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Optimisation of a Rectangular Microstrip patch Antenna for 2.4 GHz ISM Band Operation

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Abstract

Microstrip patch antennas are widely used in wireless communication due to their low profile and ease of fabrication. This makes them useful in the 2.4GHz ISM band. In this paper, the effects of different geometrical notches and slots on a basic rectangular microstrip patch antenna are analysed. Triangular, rectangular and hexagonal slots; and notches on only two corners and on all four corners are investigated using High Frequency Structure Simulator (HFSS) to determine which produce the most improvement on the operation of a rectangular microstrip patch antenna. The simulated results show that hexagonal slots and notches on two corners produce the most improvement.

Keywords: Microstrip Patch Antenna, Inset Fed, Notch, Slot

INTRODUCTION

Microstrip patch antennas (MPA) have become very popular in today's wireless communication systems because of their attractive features that include compact size, low profile, being lightweight, they are easy to fabrication, and they are compatibility with integrated circuits [1]. Applications for MPAs are wide and range from mobile communication systems; satellite navigation to radar systems and wireless sensor networks. These MPAs are made up of a patch that radiates the signal, this is made of a metal that is a good conductor like copper or gold. The metal is mounted on a dielectric substrate, as well as a ground plane that is usually made from the same material. FR4, Rogers, or Taconic typically form the substrate materials s they have a low dielectric constant to minimize signal losses [2].

The patch that radiates the signal may be designed in a number of shapes that include rectangular, circular, or square [3]. The resonance frequency of the antenna is determined by effective dielectric constant of the substrate (Ɛ), the dimensions of the patch, and the height of the substrate that separates the patch and the ground plane [4].

Achieving optimal performance from a rectangular MPA for various applications in the ISM (Industrial, Scientific and Medical) band through careful design and optimization is important. The ISM band ranges from 2.4-2.5 GHz and are crucial for the proliferation of short-range, unlicensed wireless communication technologies that are an integral part of our daily lives and modern industrial applications. Key performance parameters such as return loss, bandwidth, gain, radiation pattern, and efficiency are highly dependent on the antenna's physical dimensions, substrate characteristics, and feeding techniques [5]. However, the MPAs have disadvantages in their primary forms, such as low gain, narrow Bandwidth, and low efficiency [6].

High Frequency Simulation Software (HFSS) is utilized as a software tool to design the antenna and analyze its parameters. It provides the platform to identify antenna parameters such as return loss and ban

dwidth. HFSS can simulate precisely and optimize the device performance.
This report compares and analyses the effects of different geometrical modifications on the patch. Different performance parameters will be compared. The first parameter to be compared is return loss. This is also known as the reflection coefficient, represented by the symbol $S11$.Return loss shows how the input and output ports work together and how much power is reflected from the antenna. The plot of the reflection coefficient shows how the feedline and antenna should be matched [7]. An $S11$ value of at least -10 dB shows that the antenna is delivering an effective performance. The return loss value shows how well the antenna works; a smaller number means the antenna is showing better performance. The return loss is measured in decibels [6].
Another performance parameter to be compared is radiation efficiency. This refers to the amount of energy that has to be fed into an antenna for it to communicate effectively. The power fed into an antenna and the power that the antenna itself either emits or dissipates can be used as benchmark to determine how effective the antenna is [8]. The bulk of the power sent to an antenna with low efficiency is lost due to either losses within the antenna itself or is reflected away due to an impedance mismatch. The ratio of the total power that the antenna transmits to the net energy that is fed from a linked transmitter is used to calculate the antenna's radiation efficiency [9]. The gain of an antennas will also be compared. Gain is one of the most important indicator of an antenna's overall performance. For the antenna to operate efficiently at the resonant frequency band the gain has to be positive [8].
The last parameter to be compared during analysis in this paper is the voltage standing wave ratio (VSWR). This is ratio of the antenna's maximum to minimum voltage [10]. When the VSWR is 1, the source is not reflecting any power. In the real world, a VSWR of 1.2 is considered very good [11]. The ratio of 1.2:1 between the greatest standing wave amplitude and the minimum standing wave value means that the maximum standing wave height is 1.2 times greater than the minimum standing wave value. This ratio is used to evaluate the amount of power reflected by the antenna [12]. It is recommended that the value of the VSWR be a figure that is both positive and actual. VSWR shows the impedance match of the transmission line and it shouldn't be any higher than 2, and it shouldn't be any lower than 1. VSWR can be used to find problems in transmission lines [11].

METHODOLOGY

In the first stage, the standard formulae of a rectangular MPA are used to calculate the dimensions of the proposed antenna as indicated in equations below [13]. Formula (1) is used to calculate the width of the designed patch.

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

Where c is the velocity of light, is the resonant frequency and ε_r is the relative permittivity. Since the field is not only limited to the inside of the substrate material, we must consider the effective dielectric material of the substrate, which is determined by equation below

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

Where h= height of the patch, W= width, and ε_r = dielectric constant of the substrate
The actual length of the patch is determined by

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

Where the effects of the fringing fields are a result of the effective length, which is determined by

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

ΔL is the extension of the length because of fringing effects. The microstrip antenna patch is electrically longer than the physical scope.

$$\Delta L = h \times 0.412 \frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0,8\right)} \quad (5)$$

The ground plane's length L_g and the ground plane's width W_g are given by

$$L_g = 6h + L \quad (6)$$

$$W_g = 6h + W \quad (7)$$

The microstrip feeding technique adopted in this paper is the inset feed method. The feed width (wf) and length (Lf) are calculated using the following equations

$$Wf = \frac{2H}{\pi}\left\{B - 1 - ln(2B-1) + \frac{\varepsilon_o - 1}{2\varepsilon_r}\left[ln(B-1) + 0,39 - \frac{0.61}{\varepsilon_r}\right]\right\} \quad (8)$$

Where $B = \frac{377\pi}{2z_o\sqrt{\varepsilon_r}}$ and $z_o = 50\Omega$

And $L_f = 3.96 \times W_f$ (9)

PARAMETER	VALUE (mm)
W (patch)	28,61
L (patch)	37,93
W_g (substrate)	57,23
L_g (substrate)	75,85
W_f(feed)	2,52
L_F (feed)	9.98
Inset Feed Gap (g)	0.21

Table 1: Calculated Values of the MPA Dimensions

The basic rectangular MPA designed from the above parameters is shown in figure 1 below.

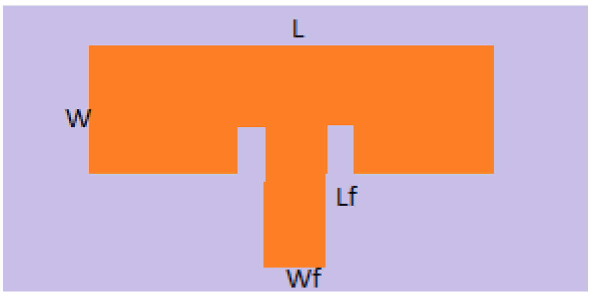

Figure 1: Basic Rectangular MPA

Different geometric slots are added to the MPA, through a series of experiments the size of the slots that resonated at the desired frequency were simulated. The simulated results are analysed and compared. Figure 2a, 2b and 2c below show the rectangular MPA with rectangular, triangular and hexagonal slots respectively. Throughout the whole DOE process the slots are kept on the same position as the gap in the original basic MPA design.

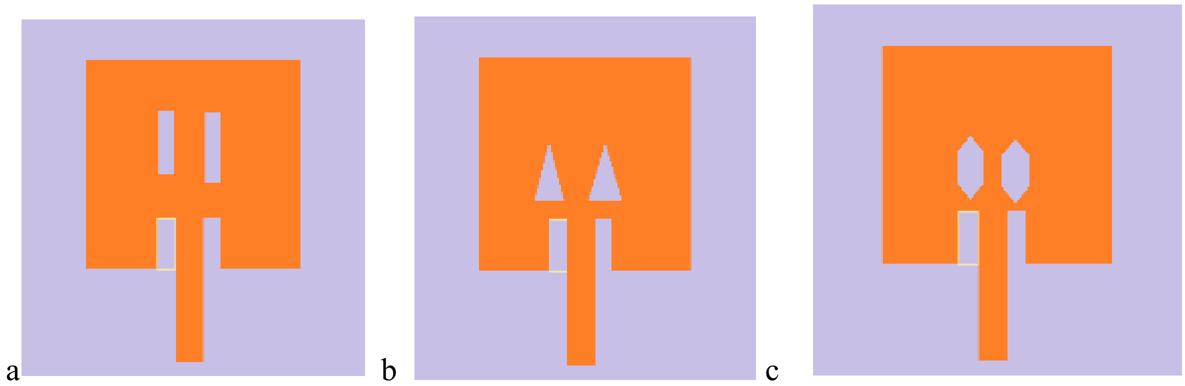

Figure 2: a-Rectangular Notches, b-Triangular Notches, c-Hexagonal Notches

Notches are also added to the basic MPA through a DOE process. The effects of two different notch configurations are simulated and analysed. Figure 3a shows notches on only two corners of the rectangular MPA and figure 3b shows notches on all the corners of the MPA.

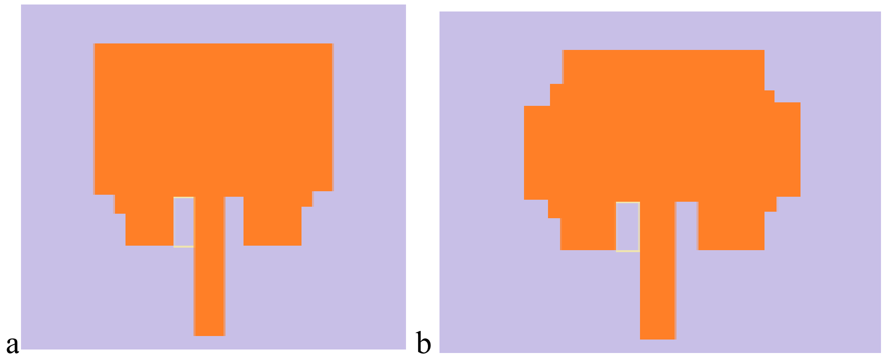

Figure 3a and b Showing Notches On Two Corners And On All Four Corners

RESULTS AND DISCUSSION

The designed antennas were simulated on HFSS and the following results were obtained

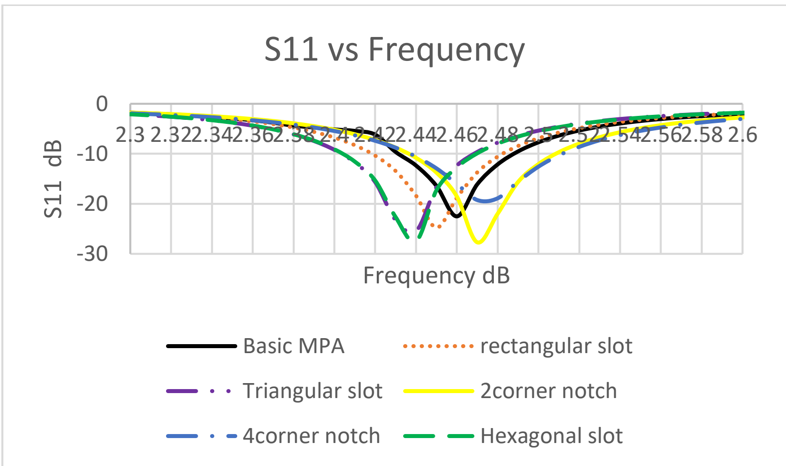

Figure 4: S_{11} VS Frequency Comparing the Basic Antenna and the Modified Antennas.

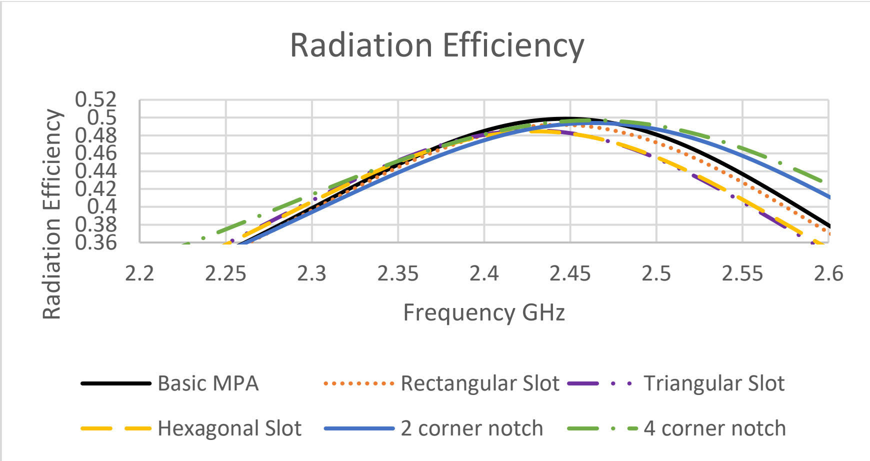

Figure 5: Radiation Efficiency VS Frequency Comparing the Basic Antenna and the Modified Antennas

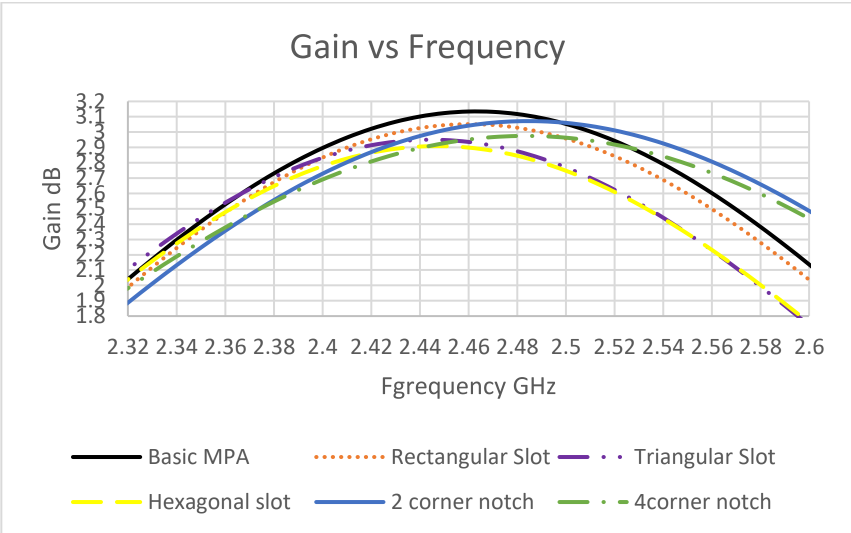

Figure 6: Gain VS Frequency Comparing the Basic Antenna and the Modified Antennas

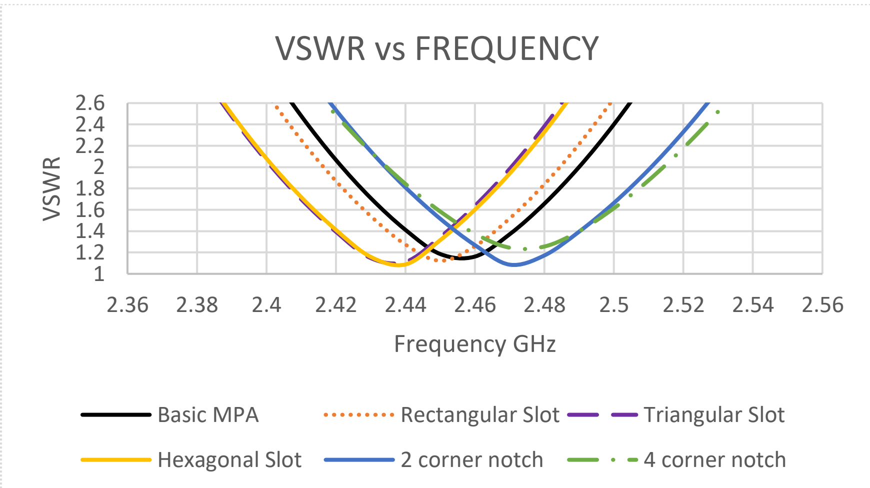

Figure 7: Vswr Vs Frequency Comparing Basic MPA and Modified Antennas

Three geometrical modifications show an improvement in bandwidth and the reflection co-efficient as shown in Figure 4. The bandwidth is the range of frequencies where the S_11 parameter is less than -10dB [14]. The notches on all four corners do not improve the performance of the antenna in any way and showed poor performance in all the parameters that were analysed.

The S_{11} improved by the use of the rectangular slot, hexagonal slot and notches on the two bottom corners of the basic MPA, this was at the expense of the antenna gain. This improvement can be attributed to the increased effective radiating area and reduced surface wave propagation, which enhances the overall efficiency of the antenna [15]. The basic MPA design maintained a higher gain (figure 6) than all the modifications. All the antennas have a very low VSWR (figure 7) showing that throughout all the modifications a very good matching was archived and maintained between the feeding system and the antenna [16].The results obtained can be summarized in table 2 below:

Type of Modification	Resonant Frequency(GHz)	S_{11} Parameter(dB)	%change	Bandwidth(MHz)	%change	Gain
Basic MPA	2.46	-22.5	-	50	-	3.13
Rectangular slot	2.45	-24.7	9%	60	20 %	3.05
Triangular slot	2.44	-25.3	12%	70	40 %	2.94
Hexagonal Slot	2.44	-27.4	23%	70	40 %	2.91
Notches on 2 corners	2.46	-27.8	23%	80	60 %	3.07
Notches on 4 corners	2.48	-18.8	-16%	70	40 %	2.97

Table 2: Summary of results

The proposed designs for geometric modifications give satisfactory results acceptable for ISM use. It can be seen that inserting slots or notches on certain portions of the radiating element of the MPA improves the antenna properties. These modifications give a good return loss and can be utilised as a method for the bandwidth enhancement that is simple but effective. Some researchers have used other methods like incorporating contours on the radiating patch element, but the approach adopted in this paper is simpler to archive in optimizing the microstrip patch antenna [16].

CONCLUSION

The optimization of rectangular MPA through the use of geometric modifications has shown significant potential for enhancing performance as shown in the above analysis. The analysis revealed that notches on all two corners offer the most improvement in bandwidth and efficiency making them the better choice for antenna design. It also shows that rectangular slots provide the least improvement, indicating that not all geometric alterations are equally effective in optimization. Future work may explore additional modifications and their effects on antenna performance.

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