Design and Simulation of Microstrip Antenna Array Operating at S-band for Wireless Communication System

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Abstract *– In this article, different design configurations of rectangular microstrip patch antenna (RMSA) array operating at S-band frequency are presented. The substrate material utilized in the designs is Rogers-RT-5800 with dielectric permittivity (Ɛr= 2.2), thickness of (h=1.6 mm), and loss tangent of (δ = 0.009). The performances of a single element, (1×2), (2×2) and (1×4) array elements operating at (3.6 GHz) are investigated using the CST and HFSS numerical techniques. The simulation results indicates that the antenna gain of (8.68, 10.35, 10.43 and 10.52) dB, VSWR (1.045, 1.325, 1.095 and 1.945), return loss (-34.91, -17.15, -27.42 and -12.26) dB, and bandwidth (85.00, 200.00, 215 and 106.4) MHz are achieved with the implementation of HFSS for advanced single element, (1×2), (2×2) and (1×4) array elements, respectively. Besides, the corresponding antenna parameter values provided by CST are, gain (7.36, 9.8, 9.87 and 10.30) dB, VSWR (1.011, 1.304, 1.305 and 1.579), return loss (-44.97, -17.58, -17.55 and -14.01) dB, and bandwidth (92.28, 204, 229.49 and 129.12) MHz, respectively. The results also reveals that the higher gain and wider bandwidth are, respectively, achieved with (1×4) and (2×2) array configuration arrangement and with both simulation techniques. Additionally, a good agreement and an advancement between the obtained results with the ones previously studied for the same array types operating at S-band frequencies are also observed.*

Keywords*: Patch Antenna, Microstrip antenna, antenna array, wireless communication, s-band.*

1. INTRODUCTION

In the field of wireless communications, the antennas have played a significant role, and have many forms including patch antennas, wire antennas, horn antennas and parabolic antennas, having own properties and applications and without which the world could never reached at this stage of developed technology systems [1,2]. In the last two decades, the wireless communication systems have been developed from analog into digital technologies systems to improve the data rate capability and increase the speed of multimedia transmission [3]. New 5G frequency bands which utilized (3.3-3.8) GHz in several countries around the world, for the 6 GHz sub-band, have been approved to support higher data speed transfer [3,4].

On the other hand, as technological innovations for instance smart phones, Internet-of-Things (IoT), wearable and handheld devices become smaller over the time, it is critical yet challenging to develop an antenna geometrical arrangement that maintains at a particular band frequency providing high directivity, gain, wider bandwidth, and high-quality services [1,5]. Therefore, the MSA can be regarded as a reliable candidate for the new wireless application systems due to its low cost, light weight and ease of fabrications. However, the MSA has a number of drawbacks, including low gain and narrow bandwidth which make the researcher to develop methods to overcome these MSA disadvantages.

Many studies were published in the literature proposing different feeding methodologies, slots, defected ground plane, various antenna arrangement arrays to achieve antenna improvement characteristics [6,7]. Among these methods, the MSA arrays of various geometrical construction have been increasingly employed in recent years, since they are durable and provide very attractive performance for several application systems such as, 5G, satellite, medical applications, WLAN, radar, personal technology and military application systems [8-10]. A planar slot RMSA array operating at (3.5 GHz) was designed and fabricated by [11] for a sub-6 GHz 5G wireless application systems. It was found that the proposed antenna provides a gain, efficiency and bandwidth of the order of (4.2 dB), (82%) and (19 MHz), respectively. A RMSPA gain improvement through an array of (4x1) configuration operating at (2.5 GHz) was designed and simulated on the FR4 dielectric substrate of thickness (1.6 mm) making it reliable for WiMAX applications [7]. Besides, a higher radiation performance for an inset fed single element, (1x2) and (1x4) arrays RMSPA placed on Rogers-RT-5880 with thickness (1.6 mm) operating at (2.4 GHz) for WLAN applications was achieved by [12] using IE3D numerical method. Additionally, a single RMSA array with (1x2) and (2x2) arrays was proposed to operate at S-band frequencies using FR4 dielectric substrate of thickness (1.6 mm) [13,14]. On the other hand, a coaxial probe fed single RMSPA, (1x4), (2x2) and (4x4) element arrays were designed and investigated by [15] using RT-Duriod dielectric substrates with thickness (h=3.175 mm) to operate at (1.48 GHz) for radar application systems. Moreover, the directivity enhancement of a triangular MSA operating at (5.5 GHz) was proposed and fabricated through a T-junction inset fed of (2x2) patch element arrays using FR4 epoxy as a substrate material with thickness (1.6 mm) [16]. Besides, the size reduction of RMSA array operating at (2.4 GHz) with acceptable radiation performance were investigated by [33] using different array configuration types. Generally, these research woks displayed that the gain and bandwidth could be enhanced properly with the use of reliable array constructions.

Therefore, this work is established to improve the overall radiation performance of RMSA array operating at (3.6 GHz) through an investigation of various geometrical array configurations. The design procedure is performed by arranging four element RMSA array in a form of single patch, (1x2), (2x2), and (1x4) array geometrical configurations and the fundamental antenna parameters for each of them are calculated using both HFSS and CST simulation methods. The main purpose of the study is intended to attain a lightweight antenna providing reliable gain and wider bandwidth suitable for most S-band application systems which is a part of the electromagnetic spectrum ranged between (2-4) GHz. This band frequency is selected due to the fact that it implemented for radio and television, satellite communication, radar weather station, wireless network and ship radar [17,18].

The remind section of the article is organized as follows. In section 2, a theoretical design calculation of the physical dimension for single element, (1x2), (2x2), and (1x4) array array RMSA array elements are described. The computation of the fundamental RMSA array parameters for each mentioned array configuration are presented and discussed in section 3. The main conclusion and recommendation for future work are mentioned in section 4.

2. MATERIAL METHOD

In this study, a single (MSA) is designed and then upgraded to the two and four (MSA) elements in both the parallel (corporate) with series feeding method, to improve the value of gain, directivity and bandwidth. The design procedure for all mentioned array cases is performed by the implementation of both CST and HFSS software package. These two simulation methods are, respectively, based on the numerical methods known as Finite Element Method (FEM) and Finite Integral Techniques (FIT) [19]. The (FEM) is an alternative computational electromagnetic method (CEM) suggested to determine a solution of partial differential equation in the frequency domain. It was proposed in the 1940s by Courant and it was firstly employed to solve problems containing difference in electric potential but it is now widely used in the field of RF/microwave system technology. In this technique, the total domain is discretized into a sub-domain of unordered mesh which is a successful solver for complicated structures and non-uniform objects which offers a high degree of geometric tolerance [20]. Meanwhile, in (FIT), the solution of Maxwell equations can be derived from both frequency and time domains and it was firstly approved by Weiland 1977 [21]. This method is suitable to different electromagnetic problems extending from static field measurements to high frequency applications in time as well as frequency domain. The (FIT) is composed of distinct types of grids, like non-orthogonal or Cartesian and describes a volume within Maxwell's equations which can be resolved in a finite unit of discrete locations. Hence, (FIT) is extremely equivalent to the finite difference time domain method (FDTD) [2].

Furthermore, both CST and HFSS are a full-wave electromagnetic field (EM) simulation software that helps to solve all 3D electromagnetic or mechanical second differential problems [2]. As the antenna operational frequency (f_r) , dielectric substrate permittivity (ε_r) and substrate thickness (h) are specified, then the dimensions of patch and ground plane are computed through some mathematical expression provided by transmission line method. Later, the radiation performance for each of the mentioned array structures are computed using CST and HFSS simulation methods. The simulation design for single element RMSA and considered array configurations are described in the following subsections.

2.1. SINGLE ELEMENT

The design of single element RMSA with specification of its patch and fed line dimension is demonstrated in Figure (1) which are computed by implementing both mentioned simulation software techniques.

The proposed antenna is built up on Rogers-RT-5800 dielectric substrate of relative permittivity ($\mathcal{E}_r$=2.2) and thickness of (h=1.6 mm) and having loss tangent of (δ=0.009) [22,23]. In the design procedure, an extensively inset fed and transmission line feeding methods have been utilized and their patch and line dimensions are evaluated through the following equations based on transmission line method [11]. The first quantity is the patch width (W_p) and it can be determined using equation [24]:

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{\mathcal{E}_r+1}} \quad (1)$$

where, (f_r) is the antenna operating frequency, (c) is speed of light in free space and (ε_r) is the substrate relative permittivity. The second parameter that must be specified is the effective dielectric constant (ε_{eff}) which is introduced due to the fringing field effect and for RMSA is calculated as given by [24]:

$$\mathcal{E}_{eff} = \frac{\mathcal{E}_r+1}{2} + \frac{\mathcal{E}_r-1}{2}\left[1+12\frac{h}{W_p}\right] \quad (2)$$

As a consequence of radiation fringing effect on both sides of the patch, then the length is extended by an amount (ΔL) and is determined through an equation given by [24].

$$\Delta L = \frac{0.412(\mathcal{E}_{eff}+0.3)\left(\frac{W_p}{h}+0.264\right)}{(\mathcal{E}_{eff}-0.258)\left(\frac{W_p}{h}+0.8\right)}\,\mathcal{E}_{eff} \quad (3)$$

and,

$$L_{eff} = \frac{c}{2f_r\sqrt{\mathcal{E}_{eff}}} \quad (4)$$

where, (L_{eff}) is the patch effective length is expressed as:

While the actual patch length (L_p) can be obtained with respect to the extension and effective length of the patch as:

$$L_p = L_{eff} - 2\Delta L \quad (5)$$

To improve the performance of the patch antenna design, the ground plane should be larger than the patch dimensions by approximately six times as the substrate, hence the width (W_g) and length (L_g) of substrate are calculated by using the following relations [13,25]:

$$W_g = W_p + 2\left(\frac{\lambda}{4}\right) \quad (6)$$

$$L_g = L_p + 2\left(\frac{\lambda}{4}\right) \quad (7)$$

Moreover, the width of feed line (W_f) can be obtained from input impedance equations as mathematically expressed by [9] as:

$$Z_\circ = \begin{cases} \frac{60}{\sqrt{\mathcal{E}_{reff}}}\ln\left[\frac{8h}{W_f}+\frac{W_f}{4h}\right] & if \quad \frac{W_f}{h} \le 1 \\ \frac{120\pi}{\sqrt{\mathcal{E}_{ref}}\left[\frac{W_f}{h}+1.393+0.667\times\ln\left(\frac{W_f}{h}+1.444\right)\right]} & if \quad \frac{W_f}{h} > 1 \end{cases} \quad (8)$$

where, ($Z_\circ$) is the antenna impedance, and for transmission line feed is equal to 50 ohms, while, the characteristics impedance ($Z_\circ$) of the two microstrip lines is given by [6] as:

$$Z_\circ = 2 \times 50\,\Omega \quad (9)$$

Moreover, the length of the inset-fed line is specified by [7]:

$$F_i = \frac{6h}{2} \quad (10)$$

Depended on the above equations, the single RMSA dimensions after optimization through the mentioned simulation methods are determined and the results are summarized in the Table 1.

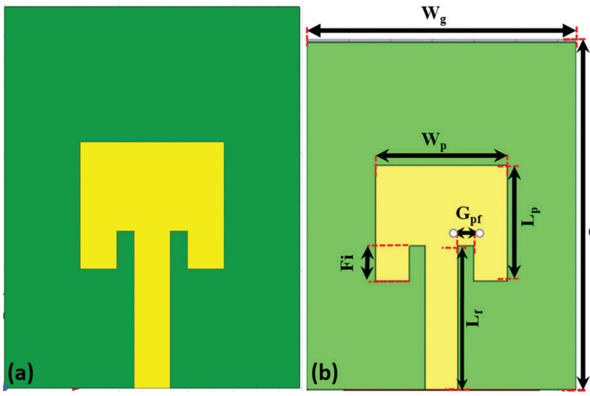


Fig. 1. Top view of simulated single RMSPA with (a) HFSS and (b) CST.

Table 1. Dimension optimization of single element

Parameters	Description	Value(mm)
W_p	Patch width	27.00
L_p	Patch length	31.48
G_{pf}	Gap between Line feed and Patch	3.75
F_i	Inset-feed length	8.15
L_f	Transition line length	33.06
W_f	Microstrip line feed width	6.75
W_g	Ground width	64.25
L_g	Ground length	82.06
H	Substrate thickness	1.575

2.2. ANTENNA ARRAY

As mentioned before, the antenna array is usually employed to enhance the antenna directivity, gain and plays different roles that are not achieved normally by a single element [26]. Generally, the array factor is depended on the array elements, space between element, geometry of the array and excitation vector. For one-dimensional linear array, the mathematical expression for the array factor is formulated as given by [27]:

$$AF(\theta,\emptyset) = \sum_{m=1}^{M} I_m e^{j(k.\hat{r}_m+\alpha_m)} \quad (11)$$

While, for two-dimensional planner array, this factor is expressed as [27]:

$$AF(\theta,\emptyset) = \sum_{m=1}^{M}\sum_{n=1}^{N} I_{mn} e^{j(k.\hat{r}_{mn}+\alpha_{mn})} \quad (12)$$

Where, ($\hat{r}$) is the elements vector location, (I_{mn}) is amplitude and (α_{mn}) is the excitation phase for (m^{th},n^{th}) elements to achieve maximum directivity in the given direction (θ,$\emptyset$)[28]. Regarding the parameters that have been evaluated for single patch element, a (1x2), (2x2) and (1x4) RMSA arrays are built. The rectangular patch elements are implemented in a linear and planer configuration, using inset line feed techniques with input impedance of (50 Ω). Each patch elements arrays are separated by (0.5 λ) with optimized dimensions as demonstrated in Figures (2 and 3) which are designed with CST ad HFSS. This arrangement has the benefit of becoming easier to establish as well as being efficiently optimized by the patch's inset-fed and length of the inset fed [29,30].

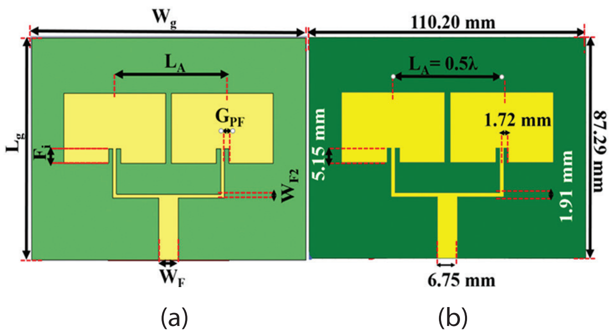


Fig. 2. Top view of proposed (1×2) RMSA arrays simulated by (a) CST and (b) HFSS.

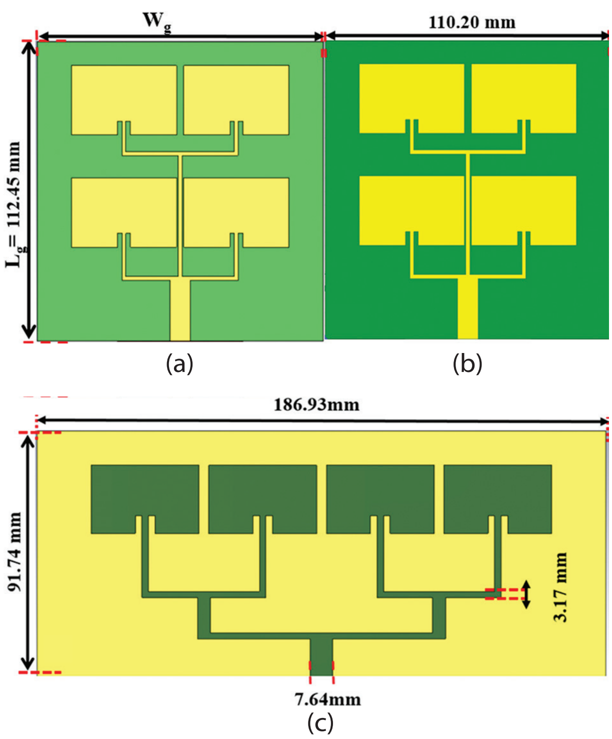


Fig. 3. Top view of proposed (2×2) RMSA arrays simulated by: (a) CST, (b) HFSS and (c) (1×4) by CST.

When the dimensions of the patch, ground plane, fed-line as well as dielectric substrate characteristics are specified, then the radiation performance of each array configuration are evaluated by both simulation method and the result are presented in the form of table or graphs as described in the next section.

3. RESULTS AND DISCUSSION

As previously mentioned, the main purpose of the present work is to develop a high gain and wider bandwidth (RMSA) with lightweight as well as offering better radiation characteristics suitable for compact S-band wireless applications systems operating at (3.6) GHz. According to the optimized patch, ground plane and inset-fed dimension values of the proposed antennas, the reflection coefficient (S11), voltage standing wave ratio (VSWR), gain, directivity, bandwidth and antenna radiation pattern for each mentioned array configuration have been analyzed by both HFSS and CST computational methods. The calculated results of the simulated RMSPA parameters are presented and explained in details in the following sub sections.

3.1. RETURN LOSS (S11) AND VSWR

The computed results of the S11 parameters for the single element and (1x2) array element RMSPA are shown in Fig. 4. It is clearly seen from this figure that the simulated (S11) for single element reaches a value of (-34.91) dB with a bandwidth of (85) MHz in HFSS, while it arrives a value of (-44.97) dB and bandwidth of (92) MHz at (3.6) GHz with implementation of CST. While, the values of (S11) are (-17.15 and -17.58) dB for (1×2) elements RMSA arrays within a bandwidth of (200 and 204.42) MHz for HFSS and CST, respectively. However, the value of S11 parameter as a function of frequency for (2x2) and (1x4) array types are (–17.55 and -27.58) dB with a bandwidth (229.49 and 215) MHz and (–14.014 and -12.969) dB with a bandwidth (129.12 and 106.90) MHz by implementing CST and HFSS, respectively as demonstrated in Fig. 5. These computed results reveal a significant enhancement in the bandwidth with increasing antenna array elements and values of (S11) are more less than (–10) dB, which indicate the impedance matching as well [9,14]. Additionally, these results also displays that the (2x2) RMSA array configuration provide higher bandwidth operation compare to the other array arrangement considered in this investigation.

In contrast, the (VSWR) that is represent the amount of radio frequency power that properly converted from the source into the transmission line towards a load is also computed for all considered cases and with both simulation methods [31]. The calculated results of VSWR obtained for single element and (1x2) array RMSA are (1.045 and 1.011) dB and (1.305 and 1.325) with the implementation of CST and HFSS, respectively as shown in Fig. 6. Besides, the simulated results of VSWR predicted by both CST and HFSS techniques for (2x2) and (1x4) array types are, respectively, (1.094 and 1.350) dB and (1.579 and 1.945) dB as demonstrated in Fig. 7. Accordingly, these figures indicates that the VSWR for all considered cases are smaller than 2 (VSWR < 2) which is regarded as an optimal limit which leads to enhanced antenna radiation performance for use in S-band wireless commutation systems [31].

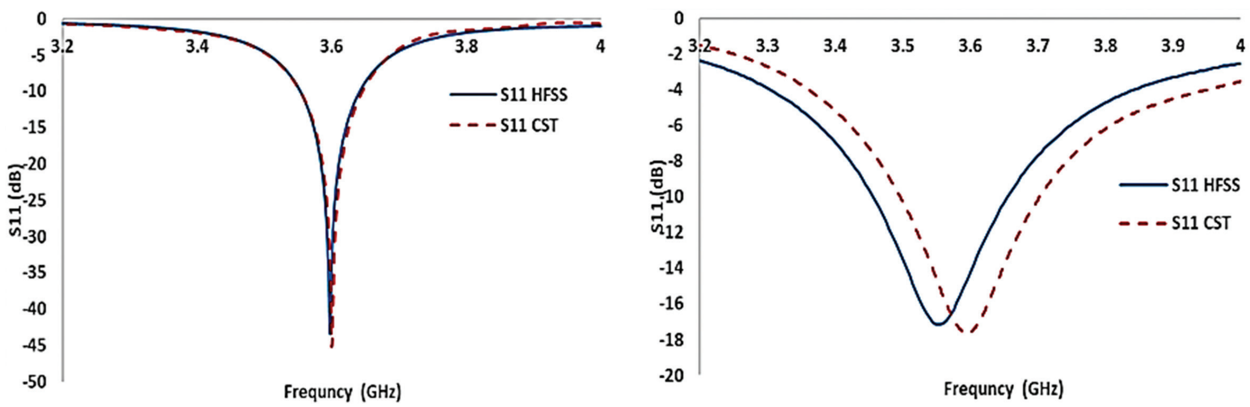
3.2. ANTENNA RADIATION PATTERN

The antenna radiation pattern define as the graphical descriptions of radiation fields and through which the characteristics of antenna radiation power would be identified over large distances and in different spatial orientations [32]. Figs. (8 and 9), display the three-dimensional calculated gain, consequently for the proposed single element, (1x2), (2x2) and (1x4) RMSA arrays. The computed results achieve by HFSS simulator as depicted in Figs 8(a) and 9(a) suggest that the maximum values of gain are (8.68, 10.35, 10.43 and 10.52) dB for advanced single element, (1x2), (2x2) and (1x4) (RMSA arrays operating at (3.6) GHz, respectively.

Furthermore, the higher antenna gains values provided by CST techniques for single element, (1x2), (2x2) and (1x4) RMSA arrays are, respectively, (7.36, 9.8, 9.87 and 10.30) dB, as obviously seen in Figs. 8(b) and 9(b). Generally, according to the results displayed in these figures, one clearly observes that the antenna gains increase with increasing antenna elements and all of which lies within an acceptable value reliable for S-band application systems. In addition, these results also implies that the (1x4) and (2x2) array configurations maintain higher antenna gain compare to the other considered geometrical arrangements. Besides, both simulation techniques are also employed to compute the two-dimensional polar pattern view of E-plane radiation fields and the results are graphically presented in Figs. 10 for single element, (1x2), (2x2) and (1x4), respectively. It is clearly seen from these figures that as the number of patch element increase more side and back lobes are introduced while maintain the main beam in the same direction. Among which, the (2x2) array configuration provide lower side lobe level power as can be depicted in Fig 10(c) which support the reliability of this configuration to be applicable for more practical wireless communication systems.

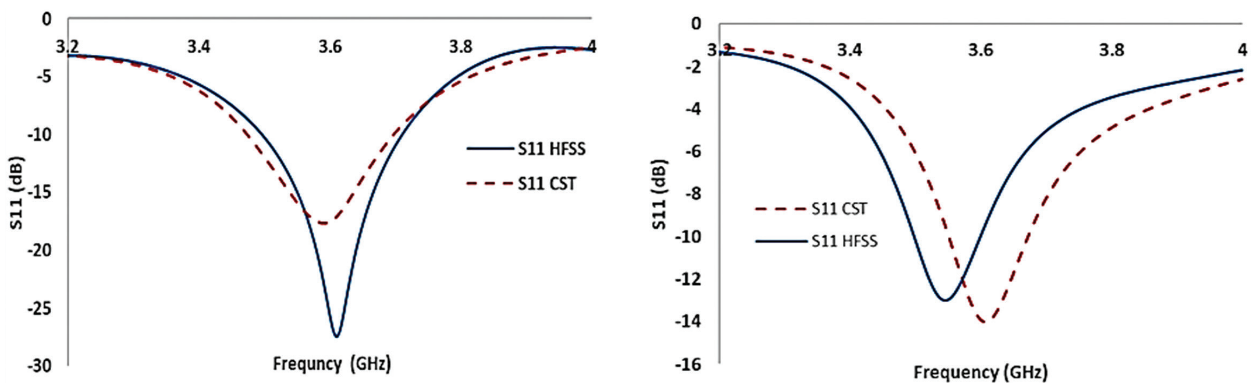
Moreover, the overall RMSA array parameters such as, S11, VSWR, gain, directivity, efficiency and bandwidth that have been achieved with both simulation softwares and for each considered array congigurations operating at (3.6 GHz) are summurized in Table 2.

Finally, these calculated parameters are compared to their corresponding value achieved by other researcher working on the same array configuration and operating at various S-band frequencies and the results are presented in Table 3. The accuracy and advancement of our calculated gain and bandwidth parameters are observed from this table as compared to the corresponding available works performed previously.



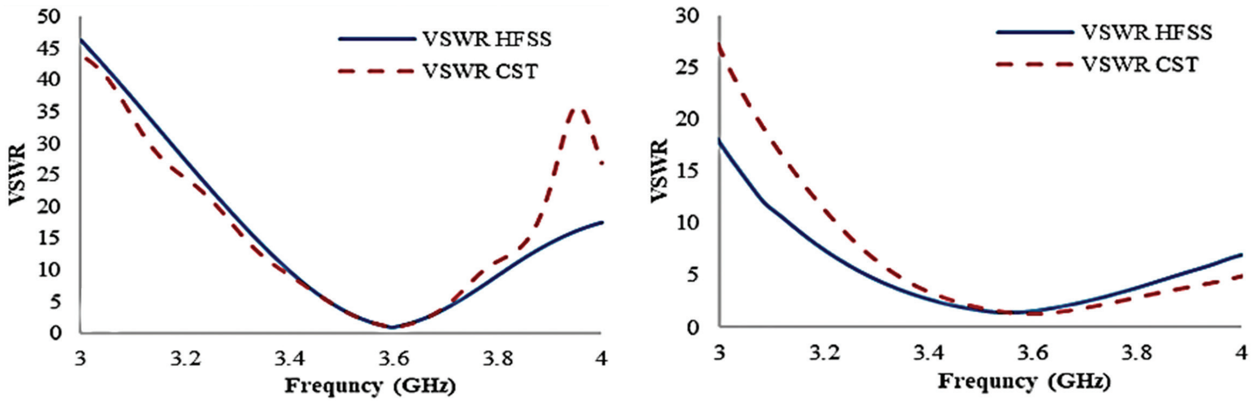
(a) (b)

Fig. 4. Change of S11 depeneded on frequncy for (a) single element and (b) (1×2) array



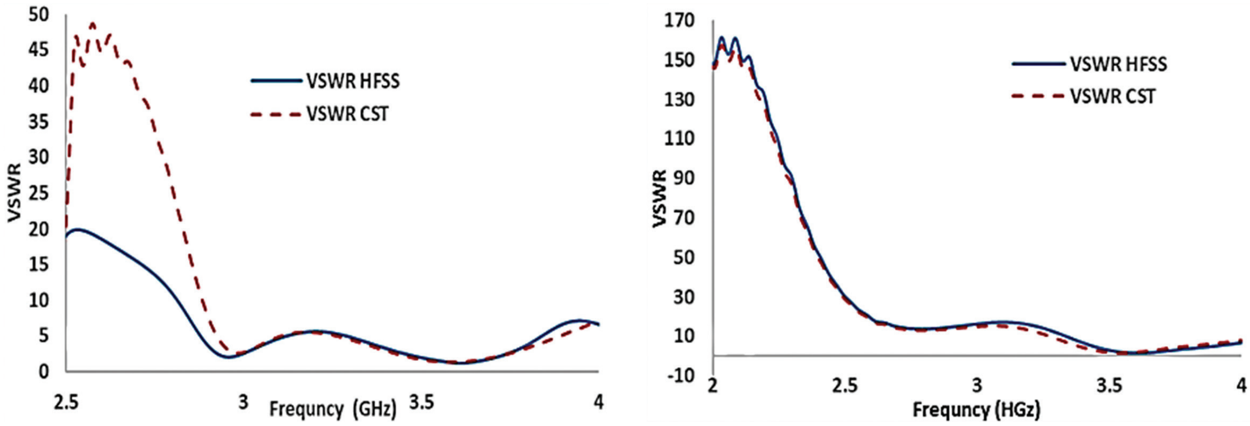
(a) (b)

Fig. 5. Change of S11 depeneded on frequncy for (a) (2×2) and (b) (1×4) array



(a) (b)

Fig. 6. Change of VSWR depeneded on frequncy for (a) single element and (b) (1×2) array



(a) (b)

Fig. 7. Change of VSWR depeneded on frequncy for (a) (2×2) and (b) (1×4) array

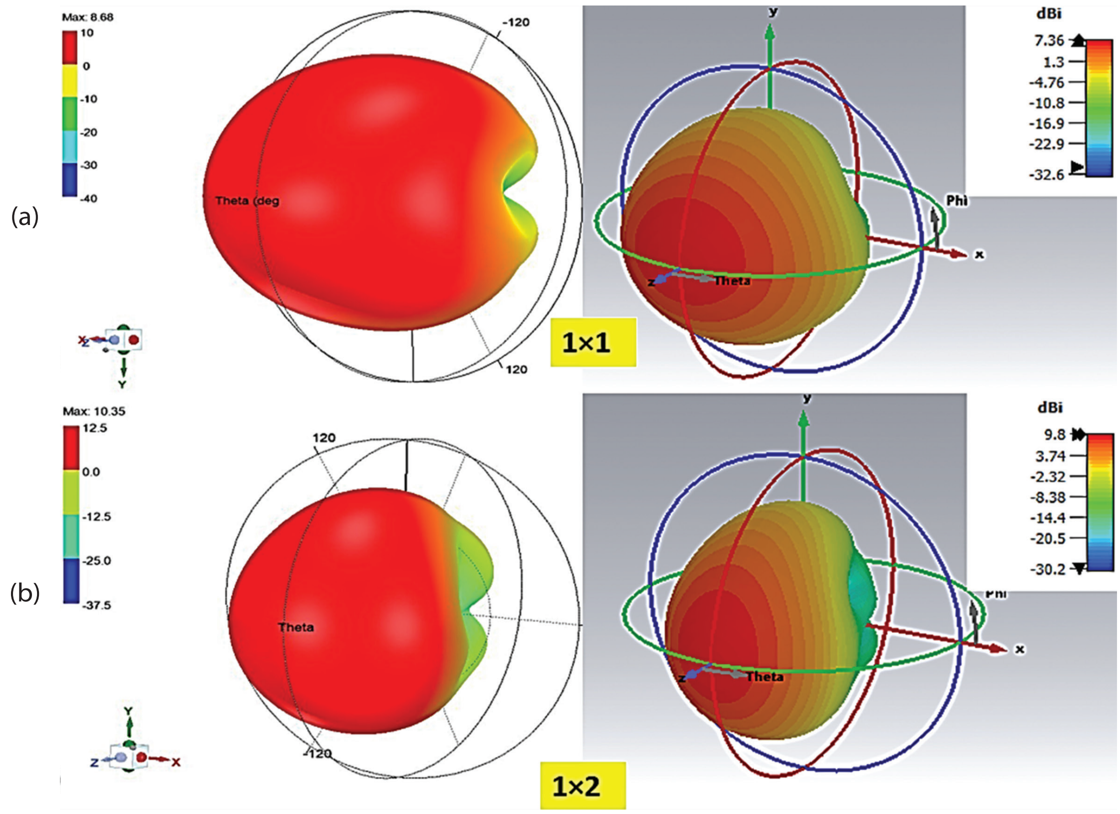


Fig. 8. 3D view of RMSA gain by (a) HFSS and (b) CST for single element and (1×2) arrays

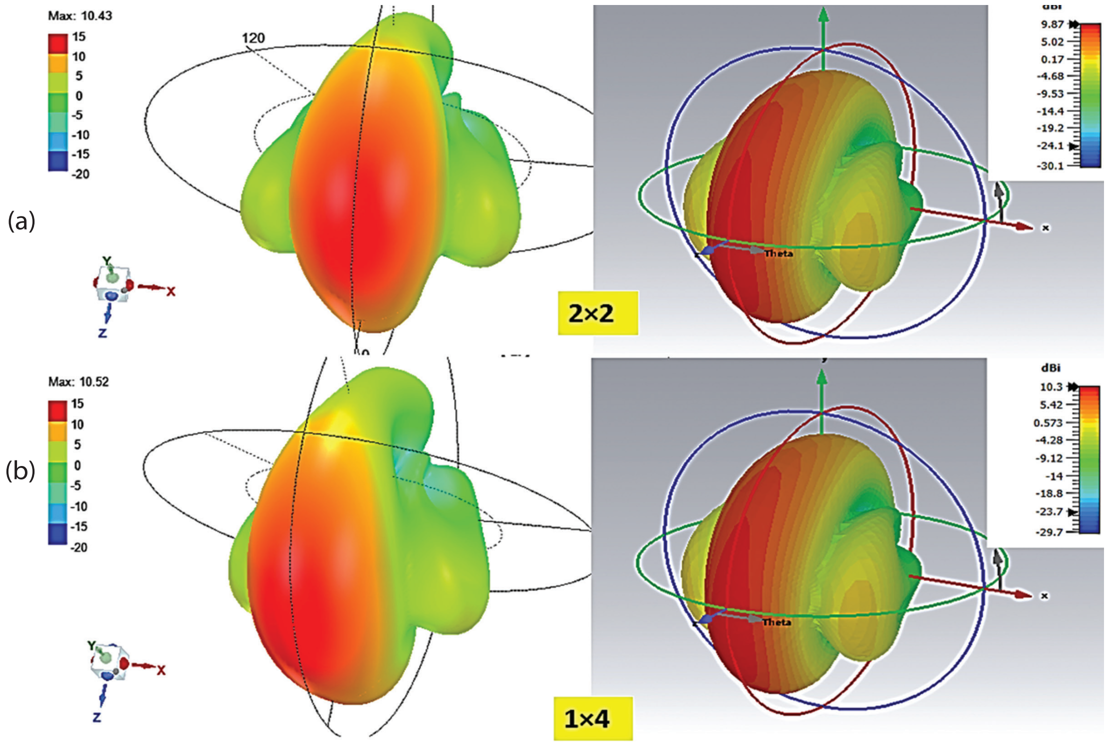


Fig. 9. 3D view of RMSA gain by (a) HFSS and (b) CST for (2×2) and (1×4) arrays

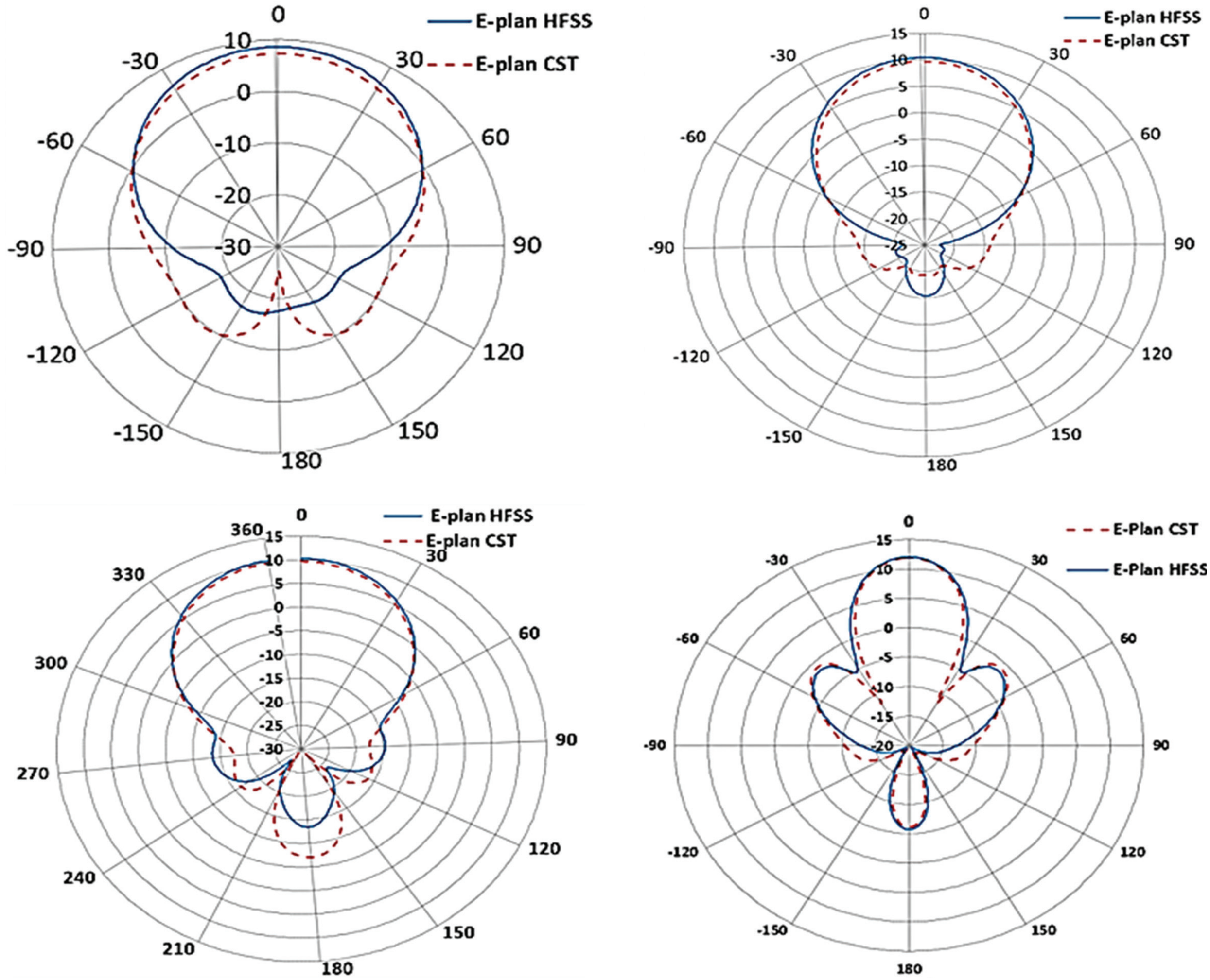


Fig. 9. 2D polar view of E-plane for (a) single element (b) (1×2) (c) (2×2) and (d) (1×4) arrays

Table 2. Overall simulated antenna chrematistic results for each considered arrays.

Element No.	Simul. Tech.	S11(dB)	VSWR	Gain (dB)	Dir(dB)	Efficiency %	BW(MHz)
Single	HFSS	-33.12	1.045	8.61	8.73	98.62	85.00
1×2	HFSS	-17.15	1.325	10.35	10.44	99.13	200.00
2×2	HFSS	-27.42	1.094	10.43	10.81	99.42	215.00
1×4	HFSS	-12.96	1.945	10.52	10.49	99.71	106.90
Single	CST	-44.97	1.011	7.36	8.30	88.67	92.28
1×2	CST	-17.58	1.304	9.80	10.10	97.03	204.42
2×2	CST	-17.55	1.305	9.87	10.30	97.19	229.49
1×4	CST	-14.01	1.579	10.30	10.70	95.82	129.12

Table 3. Comparison of propose antenna parameter results with previous researches.

No. Elements	S11(dB)	VSWR	Gain (dB)	Dir(dB)	BW(MHz)	f (MHz)	Ref.
Single Element (**FEM**)	-15.62	1.440	6.09	7.09	-	2.40	[20]
	-16.624	-	5.1877	-	55	2.40	[29]
	-22.89		3.29		70	2.38	[30]
	-22.417	1.317		6.9981	20	1.44	[31]
	-18.5		1.26	-	-	2.40	[13]
	-33.12	**1.045**	**8.610**	**8.660**	**85.00**		**Present work**
(1×2) Elements (**FEM**)	-17.30	1.670	7.58	8.14	-	2.40	[20]
	-9.5	-	9.186	-	-	2.40	[29]
	-11.5	-	4.17	-	15	2.50	[30]
	-22.99	1.150	-	4.62	250	5.50	[32]
	-27.61	1.080	-	7.35	205	5.55	[32]
	-7.25	2.540	9.24	-	-	2.40	[13]
	-19.31	1.650	11.42	12.17	-	2.40	[20]
	-17.15	**1.325**	**10.310**	**10.408**	**200.00**		**Present work**
(2×2) Elements (**FEM**)	-30.34	1.070	-	12.91	173	5.58	[32]
	-32.34	1.170	-	11.28	186	5.55	[32]
	-72.5555	0.004	-	14.739	20	1.44	[31]
	-27.42	**1.094**	**10.430**	**10.450**	**215.00**		**Present work**
(1×4) Elements (**FEM**)	-22	-	13.2 -	--	60	2.40	[29]
	-19.906	1.762		14.576	20	1.44	[31]
	-8.25	2.260	10.29	-	-	2.40	[13]
	-12.969	**1.945**	**10.52**	**12.250**	**106.90**		**Present work**
Single Element (**FIT**)	-13.934	1.502	2.144	-	61	2.20	[26]
	-44.830	-	1.369	6.759	-	2.40	[21]
	-12.89	1.590	4.25	5.63	-	2.40	[33]
	–26.5	-	4.2	-	190	3.50	[34]
	-28.76		2.52	2.60	130	3.60	[3]
	-44.97	**1.011**	**7.357**	**8.298**	**92.28**		**Present work**
(1×2) Elements (**FIT**)	-20.371	1.211	4.58	-	83	2.2	[26]
	-11.21	1.750	9.225	9.633	29.3	2.45	[25]
	-17.58	**1.304**	**9.670**	**9.924**	**204.42**		**Present work**
(2×2) Elements (**FIT**)	-18.086	1.280	4.714	-	83.6	2.2	[26]
	-17.55	**1.305**	**9.87**	**11.90**	**229.49**		**Present work**
(1×4) Elements (**FIT**)	-20.372		5.284	10.59	-	2.5	[21]
	-7.95	2.530	7.31	9.58	-	2.4	[33]
	-12.74	1.590	11.73	11.79	35.5	2.45	[25]
	-22.5	-	4.52	-	-	3.5	[12]
	-14.014	**1.579**	**10.30**	**12.30**	**129.12**		**Present work**

4. CONCLUSIONS

This article has proposed a theoretical calculation methodology for designing a new single element, 1x2, 2×2 and 1x4 elements RMSA array operating at (3.6 GHz) suitable for S-band wireless communication systems. The array performances presented here were investigated using both HFSS and CST numerical methods. Generally, the computed results reveals that a lower side lobe level power, reasonable gain and wider bandwidth of the order of (10.43, 10.40) dB and (215, 229.49) MHz was achieved, respectively, for the case of (2x2) array elements. In addition, the simulation results indicated that the values of S11 are (-34.91, -17.15, -27.42 and -12.26) dB with bandwidth (85.00, 200.00, 215 and 106.4) MHz and gain of (8.68, 10.35, 10.43 and 7.86) dB by the execution of HFSS for designed single element, (1×2), (2x2) and (1×4) array configurations, respectively. Whereas the corresponding values of S11 are (-44.97, -17.58, -17.55 and -14.01) dB, bandwidth (92.28, 204, 229.49 and 129.12) MHz and gain of (7.36, 9.8, 10.40 and 9.87) dB with the implementation of CST for suggested element arrays, respectively. The issue of low bandwidth and gain which usually achieved by single element RMSA array has been resolved by the novel (RMSA) array models provided in this paper. The newly developed antennas are suitable to employ in radar, WLAN, S-band communications, and 5G wireless communication technologies.

Conflict of interest

The authors have no conflict of interest to declare.

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5. REFERENCES

[1] Z. Ying, "Antennas in cellular phones for mobile communications", Proceedings of the IEEE, Vol. 100, No. 7, 2012, pp. 2286-2296.

[2] S. K. Ezzulddin, S. O. Hasan, M. M. Ameen, "Microstrip patch antenna design, simulation and fabrication for 5G applications", Simulation Modelling Practice and Theory, Vol. 116, 2022, p. 102497.

[3] A. Kapoor, R. Mishra, P. Kumar, "Compact wideband-printed antenna for sub-6 GHz fifth-generation applications", International Journal on Smart Sensing and Intelligent Systems, Vol. 13, No. 1, 2020, pp. 1-10.

[4] K. Gilly, C. Bernad, P. J. Roig, S. Alcaraz, S. Filiposka, "End-to-end simulation environment for mobile edge computing", Simulation Modelling Practice and Theory, Vol. 121, 2022, p. 102657.

[5] R. Cárdenas, P. Arroba, R. Blanco, P. Malagón, J. L. Risco-Martín, J. M. Moya, "Mercury: A modeling, simulation, and optimization framework for data stream-oriented IoT applications", Simulation Modelling Practice and Theory, Vol. 101, 2020, p. 102037.

[6] S. N. Dahake, N. R. Kolhare, "Design & development of 2× 2 microstrip patch antenna array in SAR for satellite application", Proceedings of the International Conference on Computing Methodologies and Communication, 2017, pp. 800-804.

[7] N. Ab Wahab, S. A. Nordin, W. N. W. Muhamad, S. S. Sarnin, "Microstrip Rectangular Inset-Fed Patch Array Antenna for WiMax Application", Proceedings of the IEEE International RF and Microwave Conference, 2020, pp. 1-4.

[8] M. M. Nahas, "Gain Enhancement of a Microstrip Patch Antenna with Quasi H-Shaped Slot for UHF RFID Reader", Journal of Applied Science and Engineering, Vol. 26, No. 4, 2022, pp. 565-569.

[9] M. Nahas, "Design of a high-gain dual-band LI-slotted microstrip patch antenna for 5G mobile communication systems", Journal of Radiation Research and Applied Sciences, Vol. 15, No. 4, 2022, p. 100483.

[10] H. Huang, W. Zhao, "A triple-band multi-functional antenna for LTE/GSM/UMTS/WiMAX handsets", Proceedings of the Asia-Pacific Microwave Conference, Nanjing, China, December 2015, Vol. 2, pp. 1-3.

[11] M. Z. B. Chowdhury, M. T. Islam, H. Rmili, I. Hossain, M. Z. Mahmud, M. Samsuzzaman, "A low-profile rectangular slot antenna for sub-6 GHz 5G wireless applications", International Journal of Communication Systems, Vol. 35, No. 17, 2022, p. e5321.

[12] Y. S. Khraisat, "Design of 4 elements rectangular microstrip patch antenna with high gain for 2.4 GHz applications", Modern Applied Science, Vol. 6, No. 1, 2012, p. 68.

[13] A. B. Obot, G. A. Igwue, K. M. Udofia, "Design and simulation of rectangular microstrip antenna arrays for improved gain performance", International Journal of Networks and Communications, Vol. 9, No. 2, 2019, pp. 73-81.

[14] A. Santoso, F. Cahyono, I. Suwondo, B. Harianto, "Microstrip Antenna Design with Array Rectangular Patch

2x2 for Ship Radar at 2.2 GHz", Journal of Physics: Conference Series, Vol. 2117, No. 1, 2021, p. 012019.

[15] B. S. S. Reddy, P. Parvathi, B. S. Kumar, "Construction and Implementation of Coaxial Probe Feed Microstrip Patch Array Antenna", International Journal of Innovative Technology and Exploring Engineering, Vol. 8, No. 11, 2019, pp. 814-821.

[16] V. R. Ekke, P. L. Zade, "Design and Implementation of T-junction Triangular Microstrip Patch Antenna Array for Wireless Applications", International Journal of Engineering and Technology, Vol. 8, No. 5, 2016, pp. 2105-2114.

[17] M. M. Alam, R. Azim, N. M. Sobahi, A. I. Khan, M. T. Islam, "A dual-band CPW-fed miniature planar antenna for S-, C-, WiMAX, WLAN, UWB, and X-band applications", Scientific Reports, Vol. 12, No. 1, 2022, p. 7584.

[18] F. Wang et al. "Design of an ultra-thin absorption layer with magnetic materials based on genetic algorithm at the S band", Journal of Magnetism and Magnetic Materials, Vol. 451, 2018, pp. 770-773.

[19] S. O. Hasan, "Design and Comparison Study of Circular and Elliptical Microstrip Patch Antennas for 5G Applications", International Journal on Communications Antenna and Propagation, Vol. 12, No. 6, 2022, pp. 437-447.

[20] J.-M. Jin, D. J. Riley, "Finite element analysis of antennas and arrays", John Wiley & Sons, 2008.

[21] T. Weiland, "A discretization model for the solution of Maxwell's equations for six-component fields", Archiv Elektronik und Uebertragungstechnik, Vol. 31, 1977, pp. 116-120.

[22] M. J. Hakeem, M. M. Nahas, "Improving the Performance of a Microstrip Antenna by Adding a Slot into Different Patch Designs", Engineering, Technology & Applied Science Research, Vol. 11, No. 4, 2021, pp. 7469-7476.

[23] A. Abdelaziz, E. K. I. Hamad, "Design of a Compact High Gain Microstrip Patch Antenna for Tri-Band 5 G Wireless Communication", Frequenz, Vol. 73, No. 1-2, 2019, pp. 45-52.

[24] Y. Huang, "Antennas: From Theory to Practice", 2nd Edition, John Wiley & Sons, Ltd, 2021.

[25] L. C. Yu, M. R. Kamarudin, "Investigation of patch phase array antenna orientation at 28 GHz for 5G applications", Procedia Computer Science, Vol. 86, 2016, pp. 47-50.

[26] R. J. Mailloux, "Phased array antenna handbook", Artech house, 2017.

[27] C. A. Balanis, "Antenna Theory Analysis and Design", 4th Edition, John Wiley & Sons, 2016.

[28] C. A. Balanis, "Antenna Theory Analysis and Design", 3rd Edition, Wiley-Interscience, 2005.

[29] T. T. S. Borel, A. R. Yadav, U. Shah, "Design of rectangular patch array antenna for satellite communication", Proceedings of the 3rd International Conference on Computing Methodologies and Communication, Erode, India, 27-29 March 2019, pp. 759-764.

[30] V. Prakasam, P. Sandeep, K. A. LaxmiKanth, "Rectangular micro strip patch array antenna with corporate feed network for wireless communication applications", Proceedings of the 5th International Conference on Communication and Electronics Systems, Coimbatore, India, 10-12 June 2020, pp. 311-316.

[31] O. Sokunbi, H. Attia, S. I. Sheikh, "Microstrip antenna array with reduced mutual coupling using slotted-ring ebg structure for 5G applications", Proceedings of the IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Atlanta, GA, USA, 7-12 July 2019, pp. 1185-1186.

[32] R. Kazemi, S. Yang, S. H. Suleiman, A. E. Fathy, "Design procedure for compact dual-circularly polarized slotted substrate integrated waveguide antenna arrays", IEEE Transactions on Antennas and Propagation, Vol. 67, No. 6, 2019, pp. 3839-3852.

[33] M. T. Srilakshmi, S. T. Bhanu, "Performance Comparison of S Band Antenna with Series Fed and Corporate Fed Microstrip Array", International Journal of Engineering & Technology, Vol. 7, No. 2, 2018, p. 4.

[34] W. N. Ab Wahab, W. Muhamad, Z. I. Khan, S. S. Sarnin, "Microstrip array antenna with inset-fed for WLAN application", Indonesian Journal of Electrical Engineering and Computer Science, Vol. 17, No. 1, 2020, pp. 340-346.