Design of microstrip patch antenna at 2.4 GHz for Wi-Fi and Bluetooth applications

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Abstract. In this paper, the Rectangular Patch Antennas are designed and their performance parameters such as return loss, voltage standing wave ratio, gain, and radiation pattern have been calculated and compared. Design frequency is 2.4 GHz, the copper-coated substrate material is FR-4 Epoxy having dielectric constant $\varepsilon=4.4$ and thickness is 1.5 mm. The feeding technique, used in MSA is Microstrip 50 $\Omega$ feed line. Using a parametric study found that the proposed antenna design will be useful for ISM band applications like Wi-Fi, Bluetooth.

Keywords. Rectangular Patch, Return Loss, copper-coated Substrate, Microstrip, ISM Band.

1. Introduction
Microstrip Patch Antenna (MSA) is one of the most favoured antenna structures because of its ease of fabrication and have many applications in wireless communication. They are very useful nowadays because they are directly printed onto the circuit boards. In this paper, FR-4 Epoxy material is used as a substrate. The MSA (Microstrip Patch Antenna) is widely used nowadays because of its various advantage but it also has some disadvantages but due to its various advantages, it surpasses its disadvantages. These are some advantages of MSA: -

a) Light Weight
b) Low Profile
c) Capable of dual and triple frequency operation.

It also has some drawbacks like low gain, low bandwidth. To overcome this type of disadvantage, in this paper authors made plenty of types of Microstrip antennas. Accordingly, in present paper, first a MSA is designed with a single layer of a substrate, then calculated its parameter like return loss, voltage standing wave ratio, gain, and directivity. Secondly, another MSA with two layers of a substrate is designed in which the second layer was stacked over the first substrate of the same material. Thirdly, the diagonal slots are cut on the MSA, and in final attempt slots are also cut at all the corners on the MSA, and then comparison has been made between performance parameters of the antennas. The motive of paper is to meet increasing demands of wireless communication in various applications. The main objective behind this research work is to: -

A. Increase the bandwidth of an antenna
The bandwidth of the antenna can be improved by increases the height of the antenna, by lowering the dielectric constant.
B. Increase the gain of an antenna
A gain can be improved by changing the shapes of a patch, in this paper, a rectangular patch is used because this configuration reduces patch area by around 65-70% and also enhances the gain.

2. Antenna Design and its Dimensions
The proposed antenna geometry containing of a dielectric substrate, patch along with microstrip feed line, is shown in Fig 1. The rectangular patch is separated from the ground plane with FR-4 Epoxy Dielectric substrate with the above-shown dimensions. [1]

| Parameters         | Values (in mm) |
|--------------------|----------------|
| Length (Substrate) | 47.04          |
| Width (Substrate)  | 38.48          |
| Height (Substrate) | 1.5            |
| Length (Patch)     | 38.04          |
| Width (Patch)      | 29.48          |
| Length (Feedline)  | 5.2            |
| Width (Feedline)   | 1.0            |

All the dimension of designed parameters of MSA is shown above in Table 1. The figure beneath shows a structure of a rectangular microstrip patch antenna. It consists of a dielectric substrate (FR-4), patch, and ground plane.[1]

![Figure 1. Structure of a Microstrip Patch Antenna [2]](image)

In this paper, the ground is located at the co-ordinate on (22.04, -18.7, -1.5), and the substrate is located over a ground plane having a co-ordinate on (-25.19.78,0). Now, a patch is positioned at the co-ordinate on (-19.02, -14.74,0). However, the proposed antennas are fed with the microstrip line feeding technique, which one of the convenient feeding approaches of MSA. The co-ordinate of the feed point of the antenna is given as (-0.49, -13.5,0). The feed point must be located on a patch. The solution frequency or resonant frequency is 2.4GHz, and operating frequency is chosen to in range of 1.5-5.0 GHz.
3. Antenna Designed in HFSS

Fig. 2 represents a Rectangular Microstrip Patch Antenna (MSA) having a single layer of a substrate. Fig. 3 shows a rectangular MSA having a double layer of a substrate. In the double-layer Rectangular Patch Antenna design, another layer of the substrate was stacked over the first substrate having the same thickness of 1.5 mm and having the same material (FR-4 Epoxy). Fig. 4 represents a diagonal slotted MSA. In a diagonal slotted rectangular patch antenna, the slots were created diagonally in the patch to analyse the effects of performance parameters (increases or decreases) on introducing the slots. The dimension of the slot is 2.01 mm and 4.64 mm and the co-ordinate of the first slot is (-19.02, 14.74, 0) and the co-ordinate of the second slot is (19.02, -14.74, 0). Fig. 5 represents a Slotted Rectangular MSA. In a slotted (all corners) rectangular patch antenna, the slots were introduced in a patch at all the corners to analyse the effects of performance parameters (increases or decreases). The dimension of slots is 2.01 mm and 4.64 mm and the co-ordinate of slots are (-19.02,14.74,0), (19.02,14.74,0), (19.02, -14.74,0), (-19.02, -14.74,0).

4. Result and discussion
After accomplishment of the design of the proposed antennas, the simulation was done using HFSS for antenna parameters such as return loss (S11 parameter), VSWR, 2D radiation pattern, Gain, and Directivity, characteristics have been shown in Fig 6-9. Fig. 6 reveals that the designed antenna (Single
layer Rectangular MSA) provides -29.601 dB return loss at the resonant frequency of 2.37 GHz $\equiv$ 2.4 GHz, while Fig. 7 shows that the designed antenna (Double layer Rectangular MSA) is providing -33.26 dB return loss at the frequency of 2.33 GHz. Fig. 8 displays the variation of return loss with frequency and indicates that the designed antenna (diagonal Slotted Rectangular MSA) offers -41.65 dB return loss at the frequency of 2.35 GHz, however, Fig. 9 indicates that Slotted Rectangular MSA is providing -32.09 dB return loss at the frequency of 2.37 GHz. The variation of frequency is taken from 1.50 -5.50 GHz.

**Figure 6.** Return Loss vs Frequency for single layer Rectangular MSA. **Figure 7.** Return Loss vs Frequency for double layer Rectangular MSA.

**Figure 8.** Return Loss vs Frequency for diagonal slotted Rectangular MSA. **Figure 9.** Return Loss vs Frequency for slotted Rectangular MSA.

Fig 10, shows the voltage standing wave ratio (VSWR) of the single-layer Rectangular MSA, and the value of VSWR is 1.58 at 2.4 GHz. However, after forming another layer of a substrate over the previous one, VSWR decreases to 1.19 and the corresponding frequency is 2.33 GHz as shown in Fig 11. If diagonal slots are created in the double layer substrate MSA, the value of VSWR is further reduces to 1.01 at the operating frequency of 2.35 GHz (Fig 12). The final design in which slots are created at the four corners of the double layer slotted antenna, obtained values of VSWR is plotted in Fig. 13. It is observed that the value of VSWR is found to be 1.09 at the operating frequency of 2.4 GHz.
Radiation pattern shown in Figs. 14-17, indicates that antennas are highly directive in the directions angle ‘0’ degree, with a very small amount of radiation in the direction of angle ‘90’ degree. That is the ratio of forward to backward power radiation (FBR) is finite. Directivity of antennas increases as one moves from a single-layer antenna to derivatives of the antennas.
The plot of antenna gain shows the strength of a signal that an antenna can send/receive in a particular direction, and the variation of gain of an antenna with frequency is revealed in Figs 18-21. Fig. 18, shows that the designed antenna (Single layer MSA) has got a maximum gain of 0.25 at the frequency of 2.5 GHz. However, the maximum gain of double layer and diagonal coupled Microstrip Antennas was found to be 1.48 at the same frequency, as shown in Fig 19 and 20. The maximum gain of Slotted MSA is 1.75 at frequency 2.65 GHz. Obtain results for all the antenna designs reveals that maximum gain lies between 0.25 dB -1.75 dB in the operating frequency range 2.5-2.65 GHz. MSA Parameters at First Resonance and Second Resonance are given in Table 2 and Table 3 respectively.

Figure 14. 2D Radiation Pattern for single layer Rectangular MSA.

Figure 15. 2D Radiation Pattern for double layer Rectangular MSA.

Figure 16. 2D Radiation Pattern for diagonal slotted Rectangular MSA.

Figure 17. 2D Radiation Pattern for slotted Rectangular MSA.

Figure 18. Gain vs Frequency for single layer Rectangular MSA.

Figure 19. Gain vs Frequency for double layer Rectangular MSA.
Figure 20. Gain vs Frequency for diagonal slotted Rectangular MSA.

Figure 21. Gain vs Frequency for slotted Rectangular MSA.

The directivity graph (Figs. 22-25) shows the strength of a signal that an antenna can send/receive in a particular direction is maximum at a resonance frequency of the antennas, and its values between 3.95 dB-4.14 dB.

Figure 22. Directivity vs Frequency for single layer Rectangular MSA.

Figure 23. Directivity vs Frequency for double layer Rectangular MSA.
Figure 24. Directivity vs Frequency for diagonal slotted Rectangular MSA.

Figure 25. Directivity vs Frequency for slotted Rectangular MSA.

Table 2. MSA Parameter at First Resonance

| Antenna (MSA)       | Return Loss(dB) | VSWR | Fr1 (GHz) | Changes in Return Loss(dB) |
|---------------------|-----------------|------|-----------|----------------------------|
| Single Layer        | -29.601         | 1.58 | 2.4       | ___                        |
| Double Layer        | -33.26          | 1.19 | 2.33      | 3.26                       |
| Diagonally slotted  | -41.65          | 1.01 | 2.35      | 8.39                       |
| Slotted             | -32.09          | 1.09 | 2.4       | -9.56                      |

Table 3. MSA Parameter at Second Resonance

| Antenna (MSA)       | Return Loss(dB) | VSWR | Fr2 (GHz) | Changes in Return Loss(dB) |
|---------------------|-----------------|------|-----------|----------------------------|
| Single Layer        | -21.96          | 1.09 | 4.66      | ___                        |
| Double Layer        | -24.52          | 1.67 | 4.54      | 2.56                       |
| Diagonally slotted  | -28.32          | 1.004| 4.59      | 3.80                       |
| Slotted             | -26.38          | 1.07 | 4.70      | -1.94                      |
Table 4. Variation of Gain, Directivity, and BW Resonances at 2.4 GHz.

| Antenna (MSA) | Gain (dB) | Directivity (dB) | BW1 (MHz) | BW2 (MHz) |
|---------------|-----------|------------------|-----------|-----------|
| Single Layer  | 0.16      | 4.14             | 80        | 100       |
| Double Layer  | 1.37      | 4.03             | 90        | 110       |
| Diagonally slotted | 1.29    | 3.95             | 100       | 200       |
| Slotted       | 1.38      | 3.98             | 110       | 90        |

5. Conclusion
This paper presents the design and simulation of the double layer and slotted coupled microstrip patch antennas to be operated at a frequency 2.4 GHz. The performance parameters such as VSWR, return loss, gain and directivity are obtained using HFSS 13, and reveals that diagonally coupled MSA provides a minimum reflection of power compared to single-layer MSA. The gain of the antennas (single layer, double layer, diagonally slotted, and corner slotted antennas) lies between 0.16-1.38 dB However, corresponding directivity lies between 4.14-3.98 dB, the significant improvement is observed in the case of diagonally coupled slot antenna where return loss value is improved by 8.39 dB (Table 4). The 10 dB operating bandwidth of the antennas is in the range of 80-200 MHz, hence will be useful for Wi-Fi and Bluetooth services.

6. References
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