Designing and Analysing of a Modified Rectangular Microstrip Patch Antenna for Microwave Applications

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Abstract—The microstrip patch antenna is commonly recognised for its diversity in term of achievable structures that make them appropriate to a wide variety of applications. The lightweight and compact size of the structure make these types of antennas suitable for use besides the microwave embedded circuits two more of their diverse benefits. In this paper, a modified design of the rectangular Microstrip Patch Antenna (MPA) beside edge feeding technique is simulated and optimised to cover a multi-band of the microwave frequency. The proposed antenna has been analysed based on the High-Frequency Structure Simulator (HFSS) using an $FR-4$ substrate. The introduced MPA design constitutes of a radiating patch from copper metal with a copper extension directly coupled to the lowest edge of the radiating patch via three stubs to covering three operating frequency bands: f_1 = 6.19 GHz (6.13-6.26 GHz), f_2 = 7.63 GHz (7.55-7.7 GHz), and f_3 =10 GHz (9.3-10.82 GHz). Consequently, the obtained results of the modified antenna design show a good gain with $S_{11} < -10\ dB$ in the previous operating frequency bands, which are suitable for most wireless communication applications.

Index Terms—Edge feeding technique, HFSS, Microstrip patch antennas, Microwave, Stubs

I. Introduction

The rapid growth in wireless communication systems has led to expanding the demand for a compact-sized antenna that resonating at multiple bands of frequency. In the C, X, and the Ku bands the microstrip antennas are extensively utilised for the applications that are required the point-to-point wireless communication approach like as the on-road traffic controlling, the air traffic monitoring, the imaging radar, the satellite communications, compact electronic appliances for radio communication to aircraft, spacecraft, the martial applications, Industrial Scientific and Medical (ISM) purposes [1]-[3].

Microstrip patch antennas meet such these requirements, these types of the antennas are characterised by a low profile, simple in construction, compact size with lightweight, low fabrication cost, and applicable to planar or non-planar surfaces utilising printed circuit board making them low-priced [4].

Seldom, systems such as the radar, global positioning system, and satellite communications are too far from each other in term of the operating frequency band, in other words, operated at various of the frequencies. Microstrip Patch Antenna (MPA) could be utilised to fulfil such of these imperatives even utilising distinct antennas for different frequencies. Hence, there is constantly troublesome issue for the designers to design a compact antenna able to operate in multiple frequencies and broadband characteristics [5].

Nevertheless, MPA suffers from tuning difficulty due to narrowband problems. Recently, the researchers have finds various solutions to enhance the MPA bandwidth for the multiband behaviour, some of which is summarised as the partially ground technique, tunable antennas, stubs loaded antennas, and metamaterials or by using graphene material for tunable antennas [6]-[14].

Many of the investigations in the literature have been studied regarding the MPA, some of which are presented as following: In [15] the authors S. Srivastava, and D. Somwanshi have been proposed a rectangular MPA for 915 MHz utilisations, which are utilised for Zigbee and Bluetooth. The proposed MPA was based on the FR-4 epoxy substrate that has a thickness of 1.6 mm and a 4.4 dielectric constant. The introduced MPA was employed to operate in the range of 902-928 MHz with reasonable omnidirectional radiation patterns, its narrow bandwidth was employed to maintain it against the interference issues due to the other utilisations in the ISM band. The authors N. A. Muhammad, et al have been designed, simulated, optimised, and analysed a simplistic MPA for the global WLAN applications based on the MATLAB and CST simulation software. The simulated MPA was designed to operate at 5.2GHz for the IEEE 802.11/a WLAN, IEEE 802.11a/b/g Wi-Fi, broadband internet access and other applications [16]. In this article, the authors M. Yasir and P. Savi have been presented a novel of rectangular tunable MPA by utilising graphene sheets. The suggested MPA was organised of a rectangular patch with a copper extension called a microstrip stub combined directly with the radiating edge, and a graphene mattress located at the input of the stub. The proposed MPA is useful for enhancing the MPA bandwidth due to the increase in the physical length by the means of the stub to covered 5.05, 4.69, and 4.5 GHz dependent on the applied voltage on the graphene [17].

In this paper, a modified configuration of a rectangular MPA is simulated and optimised based on High-

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Frequency Structure Simulator (HFSS) to operates in certain frequencies of the C, and X band. The proposed MPA comprises of a copper radiating patch with a copper extension directly coupled to a radiating patch across three stubs to covering three operating frequency bands $f_1 = 6.19$, $f_2 = 7.63$, and $f_3 = 10$ GHz, in the above-mentioned band. Also, the proposed MPA has a good return loss characteristic variate between -13 to -36.5 dB dispensing the best impedance matching amidst the antenna radiating patch and the feeding line, with an antenna gain variates between 2.6 to 5.34 dBi in the operation frequency bands. The organisation of this article can be summarised as following: Section#2 presents a short introduction about the rectangular MPA configuration. Section#3 presents the process of the simulation for the proposed rectangular MPA, utilising the MATLAB software to acquire the size of the antenna (i.e., dimensions of the antenna) and the HFSS to carried out the simulation process for the proposed rectangular MPA. Section#4 clarify the debate for the achieved results from the solver of the HFSS after completion the simulation process for the proposed rectangular MPA. Finally, Section#5 demonstrates the conclusion from this work.

II. Methodology

The proposed methodology to design and simulation of the proposed MPA can be summed by increasing the physical length of the rectangular MPA through adding a rectangular copper extension with the lower edge of the antenna radiating patch coupled via three copper stubs. The proposed approach is aimed to make the proposed MPA operate in multi-operating frequency bands to solve the narrow band issue of the MPA.

III. Rectangular MPA

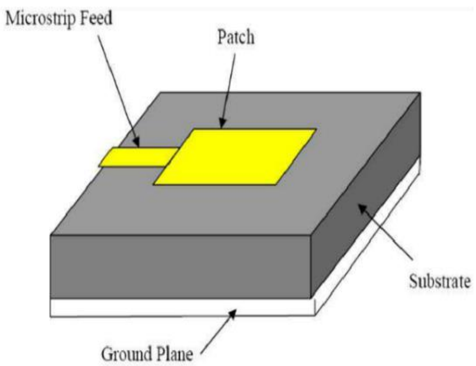


Fig. 1. Rectangular MPA structure.

The rectangular MPA is by far the most commonly utilised configuration for many wireless communication applications. Generally, the MPA can be feeding by several techniques including the conduction or non-conducting methods, the most common of which is the microstrip line method. The rectangular MPA comprises a radiating patch printed on the face of a dielectric material known as a substrate has a thickness (h) and a relative permittivity (ε_r) with a ground plane printed on the bottom of the substrate, as presented in Fig. 1. The radiating patch, feed line, and the ground plane usually made from a highly conductive metal (typically copper) [18], [19].

IV. Antenna Design

The design specification of the proposed rectangular MPA has been discussed and clarified in this section. The proposed antenna is simulated via the $HFSS$ based on $FR-4$ substrate due to its low cost and availability, which has $\varepsilon_r = 4.4$, $h = 1.6\,mm$, and the loss tangent $\delta = 0.02$. In order, to design the proposed antenna some essential parameters should be considered, which are the substrate parameters previously mentioned, input impedance that usually selected to equal 50 Ω, and operating frequency (f_r) that selected to be equals 5.2 GHz in this work.

The feeding method of the antenna has to be carefully selected; the feeding method has a decisive influence on the bandwidth of the MPA. In the MPA the maximum value the patch input resistance befalls at the edge of the patch wherever the voltage is maximum and the current is minimum; typically, its value variates between 150 to 300 ohms and decreases gradually toward the center to be zero in the center where the voltage is zero and the current is maximum [20].

In order to ensure the best coupling among the MPA and the electrical signal source, one of the three popular feed methods can be utilised: a quarter-wave transformer, proximity coupling feed, and an inset feed [21]. In this work, a quarter-wave transformer feed was selected and simulated to achieve the best impedance matching for the MPA. In this method, the feed line comprises of 50 Ω feed line its length started from the substrate edge and a quarter-wave feed line allocated between the antenna radiating patch and the 50 Ω feeding line as presented in Fig. 2.

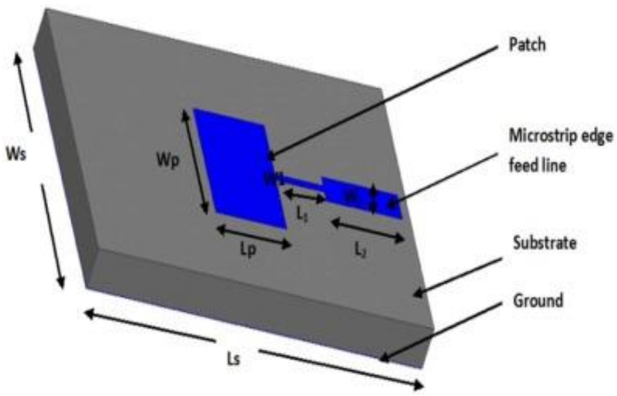


Fig. 2. Rectangular MPA with quarter-wave transformer.

The dimensions of the antenna radiated patch, the ground plane, the substrate, and the feeding line for the simulated MPA are summarised in Table I, that have been obtained via the $MATLAB$ software and the utilising of the following Equations [22], [23]:

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

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}} \quad (2)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left[\frac{W_p}{h} + 0.264\right]}{(\varepsilon_{reff} - 0.258)\left[\frac{W_p}{h} + 0.8\right]} \quad (3)$$

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

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

$$W_s = 2 \times W_P \quad (6)$$

$$L_s = 2 \times L_P, \quad (7)$$

where ε_{reff} is referred to the effective dielectric constant, ε_r is referred to the dielectric constant of the MPA substrate, h is referred to the thickness of the dielectric, W_p is referred to the width of the antenna patch, L_{eff} is referred to the functional length, L_p is referred to the actual patch length, ΔL is referred to the length protraction due the fringing effect. For the calculation of the feed line, the first step can be summarised by the calculation of the dimensions of the 50Ω line, then the quarter-wave transformer line dimension should be obtained through the following Equations [24]-[26]:

$$L = \frac{\cos^{-1}\left(\sqrt{\frac{Z_o}{R_{in}}}\right)}{\frac{\pi}{L}} \quad (8)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (9)$$

$$W = \frac{2h}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B - 1) + 0.39 - \left(\frac{0.61}{\varepsilon_r}\right)\right]\right\} \quad (10)$$

$$L_{qw} = \frac{\lambda_0}{4\sqrt{\varepsilon_{reff}}} \quad (11)$$

$$Z_{qw} = \frac{60 \times \left(\ln\left(\frac{8h}{W_{qw}} + \frac{W_{qw}}{4h}\right)\right)}{\sqrt{\varepsilon_{reff}}} \quad (12)$$

$$Z_{qw} = \sqrt{Z_a \times Z_o} \quad (13)$$

$$Z_a = 90 \times \left(\frac{{\varepsilon_r}^2}{\varepsilon_r - 1}\right) \times \left(\frac{L_p}{W_p}\right)^2, \quad (14)$$

where L is referred to the length of the 50 Ω feeding line, Z_o is referred to the comparable feeding line impedance and equals 50Ω, R_{in} is referred to the resonant input resistance of the patch, W is referred to the width of the 50 Ω feed line, L_{qw} is referred to the length of the quarter-wave transformer, λ_0 is referred to the free space wavelength, W_{qw} is referred to the width of the quarter-wave transformer, Z_{qw} is referred to the equivalent impedance of the quarter-wave transformer, and Z_a is referred to the equivalent impedance of the patch.

When the rectangular MPA parameter computation were carried out through the previously mentioned Equations, the antenna design and simulation procedure is begun by utilising the $HFSS$. Fig. 3 shows the rectangular MPA within the $HFSS$.

TABLE I: DIMENSION OF THE RECTANGULAR MPA

Component	Value (mm)
Patch width (W_p)	17.55
Patch length (L_p)	13.2
Substrate width (W_S)	36.51
Substrate length (L_S)	27.52
Length of 50 Ω feed line (L)	4.88
Width of 50 Ω feed line (W)	3.083
Length of quarter-wave feed line (L_{qw})	7.32
Width of quarter-wave feed line (W_{qw})	0.3

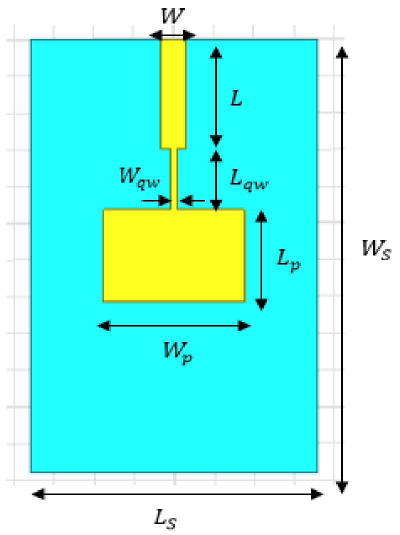


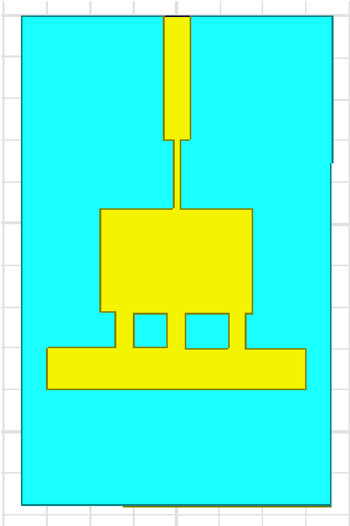
Fig. 3. Rectangular MPA inside HFSS.

In this work, the principal purposes of the optimisation procedure are to improve the antenna rendering and expedite the antenna manufacturing process, wherever the laser machine precision in the fabrication of the antennas is around 0.08 mm. Subsequently, the optimisation mechanism for the antenna done by maximising or minimising some parameters of the MPA by sweep parameters technique obtaining the better results. Table II illustrates the optimised parameters of the rectangular MPA.

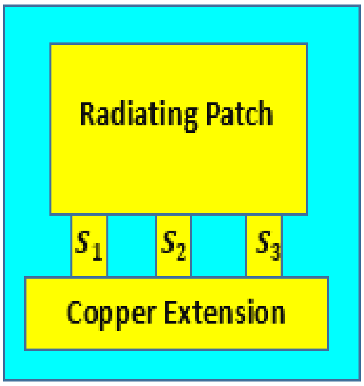
TABLE II: OPTIMISED MPA DIMENSION VALUES

Parameter	Optimised (mm)
Patch width (W_p)	17.56
Patch length (L_p)	12.56
Substrate width (W_S)	35.9
Substrate length (L_S)	58.94
Length of 50 Ω feed line (L)	14.89
Width of 50 Ω feed line (W)	3.059
Length of quarter-wave feed line (L_{qw})	8.3
Width of quarter-wave feed line (W_{qw})	0.723

After completing of the simulation of the optimised rectangular MPA, the shape modification process has been started by trial and error [23], this approach has been utilised due to its simplicity and the ease to reach satisfactory results. The better results were achieved by adding a rectangular copper extension and directly coupled to the bottom edge of the antenna radiating patch via a copper stub. The stub acts as a transmission line to add the effects of the copper extension with the antenna radiating patch resulting in a risen in the physical dimensions of the antenna radiated patch and thus an increase in the operating frequency bands. In order to ensure the best coupling between the copper extension and the antenna radiating patch, two additional stubs were added as illustrated in Fig. 4. Table III presents the dimension as well as the position of the stubs and the copper extension over the substrate.



(a)Proposed antenna inside HFSS



(b) Dimensions description

Fig. 4. Proposed rectangular MPA structure.

TABLE III: DIMENSION OF COPPER EXTENSION AND STUBS

Parameter	Dimensions	Position (x, y, z)
Copper Extension	30 mm ×5 mm	15 ,40 ,0
S_1	2 mm ×5 mm	5 ,35 ,0
S_2	2 mm ×5 mm	1 ,35 ,0
S_3	2 mm ×5 mm	-7 ,35 ,0

V. OBTAINED RESULTS AND DISCUSSION

The achieved results after the introduced MPA simulation procedure has been carried out in the $HFSS$ software will be explained and discussed in this section. The results for return loss (S_{11}) of the proposed rectangular MPA from the $HFSS$ solver is shown in Fig. 5 which covers three operating frequency bands.

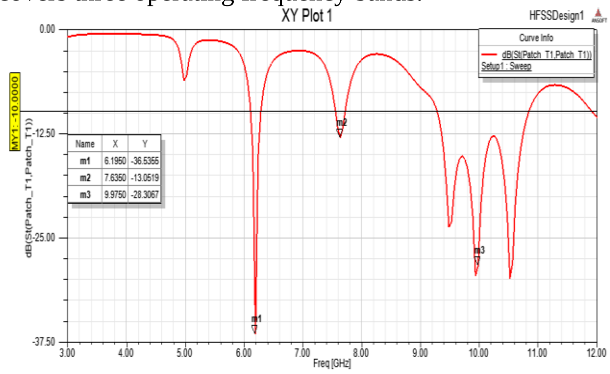


Fig. 5. Return loss (S_{11}) for the proposed rectangular MPA.

In general, the bandwidth of the antenna is usually measured at $S_{11} = -10\ dB$. This criterion means that only 10% of the power is reflected back to the source of the electrical signal as the rest (i.e., 90%) is transferred to the antenna and this is an acceptable case [25]. The bandwidth results for the proposed antenna are presented in Table IV.

TABLE IV: BANDWIDTH RESULTS OF THE PROPOSED MPA.

Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz)
6.19	-36.5	173.9
7.63	-13	164.3
10	-28.3	1546.6

For the gain related issues, in general, the MPA suffers from the low gain due to the gain of the MPA associated with the substrate specifications, where the gain of the MPA increased with the increasing of the substrate thickness and degrades with the increase of the dielectric constant [27]. Figures 6-8 illustrates the $3D$ results for the gain for the simulated MPA at the resonat frequency bands f_r= 6.19, 7.63, and 10 GHz. The proposed rectangular MPA has an acceptable gain in the frequency range 6.19-10 GHz.

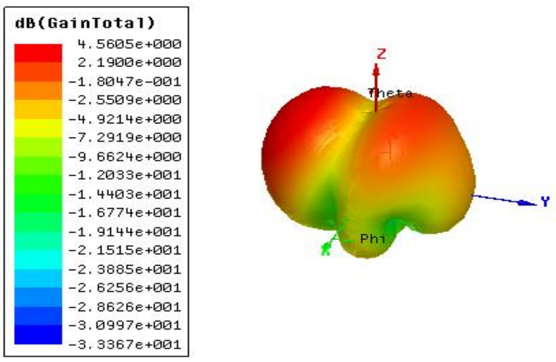


Fig. 6. Gain results for the simulated MPA at f_r= 6.19 GHz.

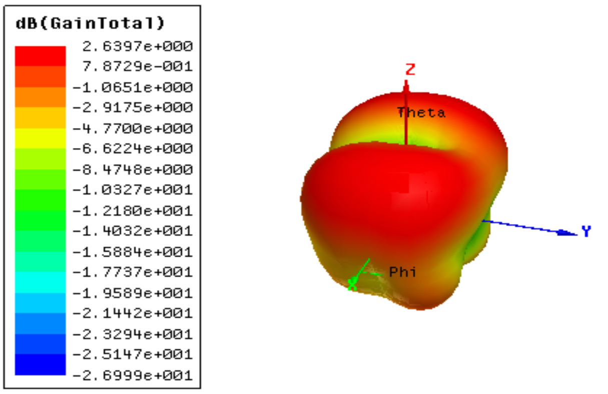


Fig. 7. Gain results for the simulated MPA at f_r= 7.63 GHz.

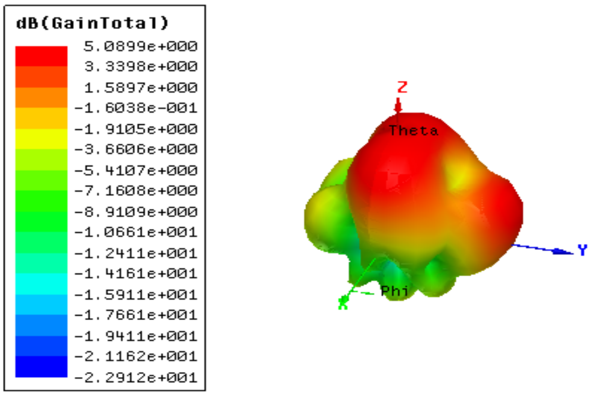


Fig. 8. Gain results for the simulated MPA at f_r= 10 GHz.

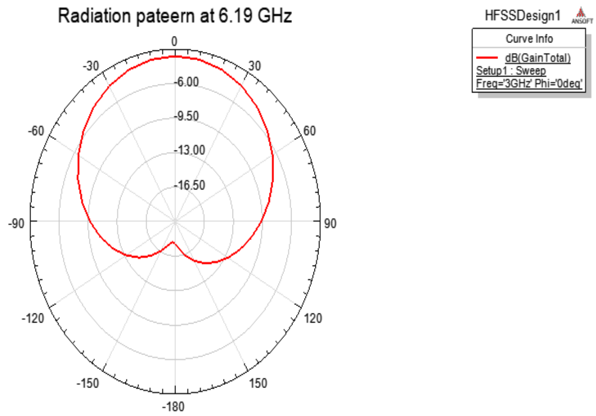


Fig. 9. The radiation pattern for the introduced MPA at f_r= 6.19 GHz.

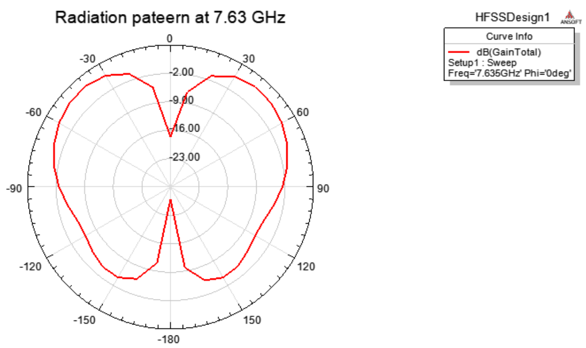


Fig. 10. The radiation pattern for the introduced MPA at f_r= 7.63 GHz.

The radiation pattern for the general MPA is defined as an odd major lobe of reasonable beamwidth. Oftentimes, the beamwidth in the azimuth and elevation planes are congruous, fulfil in a totally circular beam, in spite of this is doesn't general case. The beam widths could be controlled and tuned to construct an antenna with high or low gain, according to the desired utilisations. The radiation pattern of the simulated rectangular MPA at the previously mentioed frequencies are presented in Figures 9-11.

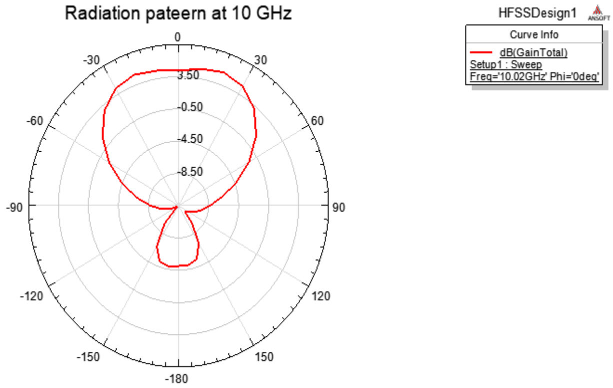


Fig. 11. The radiation pattern for the introduced MPA at f_r= 10 GHz.

VI. Conclusion

In this article, a modified design of a rectangular MPA with edge feed technique has been simulated as well as optimised for certain frequencies of the C, and X band applications through the $HFSS$ package. The utilised method in this work can be summarised by changing the antenna radiated patch physical length through utilising a rectangular copper extension coupled with the bottom edge of the antenna radiated patch via three stubs to ensure a good coupling. The proposed antenna has a rational gain with several operating frequency bands in ambit of 6.19 to 10 GHz. From this work, it can be concluded that the rising in the radiating patch and the using of stubs lead to gives many operating frequency bands. Finally, the MPA operating frequency band is expanded.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

In this research work, we, as a scientific team, created and developed this work, whereas the tasks were distributed as follows: The first researcher in carrying out the design of the proposed antenna using mathematical equations and the MATLAB software, and then conducted the simulation process in the HFSS antenna simulation software. The second researcher carried out the process of writing and arranging the parts of the paper in addition to adding the results that were achieved. Finally, the last researcher carried out the process of typesetting and linguistic revision for the proposed work.

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