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Novel Microstrip Patch Antenna with Modified Ground Plane for 5G Wideband Applications

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Sadiya Afrin Swarna [α], Salma Faria [σ], Sakhawat Hussain [ρ] & Anis Ahmed [ω]

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I. Introduction

A revolution has occurred in the world of wireless communication systems with the introduction of 5G network. It provides high speed data transmission rates more than 1Gbps to broadcast live events, high definition video streaming, autonomous driving, robotics, aviation, health care applications, etc. This 5G wireless technology is nearly capable of the wired fiber optic internet connection. Another feature of 5G is that it can transfer both voice and high-speed data at the same time more efficiently than the other conventional mobile cellular technologies. Depending on the implementation policy of 5G in various countries, the lower and higher end of the fifth generation frequency spectrum are approximately 3-5 GHz and 24-71 GHz, respectively [1]. To interconnect the existing mobile devices and various sensors, sub-6 GHz frequencies are being used by 5G technology. For maintaining high speed transmission and reception, high-gain wideband antennas are needed for reliable wireless communication. Recently use of a wideband antenna for multichannel transmission and reception has become more popular. Besides, low-profile antennas are preferable for mobile base station, intra-satellite communication purposes, missiles and so on. For these application areas, microstrip patch antennas (MPAs) are better choice over the other types of antennas. Some of the advantages of MPA are light weight, smaller size, low fabrication cost, easy installation, mechanical robustness and freedom of design [2-3].They also minimize the excitation of other undesired modes [4]. Due to the miniaturized structure of MPAs, they feasibly can be used in smaller electronic devices to improve the portability and efficiency [5].But they are not widely used antennas because of their low gain, narrow bandwidth, low directivity, low power handling capacity, distorted radiation pattern and multiple resonances [6-7].So the target of the research on MPA is to increase the bandwidth, gain, and desired radiation pattern for various sorts of 5G applications. Antenna characteristics can be improved by introducing slots of different shapes, defected ground plane, metamaterial, and shorting pins. etc. [7-10]. Besides by increasing the substrate height, and lowering the dielectric constant, antenna characteristics can also be increased [11]. Moreover feeding techniques affect some important antenna parameters such as bandwidth, return loss, VSWR etc.[12].

In this paper we proposed a microstrip patch antenna having 6 rectangular slots placed symmetrically on both sides the feed line. The introduction of slots on the patch changes the resonance characteristics from conventional multiband to a single resonant one. The ground plane is modified with a new structure to increase bandwidth. The bandwidth of the slot loaded MPA with modified ground plane is increased approximately 18 times than that of the conventional MPA. The design and simulation process of the MPA are done by CST software. The radiation pattern and S_{11} of the fabricated antenna are measured using Vector Network Analyser (Rohde & Schwarz-ZVH8) and Wave and Antenna Training System (Man and TEL Co.).

II. Design of the Proposed MPA

The proposed MPA is a rectangular inset feed patch antenna as shown in Fig. 1. To enhance the

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resonance characteristics at a single frequency, slots are introduced in the patch (see Fig. 1(a)). The patch is placed in the middle of the substrate. Three slots of different sizes are placed symmetrically on both sides of the microstrip feed line. The width and length of patch are represented by W and L. In general, the width and length of substrate are taken 1.5 times than that of patch dimensions. The width, gap and length of inset feed microstrip line are denoted by W_f, G_f and F_i, respectively.

The slots are denoted by 'a', 'b' and 'c' as shown in Fig. 1(b). The widths and lengths of slots are represented by W_i and L_i, where $i = 1, 2, 3$ corresponds to the slots 'a', 'b' and 'c', respectively. The position of each slot is very sensitive to the patch characteristics. For example, the distances of slot 'c' from the bottom edge, side edge and top edge of the patch are denoted by c_1, c_2 and c_3, respectively (see Fig.1(b)). Similarly the positions of slot 'a' and 'b' are taken as a_i and b_i $(i = 1, 2, 3)$.

Figure 1 (c) shows the modified ground structure of the proposed MPA. To increase the bandwidth of patch antenna, the ground side is modified to form a helipad-like structure. Three English letter 'I' are made along the length of patch. All 3 I-structures are connected at the middle. The middle I has larger width than the other two Is. This middle I also has a rectangular slot in the middle and two side-slots at the top and bottom edges. The hatched part in ground plane represents the existence of copper layer and the rest regions are etched out. The widths of the side I and central I are expressed by G_1 and G_2, respectively. The distance between the outer edges of 2 side I's is denoted by G_3 which is taken 10 times of the width of each side I i.e. $G_3 = 10 \times G_1$.The whole ground plane has been finally appeared as a helipad-like structure.

For the analysis, the substrate is considered FR4 whose dielectric constant,ϵ_r is 4.3 with a thickness $h = 1.6$ mm. The effective dielectric constant ϵ_{reff} is expressed as [8]

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

The width W of the patch is calculated for the resonant frequency f_r at 3 GHz using the following equation

$$W = \frac{v_0}{2\times f_r} \times \sqrt{\frac{2}{\epsilon_r+1}} \quad (2)$$

where v_0 is the speed of light in free space.

The relation between the actual length L and the effective length L_{eff} is

$$L = L_{eff} - 2\Delta L \quad (3)$$

Where ΔL is the fringing correction factor and is expressed as

$$\Delta L = 0.412h \times \frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

The expression for the effective length L_{eff} is

$$L_{eff} = \frac{v_0}{2\times f_r \times \sqrt{\epsilon_{reff}}} \quad (5)$$

Microstrip transmission line width W_f has been varied from W/5 to W/15 to achieve the best result through simulation. The value is found to be 3.06 mm for the best antenna characteristics.

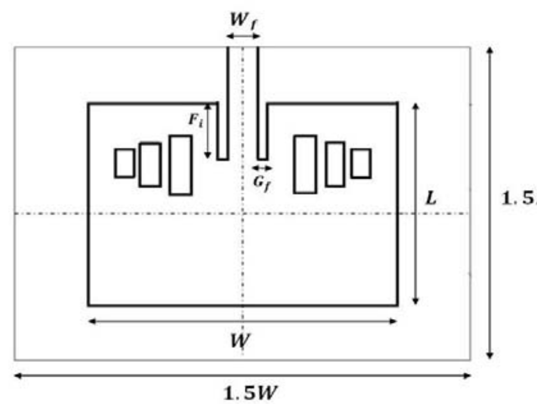
The equation used for determining the exact length of inset feed F_i for thin dielectric substrate to achieve an input impedance of 50Ω is as follows [13]:

$$F_i = 10^{-4}(F_{c7}\epsilon_r^{\,7} + F_{c6}\epsilon_r^{\,6} - F_{c5}\epsilon_r^{\,5} + F_{c4}\epsilon_r^{\,4} - F_{c3}\epsilon_r^{\,3} + F_{c2}\epsilon_r^{\,2} - F_{c1}\epsilon_r + F_{c0})L/2 \quad (6)$$

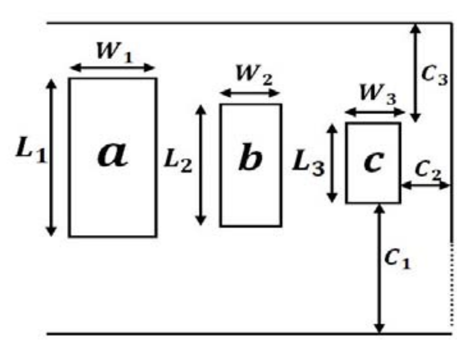
Where

$F_{c7} = 0.001699, F_{c6} = 0.13761, F_{c5} = 6.1783, F_{c4} = 93.187, F_{c3} = 682.93, F_{c2} = 2561.9, F_{c1} = 4043$ and $F_{c0} = 6697$,respectively.

Using the above stated equations, all the parameters (such as ϵ_{reff}, L, W, F_i) are calculated for f_r = 3 GHz. These calculated values are used to design a conventional MPA as well as the proposed MPA using CST software. It is found that the calculated values of different parameters are slightly modified to obtain the optimized values which give better antenna characteristics. The gap between the patch and the inset-feed microstrip line G_f has been changed from 0.5 to 3.5 mm to get the best result. It is found that G_f = 0.95 mm gives the satisfactory result.



(a)



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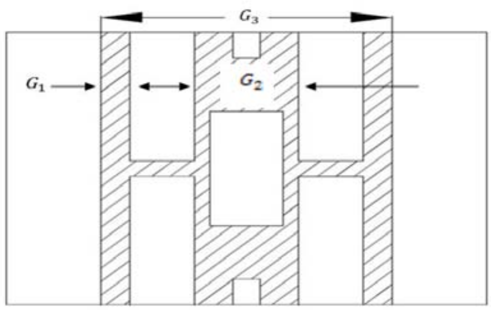


(c)

Fig.1: Structure of the proposed MPA; (a) slotted patch side, (b) enlarged view of slots with dimensions and (c) modified ground plane side.

The length L_3 and width W_3 of the smallest 'c' slot are found 3.2 mm and 1.9 mm, respectively. Two smallest 'c' slots are placed symmetrically on both sides of the feed line. Each smallest 'c' slot is positioned at distances $c_1 = 14.605$ mm, $c_2 = 2.745$ mm and $c_3 = 5.205$ mm away from the bottom edge, side edge and top edge of the patch antenna, respectively. The dimensions of medium type 'b' pair of slots are $L_2 =$ 5mm and $W_2 = 1.9$mm.These 'b' slots are positioned at $b_1 = 13.505$ mm, $b_2 = 5.345$ mm and $b_3 = 4.505$ mm apart from the bottom edge, side edge and top edge of the patch, respectively.The length and width of the biggest two symmetrical rectangular 'a' slots are $L_1 = 6.5$ mm and $W_1 = 2.2$mm, respectively. The slots are positioned at $a_3 = 3.805$ mm, $a_2 = 8.245$ mm and $a_1 = 12.705$ mm apart from the top edge, side edge and bottom edge of the patch, respectively.The positions and dimensions of the slots are determined using trial and error method to get good antenna characteristics such as S-parameter, radiation pattern, bandwidth, directivity etc. All the optimized structural parameters of the proposed MPA are given in Table1.

Table1

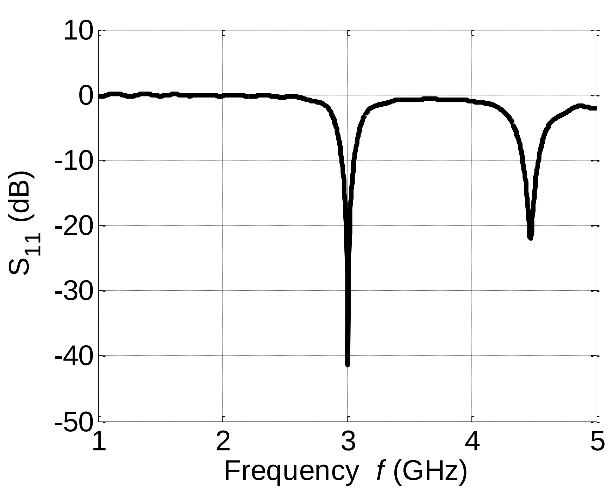
Parameters	Optimized value	Parameters	Optimized value
Frequency, f_r (GHz)	3	W_1(mm)	2.2(≅0.022λ)
Wavelength, λ (mm)	100	W_2(mm)	1.9(≅ 0.019λ)
Dielectric constant, ϵ_r	4.3	W_3(mm)	1.6(≅ 0.016λ)
Substrate Height, h (mm)	1.6	a_1(mm)	12.705(≅ 0.127λ)
Patch Width, W (mm)	31.29(≅ 0.313λ)	a_2(mm)	8.245(≅ 0.082λ)
Patch Length, L (mm)	23.01(≅ 0.23λ)	a_3(mm)	3.805(≅ 0.038λ)
Substrate Width, 1.5W (mm)	46.04(≅ 0.46λ)	b_1(mm)	13.505(≅ 0.135λ)
Substrate Length, 1.5L (mm)	35.52(≅ 0.355λ)	b_2(mm)	5.345(≅ 0.053λ)
Microstrip Transmission Line Width, W_f(mm)	3.06(≅ 0.0306λ)	b_3(mm)	4.505(≅ 0.045λ)
Microstrip Line Inset Feed Length, F_i(mm)	6.5(≅ 0.065λ)	c_1(mm)	14.605(≅0.146λ)
Gap between patch and feed line, G_f (mm)	0.95(≅ 0.009λ)	c_2(mm)	2.745(≅ 0.027λ)
Thickness of Copper Layer,M_t(mm)	0.035	c_3(mm)	5.205(≅0.052λ)
L_1(mm)	$L_1 = 2.0L_3$ 6.5(≅ 0.065λ)	G_1(mm)	2.8(≅ 0.028 λ)
L_2(mm)	$L_2 = 1.5L_3$ 5(≅ 0.05λ)	G_2(mm)	$G_2 \cong 3.6G_1$ 10(0.1λ)
L_3(mm)	3.2(≅ 0.032λ)	G_3(mm)	$(G_3 = 10G_1)$ 28(= 0.28λ)

III. Simulation Results

To observe the effects of slots and ground modification, we have designed two types of MPAs using CST simulation software. A conventional MPA has also been designed to compare the improvement of characteristics of the proposed MPA. The substrate is taken FR4 with a copper cladding thickness of 35 μm and the final dimension of the MPAs is 40.1X35.5 mm. Obtained return losses (S_{11}) and far-field radiation patterns of three types of MPAs are shown in Figs. 2 and 3, respectively.

We have shown the return loss (S_{11}) of the conventional MPA (without slot and with full ground plane) in Fig.2 (a). We have seen that there are two resonant peaks at 3.008 GHz and 4.48 GHz with the magnitudes of -41.35 dB and -22.04 dB, respectively. The corresponding bandwidths of these two frequencies are 100 MHz and 120 MHz, respectively. Introducing slots in the patch with the full ground as conventional one, the magnitude of S_{11} is found to be -35.32 dB at 3.00 GHz which is very close to the designed resonant frequency of 3 GHz (see Fig.2 (b)). We have eliminated the second resonant peak of the conventional antenna by incorporating six slots on the patch. We have gradually decreased the size of the slots from middle to the patch-edge. The bandwidth of the resonant peak at 3.00 GHz is found 100 MHz which is similar to the conventional one.

To increase the bandwidth, the ground plane is modified to form a helipad-like structure keeping slots in the patch. The obtained S_{11} is shown in Fig. 2(c). The bandwidth and minimum return loss of the final proposed MPA are 1.77 GHz and -46.5 dB at 3.028 GHz, respectively. Thus the bandwidth has been increased remarkably, and our proposed MPA is appropriate for wideband applications.



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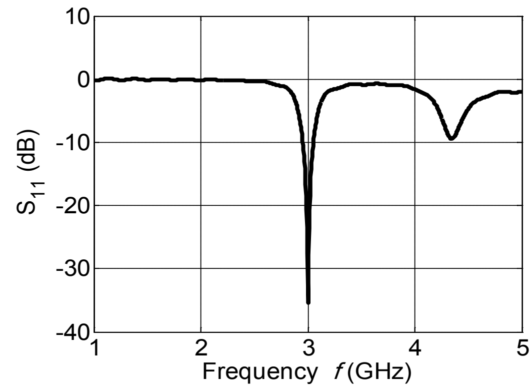

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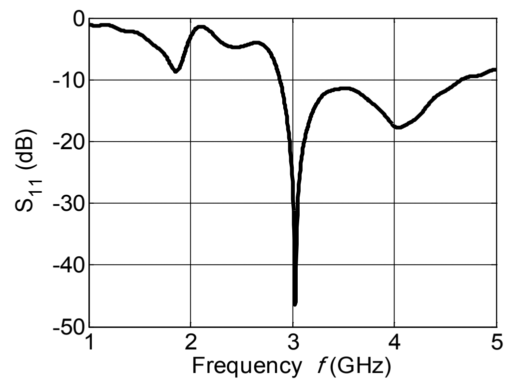
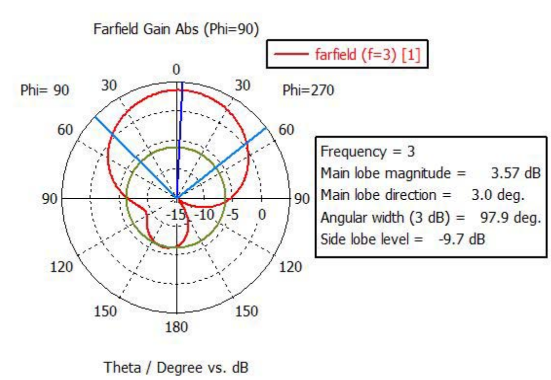


(c)

Fig.2: Variation of $S11$with frequency for (a) Conventional MPA (b) MPA with slotted-patch and the full ground plane(c) Proposed MPA (slotted-patch with modified ground plane).

We have shown the far-field radiation patterns of the conventional and the proposed MPAs in Fig.3 (a) and 3(b), respectively. The radiation pattern of the conventional one is hemispherical as a theoretical one. But the radiation pattern of the proposed MPA is bi-directional and symmetric. Such a bidirectional antenna is suitable for WLAN, intra-satellite communication and beam forming applications [14-16]. The main lobe magnitude of the proposed MPA is found to be 1.89 dB. We have found VSWR 1.5 ± 0.2 in the whole bandwidth range of 2.8 to 4.6 GHz for the final proposed MPA.



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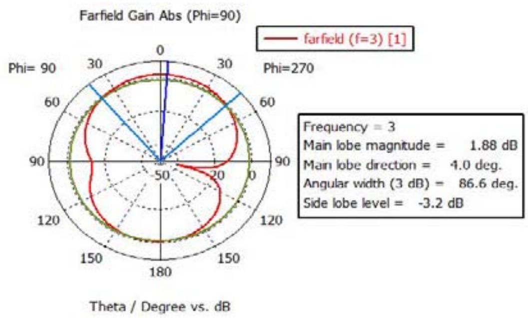


(b)

Fig.3: Far-field radiation of MPA: (a) Conventional MPA (without slot with modified ground plane) and (b) Proposed MPA (slotted-patch with modified ground plane).

IV. Measured Results

The conventional and the proposed MPAs are fabricated in our laboratory by liquid etching technique. First of all, Copper substrate has been cut into rectangular pieces with the dimensions according to the optimized values shown in Table-1. Then the patch and ground sides of the MPA are masked using photo resist. Ferric Chloride solution is used to chemically etch out the unwanted copper to get the desired portions of the patch and ground plane. After cleaning up the mask with Ethanol, SMA connectors are fixed on the mount at the antenna port. In Fig. 4, the photograph of the patch side (left) and the ground plane (right) of the proposed MPA are shown.

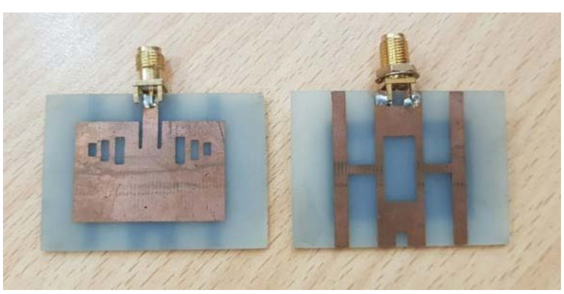
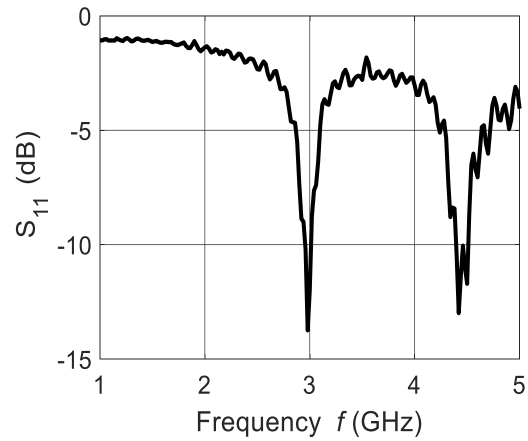
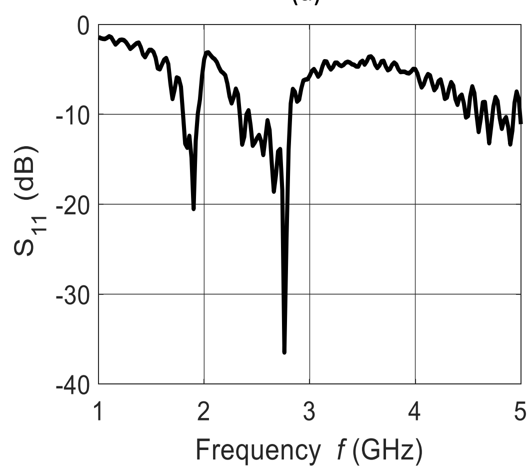


Fig. 4: Patch side and ground plane of fabricated proposed MPA

The measured scattering parameters of the the conventional and the proposed MPA in Fig. 5(a) and 5(b), respectively. There are two resonant peaks for conventional MPA. The magnitudes of the resonant peaks are -13.74 dB and -8.5 dB at 2.98 GHz and 4.3 GHz, respectively (see Fig. 5(a)). The bandwidth of the resonant peak at 2.98 GHz is found 80 MHz. For conventional MPA, the measured return loss is found very similar to the simulated one. Finally the measured S_{11} of the proposed MPA is shown in Fig. 5(b). The bandwidth is increased with a fraction bandwidth increment of 14% and found to be 380 MHz which is almost 5 times larger than the bandwidth of conventional MPA. The magnitude of S_{11} is found to be -36.48 dB at the resonant peak of 2.76 GHz. May be due to the fabrication and measurement (without anechoic chamber) inaccuracy, the obtained results of measurement have some deviation from that of of simulation.



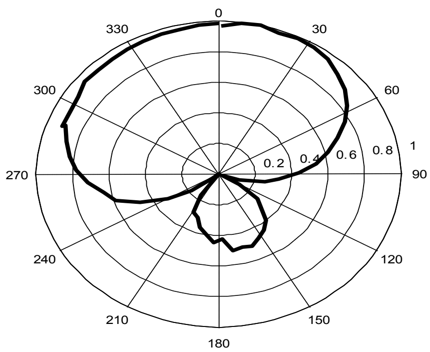
(a)



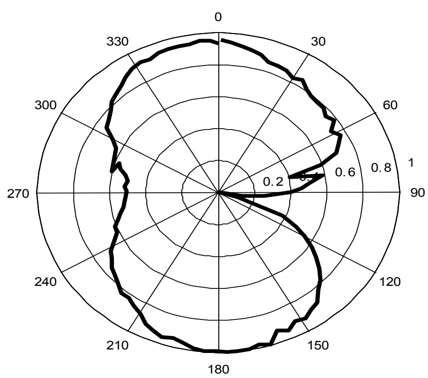
(b)

Fig.5: Experimental measured results of S_{11} of fabricated two types of MPA:(a) conventional rectangular MPA (b) Proposed MPA (slotted-patch with modified ground plane)

The measured far field radiation pattern of the conventional MPA is shown in Fig.6 (a). The radiation pattern has a hemispherical main lobe and a small back lobe. By comparing Figs. 3(a) and 6(a) it is seen that the measured radiation pattern is almost same as the radiation pattern obtained from simulation. Figure6 (b) shows the characteristics of measured radiation pattern for the proposed MPAwith modified ground plane. This result also agrees very well with the simulated one. Since bandwidth of our proposed MPA has increased remarkably, the gain has reduced. The measured radiation pattern of our proposed MPA is also found bi-directional pattern which is similar to that of simulated one.



(a)



(b)

Fig. 6: Measured radiation patterns of (a) conventional MPA and (b) proposed MPA

V. Conclusion

A new slot-loaded patch antenna with ground modification has been designed to enhance the resonance characteristics with improved bandwidth. The antenna works at the resonance frequency in S-band i.e. at 3 GHz. The return loss magnitude of the proposed MPA is found quite satisfactory than the conventional structure. The simulated return loss bandwidth of the proposed MPA has been increased from 100 MHz to 1.77 GHz compared to the convention MPA. The measured return loss characteristics and radiation pattern of the proposed antenna match well with the simulated results. The bandwidth of the measured MPA is found 380 MHz, a reduced bandwidth value due to the inaccuracy of fabrication and measurement in our laboratory without anechoic chamber. The far field gai and directivity of the fabricated antenna are quite satisfactory. The radiation pattern of the proposed MPA is bi-directional and is suitable for WLAN, intra-satellite communication and beam forming applications.

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