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Design of a Dual-Band 12-Element MIMO Antenna Array for 5G Mobile Applications

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Abstract—This article presents a dual-band 12-element antenna system based on slot antennas for fifth-generation (5G) of mobile communication. The basic structure of each antenna element is composed of a T-shaped slot. The antenna array is designed to operate at LTE 42 and LTE 43 bands ranging from 3400–3600 MHz and 3600–3800 MHz, respectively. The impact on the antenna parameters due to the user's hand is also explored. The isolation between antenna elements is better than 14.8 dB with a total efficiency of more than 74%. A small envelope correlation coefficient less than 0.05 and the channel capacity of 61.9 bps/Hz make the proposed array a viable solution for 5G smartphones.

1. INTRODUCTION

In this modern world of communication, where technologies are changing very fast, the new generation of mobile communication is on its way which is the fifth generation of mobile communication (5G). It is the next phase of mobile communication standards, which will bring many alluring advantages over its predecessors. Higher data rates than the fourth generation (4G) mobile communication, low time delay, and enhanced channel capacity along with better spectral efficiency are the primary benefits that 5G will provide [1]. The two new spectrums allocated to 5G are in the sub-6 GHz and millimeter-wave (mm-wave) range. In sub-6 GHz, LTE 42/43 (3400–3800 MHz) is assigned for 5G [2].

In 5G mobile communication, multiple-input multiple-output (MIMO) technology has been used by the researchers. Since MIMO can fulfill the user's desire for high data rates, it can be used to address numerous other 5G specifications. The channel capacity of the wireless communication system can be effectively increased by accommodating a greater number of antennas in the mobile handsets [3]. However, due to the area constraints in mobile handset, it is difficult to deploy a large number of antennas within this confined space, while maintaining decent isolation and a small envelope correlation coefficient (ECC) [4].

Recently, much of the work in the literature is based on the densely deployed MIMO antenna arrays [5–12]. L- and U-shaped slot and monopole antennas are used to design an eight-element antenna array which provides the isolation of 12 dB [5]. In [6], a tri-band 12 port antenna array has been reported, out of which six elements operate at two different bands, i.e., LTE 42 and LTE 43; four elements operate at LTE 46 band, and the remaining two elements operate at all the three bands. Therefore, the design does not utilize the twelve elements fully to increase the channel capacity as each element is not operating at LTE 42/43/46 bands simultaneously. In [7], an eight-element antenna array is formed using neutralized lines to mitigate the mutual coupling and to achieve 11.5 dB isolation. Another ten element multiband antenna array has been implemented that provides isolation better than 11 dB [8]. In [9], the polarization diversity technique is used for reducing mutual coupling. A parasitic structure consisting of two sets of open-ended circular rings is implemented to provide isolation of 15 dB [10].

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In [11], a dual-band eight-element antenna array is proposed, which makes use of decoupling stub to mitigate mutual coupling. Balanced antenna elements are used to attain enhanced isolation [12].

Considering the above-mentioned discussion on the challenges of MIMO antenna designs in 5G, a 12-element slot antenna array is proposed for the future 5G mobile handset applications. The designed antenna array operates in the two sub-6 GHz's 5G bands (LTE 42/43). The manuscript is organized as follows. The structure of the designed array is defined under Section 2 along with the simulation results. In Section 3, measured results such as radiation pattern, antenna efficiency, S-parameter, and ECC of the suggested antenna array are discussed. Section 4 explains the effect of the hand proximity of the user on the antenna response. Finally, the article is concluded in Section 5.

2. PROPOSED TWELVE ELEMENT MIMO ANTENNA ARRAY

2.1. Antenna Design

The configuration and detailed dimension of the suggested slot antenna array are displayed in Fig. 1. The dimension of the circuit board used to place the antenna array is $150 \times 80 \times 0.8\,\text{mm}^3$, which is reasonable for general 6-inch mobile phones. An FR4 substrate with 0.8 mm thickness (loss tangent = 0.02 and dielectric constant = 4.4) is used. Each antenna element consists of a $50\,\Omega$ micro-strip line mounted on the top layer of the substrate, and a T-shaped slot is etched on the ground plane. Two orthogonal slot locations are used to reduce mutual coupling. One is along the shorter edges of the ground plane with four antenna elements (Ant1, Ant6, Ant7, and Ant12) mounted on it, and the other is along the longer edges with eight antenna elements (Ant2–Ant5 and Ant8–Ant11) mounted on it, as shown in Fig. 1(a).

2.2. Antenna Unit

The detailed dimension of a single antenna element is depicted in Fig. 1(b). The complete slot antenna is composed of one open slot of length $L = 1.5$ mm and three horizontal slots of length $L_1 = 6.1$ mm, $L_2 = 6$ mm, $L_3 = 6.1$ mm, and the width of horizontal slots is $W_1 = 2$ mm. The slot L_2 has an extended width of W_2 which is added to reduce the length of the slot [12]. The width W_2 of all the antennas

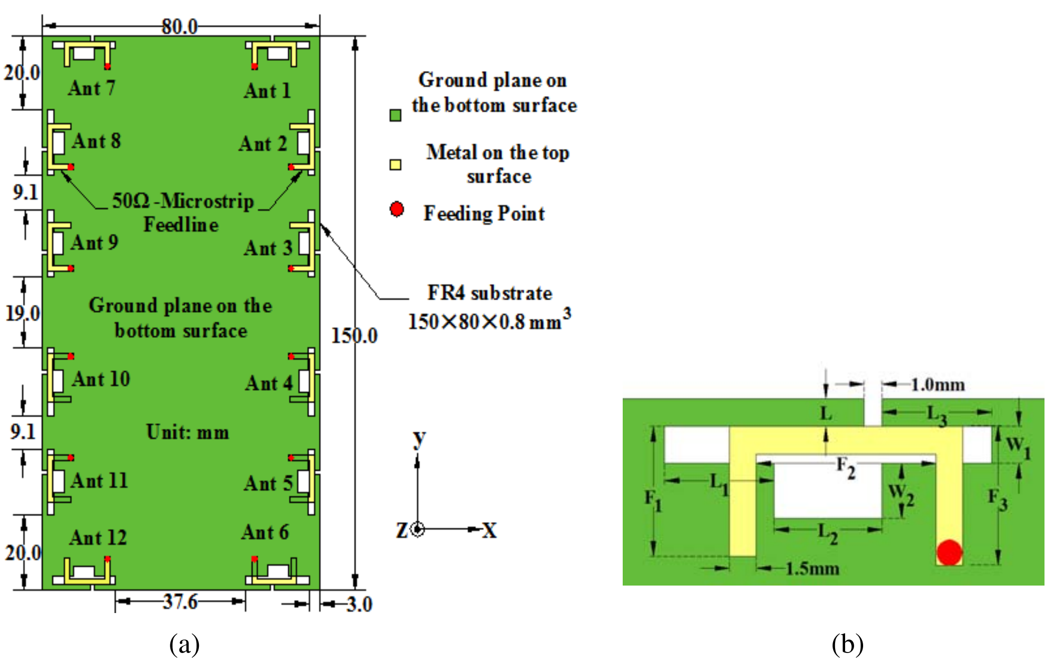


Figure 1. (a) Overall geometry of the proposed slot antenna array. (b) Configuration of the single antenna.

elements is chosen in such a way that the proposed antenna array precisely gets tuned regarding their locations. Therefore, Ant1, Ant2, Ant5, Ant6, Ant8, Ant11, and Ant12 have width $W_2 = 3\,\text{mm}$, and Ant3, Ant4, Ant9, and Ant10 have a width $W_2 = 2.5\,\text{mm}$. To achieve the compact design, the feeding strip is bent into a C-shape structure. Thus, the feeding strip has three sections of lengths $F_1 = 7\,\text{mm}$, $F_2 = 10\,\text{mm}$, and $F_3 = 7.5\,\text{mm}$ with a width of 1.5 mm.

2.3. Parametric Analysis

This section presents those parameters of the suggested slot antenna, which have a major effect on the antenna characteristics, such as resonance frequency and the operating band. The S_{11} characteristic of antenna for varying the width W_2 and length L_2 is studied in Fig. 2(a) and Fig. 2(b), respectively.

From Fig. 2(a) it is observed that, as the width W_2 increases from 0.5 mm to 5.5 m, the resonance frequency shifts to the lower frequency spectrum, i.e., from 3.75 GHz to 3.2 GHz. When the width is 2.5 mm, the structure is resonating at 3.5 GHz. The length L_2 can also adjust the resonant frequency as shown in Fig. 2(b). Frequency increases with the decrease in length L_2. Notably, the desired resonant frequency can be obtained by properly selecting the width W_2 and length L_2.

The simulated reflection coefficients and isolation between two neighbouring antennas are presented in Fig. 3. The reflection coefficients of all antenna elements are better than 20 dB as revealed in Fig. 3(a) and Fig. 3(b). The proposed antenna array resonates at 3.5 GHz and supports LTE bands 42/43 ranging from 3.3 GHz to 3.8 GHz. In Fig. 3(c), the isolation of adjacent antennas is presented. The design provides isolation better than 15 dB between any two antennas. Orthogonal placements of

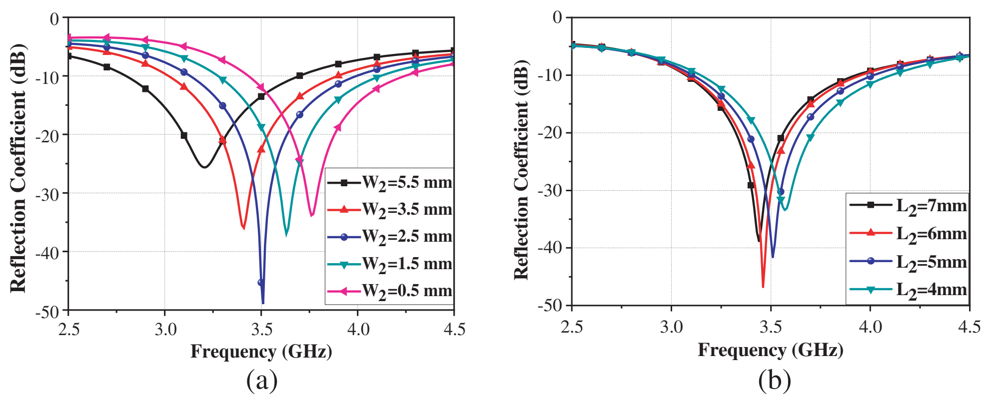


Figure 2. Reflection coefficient for varying. (a) Width W_2, and (b) length L_2.

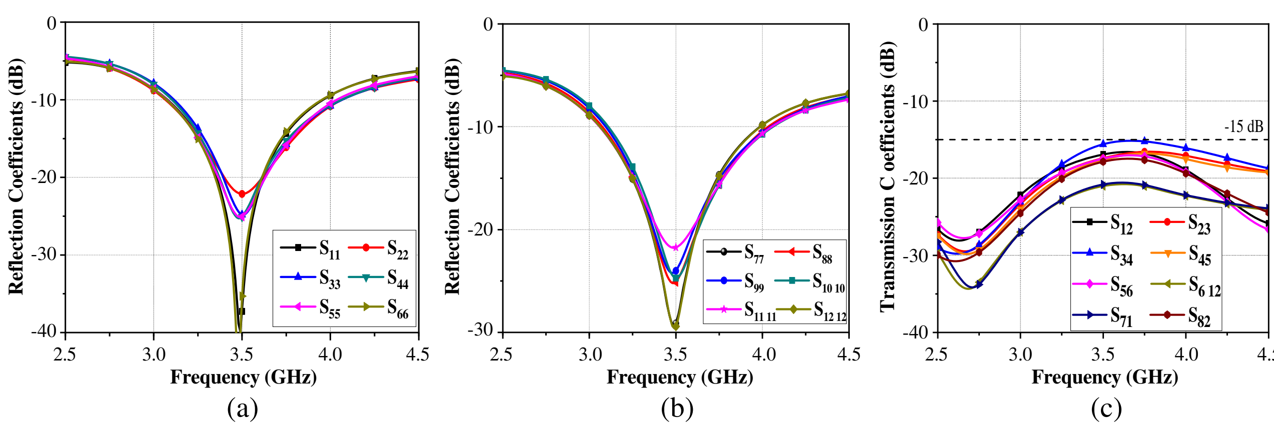


Figure 3. Simulated S-parameters of proposed array. (a) Reflection coefficient of Ant1 to Ant6. (b) Reflection coefficient of Ant7 to Ant12. (c) Transmission coefficients.

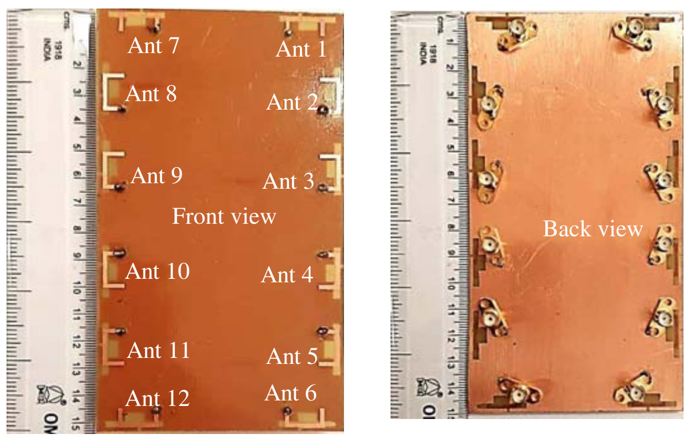
the antenna and space diversity (feeding strips of two antennas are not pointing at each other; therefore, the separation between the two ports is more) are the two main reasons for achieved isolation. Better diversity and multiplexing performance of MIMO can be achieved with the reasonable reflection and isolation performance.

3. RESULTS AND DISCUSSION

In order to validate the simulated results, a prototype antenna is fabricated. The fabricated prototype of the proposed antenna array is presented in Fig. 4. An Agilent vector network analyzer (VNA) is used to measure the S-parameters and to obtain results from this analysis, as shown in Fig. 5.

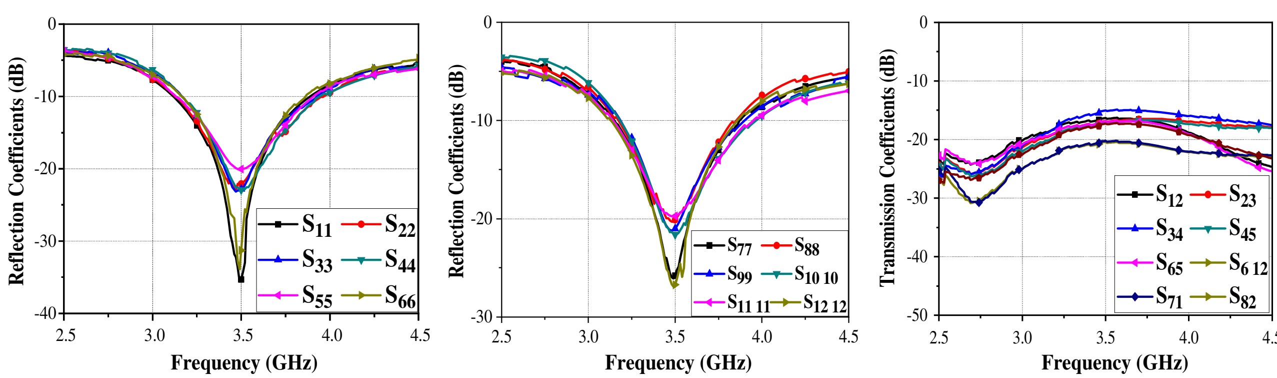
3.1. *S*-Parameters

Measured reflection coefficients of the suggested antenna array are depicted in Figs. 5(a) and (b). Fig. 5(c) depicts the measured transmission coefficients of antenna elements, where S_{12}, S_{23}, S_{45}, S_{56}, S_{612}, $S_{82,}$, and S_{71} are better than 17 dB, and S_{34} is better than 14.8 dB. The deviation in the results is attributable to fabrication loss and connector loss, but overall, these results are in good agreement with the simulated one. It is inferred from the measured S-parameters that the proposed antenna array fulfils the criterion of 5G mobile handset by achieving return loss and isolation better than 20 dB and 14.8 dB, respectively.



(a) (b)

Figure 4. The fabricated prototype of the proposed antenna. (a) Front view. (b) Back view.



(a) (b) (c)

Figure 5. Measured S-parameters of the proposed array. (a) Reflection coefficient of Ant1 to Ant6. (b) Reflection coefficient of Ant7 to Ant12. (c) Transmission coefficients.

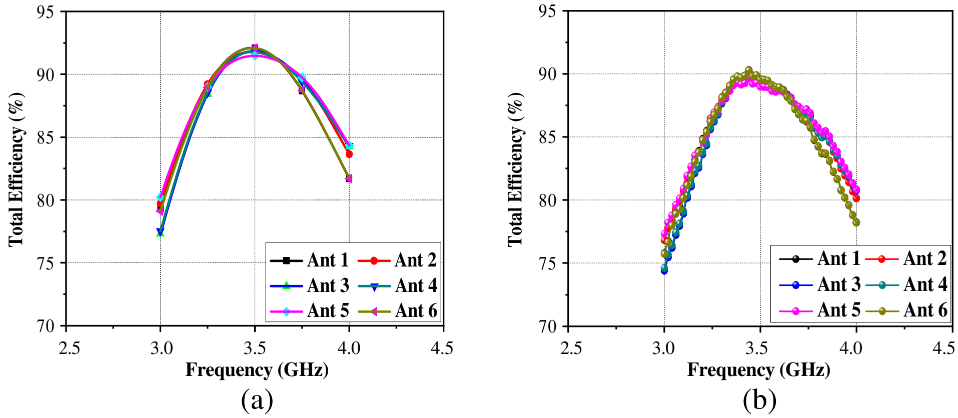


Figure 6. (a) Simulated total efficiencies of Ant1–Ant6. (b) Measured total efficiencies of Ant1–Ant6.

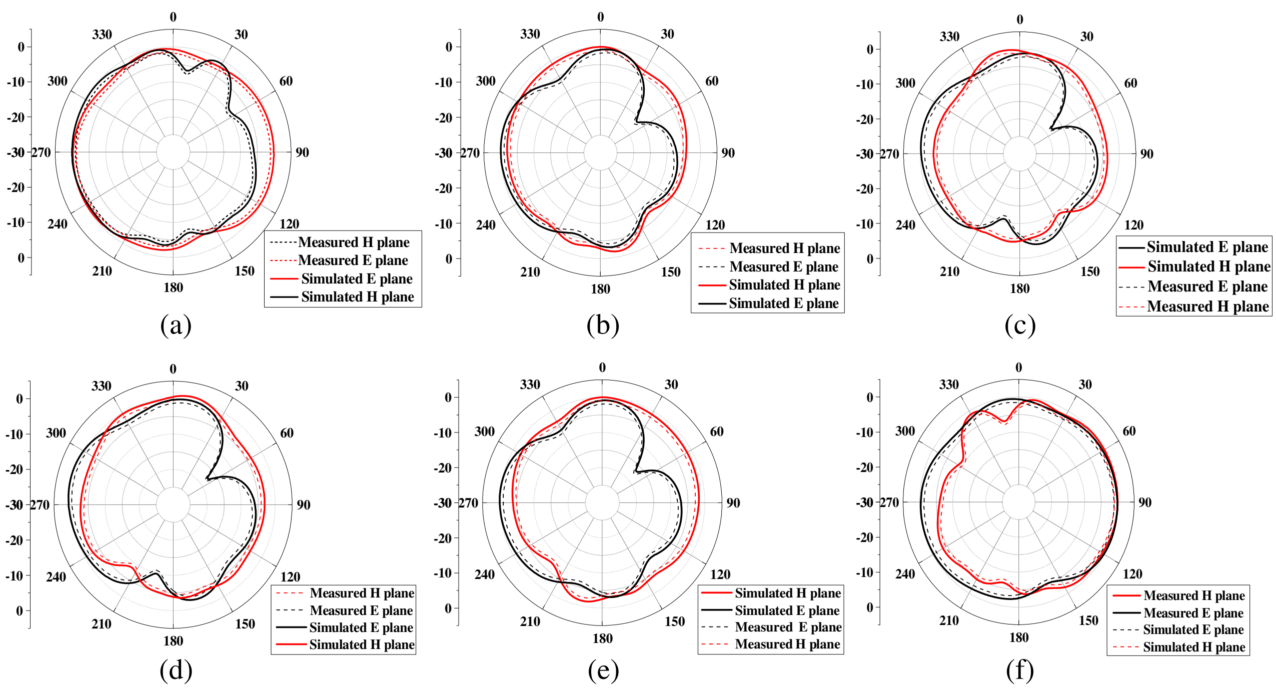


Figure 7. Simulated and Measured radiation pattern of (a) Ant1, (b) Ant2, (c) Ant3, (d) Ant4, (e) Ant5 and (f) Ant6.

3.2. Radiation Performance

Since all antennas of the proposed array have identical dimensions and they are symmetrically placed, only results of Ant1 to Ant6 are shown. The simulated and measured total efficiencies of the suggested array are depicted in Fig. 6(a) and Fig. 6(b), respectively.

Efficiency varies between 74 and 89%, which is quite good, and there is a 3% variation from simulated total efficiency. For brevity, the radiation performance of half of the antennas (Ant1 to Ant6) is shown in Fig. 7, since the radiation patterns of Ant7–Ant12 are just a mirror image of the radiation pattern of Ant1–Ant6. A good radiation performance of the antenna array is observed from Fig. 7.

3.3. MIMO Parameters

There is a need to study the two types of performance parameters of a MIMO system which will determine its diversity and multiplexing performance. The diversity performance of MIMO is depicted

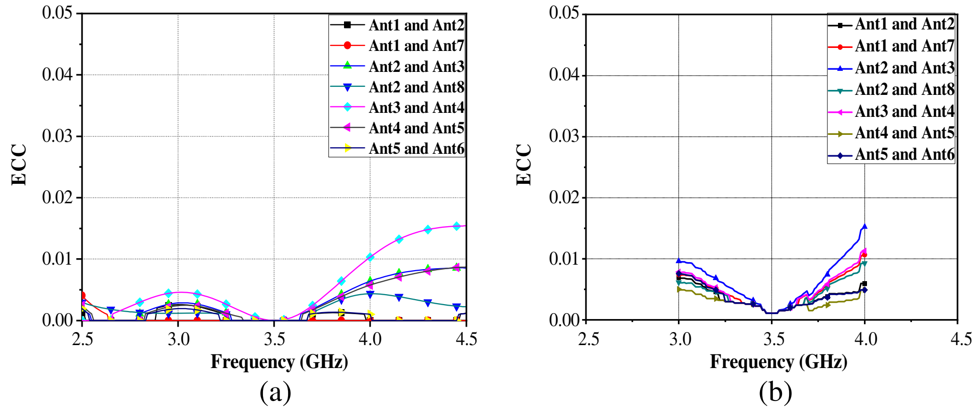


Figure 8. (a) Simulated ECC variations with frequency. (b) Measured ECC variations with frequency.

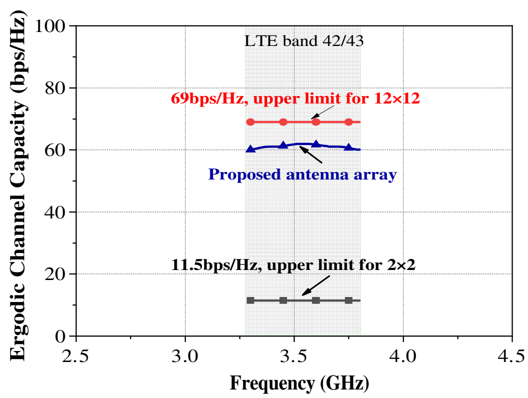


Figure 9. Channel capacity of proposed 12 element antenna array.

from the ECC graph, which is shown in Fig. 8.

For the entire frequency band, the ECC value is below 0.05 which suggests the decent diversity performance of the suggested MIMO antenna array.

The channel capacity of the proposed MIMO is responsible for multiplexing performance [13]. Under the conditions, when equal power is assigned to every antenna and no knowledge is present at the transmitter side regarding the channel state, channel capacity [14] is given

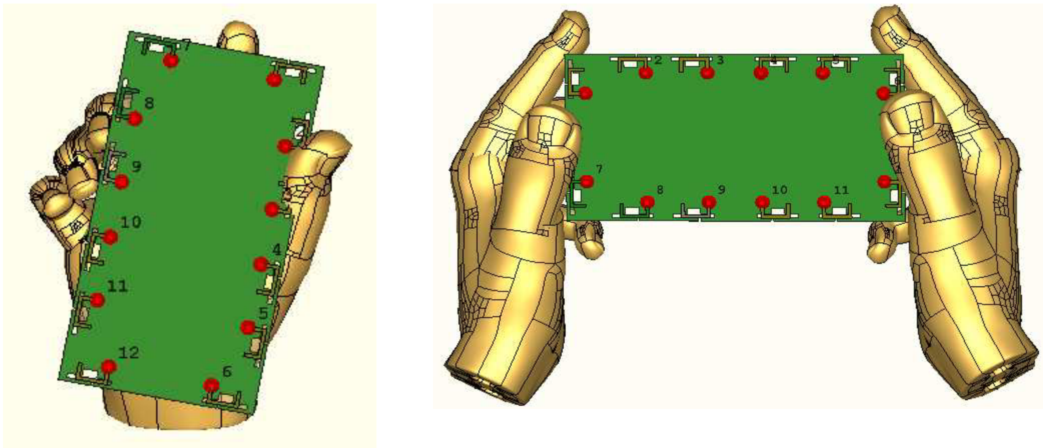
$$C = \log 2\left[\det\left(I_N + \frac{\rho}{N} H H^T\right)\right] \tag{1}$$

where H is the channel matrix, ρ the average SNR, and I_N the $N \times N$ identity matrix.

The proposed array achieves the channel capacity of 61.9 b/s/Hz as shown in Fig. 9. The proposed structure provides a higher channel capacity than a 2×2 MIMO antenna array.

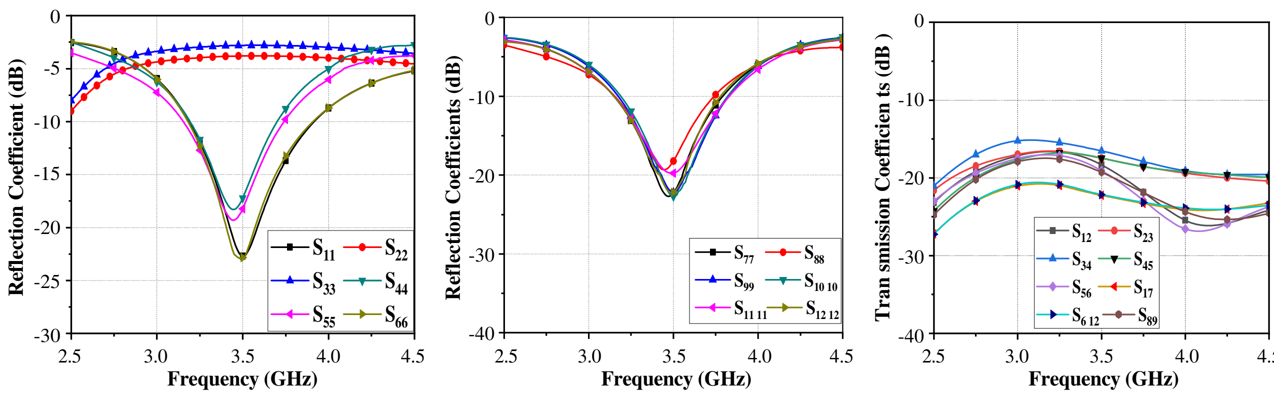
4. IMPACT OF USER'S HAND

For practical application, the influence of the user's hand on the array performance has been studied which is discussed in this section. Two different setups are considered for measuring the user's interaction with antenna. One is single hand mode (SHM), and the other is dual hand mode (DHM) as shown in Fig. 10. The reflection coefficients of Ant1 to Ant6 and Ant7 to Ant12 under the SHM and DHM scenario are shown in four graphs Fig. 11(a), Fig. 11(b), Fig. 12(a), and Fig. 12(b), respectively. In SHM, the adverse effect of user vicinity on reflection coefficients of antennas 2 and 3 can be seen from Fig. 11(a). This occurs due to the direct contact of the thumb with these two antennas. The rest of the antennas perform well. The mutual coupling is still better than 10 dB as shown in Fig. 11(c). For DHM,



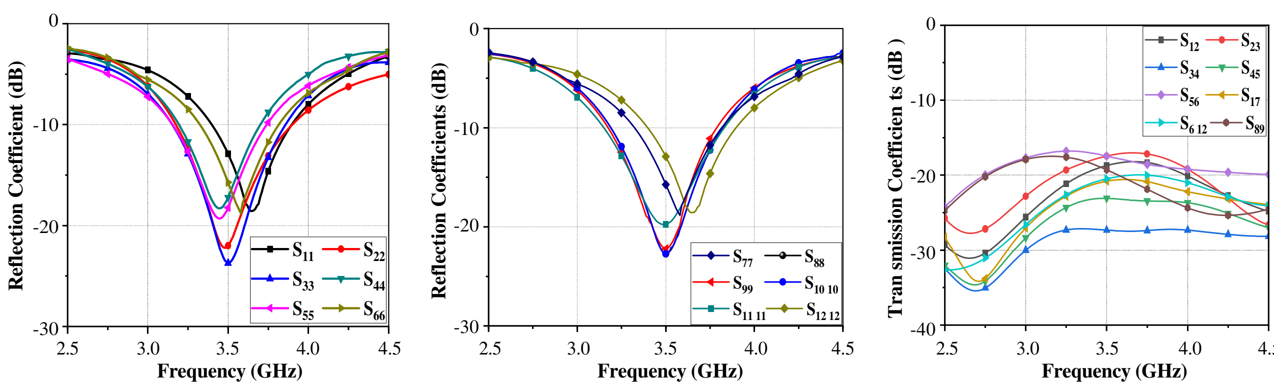
(a) (b)

Figure 10. Antenna array with the user's hand. (a) Single Hand Mode. (b) Dual Hand Mode.



(a) (b) (c)

Figure 11. Simulated S-parameters under SHM. (a) Reflection coefficients of Ant1 to Ant6. (b) Reflection coefficient Ant7 to Ant12. (c) Transmission coefficient.



(a) (b) (c)

Figure 12. Simulated S-parameters under DHM. (a) Reflection coefficient of Ant1 to Ant6. (b) Reflection coefficient of Ant7 to Ant12. (c) Transmission coefficient.

Ant1, Ant6, Ant7, and Ant12 are in close vicinity of thumbs, hence the slight variation in resonance frequency can be observed in the reflection coefficients of these antennas, as presented in Fig. 12(a) and Fig. 12(b). The rest of the antennas exhibit decent performance. The isolation better than 10 dB is attained as shown in Fig. 12(c).

To estimate the performance of the proposed antenna array, a comparative study of the antenna array with recently reported works is presented in Table 1. The key parameters such as frequency bands, number of elements, efficiency, ECC, and isolation are compared. From the comparative analysis, it is indicated that the proposed antenna array exhibits decent performance in terms of efficiency and isolation.

Table 1. Performance comparison amongst the referenced and proposed array.

Ref.	**Frequency band (GHz)**	**Number of Element**	**Efficiency (%)**	**ECC**	**Isolation (dB)**	**Channel capacity (b/s/Hz)**
[2]	3.4–3.8, 5.15–5.92	12 (8 (LB) 6 (HB))	41–82 (LB) 47–79 (HB)	< 0.15 (LB), < 0.1 (HB)	> 12	37 (LB) 29.5 (HB)
[7]	3.4–3.6, 4.8–5.1	8	41–72 (LB) 40–85 (HB)	< 0.08 (LB), < 0.05 (HB)	> 11.5	38.5 (LB) 38 (HB)
[8]	3.4–3.8, 5.15–5.925	10	42–65 (LB) 62–82 (HB)	< 0.15 (LB) < 0.05 (HB)	> 11	40 (LB) 51.4 (HB)
[10]	3.4–3.8	8	60	< 0.5	> 15	-
[12]	3.4–3.6	8	62	< 0.05	> 17.5	40.8
[15]	3.31–3.7 4.3–5.18	12	42.5–79.5 (LB) 81.1–83.3 (HB)	< 0.4	> 12.5	-
[16]	779–971, 1496–2755, 3300–3600, 4800–5000	8	42–50 (LB) 52–65 (HB)	-	> 10, > 15	8.8–10.1 30.1–30.6
[17]	3.4–3.6, 4.8–5.1	8	61–72 (LB) 64–74 (HB)	-	> 17	42.6 (LB) 43 (HB)
[18]	3.3–3.8, 4.8–5, 5.15–5.925	8	55–72 50–65 43–73	< 0.12	> 10.5	37.6
Proposed Antenna	**3.3–3.8**	**12**	**74–89**	**< 0.05**	**> 14.8**	**61.9**

5. CONCLUSION

A twelve elements MIMO antenna array using a slot antenna has been designed and investigated successfully for LTE 42/43 bands. Space diversity and orthogonal placement of the antenna in the suggested antenna array yield the isolation of 14.8 dB. Decent MIMO performance is achieved with ECC < 0.05 along with a high channel capacity of 61.9 bps/Hz. The suggested array demonstrates acceptable isolation of better than 10 dB even in the user's vicinity. Hence, the proposed antenna array fulfills the challenging needs of 5G smartphones, and aforementioned results confirm that it is appropriate for 5G smartphone applications.

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