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Optimization of Rectangular Microstrip Antenna Substrate Parameters to Operate at High Radiation Performances for 5G Applications

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Abstract
The purpose of this work is to analyze and simulate the single patch rectangular microstrip antenna operating at 28 GHz to be utilized in 5G wireless communication system applications. The computed results of the proposed antenna are obtained through the use of Computer Simulation Technology microwave studio. For this purpose, a single patch with a dielectric substrate (RT Duroid-5880) is selected and optimization of their parameters such as substrate height, loss tangent, dielectric constant and substrate dimensions are implied to operate at 28 GHz with a suitable gain and bandwidth performance. The simulated results show that a high radiation rectangular microstrip antenna performance is achieved with the (RT Duroid-5880) substrate dimensions of (7.2) mm^3, the height of (0.2 mm), the loss tangent of (0.0009) and a relative permittivity of the order of (2.2). At these optimized substrate parameter values, the antenna designed to operate at 28 GHz provides a bandwidth of (0.770 GHz) with return loss S11(-45.23), the gain of the order of (6.72 dB) and a (1.01) voltage standing ratio. Besides, most of the current computed parameters are compared to the results of the previous works which showed a good agreement with an improvement in the size reduction, antenna gains and antenna bandwidth are achieved via the use of the mentioned optimized substrate parameters. Moreover, the analyzed procedure using CST simulation software indicates that a suitable antenna performance with a small size and low cost could be designed adequately by the optimization of substrate parameter values for a given frequency application in the wireless communication systems.
Keywords: Microstrip antenna; Return loss; Gain; Directivity; Bandwidth; Radiation pattern.

Introduction

Due to its small size and low cost with easy fabricate installation, the microstrip antennas has become one of the most candidate antennas that are generally used for satellite communication, radar, radio broadcasting and global system for mobile communication (GSM) especially in 4G and 5G applications[1]. The term five generation (5G) in wireless communication technology is used in many research articles and scientific papers to identify the incoming common stage of wireless communication systems in front of the present generation which is 4G. Nowadays, the researchers make pre-arrangements for 5G in order to solve the problem of overload transfer data all over the world as a result of using 4G. The generation of each mobile technology systems has brought with itself an increase in the speed of data transmission along with an improved connection quality and new functionalities.

The five generation (5G) network will enable several new services, including those related to the Internet of Things (IoT), an enhanced mobile broadband (EMBB), which enables high-speed internet access (up to 1 Gbps), ultra-reliable low latency communications (URLLC), which will be a technology providing a minimum (1 ms) latency for data exchange over a mobile network for critical applications (e.g., drone control) [2].

The primary goals of the 5G will be improving the ability of the networks to transfer information data at a lower cost and assessing consumer requirement for high-speed data communication. There is a convectional understanding between distinct groups of researchers trying to work on a great deal of flexibility of 5G technologies to reach an excellent data transfer speed of the order of 1Gb/s for users in movement as well as 10 Gb/s for users at steady-state and not lower than 100 Mb/s in residential zone[3]

With the deployment of 5G network systems and demands for high-quality data rates, a significant number of antennas will be installed inside buildings such as stadiums, railway stations, and shopping centers. Besides, the size of the antennas that would be installed in the vicinity of the crowded locations must be of small size configurations. This requirement is one of the fundamental components for 5G cellular mobile networks. Therefore, the preparation of antenna infrastructure and implementation of new technological solutions is of great importance which is mainly achieved with the use of microstrip antennas [4, 5]. Microstrip patch antenna (MPA) plays a crucial role in a transmitting as well as a receiving element in all communication systems. Generally speaking, microstrip antennas have been classified into four groups; the first is travelling wave microstrip, the second is microstrip patch antennae, the third is microstrip active antenna and the final one is slotted microstrip antenna [5]. Various kinds of MPA are established with different configuration geometries such as rectangular, circular, square, and elliptical or possess any other alternative shapes. Among these, the rectangular and circular patch antenna shapes are mostly used in mobile communication systems due to their simplicity in modelling, fabricating and analyzation.

In this paper, optimization of dielectric substrate parameters such as substrate height, loss tangent, substrate permittivity and substrate dimensions are investigated for a rectangular microstrip patch antenna RMPA operating at 28 GHz. The optimization process for each of the mentioned substrate parameters is performed individually until attaining an acceptable antenna gain with suitable bandwidth performance that is reliable to be used in 5G communication systems [6].

The simulated antenna possesses a good 50 Ω impedance matching when S11 value is lower than (-10) dB and it has a wide bandwidth greater than 0.5 GHz followed by stable antenna radiation patterns and is capable to assist the predicted data speed of the next generation in communication devices [7]. In this article, a RMPA is simulated and designed with the inset-feed techniques which are reliable for the upcoming 5G technology application. For this, a single patch RMPA is proposed; due to its flexibility, impact in size, inexpensive, lightweight, and compact in terms of structure profile with small-sized dimensions and operating at 28 GHz. In the following sections, a description of the simulation and optimization procedure for each of the mentioned parameters are presented in detail.

Materials and Methods

A rectangular microstrip patch antenna (RMPA) consists of a radiating patch in the rectangular geometrical configuration on one side of the dielectric substrate as well as a metallic ground plane on the opposing side of the substrate as shown in Fig. 1.

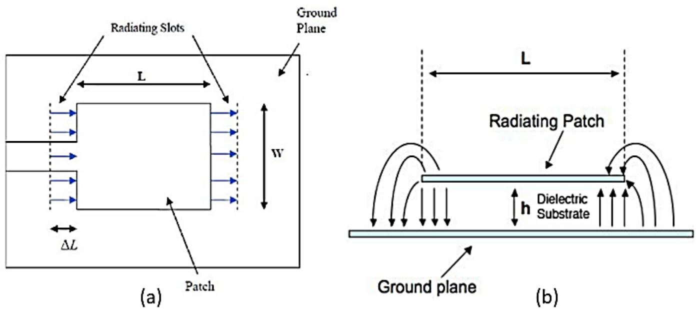

Figure 1. RMPA antenna (a) Top View of Antenna (b) Side View of Antenna

The patch is normally composed of a conductor patch material like gold, silver or copper which can be formed in various geometry shape [1, 8–10]. In this work, the rectangular patch shape is considered where the length of the patch (L) is varied between $0.3333\lambda_o<L<0.5\lambda_o$ where λ_o is the free-space wavelength [11, 12]. Furthermore, the height (h) of dielectric substrate is commonly varied between $(0.003\lambda_o \leq h \leq 0.05\lambda_o)$ and substrate dielectric constant (ε_r) is regularly change between $(2.2 < \varepsilon_r < 12)$ [9].

For the parameter optimization, a dielectric substrate material (RT Duroid-5880) operating at resonating frequency of (28 GHz) is considered. The main dimension parameters of the proposed antenna such as width (W) and length (L) of the patch with the effective material dielectric constants ε_{eff} are demonstrated in Figure 1 and their values were evaluated through the implementation of the following estimation formula [1,13,14].

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Where (c) is velocity of electromagnetic wave in free space and (f_r) is resonance frequency. The effective dielectric constant (ε_{eff}) is:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W_p}\right] \qquad (2)$$

In actual case, due to the fringing fields the physical dimensions patch is a bit smaller than it is electrically and this electrical extension is calculated using the formula given by [5] as:

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

The effective length, (L_{eff}) is

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \qquad (4)$$

Then:

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

The simulated patch antenna was linked through an inset feed transmission feedline with an impedance of 50 Ω as shown in Fig. 2. This feed method is used because it does not need extra matching component. The feed location is moved to (1.44) mm going from the antenna border in order to reach input impedance matching, whereas (G_{pf}) the space between the feed line and the patch which is fixed at (0.1) mm and the inset feed distance (Fi) is placed at (0.15) mm while the width of feed line (Wf) is equal to (0.625) mm.

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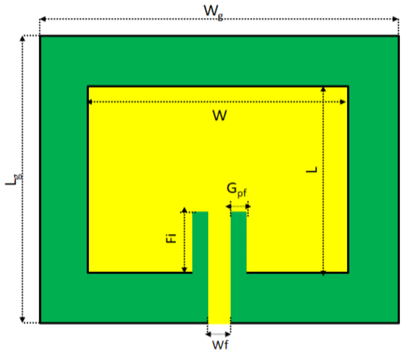

Figure 2. The proposed RMPA

Table 1. Proposed antenna parameters

Parameters	**Description**	**Value (mm)**
W_g	Substrate Width	6.0
L_g	Substrate Length	6.0
W	Patch Width	4.4
L	Patch Length	3.5
h	Substrate Height	0.2
Gpf	Gap between Patch and feed line	0.1
Fi	Distance inset feed	1.15
W_f	Microstrip line feed width	0.6

Results and Discussion

It is evident from the work of the previous researches in the field of MPA that the dielectric substrate parameters have a great effect on the performance of MPA parameters [15]. Therefore, an accurate determination of MPA return loss (S11), Voltage Standing Wave Ratio (VSWR), Directivity (Dir.), Gain (G), Radiation Efficiency (E_R), Total Efficiency (E_T), Bandwidth (B.W) and Response frequency (f_r) under influence of those parameters are of great significance. Hence, in this present work, an optimizations procedure is employed using CST simulation software to identify with which mentioned substrate parameters values a high RMPA performance is accomplished.

The optimization is based on five different scenarios or a step, for each step, one of the parameters is varied and all the other parameters are fixed at a given value. In the first step, substrate height is varied, while in the second scenario the substrate loss tangent (tan (δ)) is changed, in the third step, dielectric constant or relative permittivity (ε_r) is changed, in the fourth step, the substrate width (W_g) is varied and the effect of substrate length is investigated in the final step. In each step, the optimized mentioned parameters are specified and then this optimum value is employed for the next optimization steps. The optimum substrate values are those that provide RMPA bandwidth of the order of (0.770 GHz), antenna gain values greater than (6.68 dB) and operates specifically at 28 GHz .

In the first step, the substrate height is allowed to vary from 0.1 mm to 0.35 mm, while the other substrate parameters are fixed at (tan δ=0.0009), (ε_r=2.2), (W_g =6 mm) and (L_g =6 mm) and their effects on the RMPA parameters are shown in Table 1.

Throughout the optimization procedure, the microstrip patch dimensions are fixed at a length of (L=3.5 mm) and a width of (W=4.4 mm). The obtained results, as presented in Table 2, indicate that the bandwidth and radiation efficiency increase with increasing the height of the substrate with a rate of greater than 120% from (h =0.1 to h =0.350) mm. This behavior is attributed to the increase in the fringing field as substrate height increases leads to a better return loss characteristic as shown in Fig 3.

Furthermore, the increases in substrate thickness lead to an increase in the antenna input impedance from (17.83 Ω to 108.18 Ω) due to an increase in the dielectric losses produced in the dielectric substrate and hence raise antenna radiation efficiency as well as its bandwidth as they are graphically represented in Figs. 4 and 5, respectively .

Moreover, when the substrate height increases gradually from 0.1 mm to 0.35 mm, a peak value for both antenna gain and antenna efficiency are observed near a substrate height value of the order of 0.2 mm that is seen observed in Fig. 6. Follow that, their values starting to decrease as (h) increases beyond 0.2 mm. This behavior can be interpreted based on the formation of high electrical capacity on the ground of MPA as the substrate height is dimensioned, which in turn leads to an increase in the antenna quality factor and hence decreases total radiation rates and bandwidths.

Table 2. Variation of (RMPA) characteristics as function of substrate thickness

h (mm)	S11(dB)	VSWR	Dir. (dB)	G (dB)	E_R %	E_T %	B.W(GHz)	f_r (GHz)
0.1	-5.080	3.51	7.465	5.801	78.43	68.17	0.469	28.48
0.15	-13.30	1.55	7.429	6.771	85.98	85.95	0.629	28.20
0.175	-19.91	1.22	7.372	6.781	88.30	87.27	0.680	28.10
0.200	-45.23	1.01	7.328	6.679	89.89	86.11	0.762	28.00
0.225	-21.56	1.18	7.291	6.524	91.19	83.80	0.819	27.29
0.250	-16.22	1.36	7.257	6.336	92.08	80.89	0.896	27.82
0.275	-13.34	1.54	7.222	6.130	92.68	77.76	0.912	27.72
0.300	-11.48	1.72	7.190	5.929	93.24	74.80	0.972	27.62
0.325	-10.93	1.90	7.158	5.728	93.70	71.95	1.033	27.54
0.350	-9.100	2.07	7.126	5.525	93.94	69.16	1.037	27.44

On the other hand, and according to the results presented in Table 2, the optimum dielectric substrate values that provide high bandwidth and reliable antenna gain operating exactly at 28 GHz are accomplished with the (h=0.2 mm). Since at this substrate height, the value of (VSWR) is equal to (1.01) which corresponds to return loss values of (-45.23 dB) as shown in Fig. 7. Moreover, it is evident from Table 2 that the increase in the substrate thickness leads to the decrease in the directivity and resonance frequency of the proposed RMPA. Therefore, these results reveal that an optimum value of substrate height that provide an acceptable RMPA performance for 5G application is of the order of (0.2) mm.

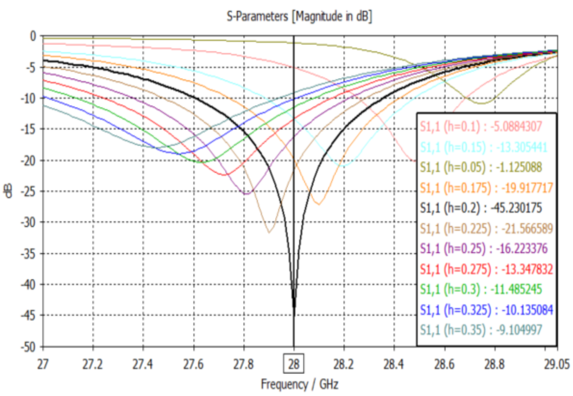

Figure 3. Variation of S11 with substrate height

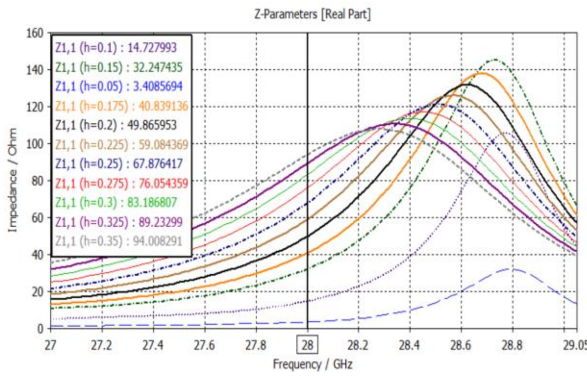

Figure 4. Variation of impedance with substrate height

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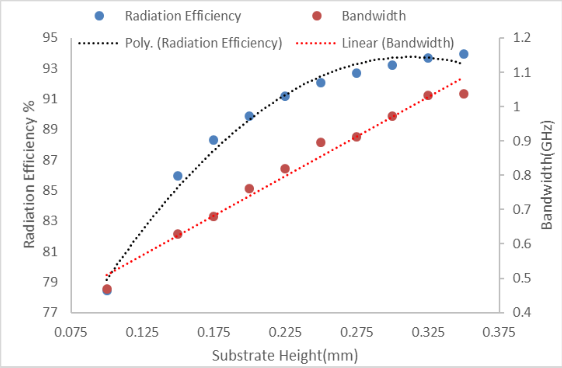

Figure. 5 Variation of radiation efficiency and bandwidth with substrate height

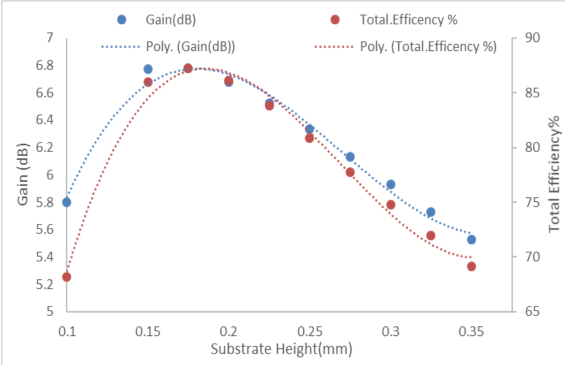

Figure. 6 Variation of antenna gain and total efficiency with substrate height

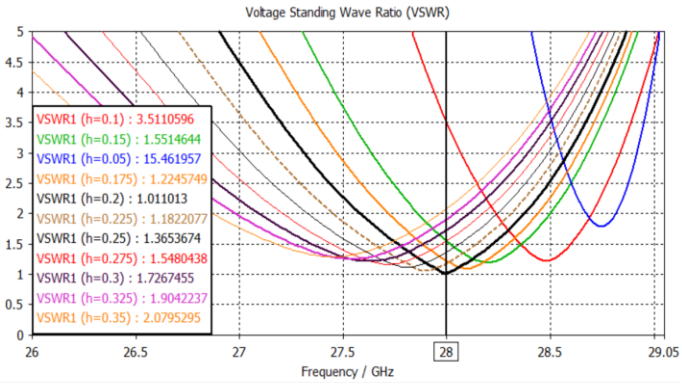

Figure 7. Variation of VSWR with of substrate height

In the second stage, the values of the substrate parameters are fixed at (h=0.2 mm), ($\mathcal{E}_r$=2.2), (W_g=6 mm) and (L_g=6 mm) while the value of loss tangent (tan δ) is changed from (0 to 0.0017). With the use of these substrate parameter values, the performance of RMPA characteristic is simulated and the results are presented in Table 3.

Table 3. Represents the variation of characteristics of the (RMPA) as function of loss tangent (tan (δ))

tan(δ)	S11(dB)	VSWR	Dir. (dB)	G(dB)	E_R %	E_T %	B.W(GHz)	f_r (GHz)
0.0000	-35.51	1.034	7.329	6.767	91.84	87.86	0.743	28.00
0.0002	-37.10	1.028	7.329	6.749	91.44	87.49	0.746	28.00
0.0004	-38.74	1.020	7.329	6.731	91.34	87.31	0.747	28.00
0.0006	-40.75	1.018	7.329	6.712	90.62	86.76	0.760	28.00
0.0009	-45.23	1.010	7.328	6.679	89.89	86.11	0.762	28.00
0.0011	-49.01	1.007	7.328	6.661	89.50	85.76	0.766	28.00
0.0013	-51.93	1.002	7.328	6.643	89.11	85.40	0.772	28.00
0.0015	-49.30	1.005	7.328	6.625	88.72	85.05	0.777	28.00
0.0017	-45.50	1.106	7.327	6.607	88.34	84.70	0.786	28.00

The results of this simulation reveal that the increase in substrate loss tangent leads to decrease in the RMPA radiation efficiency, gain and directivity while antenna bandwidths slightly increase from (0.743 to 0.786) as clearly seen in graphical representation in Figs. 8 and 9. This means that the low loss substrate material enhances the MPA bandwidth while it causes to decrease in the antenna efficiency and hence providing lower antenna gain. Therefore, it is of utmost importance to make a balance between the reliable value of both antenna gain and bandwidth through the selecting various substrate parameter values.

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In addition, from Fig. 10, one can easily observe that the minimum values of (S11) and (VSWR) are achieved with the substrate loss tangent is equal to (0.0013), which is (-51.93dB) more less than (-10 dB) and (1.002) where nearly impulse to unity, respectively. Therefore, it can be decided that the (RT Duroid-5880) substrate loss tangent values are of the order of (0.0013) which is an optimum value, since at this value the RMPA patch operates exactly at 28 GHz and with a suitable performance that requires for 5G application networks.

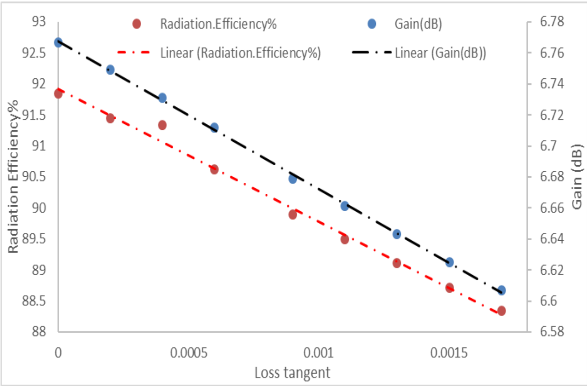


Figure 8. Represents changing of radiation Efficiency and Gain for difference loss tangent

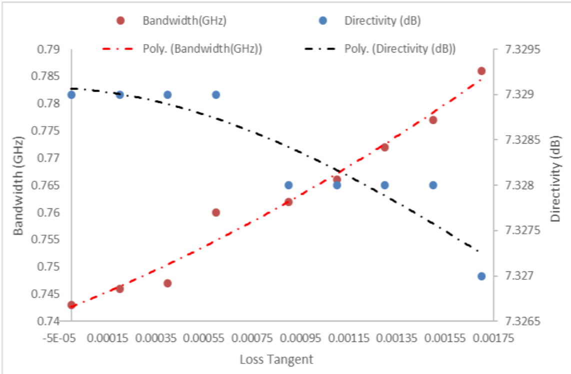


Figure 9. Shows changing of bandwidth and directivity for difference loss tangent

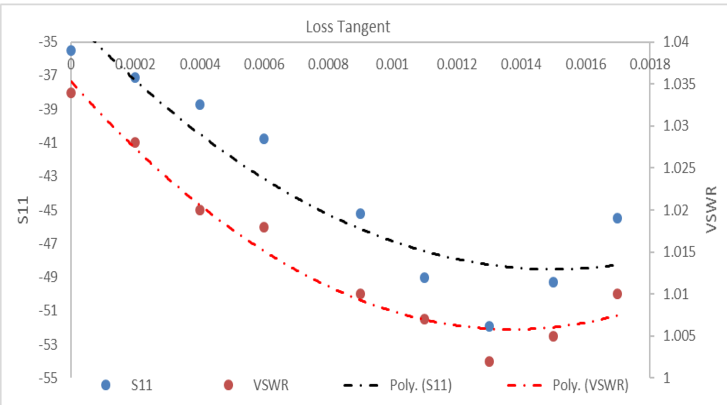


Figure 10. Shows changing of bandwidth and directivity with loss tangent

In the third scenario, the value of the substrate permittivity is changed, while the other parameters are fixed at (W_g=6 mm), (L_g =6 mm), (h=0.2 mm) and (tan δ=0.0013). With the use of these substrate parameter values the RMPA characteristics are simulated and the results are given in Table 4. Generally, the calculated results presented in Table 4 indicate that as the permittivity of the antenna substrate is increased, the antenna directivity and bandwidth decease while both antenna gain and antenna efficiency increase at first time then beyond a value of nearly (ε_r=2.2) they start to decrease. In addition, the minimum values of the (S11) and (VSWR) are also identified with the substrate permittivity values of the order of (ε_r=2.2) as clearly seen in Fig. 11. Therefore, in order to specify the substrate permittivity values that acquire suitable antenna bandwidth and high gain performance, it is necessary to show their variation with substrate permittivity on the same graph. Fig. 12 displays this variation behavior and through which one can easily identify the optimum substrate values which is nearly equal to (ε_r=2.2). Hence, at this value of substrate permittivity, the simulated RMPA exactly operates at 28 GHz and with an acceptable bandwidth and antenna gain performance.

Table 4. Represents the changing characteristics of the (RMPA) with Dielectric constant (ε_r).

ε_r	S11(dB)	VSWR	Dir.(dB)	G(dB)	E_R %	E_T %	B.W(GHz)	f_r (GHz)
1.85	-1.0180	17.08	7.506	1.660	88.41	15.69	0.802	31.28
1.90	-2.065	8.449	7.401	2.508	91.11	32.41	0.796	29.82
1.95	-2.603	6.721	7.384	3.400	90.98	39.95	0.795	29.50
2.00	-3.3820	5.201	7.370	4.447	92.93	51.10	0.790	29.18
2.10	-7.3820	2.493	7.344	6.430	92.40	77.55	0.780	28.58
2.15	-12.724	1.601	7.334	6.840	90.95	89.23	0.768	28.28
2.20	-45.230	1.010	7.328	6.679	89.89	86.11	0.762	28.00
2.25	-12.152	1.655	7.323	5.964	90.15	73.12	0.749	27.72
2.30	-6.5280	2.785	7.318	4.770	90.65	55.61	0.737	27.46
2.35	-3.8400	4.597	7.316	3.292	89.96	39.58	0.724	27.20
2.40	-1.7510	9.950	7.314	0.386	81.99	20.28	0.720	26.72

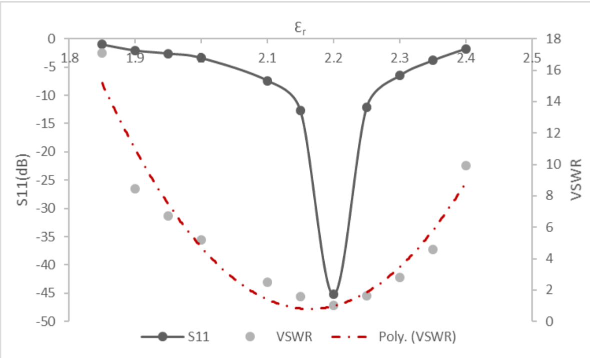


Figure 11. Represents variation of S11 and VSWR with substrate permittivity

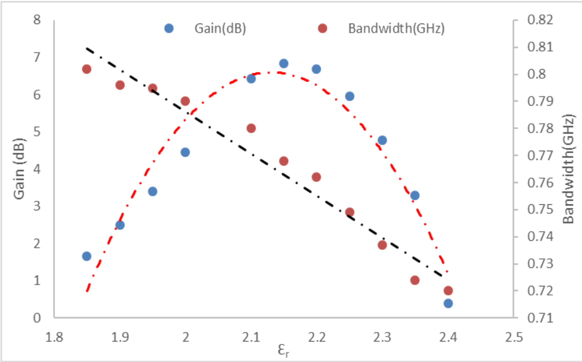


Figure 12. Shows variation of bandwidth and gain with substrate permittivity

In the final two steps of the optimization procedures, the substrate height at (h=0.2 mm), loss tangent at (tan δ=0.0009) and permittivity at (ε_r=2.2) are fixed at their optimum values while the substrate length (L_g) and substrate width (W_g) are allowed to vary individually from (5 to 7) mm. The simulation results of the effect of substrate dimension on the RMPA characteristics are presented in Table 5 and Table 6 for (W_g) and (L_g), respectively. Form the data indicated in these two Tables, one can clearly observed that the antenna efficiency and bandwidth decrease with increasing substrate width and substrate length as they are graphically displayed in Figs. 13 and 14, respectively.

However, with the increase in substrate width there are increase in the antenna gain and directivity from (6.293 to 6.899) dB and from (6.961 to 7.604) dB, respectively, as shown in Fig. 15. In contrast, the increase in substrate length leads to decrease in antenna gain whereas increasing total antenna efficiency until it reaches to a value of the order of (L_g=5.75) as shown in Fig. 16. Generally, these two diversified variations mean that the increase in substrate width leads to the increase in antenna input impedance while it decreases with increasing substrate length due to decrease in the antenna losses or decrease in the antenna radiation resistance as shown, respectively, in Figs. 17 and 18.

Table 5. Represents the characteristics of the (RMPA) variation with substrate width (W_g)

W_g(mm)	S11(dB)	VSWR	Dir. (dB)	G(dB)	E_R %	E_T %	B.W(GHz)	f_r (GHz)
5.00	-24.750	1.122	6.961	6.293	90.97	85.75	0.797	27.98
5.25	-28.852	1.074	7.064	6.409	90.59	86.00	0.793	28.00
5.50	-34.002	1.040	7.159	6.511	90.33	86.13	0.773	28.00
5.75	-46.681	1.009	7.246	6.602	90.15	86.22	0.767	28.00
6.00	-45.230	1.011	7.328	6.679	89.89	86.11	0.767	28.00
6.25	-32.454	1.048	7.404	6.728	89.77	85.58	0.747	27.98
6.50	-28.276	1.080	7.478	6.779	89.71	85.14	0.737	27.98
6.75	-26.917	1.094	7.540	6.833	89.55	84.97	0.736	27.96
7.00	-25.999	1.105	7.604	6.899	89.50	85.00	0.736	27.96

Table 6. Represents the characteristics of the (RMPA) variation with substrate length (L_g)

L_g (mm)	S11(dB)	VSWR	Dir. (dB)	G(dB)	E_R %	E_T %	B.W(GHz)	f_r (GHz)
5.00	-13.480	1.401	7.242	6.574	90.42	85.49	0.876	27.80
5.25	-16.061	1.373	7.262	6.616	90.07	86.17	0.870	27.88
5.50	-19.110	1.218	7.277	6.618	90.31	85.74	0.855	27.94
5.75	-26.010	1.105	7.313	6.689	90.11	86.61	0.808	27.98
6.00	-45.230	1.011	7.328	6.679	89.89	86.11	0.770	28.00
6.25	-27.566	1.087	7.346	6.625	86.67	84.69	0.705	27.98
6.50	-21.540	1.182	7.385	6.614	89.55	83.73	0.636	27.96
6.75	-17.929	1.290	7.406	6.566	89.31	82.40	0.588	27.92
7.00	-15.696	1.392	7.429	6.541	89.00	81.51	0.540	27.90

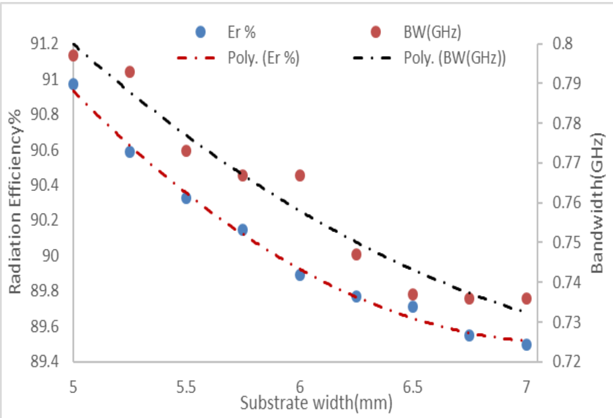


Figure 13. Represents variation of radiation efficiency and bandwidth with substrate width

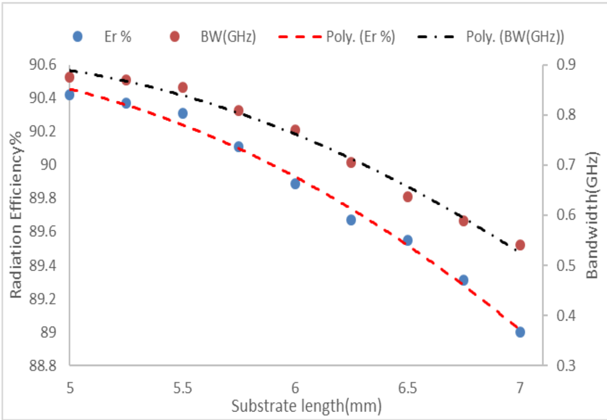


Figure 14. Represents changing radiation efficiency and bandwidth with substrate length

On the other hand, Figs. 19 and 20 indicate that the minimum values of (S11) and (VSWR) are achieved with a substrate width of the order of (5.75 mm), at which their respective values are (-46.68) dB and (1.0009). Moreover, Figs. 21 and 22, reveal that the values of (S11) and (VSWR) become minimum with the substrate length values are equal to (6 mm), which are (-45.23) dB much less than (-10 dB) and (1.011) nearly impulse to unity, respectively. Therefore, it can be said that the substrate width of (6 mm) and substrate length of (6 mm) have optimum values that make the RMPA operates with a high gain and suitable bandwidth performance at 28 GHz for the proposed antenna with the use of substrate material type named (RT Duroid-5880).

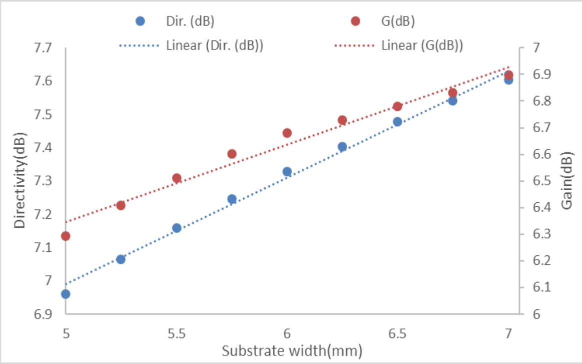


Figure 15. Represents variation of directivity and gain with substrate width

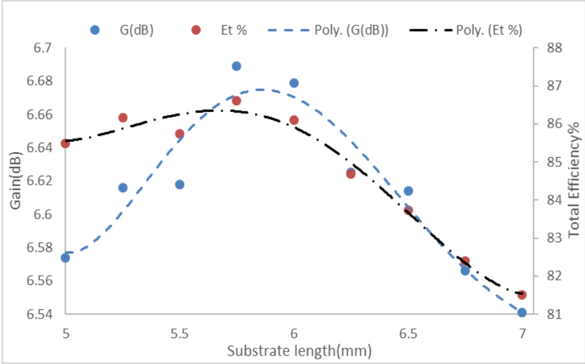


Figure 16. Represents changing gain and total efficiency with substrate length

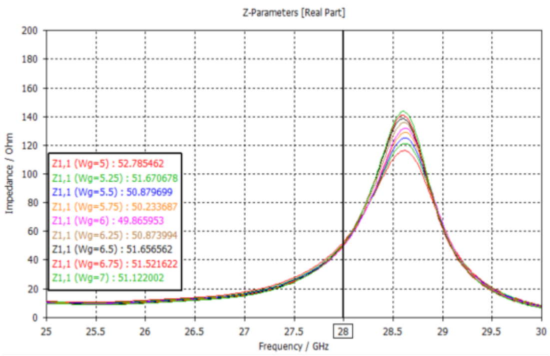


Figure 17. Represents changing of real input impedance with substrate width

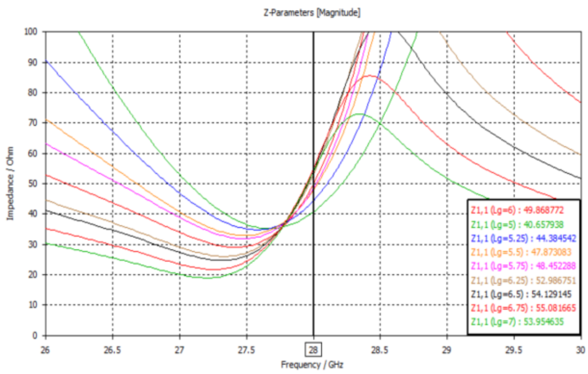


Figure 18. Represents changing real input impedance with substrate length

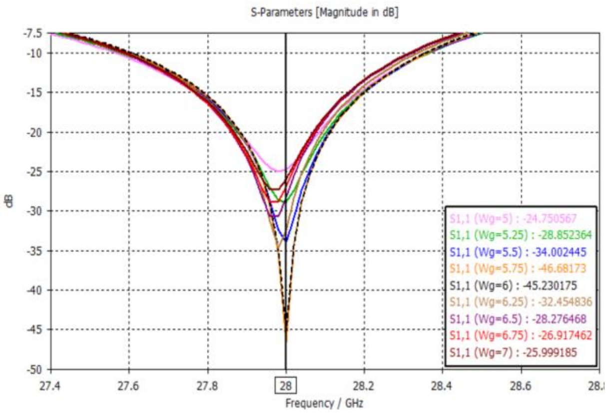


Figure 19. Represents changing of S11 with substrate width

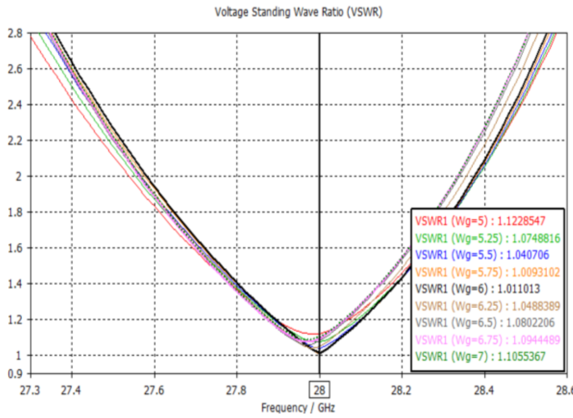


Figure 20. Represents changing of VSWR with substrate width

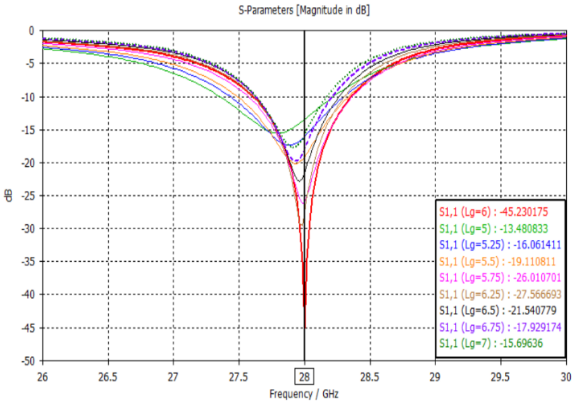


Figure 21. Represents changing of S11 with substrate length

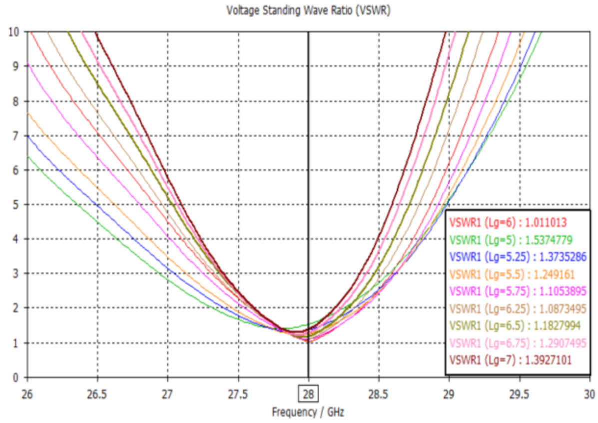


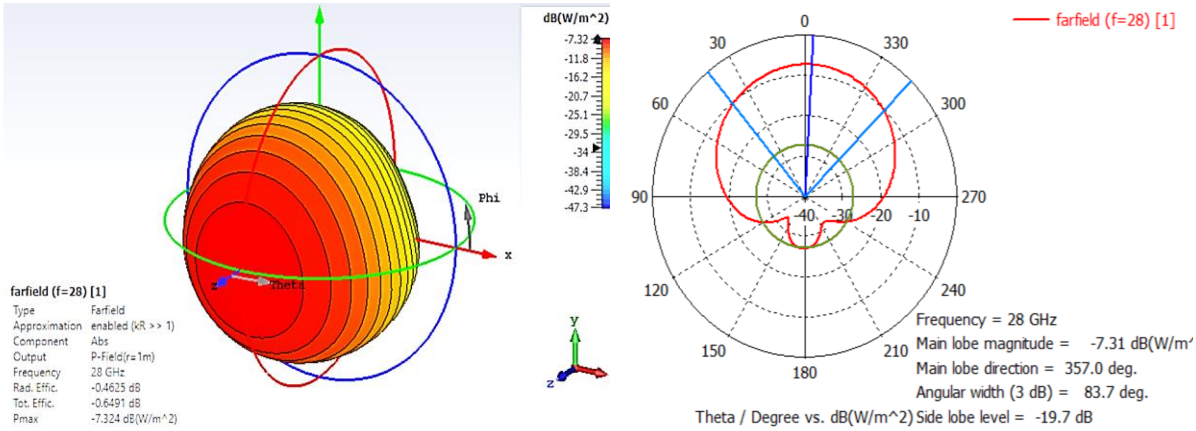
Figure 22. Represents changing of VSWR with substrate length

At the end of these simulation procedures, the overall radiation characteristic of the proposed RMPA with the implementation of the optimized substrate parameters are summarized in Table 7. In addition, the 2D and 3D- view representation of the radiation pattern for the simulated RMPA proposed in this article are displayed in Fig. 23. Moreover, the accuracy and impact of the our RMPA characteristic have been verified through a comparison of the obtained results with those previously evaluated by other research investigators for the same type of MPA shape and operating at the same resonance frequency of 28 GHz and the results are summarized in Table 7.

It is clearly seen from the data presented in Table 8 that the simulated results obtained in this work are in good agreement with those results mentioned in the table. In addition, it can also be seen that the size, antenna gains and antenna bandwidth values that have been achieved in this article with the use of the mentioned optimized substrate parameters are better than most of those data developed in the table. Since, the performance of MPA are mostly specified through its gain and bandwidth values, so accurate determination values of which have great effects on the overall MPA performance. In view of this short discussion, one can conclude that present optimization process that has been taken into consideration with the outcome results of the antenna parameters are of great importance for practically application design.

Table 7. Radiation characteristic values of the simulated RMPA with the optimized substrate parameters

Gain(dB)	**Dir. (dB)**	**S11(dB)**	**VSWR**	**Antenna size (mm^3)**	**B.W(GHz)**	**E_T%**
6.68	7.328	-45.23	1.01	6.90	0.770	89.89



(a) (b)

Figure 23. a) Radiation pattern in 3D and b) Radiation pattern in 2D -represents view

Table 8. Optimized antenna parameter comparison with results of other international works

Gain(dB)	S11(dB)	VSWR	Antenna size (mm^3)	B.W (GHz)	Reference No.
3.6	-22.51	1.62	81.76	5.570	[2]
6.35	-36.54	-	14.63	0.300	[16]
8.03	-24.50	1.28	284.17	0.278	[17]
6.15	-14.80	1.48	185.93	0.550	[18]
4.00	-11.89	1.03	115.20	-	[19]
6.72	-36.17	1.03	6.92	0.463	[20]
2.60	-21.11	1.58	44.23	-	[21]
4.09	-42.50	1.01	640.44	0.575	[22]
4.06	-13.00	1. 02	76.89	-	[23]
6.59	-12.59	1.77	29.51	0.582	[24]
6.16	-13.50	1.8	24.72	-	[25]
6.68	**-45.23**	**1.01**	**7.20**	**0.770**	**Present Work**

Conclusion

As the result of the computer simulation procedures, it was concluded that the optimum dielectric substrate parameter values that make the RMPA operate exactly at 28 GHz were achieved with the substrate (RT Duroid-5880) of dimensions (7.20) mm^3, dielectric permittivity equal to (2.2) and loss tangent (0.0009). With the implementation of these optimum substrate parameters, the proposed RMPA gain of (6.7 dB) and bandwidth of the order of (0.770 GHz) was obtained with a return loss and VSWR values of (-45.23 dB) and (1.01), respectively. These high radiation performances of the simulated RMPA make it reliable for most 5G communication system applications. Besides, most of the present computed RMPA parameters have been compared to the results of the previous works and a good agreement with an improvement in the present investigations were identified. Since, the size, antenna gains and antenna bandwidth values that have been achieved in this article with the use of the mentioned optimized substrate parameters are better than most of the previous research works.

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