Numerical simulation of a rectangular microstrip patch antenna for 3.35 GHz applications

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Abstract. This paper described the design and numerical simulation of a rectangular microstrip patch antenna for applications at 3.35 GHz. The numerical simulation carried out with the aid of AWR software. The initial design was done by mathematical calculation. Then the initial design is modeled and numerically simulated to get the optimal design. Optimized parameters are length of the patch and width of the feed line. Based on the optimal results obtained a minimum return loss of -15.98 dB and bandwidth below the return loss of -10 dB is 9.3 MHz (3.311 - 3.404 GHz).

1. Introduction
The rectangular microstrip patch antenna (RMPA) is the popular antenna with its simplicity. Various wireless systems have offered to use the RMPA such as radar applications [1], cellular communication [2], Wi-fi [3] and WiMAX [4]. The RMPA printed on the double side of PCB (printed circuit board). The printing is very necessary for an accurate design. If the RMPA has already been printed and to be incompatible, it cannot be changed but must replace it with another design. Therefore, before printing, the most optimal design must be obtained. The optimal design obtained at a lower cost by numerical simulations. This paper discussed the RMPA design with a resonant frequency of 3.35 GHz which is one of the bands for broadband communication applications. The design initialized with mathematical calculations and then investigated numerically simulation with the help of AWR software. An iterative investigation is carried out on the dimensions of the design of the RMPA namely the patch length and the width of the feed line to get optimal results.

2. Antenna Design
The RMPA configuration showed in Fig. 1, there are four elements, namely patch, ground plane, substrate and feed line. The RMPA design used epoxy fiberglass (FR4) dielectric substrate with $\varepsilon_r = 4.4$, thickness of 1.6 mm and loss tangent of 0.02.

![Fig. 1 The RMPA configuration](image-url)
The theoretical calculations have been formulated, the design of the RMPA can be done as follows:

2.1 Patch Dimension
Patch dimension consists of width \((W)\) and length \((L)\). The dimension can be calculated with this equation [5]:

\[
W = \frac{v_0}{2f_r} \sqrt{\frac{2}{\varepsilon_r+1}}
\]

\[
L = \frac{v_0}{2f_r\sqrt{\varepsilon_{\text{reff}}}} - 2 \Delta L
\]

with,

\[
\frac{\Delta L}{h} = 0.412 \left( \frac{\varepsilon_{\text{reff}} + 0.3}{\varepsilon_{\text{reff}} - 0.238} \right) \left( \frac{W}{h} + 0.264 \right)
\]

and

\[
\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} \left( \frac{\varepsilon_r - 1}{2} \right) \left( \frac{1 + 12\frac{h}{W}}{1.444} \right)^{-1/2}
\]

where \(v_0\) is the speed of light in free space, \(f_r\) is resonance frequency, \(\varepsilon_r\) is dielectric constant of substrate and \(h\) is height of the substrate.

2.2 Feed Line Dimension
In this design, the feed line used is a microstrip line with it dimension consists width \((W_f)\) and length \((L_f)\) of the feed line. The need for the dimension is adjusted to the required characteristic impedance \((Z_c)\) which is can be calculated with [5][6]:

\[
Z_c = \sqrt{\varepsilon_{\text{reff}}} \left[ \frac{W_f}{h} + 1.393 + 0.667 \ln \left( \frac{W_f}{h} + 1.444 \right) \right]
\]

If the type of substrate has been determined, then for \(Z_c = 50 \, \Omega\) can be achieved by setting the \(W_f\). The length of the \(L_f\) can be adjusted to the dimensions of the ground plane, or use the equation [6]:

\[
L_f = \frac{\lambda_0}{4\sqrt{\varepsilon_{\text{reff}}}}
\]

where \(\lambda_0\) is the free space wavelength.

2.3 Ground Plane Dimension
The ground plane is grounding for the microstrip antenna system which generally covers the entire underside of the substrate. The wider the ground plane, the better, but smaller ground plane dimensions are desirable. The ground plane dimension for RMPA can be given by \(\lambda/4\) from the edge of the patch [6] or by using:

\[
L_g = 6h + L
\]

\[
W_g = 6h + W
\]

where \(L_g\) is length of the ground plane and \(W_g\) is width of the ground plane.
2.4 Numerical Modelling

The numerical value of the design RMPA using Eq. (1) through (8) showed in Table 1. This value is the value of initial design for numerical simulation. The numerical modelling of RMPA shown in Fig. 2.

Table 1. The initial design for $f_i = 3.35$ GHz, $h = 1.6$ mm and $\varepsilon_r =4.4$

| Symbol | Value (in mm) | Description |
|--------|---------------|-------------|
| $W$    | 27            | Width of patch |
| $L$    | 19            | Length of patch |
| $W_f$  | 2             | Width of feed line |
| $L_f$  | 10            | Length of feed line |
| $W_g$  | 37            | Width of ground plane |
| $L_g$  | 33            | Length of ground plane |

Fig. 2. The RMPA Modelling

The condition settings made on AWR software are as follows:
- Cell size: X = 1 mm, Y = 1 mm.
- Layer 1: air (thickness = 12 mm)
- Layer 2: FR4 (thickness = 1.6 mm, $\varepsilon_r =4.4$ and tangent loss = 0.02)
- Patch and ground plane = PEC.
- Boundary: Top = 377 Ohm and Bottom = Perfect conductor.
- Start frequency sweep: 3.00 GHz
- Stop frequency sweep: 4.00 GHz
- Step: 0.01

3. Simulation Result and Discuss

The numerical results of the simulation from the initial design in the form of return loss shown in Fig. 3. Based on this result, the minimum return loss value is -10.2 dB on the 3.69 GHz frequency. It is not very good for needs in a 3.35 GHz application. Therefore, the parameters of the initial calculation results need to be set to produce an optimal design. There are many possible combinations of parameters, but in this paper, the initial step taken is to set the length of the patch ($L$). Fig. 4 shown the return loss value generated from numeric simulation with each variation of $L$ as stated in the legend.
The results shown at $L = 21$ mm are sufficient results with the expected resonance frequency of 3.35 GHz. Therefore, further numerical simulations are carried out with the value $L = 21$ mm and varying $W_f$ as shown in Fig. 5.
Fig. 5. Numerically simulated of return loss for varying width of feed line ($W_f$) and fixed $L = 21$ mm.

In Fig. 5 can be seen that a good result is achieved at $W_f = 1$ mm with a minimum return loss reaching -15.98 dB. The bandwidth below the return loss of -10 dB is 93 MHz (3.311 – 3.404 GHz). This result is the optimal decision from the two sequential changes in variation, namely length of the patch and then width of the feed line. Numerical simulation is very helpful to get optimal design results before it is done for fabrication. One is that it can reduce fabrication costs due to errors that will occur. Comparison of the results of the initial design and after optimization from the numerical simulation showed in Table 2. It shown that this optimization is enough with the iteration of change in $L$ and $W_f$.

| Symbol | Value | Initial design | Optimal design | Explanation |
|--------|-------|----------------|----------------|-------------|
| $W$    | 27    | 27             | Unchanged      |
| $L$    | 19    | 21             | Changed        |
| $W_f$  | 2     | 1              | Changed        |
| $L_f$  | 10    | 10             | Unchanged      |
| $W_g$  | 37    | 37             | Unchanged      |
| $L_g$  | 33    | 33             | Unchanged      |

4. Conclusion
This paper has explained the steps of the RMPA designing with numerical simulation. Based on the optimal results obtained a minimum return loss of -15.98 dB and bandwidth below the return loss of -10 dB is 93 MHz (3.311 – 3.404 GHz). The results show that the design can be applied for the communication system for 3.35 GHz.

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References

[1] YY Maulana, Y Wahyu, F Oktafiani, Y P Saputra, A Setiawan, Rectangular Patch Antenna Array for Radar Application, Telkomnika, 14 (4), 2016.

[2] A H Rambe and K Abdillah, A low profile rectangular patch microstrip antenna for dualband operation of wireless communication system, IOP Conf. Series: Materials Science and Engineering, 309, 2018.

[3] B R Behera and P Suraj, Rectangular microstrip patch antenna for wireless fidelity application: Design of a Wi-Fi antenna using the concept of metamaterials, IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), 2016.

[4] Ahmed Shakir Al-Hiti, Design of Rectangular Microstrip Patch Antenna For LAN and WIMAX Applications, ARPN Journal of Engineering and Applied Sciences, 14 (2), 2019.

[5] Constantine A. Balanis, Antenna Theory Analysis and Design, 2nd ed., John Wiley & Sons, New York, 1938.

[6] Yi Huang and Kevin Boyle, Antennas: from Theory to Practice, John Wiley & Sons, Ltd, 2008.