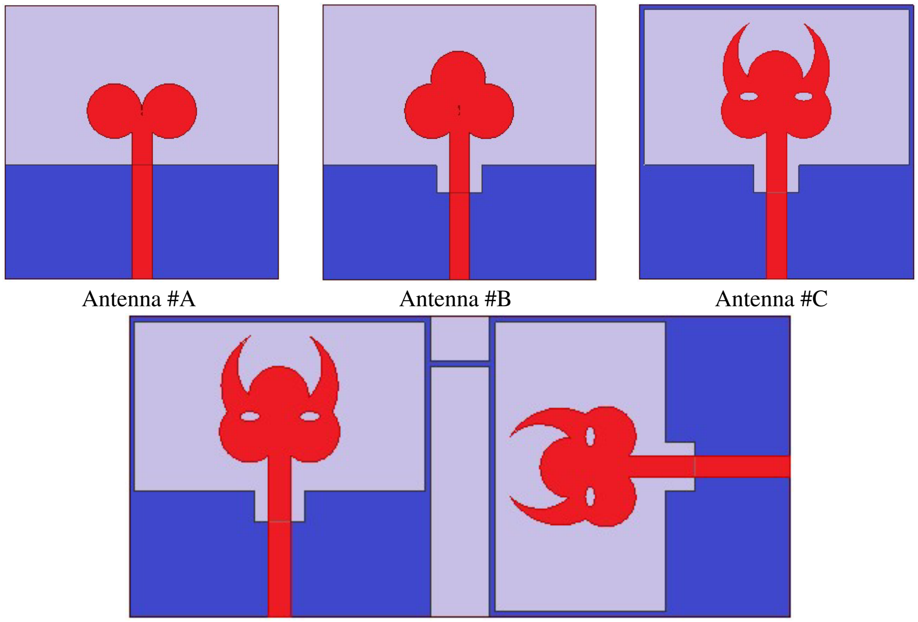

Figure 2. Proposed antenna evolution.

isolation of 18 dB and above. The proposed design evolution process is depicted in Fig. 2. Initially, two united small circular patches of radii 4 mm are attached to the microstrip line feed, and it was named Antenna #A. Due to the impedance mismatching, Antenna #A did not work in the 5G sub:6 GHz region. Later, one more circular patch is united on the top layer, and the rectangular strip is subtracted from the ground layer to form Antenna #B. However, Antenna #B covers only the N79 band, which is from 4.2 to 5.2 GHz, but impedance matching at this region is very poor. To get better impedance matching at this region, optimized dimensional values of the moon-shaped patch are added to Antenna #B. Finally, Antenna #C is also formed with the inverted C-shaped strip added to the ground layer, and two small circular slots are removed. Now, Antenna #C looks like a cow-head-shaped antenna, and it works from 3.0 to 5.2 GHz. The proposed single antenna covers all 5G sub:6 GHz bands. To extend the single antenna MIMO structure, another same antenna is placed orthogonally with a separation of 6 mm. A small strip of size $6 \times 0.5\,\text{mm}^2$ is used to connect the two antennas. Then Antenna #D is formed, and it is a MIMO antenna with connected ground. The proposed two-element cow-head shaped MIMO antenna works in the band from 3.3 to 5.0 GHz, and the isolation of above 18 dB in most of the region is attained. The S-parameter results of the evolution process are represented in Fig. 3.

2.2. Parametric Analysis

The optimized dimensional values are attained by applying parametric analysis to various required parameters of an antenna. These parameters include feed width (W_f), ground length (L_g), ground strip width (W_1), and ground slot length (L_1). Feed width 2.2 mm, ground length 12.5 mm, ground strip width 0.5 mm, and ground slot length 3 mm are considered optimized dimensional values. The simulation results of the parametric analysis are presented in Fig. 4.

2.3. Suraface Current Distribution (SCD)

The surface current distribution (SCD) is studied at various frequencies like 3.3 GHz, 3.8 GHz, 4.6 GHz, and 5.0 GHz. The parameter SCD describes the effect of surface currents of one antenna on another antenna for coupling analysis. Here, port 1 is excited with a 50 Ω microstrip line, and another port is terminated with a 50 Ω load line. The surface current distribution of various frequencies in the active region is presented in Fig. 5. Higher isolation characteristics are attained with the orthogonality arrangement of antenna elements and a connected small strip arrangement.

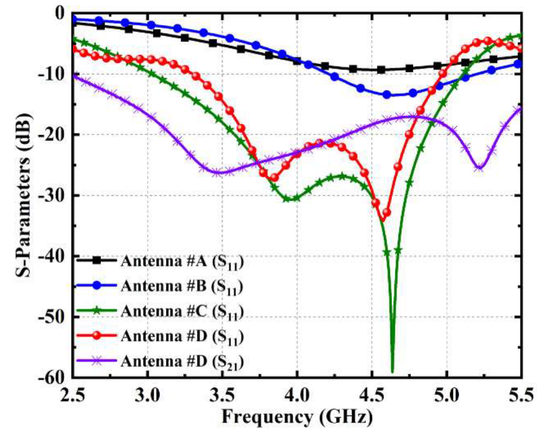

Figure 3. Evolution results of proposed antenna.

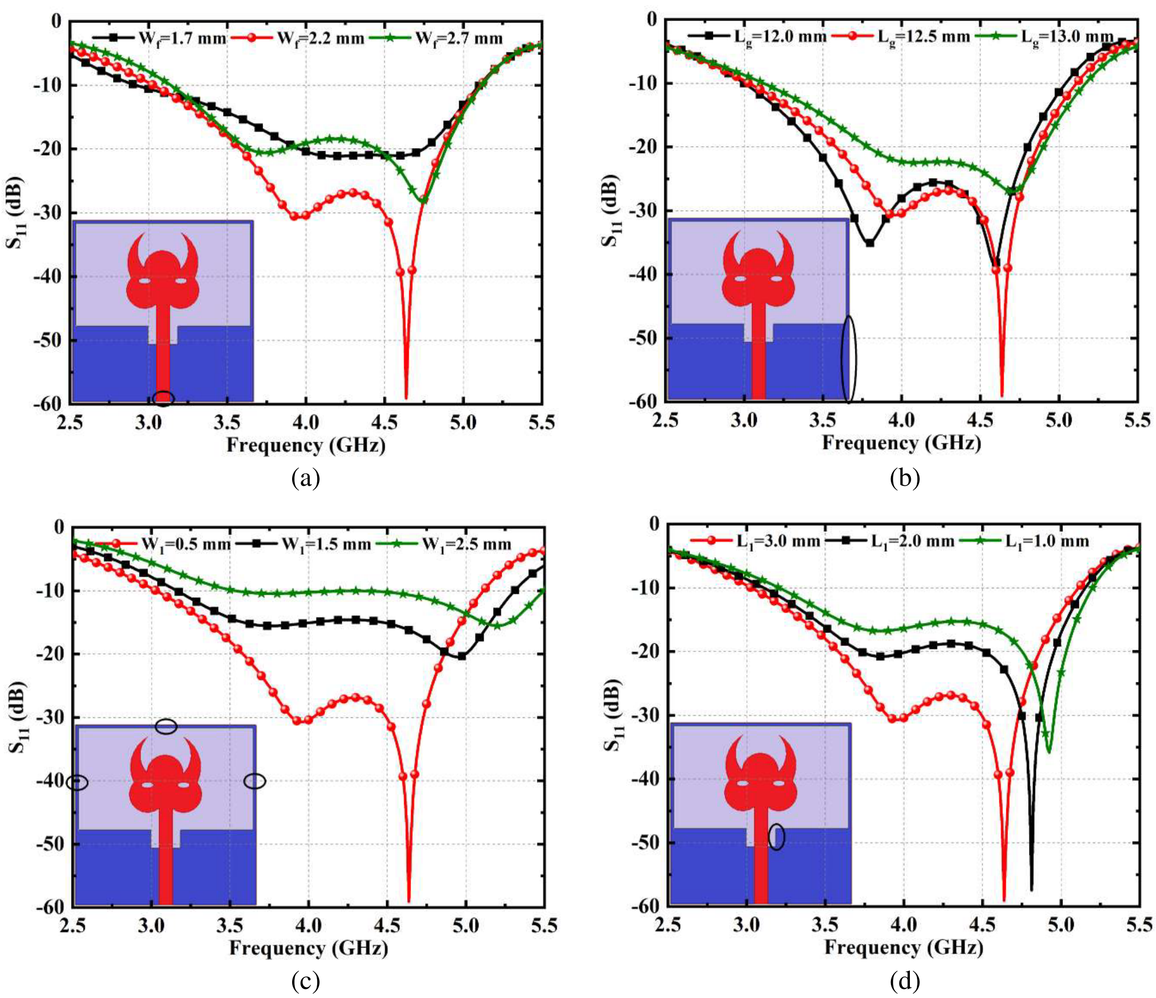

Figure 4. Parametric analysis of proposed antenna; (a) W_f; (b) L_g; (c) W_1 and (d) L_1.

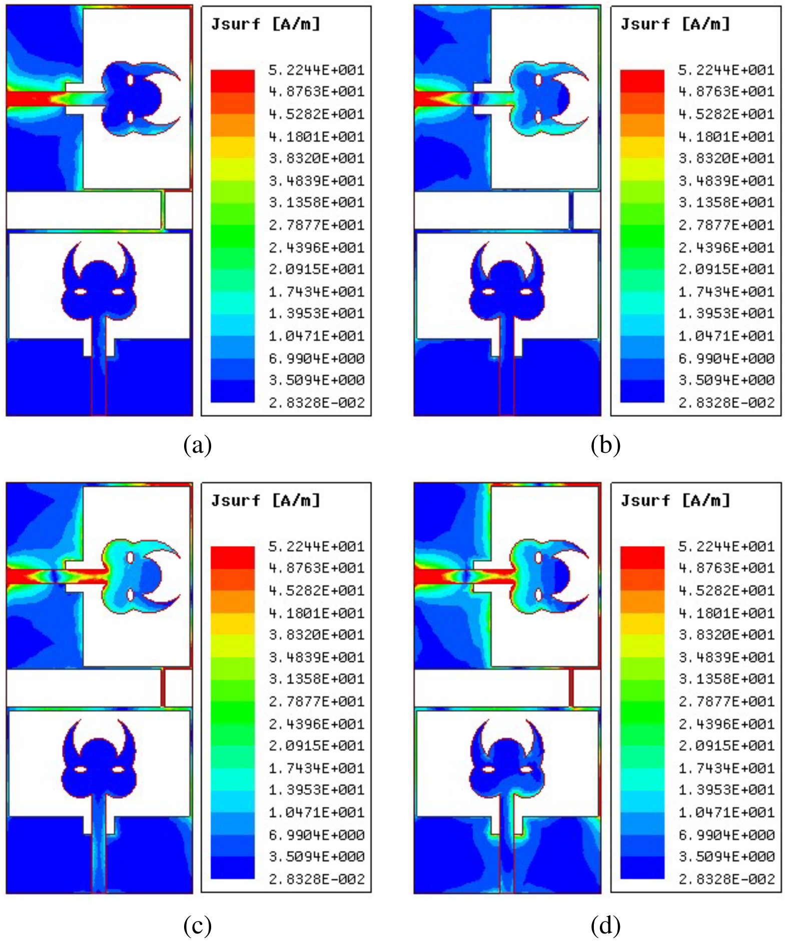

Figure 5. Surface current distribution of proposed antenna; (a) at 3.3 GHz; (b) at 3.8 GHz; (c) at 4.6 GHz and (d) 5.0 GHz.

3. RESULTS AND DISCUSSIONS

3.1. *S*-Parameters

The proposed fabricated prototype is tested, and the results include S-parameters and radiation patterns. The measured S-parameter results are compared with simulated ones which are depicted in Fig. 6(a). The results are in good agreement, except for deviations. The deviations between simulated and measured results are mainly due to tolerances in the fabrication process and soldering at ports. Anyways, both the results covered the entire bands of N77/N78 & N79 bands, and an isolation of 18 dB and above between the ports is attained in the entire working region. Figs. 6(b) & (c) present the fabricated prototype front and rear views.

3.2. MIMO Performance

The diversity performance of a MIMO antenna is checked with well-known and required parameters like ECC, DG, TARC, CCL, & MEG. These parameters are evaluated and analyzed. The correlation between antenna elements is checked with the ECC parameter. The practical acceptable value of ECC in a free space environment is 0.5. The proposed design simulated and measured results of ECC are below 0.05. Hence, the proposed design is very suitable in a free space environment to combat multipath fading. The ECC values are both simulated, and results can be determined using S-parameters. The

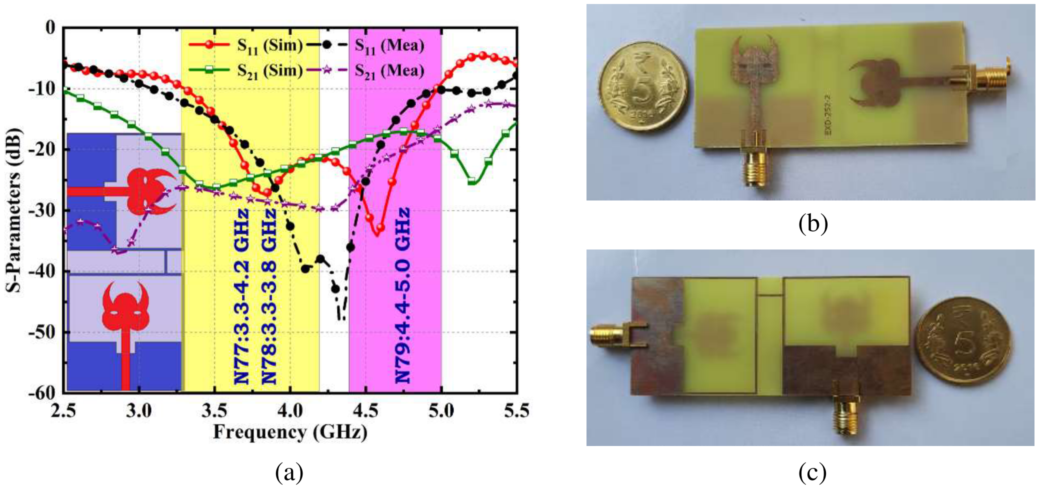

Figure 6. Proposed antenna; (a) simulated and measured results comparison; (b) front view fabricated prototype and (c) rear view fabricated prototype.

ECC using S-parameters is represented in Equation (1), and compared results are presented in Fig. 7(a) [19, 20]. The diversity gain (DG) is also calculated using ECC results. The DG values are almost at 10 dB in the entire working region as depicted in Fig. 7(b) parameters

$$ECC = \frac{|S_{11}^* S_{12} + S_{12}^* S_{22}|^2}{\left(1 - |S_{11}|^2 - |S_{21}|^2\right)\left(1 - |S_{22}|^2 - |S_{12}|^2\right)} \tag{1}$$

$$DG = 10\sqrt{1 - ECC^2} \tag{2}$$

The TARC results are also calculated using S-parameters governed by Equation (3). The simulated and measured results are compared in Fig. 7(c). TARC is a useful parameter for estimating the active reflection coefficient of the overall MIMO system because it considers the changes in self and mutual impedances [21]. The acceptable value of TARC in a free space environment is ≤ 0 dB. The proposed design simulated and measured results of TARC are below -10 dB.

$$TARC = \sqrt{\frac{|(S_{11} + S_{12}e^{j\theta})|^2 + |(S_{21} + S_{22}e^{j\theta})|^2}{2}} \tag{3}$$

The parameter CCL describes the number of bits lost during the transmission process. It is calculated using S-parameters as represented in Equation (4). The simulated and measured results of CCL are below 0.05 bits/s/Hz; practical considerable values are below 0.4 bits/s/Hz. The compared results of CCL are presented in Fig. 7(d).

$$C_{Loss} = -\log_2 det(\alpha^R) \tag{4}$$

where,

$$\alpha^R = \begin{bmatrix} \alpha_{ii} & \alpha_{ij} \\ \alpha_{ji} & \alpha_{jj} \end{bmatrix}$$

$$\alpha_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right); \quad \alpha_{ij} = -\left(S_{ii}{}^* S_{ij} + S_{ji}{}^* S_{jj}\right);$$

$$\alpha_{ji} = -\left(S_{jj}{}^* S_{ji} + S_{ij}{}^* S_{ii}\right); \quad \alpha_{ii} = 1 - \left(|S_{jj}|^2 + |S_{ji}|^2\right).$$

The receiving capability of MIMO system is estimated with the parameter known as MEG. The MEG values (simulated and measured) are calculated, represented in Fig. 7(e) and these are represented in

Equation (5). In a free space environment, acceptable MEG values are below $-3\,\mathrm{dB}$ [22, 23]

$$MEG_i = 0.5\eta_{i,rad} = 0.5\left[1 - \sum_{j=1}^{M} |S_{ij}|^2\right] \tag{5}$$

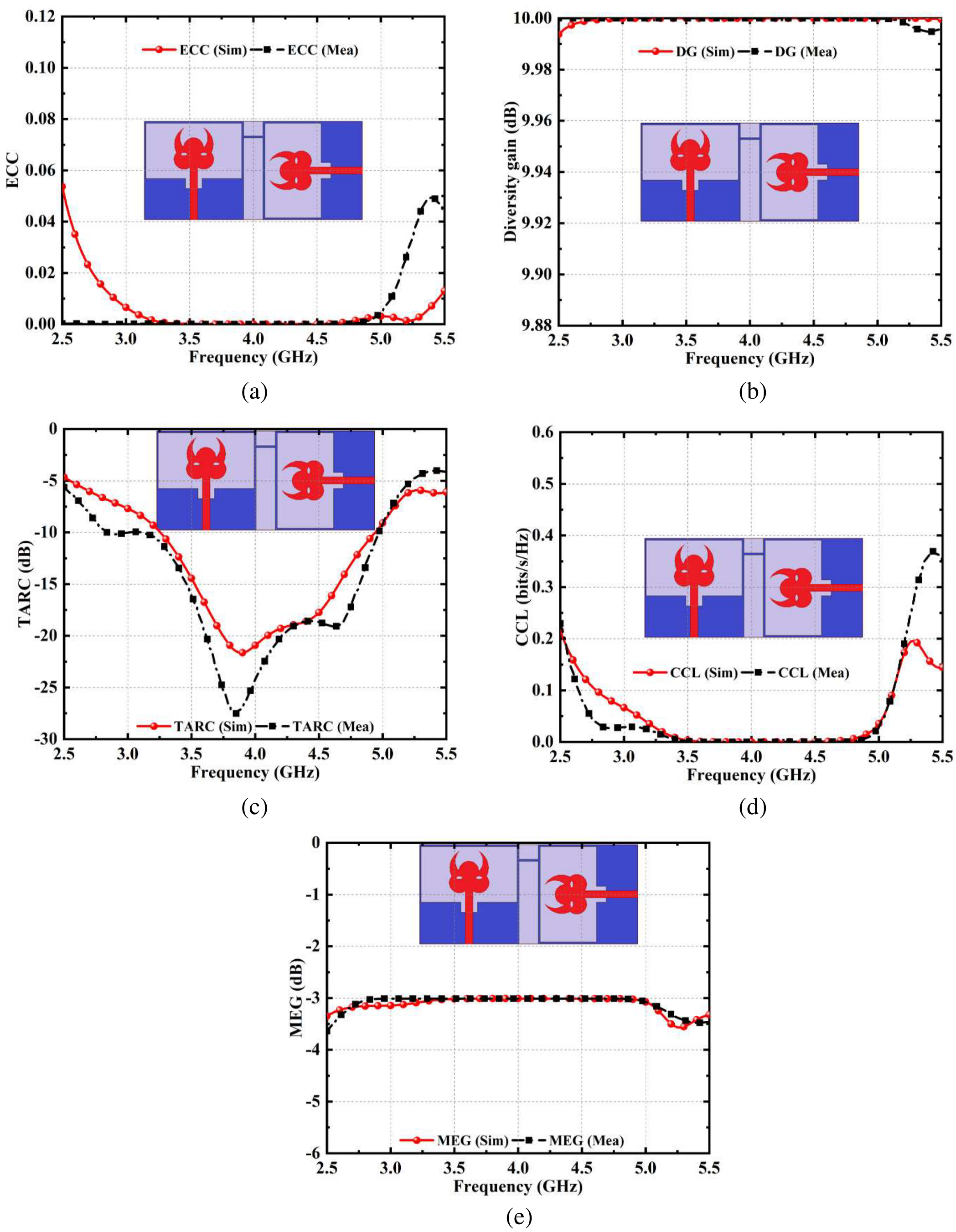

Figure 7. Proposed antenna MIMO performance; (a) ECC; (b) DG; (c) TARC; (d) CCL and (e) MEG.

3.3. Radiation Performance

The radiation performance of the proposed design is analyzed with efficiency, gain, and pattern results. The simulated radiation efficiency and peak gain results are presented in Fig. 8. The efficiency results mainly depend on impedance matching at ports. The efficiency of above 91% is attained in the entire working region. The peak results are attained in the range of 3.1 to 4.6 dBi.

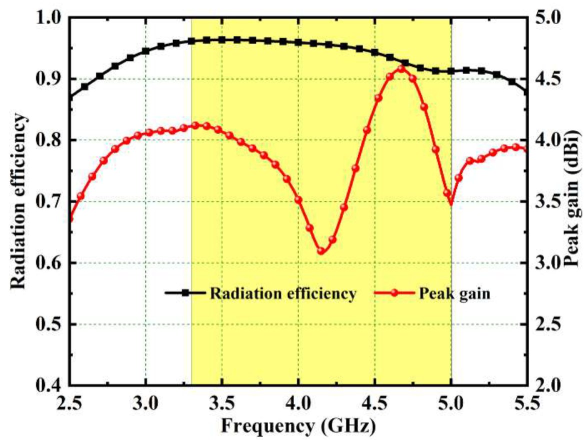

Figure 8. Proposed antenna radiation efficiency and peak gain results.

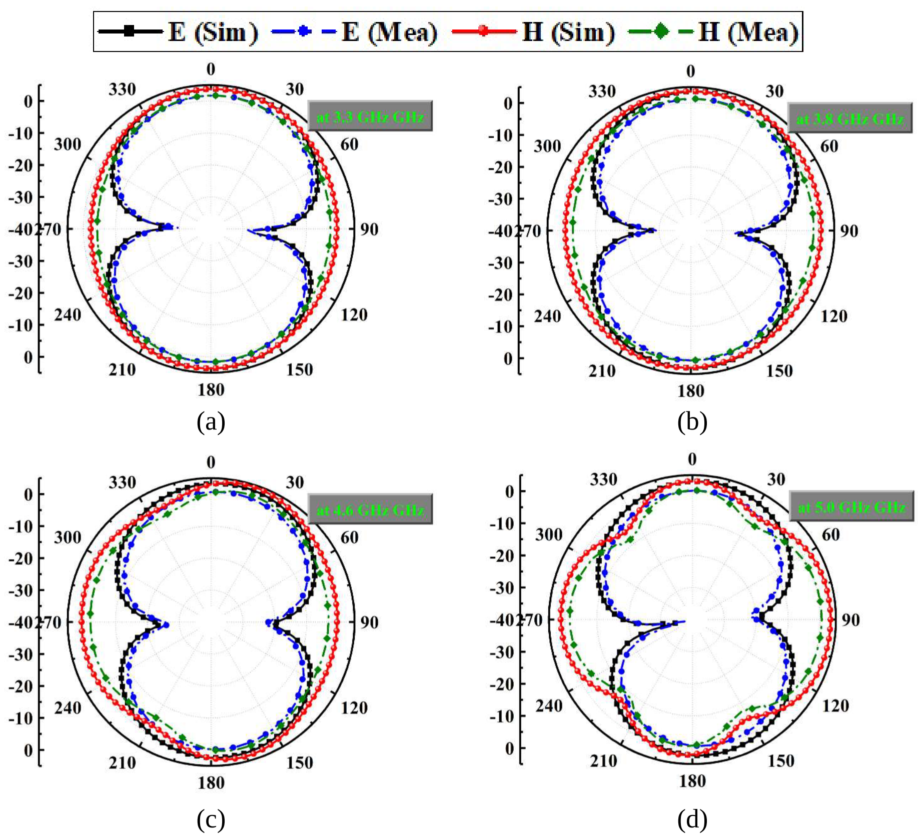

Figure 9. *E* & *H* field patterns of proposed antenna; (a) at 3.3 GHz; (b) at 3.8 GHz; (c) at 4.6 GHz and (d) 5.0 GHz.

The 2-D simulated and measured E & H fields are represented at various frequencies, which include lower (3.3 GHz) & higher (5.0 GHz) bands of working region and at two more bands (3.8 GHz & 4.6 GHz) as shown in Fig. 9. Stable radiation patterns are attained in the entire working region, and simulated & measured patterns are almost well-matched. Bore sight patterns are attained with proper optimization of parameters of the proposed design. These bore sight patterns are required for 5G MIMO systems. Hence, the proposed design is very much suitable for 5G system applications.

Table 2. Comparison of proposed work with other literature works.

Ref. No, No of Elements	**Antenna Size (mm^2)**	**Bandwidth (GHz)**	**Isolation (dB)**	**Peak gain (dBi)**	**Radiation Efficiency (%)**	**CCL (bits/s/Hz)**	**TARC (dB)**
[7], 1	135 × 80	0.75, 2.7–3.5, 4.5–5.0	—	1.66, 4.72, 4.52	60, 42, 41	—	—
[8], 2	46 × 30	1.8–3.6, 5–7.9	17.2, 22.4	4.31, 4.62	71, 70	0.35	≤ -10
[9], 2	30 × 6.75	4.9–5.06	20	1.95	79.5	—	—
[10], 1	100 × 100	2.45, 3.5	—	7.64	64.5	—	—
[11], 8	192 × 76	1.3–3.8	15	13.8	83.6	—	—
[12], 2	35 × 50	4.6–4.9	15	1.8	45	0.5	≤ -10
[13], 2	59 × 55	3–7	18	5.6	85	0.4	≤ -10
[14], 2	20 × 14.75	2.38–3.0, 3.21–3.61, 5.02–6.18	—	7.93, 4.23, 7.5	23.05, 11.73, 20.71	—	≤ -10
[16], 8	22 × 22	3.3–7.1 (−6 dB)	12	4.6	48	0.3	≤ -30
[17], 4	42 × 42	3.2–12	17	5.6	80	0.4	—
[24], 8	112 × 112	3.5–4.0	17	5.0	85	0.01	≤ -10
[25], 1	28.03 × 23.45, 1	4.9–5.7	—	6.2	70	—	—
[26], 1	23.8 × 23.8, 1	3.2–5.3	—	2.7	96	—	—
[27], 2	26 × 36	3.2–6.7	26	5.3	98	0.005	≤ -10
P*, 2	**30 × 66**	**3.3–5.0**	**18**	**4.6**	**91**	**0.05**	$\leq$ **−10**

4. CONCLUSIONS

The proposed cow-head-shaped MIMO antenna is designed for 5G sub:6 GHz applications and is presented in the current work. It works in the region from 3.3 to 5.0 GHz and covers complete bands of N77/N78 & N79 bands. The element-to-element isolation of above 18 dB is attained with proper arrangement of antenna elements, and an optimized small strip is connected between the grounds. The radiation performance of the design is checked with efficiency, gain, and pattern results. The stable and bore sight patterns are attained with a properly optimized design. The diversity metrics ECC, DG, TARC, CCL, and MEG are used to estimate the MIMO performance of the proposed design in a free space environment. Low ECC, high DG, good TARC, low CCL, & acceptable MEG values are attained. These are compared with measured ones, and they are well matched. The proposed antenna is designed and developed on cheap dielectric FR4 material with a size of $30 \times 66\,mm^2$ and height of 1.6 mm. Table 2 describes the comparison of the proposed work with other listed works in the literature. Compared to the listed ones, the proposed antenna has a novel structure, higher isolation, lower CCL values, and higher efficiency values, and the structure is designed exclusively for 5G sub:6 GHz applications.

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