A CPW fed two and four element antenna with reduced mutual coupling between the antenna elements for wireless applications

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Received: 19 March 2020 / Accepted: 17 December 2020 / Published online: 9 January 2021
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Abstract

Mutual coupling between the multiple antenna designs is a critical problem which deteriorates the performance of multiple input multiple output (MIMO) system. It affects the antenna efficiency and influences the correlation. In this paper, a study on the isolation between the multiple antenna elements is presented. The antennas are placed on a cost-effective compact dielectric substrate with different orientations to minimize the correlation. A CPW fed antenna is designed using FR4 substrate, using which two and four element antenna structures are developed. The performance parameters are analysed, wherein the envelope correlation coefficient (ECC) has to be less than 0.5, diversity gain nearer to 10 dB in the operating bandwidth, mean effective gain (MEG) less than 3 dB, channel capacity loss (CCL) less than 0.4 bits/s/Hz and the isolation between the antenna elements well above 20 dB. Acceptable gain, high radiation efficiency, and stable radiation pattern of the proposed design are analysed and the fabricated prototype of two and four element is measured for its performance parameters. All the necessary simulations are carried out in the EM simulator Ansys HFSS v.14.0 and a detailed comparison study is done based on the existing antennas.

Keywords Mutual coupling · ECC · Diversity gain · Channel capacity loss · Isolation

1 Introduction

The developing need for a rise in the data rates for wireless communication systems is increasing the demand for a productive and high data rate transmission system that can function in certain frequencies [1–3]. MIMO (multiple-input–multiple-output) system is one of the prominent solutions as it can enhance the channel capacity [4, 5]. Its characteristics to transmit the data at a fast rate with low interference could potentially help the future wireless technology. This technology can immensely improve the channel capacity, data rate, and link safety of wireless systems by multi-path data communication [6]. These systems conduct the power through multiple antennas at the transmitter and

receiver thereby enhancing the channel capacity without the use of supplementary bandwidth or power [7]. These systems are at present engaged in 4G user material and are a rising technology for service in the eventual 5G mobile terminals. Also, modern handheld devices need multiband usable features such as Bluetooth, Wi-Fi, Wi-MAX, etc., which are being integrated into a single mechanism [8, 9].

The system efficiency of a multiple antenna system can be largely improved by increasing the number of antennas in the terminals of transmitters and receivers. The within element isolation of the multiple antenna system is poor because of the close arrangement of antenna elements, thereby causing deterioration of overall design efficiency [10–12]. Thus, the improvement of inter-element isolation of the antenna system is challenging for multiple antenna design technology on the same substrate. With the rising need for a larger capacity of the MIMO communication system, the concern of the inter-element isolation improvement of the two and four-element antenna systems has gained tremendous consideration [13–15].

In this regard, numerous two and four element antenna are discussed in the literature [16–23]. In [16] the author designed a two element MIMO antenna by utilizing an

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inverted T and E-shaped radiator, wherein the isolation is improved by including a parasitic resonator between the elements. However, the achieved mutual coupling reduction is only around 20 dB. A compact quad element MIMO antenna with a split ring resonator as the radiating part is proposed in [17]. The four element is placed orthogonal to each other to improve the isolation. However, the isolation achieved by such configuration is only 14 dB which is generally less for a MIMO system. In [18] a quad element wideband MIMO antenna is proposed. The isolation in the overall MIMO structure is achieved by placing the asymmetric monopole in orthogonal orientation. However, the achieved isolation is only 20 dB and at the same time, the overall antenna dimension is large. In [19] a four element L-shaped monopole dual-band antenna loaded with complementary split-ring resonator for MIMO application is proposed. However, the achieved isolation is less and the size of the antenna is considerably large. A four port MIMO patch antenna utilizing a square ring-shaped radiator and the complementary split-ring resonator is proposed in [20] for achieving high isolation. However, the achieved isolation is only 22 dB and the size of the antenna is large. In [21] a four port Koch fractal four port MIMO antenna based on the parasitic resonator is proposed. The antenna exhibits good diversity parameters. However, the achieved isolation is around 20 dB and the size of the antenna is considerably large. Similarly, the MIMO structure proposed in [22, 23, 29–34] shows isolation around 17 dB and is large in size. However, the presented two and four port antenna in this paper removes the drawback of less isolation and large size as discussed in [16–23, 29–34]. The proposed structure serves twofold advantage over the aforementioned literature.

1. The two and four port element antenna achieves high isolation (i.e., greater than 25 dB) without utilizing any decoupling methods, thus, totally benefits from the monopole asymmetrical structure.
2. It achieves better diversity performances as compared to the antenna discussed in [16–23, 29–34].

In this research paper, a wideband CPW fed antenna operating from 4.3 to 6.45 GHz is developed on a FR4 substrate. Using this antenna, a study towards the two and four element structure is carried out by analysing the performance parameters of the multiple antennas placed and inter-element interferences. The proposed design serves three fold novelty, they are (1) the applied feeding technique (i.e., CPW) enables the antenna design on the single side of the substrate thereby making integration easier with the monolithic integrated microwave circuit (MMIC),

(2) the slotted radiating patch provides good impedance matching as well improves the bandwidth considerably, as compared to normal microstrip patch antenna, (3) the orientation of the two and four element antenna is in best interest to have optimum isolation, thereby avoiding the usage of any decoupling structure thus, helps in achieving a simple planar configuration. The entire simulations are performed using the EM simulator ANSYS HFSS v.14.0 and the optimized design is fabricated to test the operating parameters.

2 Antenna design

This section describes the designing of a single wideband monopole antenna and its evolution into the proposed two and four antenna element MIMO configuration.

2.1 Single element antenna

A CPW fed antenna is optimized to obtain a wide bandwidth operating from 4.30 to 6.45 GHz (2150 MHz). A single side design has a lower cost of fabrication with a reduced material cost. The wide bandwidth in the antenna is accomplished using a split shaped radiating patch as depicted in Fig. 1a. The slotted radiating patch affects the flow of surface current which in turn increases the total current flow path thereby tends the design to exhibit wide bandwidth. The corresponding reflection coefficient (S_{11}) which is as low as -33.5 dB at the center frequency of 5.2 GHz as seen in Fig. 2b. Table 1, details the overall design dimensions of the antenna.

2.2 Two element antenna design

A two port antenna design is developed by placing the antenna elements on both the side of the substrate material having a dimension of 20×45 mm². To have good isolation between the antenna elements, the second element's orientation is varied as seen in Fig. 2a as 'Antenna 1' and 'Antenna 2'. The corresponding isolation and reflection coefficient is depicted in Fig. 2b. It is observed from Fig. 2b that the isolation between the antenna elements is greatly increased to -30 dB just by rotating any one element by 90°, as also studied in [24].

The distribution of surface current at one of the frequency say 5.5 GHz (at port 1–2) is explained in Fig. 3. It is evident from the figure that more current distribution is noticed at port 1 when this port is excited by keeping port 2 at the matched condition or vice-versa. Also, it can be noticed that there is an opposite flow of current, thereby suppressing

(a)

(b)

Fig. 1 **a** Wide band antenna structure. **b** Reflection coefficient of the proposed single element

the flow of current to the adjacent element which in turn increases the isolation. [Note: We have taken one frequency over the entire bandwidth to explain the current behavior, because the phenomenon will be the same at other frequencies also].

2.3 Four element antenna design

The proposed four element configuration is designed to maximize the number of inputs while minimizing interference. This results in a design, where there are antennas on both the planes of the configuration. There are two possible configurations for the required conditions as depicted in Fig. 4a, b. Figure 4a shows 'Configuration 1' and Fig. 4b shows 'Configuration 2'. Figure 5 shows isolation characteristics for the two configurations and it is quite evident from that 'Configuration 2' has far better isolation characteristics

(a)

(b)

Fig. 2 **a** Two element MIMO design configurations. **b** Corresponding |S-parameters|

Table 1 Detailed dimensional parameters

Parameter	Dimensions (mm)
FW	2
KL	4
Z	20
FL	4
KW	4
T7	1
T6	9
T5	5.75
T4	6
T3	4
T2	2
T1	2

Fig. 3 Surface current pattern at **a** Port 1 and **b** Port 2

Fig. 4 Possible configurations of the proposed four element antenna **a** configuration 1, **b** configuration 2

than ‘Configuration 1’ due to the distinct spacing between the antenna elements. The final configuration is presented in Fig. 6 and Table 2 contains its specific dimensional parameters. The proposed configuration has a compact size with improved isolation between the antenna elements.

2.3.1 Parametric study of the four element

Parametric analysis is performed to analyze the effect of a dimension on the overall performance of the antenna. In this paper, this involves the analysis of return loss as well as isolation characteristics. The first parameter to be analyzed

Fig. 5 Isolation characteristics of the two configurations

is the width of the feedline (FW) of the four antennas of the proposed configuration. Figure 7 shows the results for parametric analysis for 'Antenna 1'. It is quite evident from the graph that FW = 2 mm gives the best return loss and - 10 dB bandwidth.

A similar analysis for 'Antenna 2' is carried out and similar observations as in the case of the previous antenna are made. Figure 8 gives the results for the analysis.

For 'Antenna 3' the width of FW increased till the performance starts deteriorating. The change in performance occurs at FW = 2 mm. Figure 9 gives the result of the parametric analysis performed.

Table 2 Dimensional parameters of the configuration

Parameter	Dimensions (mm)
Z1	45
Z2	45
Z3	7.071
Z4	25
Z5	25
Z6	7.071
Z7	25
Z8	25

Similarly, analysis for 'Antenna 4' is carried out. Return loss for acceptable - 10 dB bandwidth is observed when FW = 2 mm. Figure 10 shows the results of the analysis.

A similar parametric analysis is carried out for another parameter T3. Figure 11 shows the results for parametric analysis for T3 for 'Antenna 1'. Although T3 = 2 mm gives better return loss, but T3 = 4 mm is chosen, because it has better - 10 dB bandwidth.

Similarly, analysis for 'Antenna 2' is carried out, the results are shown in Fig. 12. It is visible from the results that T3 = 4 mm is chosen, because it is giving the lowest return loss while maintaining the largest - 10 dB bandwidth.

Analysis for 'Antenna 3' leads to similar observations as made in the previous one. T3 = 4 mm gives better return loss than T3 = 6 mm and better - 10 dB bandwidth than T3 = 2 mm. Figure 13 shows the results of the analysis.

Fig. 6 Final configuration of the four element antenna

Fig. 7 Analysis of FW for antenna 1

Fig. 10 Analysis of FW for antenna 4

Fig. 8 Analysis of FW for antenna 2

Fig. 11 Analysis of T3 for antenna 1

Fig. 9 Analysis of FW for antenna 3

Fig. 12 Analysis of T3 for antenna 2

Fig. 13 Analysis of T3 for antenna 3

Fig. 14 Analysis of T3 for antenna 3

A similar analysis is carried for ‘Antenna 4’, the results of the analysis are depicted in Fig. 14. It can be inferred from the graph that T3 = 4 mm gives the best bandwidth while maintaining appreciable return loss.

After parametric analysis for return loss, another analysis for the isolation characteristics which play a vital role in a multiple antenna configuration is done and is depicted in Figs. 15 and 16. For isolation characteristics, the optimum value of Z3 on the front plane of the configuration is calculated. During the analysis, it is observed that the wide operational bandwidth of all the antennas decreased and the wide operational band of ‘Antenna 4’ became dual. Figure 15 shows the results of the analysis. It is visible from the graph that only Z3 = 7.07 mm has a return loss of less than -20 dB for the entire bandwidth.

Similarly, analysis is performed for antennas on the back plane of the antenna. Figure 16 shows the variation of S_{34}

Fig. 15 Isolation characteristics analysis for the front plane adjacent element distance Z3

Fig. 16 Isolation characteristics analysis for the front plane adjacent element distance Z6

with variations in Z6. It is evident from the graph that only Z6 = 7.07 mm stays below the -20 dB.

2.3.2 Current distribution

The distribution of surface current at one of the frequency say 5.5 GHz (at port 1–4) is explained in Fig. 17. It is evident from Fig. 17a that more current distribution is noticed at port 1 when this port is excited by keeping port 2, port 3, and port 4 at the matched condition or vice-versa. The basic principle which governs here to suppress the mutual coupling is to place the antenna in orthogonal orientation in both the front and back plane. By doing so it is evident from the figure that there is a field cancellation between the orthogonally spaced elements (both in front and back

Fig. 17 Surface current pattern at **a** Port, **b** Port 2, **c** Port 3 and **d** Port 4

plane) that decouples the current between the elements. As a result of this field cancellation, the proposed design impedance characteristics change thereby improving the isolation between the antenna elements. The current flow from the ground part to the antenna is opposite in nature. This suppresses the flow of current to the adjacent element. The same can be observed at port 2, port 3, and port 4 depicted in Fig. 17b–d, respectively.

3 Results and discussion

The proposed two element and four element antennas with the best isolation design are analyzed in Ansys HFSS. The prototype of the proposed designs is fabricated on FR4 substrate with 1.6 mm thickness, 4.4 dielectric constant, and 0.02 loss tangent as illustrated in Fig. 18 for further practical analysis.

The simulated and measured $|S\text{-parameters}|$ of the two element antenna at both the ports are depicted in Fig. 19. It can be seen that at port 1, the -10 dB bandwidth ranges from 4.71 to 6.62 GHz and the transmission coefficient is well below -30 dB in simulation. The measured results are also in good agreement, where the -10 dB bandwidth ranges from 4.89 to 6.66 GHz and the transmission coefficient is well below -20 dB. Similarly, at port 2, the -10 dB bandwidth ranges from 4.44 to 6.58 GHz and the transmission coefficient is well below -30 dB in simulation. The measured results are also in a good agreement, where the -10 dB bandwidth ranges from 4.67 to 6.35 GHz and the transmission coefficient is well below -20 dB.

The simulated and measured $|S\text{-parameters}|$ of the four element antenna design at port 1 are depicted in Fig. 20. The observed frequency range and $|S\text{-parameter}|$ coefficient magnitude is summarized in Table 3. The fabricated prototype of two and four elements exhibits slightly deviated results from

Fig. 18 **a** Fabricated two element design front and back part. **b** Fabricated four element design front and back part

simulation which may be due to split shaped patch and the asymmetric orientation of antenna elements which is used to enhance the isolation between the antenna elements. Also, this difference may be due to the misalignment of SMA connector with feedline, substrate dielectric constant variation at higher frequency, fabrication tolerance and measurement facility, primary due to antenna mounting and positioning system in the laboratory.

The various diversity parameters which state the acceptable performance of the proposed two and four element antenna such as Envelope Correlation Coefficient (ECC), Diversity Gain (DG), Total Active Reflection Coefficient (TARC), Mean Effective Gain (MEG) and Channel Capacity Loss (CCL) are also studied and detailed below.

The ECC states how multiple antennas in a system are independent in its radiation pattern. The ECC between the antennas elements are calculated using [25]. Basically, ECC tells the correlation between the radiating elements. It provides a measure of correlation in the radiation pattern of m th radiating element with n th radiating element in a given antenna system. It can be noted that most of the planar antennas suffer from loss, so the use of S -parameters are generally avoided in the calculation of ECC parameter. Thus for wideband antennas, to compute ECC, far-field pattern is preferred and is given by Eq. (1):

$$ECC_{nm} = \frac{\left| \int_0^{2\pi} \int_0^\pi \left(E_{\theta m}^* E_{\theta n} P_\theta \cdot XPR + E_{\varphi m}^* E_{\varphi n} P_\varphi \right) d\Omega \right|^2}{\int_0^{2\pi} \int_0^\pi \left(E_{\theta n}^* E_{\theta n} P_\theta \cdot XPR + E_{\varphi n}^* E_{\varphi n} P_\varphi \right) d\Omega + \int_0^{2\pi} \int_0^\pi \left(E_{\theta m}^* E_{\theta m} P_\theta \cdot XPR + E_{\varphi m}^* E_{\varphi m} P_\varphi \right) d\Omega}, \quad (1)$$

Fig. 19 Simulated and measured $|S\text{-parameters}|$ at port 1 and port 2 of two element model

Fig. 20 Comparison between simulated and measured |S-parameters| at port 1

where XPR is the cross-polarization rate and is defined as the ratio of average power along $\varphi(P_H)$ and $\theta(P_V)$ coordinates. E_{φ_m} and E_{θ_n} are the complex envelope along φ and θ direction. Ideally, ECC has to be 0, and in a practical environment, the acceptable limit of ECC is less than 0.5 ($ECC < 0.5$). The ECC curves for the designed antenna are

Table 3 Performance of the proposed design

Port no.	− 10 dB bandwidth sim (GHz)	− 10 dB bandwidth meas. (GHz)	Transmission coef- ficient sim. (dB)	Transmission coef- ficient meas. (dB)
1	4.26–6.82	4.84–6.33	< − 25	< − 15
2	4.28–6.78	4.86–6.98	< − 25	< − 20
3	4.53–6.82	4.14–6.69	< − 25	< − 20
4	4.55–6.87	4.32–6.94	< − 25	< − 20

Fig. 21 ECC of the proposed structure for **a** two element, **b** four element

depicted in Fig. 21, wherein it can be seen that ECC values are well below the required limit. In Fig. 21a, the ECC calculated for the two element design is depicted. Similarly, in Fig. 21b the ECC for the four element design between adjacent and diagonal ports is calculated.

To have good quality and reliability in wireless systems, the DG of the multiple antenna design has to be high, nearly 10 dB in the operating bandwidth. The DG is calculated from the ECC value using the Eq. (2). The DG of the proposed two and four port antenna structure is illustrated in Fig. 22. It can be observed that the DG of the antenna in the entire operating range is around 10 dB:

$$DG = 10 \times \sqrt{1 - |ECC_{nm}|^2}. \quad (2)$$

The TARC is defined as the ratio between the square root of total reflected power to the square root of total incident power. The generalized TARC for N port antenna and for the case of 2×2 antenna array is calculated from the below Eqs. (3–4), respectively [26, 27]:

Fig. 22 DG for the proposed **a** two element, **b** four element

Fig. 23 TARC of the proposed two and four element MIMO design

Fig. 24 MEG analysis between the ports of two element antenna

$$\Gamma_a^r = \frac{\sqrt{\sum_{i=1}^N |b_i|^2}}{\sqrt{\sum_{i=1}^N |a_i|^2}} \quad (3)$$

$$\Gamma_a^r = \frac{\sqrt{\left(|s_{11} + s_{12}^{e_{i\theta}}|^2 + |s_{21} + s_{22}^{e_{i\theta}}|^2 \right)}}{\sqrt{2}}, \quad (4)$$

where $b_i = [s] \cdot a_i \cdot [s]$ is the scattering matrix of the multiple antenna, $[b] \rightarrow$ scattering vector and $[a] \rightarrow$ excitation vector. For N port antenna, TARC is related to total incident power

to total outgoing power. Ideally, it has to be zero which means all the power delivered is accepted by the antenna. The calculated result of the proposed two and four element design is illustrated in Fig. 23.

The MEG is an important parameter in multiple antenna design analysis and is defined as the ratio of power received by diversity antenna to power received by an isotropic antenna. The MEG analysis for the proposed two element antenna is done at port 1 and port 2 as depicted in Fig. 24. In the same manner, for the proposed four element antenna MEG analysis is also done between port 1 and port 2, port 1 and port 3 and port 2 and port 4 as shown in Fig. 25. For a good multiple antenna design with the same power level, the

Fig. 25 MEG analysis between the ports **a** 1 and 2, **b** 1 and 3, **c** 2 and 4 of four element antenna

ratios MEG-1/MEG-2, MEG-1/MEG-3, and MEG-2/MEG-4 must be less than 3 dB. The same is observed in Fig. 25, the ratios are well below 3 dB. The MEG is calculated using the following relations (5–6) [28]:

$$\text{MEG}_i = 0.5 \left[1 - |S_{ii}|^2 - |S_{ij}|^2 \right] \quad (5)$$

$$\text{MEG}_j = 0.5 \left[1 - |S_{ij}|^2 - |S_{jj}|^2 \right]. \quad (6)$$

The CCL estimates the maximum limit up to which the message transmission can take place without any loss in the communication channel. The acceptable CCL value must be

less than 0.4 bits/s/Hz. The CCL using the $|S$ -parameters| is calculated from Eqs. (7–10) [28]:

$$C_{\text{loss}} = -\log_2 |\varphi^R| \quad (7)$$

$$\varphi^R = \begin{bmatrix} \varphi_{11} & \varphi_{12} & \varphi_{13} & \varphi_{14} \\ \varphi_{21} & \varphi_{22} & \varphi_{23} & \varphi_{24} \\ \varphi_{31} & \varphi_{32} & \varphi_{33} & \varphi_{34} \\ \varphi_{41} & \varphi_{42} & \varphi_{43} & \varphi_{44} \end{bmatrix} \quad (8)$$

where

$$\varphi_{ii} = 1 - \left| \sum_{n=1}^N S_{in}^* S_{ni} \right|, \quad \text{for } i, j = 1, 2, 3 \text{ and } 4 \quad (9)$$

Fig. 26 Channel capacity loss between two antenna elements of two and four element design

$$\varphi_{ij} = - \left| \sum_{n=1}^N S_{in}^* S_{nj} \right|, \quad \text{for } i, j = 1, 2, 3 \text{ and } 4. \quad (10)$$

The CCL estimated from $|S\text{-parameters}|$ for the two element and four element antenna design is depicted in Fig. 26. It is observed that the CCL value is much below the desired

maximum value (< 0.4 bits/s/Hz) over the entire operating frequency range.

The co-polarization and cross-polarization of the fabricated antenna are measured at $\varphi = 0^\circ$ and $\varphi = 90^\circ$. The measured bidirectional and Omni-directional pattern in E-plane, and H-plane are seen at 4.5 GHz, 5.0 GHz, 5.5 GHz and 6.0 GHz for two element antenna as shown in Fig. 27. Similarly, for the four port antenna the measured pattern is shown in Fig. 28.

The radiation pattern is more symmetrical at higher frequencies which may due to slotted patch which tends to suppress the back radiation and makes pattern symmetrical at a higher frequency.

The simulated gain and radiation efficiency of the proposed two element and four element antenna is depicted in Fig. 29. It is seen that the gain is about 3.5 dBi at 5.5 GHz and ranges between 3.25 and 4.25 dBi in the operating bandwidth of two element antenna. Similarly, for four element antenna, a gain of about 4.95 dBi is observed at 5.5 GHz and ranges between 4.0 and 5.0 dBi in the operating bandwidth. The radiation efficiency is well above 90% of both the antennas in the operating region.

A comparative analysis between the proposed four element and other wideband multiple antennas are studied in literature and is presented in Table 4. It is quite evident from the table that the designed antenna provides better performance over their counterparts.

Fig. 27 Measured radiation pattern at $\varphi = 0^\circ$ and $\varphi = 90^\circ$ for two element antenna at **a** 4.5, **b** 5.0, **c** 5.5 and **d** 6.0 GHz

Fig. 28 Measured radiation pattern at $\varphi = 0^\circ$ and $\varphi = 90^\circ$ for four element antenna at **a** 4.5, **b** 5.0, **c** 5.5 and **d** 6.0 GHz

Fig. 29 Simulated gain and radiation efficiency of the proposed designs

4 Conclusion

A compact CPW fed two and four element antenna design with an operating bandwidth of 1500 MHz (4.3–6.8 GHz) is proposed and its performance parameters are studied. The focus is on the improvement in isolation between the antenna elements. This high isolation is achieved in the proposed design without utilizing any decoupling methods, thus, totally benefits from the monopole asymmetrical structure. The essential diversity parameters like ECC, DG, TARC, MEG, and CCL are analyzed to have a minimum correlation between the antenna elements. The proposed antenna is intended to be used for WLAN, Wi-MAX, and satellite bands of the range corresponding to 4.70–6.19, 5.5–5.7, and 5–6 GHz.

Table 4 Comparing the performance parameters of the proposed design with existing designs

Ref. nos.	Dim. (mm ²)	Range (GHz)	Gain (dBi)	Isolation (dB)	ECC	DG (dB)	CCL (bits/s/Hz)	MEG (dB)
[16]	4050	5.8–9.2	1.24	21.0	–	–	–	–
[17]	2025	2.2–6.28	2.75	10.0	<0.25	–	–	3.4
[18]	2460	2.19–11.07	6.5	>20.0	<0.25	–	–	–
[19]	6400	2.53	4.9	>15	<0.01	–	–	–
[20]	2400	2.45	3.4	>20	<0.4	–	–	–
[21]	2025	2–10.6	3.0	>17	0.003	–	<0.3	–
[22]	4900	5.26	4.13	>20	<0.03	9.93	–	5.76
[23]	2445	5.18–5.22	3.38	>20	–	–	–	–
[29]	3600	3.0–16.2	6.0	>17.5	<0.3	–	<0.4	<3
[30]	7225	3.0–10.6	4.8	>15	<0.2	–	–	–
[31]	11,250	3.0–3.6	–	>11	<0.1	–	–	–
[32]	8100	3.1–12	3.2	>17	<0.16	9.6	–	–
[33]	2500	2–12	3.15	>17	<0.45	–	–	–
[34]	4900	3.0–10.6	6	>17	<0.2	–	–	–
Prop.	2025	4.3–6.8	4.95	>20	<0.2	>9.8	0.018	3.03

Funding Open access funding provided by Manipal Academy of Higher Education, Manipal.

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