The 4×4 hybrid L-slotted rectangular microstrip antenna for dual band wifi communication

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Abstract. Indonesia has regulated 2.441 GHz and 5.8 GHz bands for WiFi communication. Considering these two bands requirement, L-Slot can be added into a rectangular microstrip antenna. Then, we transform the single dual band antenna into MIMO to increase the system capacity and referring the a WiFi specification. In this study, the designed 4×4 hybrid L-slotted rectangular microstrip antenna can produce: bandwidth ≥ 40 MHz for 2.441 GHz and ≥ 100 MHz for 5.8 GHz (using return loss ≤ 10 dB), and obtained mutual coupling ≤ -20 dB. The radiation pattern produced for both of 2.441 GHz and 5.8 GHz is unidirectional.

1. Introduction
Microstrip patch antenna can be designed easily based on its purposes. Basicly it has narrow bandwidth with several frequency resonant [1]. For dualband frequency response, it can be used L-Slot [2] [3]. In Indonesia, 2.441 GHz and 5.8 GHz are allocated for WiFi technology [4][5]. Those frequency also has been implemented for several devices, such as Cisco Aironet 4800 Access Point [6].

The L-Slot has several resonant frequency, as shown in [2]. The antenna design resonates at the frequencies of 2.4 GHz, 3.8 GHz, 4.9 GHz, 6.5 GHz, 7.2 GHz and 8.1 GHz. It is also has a wide bandwidth [3]. In [3], it is simulated that frequency response has -10 dB return loss from 2 to 6 GHz, to cover the WIMAX and WLAN bands. This paper modify the L-Slot to become dual band antenna design that covered WiFi frequency, the 2.441 GHz and 5.8 GHz.

After design a single antenna with dual frequency response, we transform the antenna design into Multiple Input Multiple Output (MIMO) antenna. It should be in omnidirectional or directional antenna radiation pattern because it will be used for WiFi access point. The MIMO system increased the spectral efficiency and capacity [7]. The new standard that has been set by the Institute of Electrical and Electronics Engineers (IEEE) of Wi-Fi technology is IEEE 802.11ac [8]. This technology uses the 2.4 GHz and 5.8 GHz frequencies with a bandwidth of 20-40 MHz, and supports 4 MIMO streams [10][11].

This paper consists of four section. The second section is antenna design. In this section, we design an initial antenna using equation and simulate to achieve an optimum dimension and
performance. The third section we analyze the antenna performance based on simulation and printed antenna. The last section is conclusion for the antenna design and antenna performance analysis.

2. Antenna Design
We design FR4 microstrip antenna with dielectric constant is 4.4, tangential loss is 0.035 and thickness 1.6 mm. We calculate the antenna width \( W \), antenna length \( L \), feed width \( W_f \), feed length \( L_f \), groundplane width \( W_g \) and groundplane length \( L_g \) using equations (1)-(11)[1][9].

\[
W = \frac{c}{2f_0 \sqrt{\frac{(\epsilon_r - 1)}{2}}}
\]  

(1)

Where \( c \) is the speed of light in free space, which is \( 3 \times 10^8 \) (m/s), \( f_0 \) is the antenna working frequency (Hz), and \( \epsilon_r \) is the dielectric constant of the substrate (F/m). Equation 2 can be used to calculate the antenna length,

\[
L = L_{\text{eff}} - 2\Delta L,
\]  

(2)

\( \Delta L \) which is the length increase due to the fringing effect. The equation for expressing \( \Delta L \) is

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

(3)

\( h \) is the substrate height or substrate thickness, \( W \) is the width of the patch and \( \epsilon_{\text{reff}} \) is the effective dielectric constant. The effective dielectric constant shown by,

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

(4)

To determine the patch antenna length (\( L \)), \( L_{\text{eff}} \) is also needed which is an effective length expressed in equation 5,

\[
L_{\text{eff}} = \frac{c}{2f_0 \sqrt{\epsilon_{\text{reff}}}}
\]  

(5)

Substitute equation (4) into equation (5) so that the effective length can be known by \( c \) is the speed of light in free space, namely \( 3 \times 10^8 \) (m/s) and \( f_0 \) is the antenna working frequency (Hz). Then, substitute equations (5) into equation (2) at the length of the patch can be known.

The ground plane can be defined by calculating the minimum width and length.

\[
L_g = 6h + L
\]  

(6)

\[
W_g = 6h + W
\]  

(7)

Feeding configuration from the antenna used microstrip line technique. Before determining the dimensions of the length of the feeding, first check the characteristics of the microstrip line on the ratio of the feeding width to the substrate thickness, the \( \epsilon_{\text{reff}} \) and \( Z_0 \) which can be formulated as equation (4). To determine width of feeding has given by equation (8).
\[
W_f = \frac{2}{h} \left[ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left[ \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right] \right]
\] (8)

Where,
\[
B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}
\] (9)

To determine length of feeding with matching impedance technique using transformer \(\lambda/4\) has given by,
\[
L_f = \frac{\lambda_o}{4}
\] (10)

Where,
\[
\lambda_o = \frac{\lambda_o}{\sqrt{\varepsilon_{reff}}}
\] (11)

**Figure 1.** MIMO Dual Band Antenna Design (a) Single Frequency Antenna Design (b) Dual Band Antenna Design (c) MIMO Dual Band Antenna Design (d) Printed MIMO Antenna Dual Band.
From the calculation of the initial antenna dimensions, then simulate the initial design. If the initial design antenna based on calculation does not match the expected parameters, then the optimization of the dimension is needed. To design MIMO 4x4 antenna the first step is to make a single patch antenna with a center frequency on 2.441 GHz and 5.8 GHz with the dimensions calculated using equation (1)-(11). Fig.1 is single band antenna design for 2.441 GHz and 5.8 GHz, dual band antenna design, MIMO dual band antenna design and printed MIMO dual band. Dimension of the antenna designs are in Table 1.

The second step, we add the slot antenna to achieve dual band response. Both for 2.441 GHz and 5.8 GHz in one patch antenna. The slot used is based on research [2] and [3] with a slight modification. Slot antenna design as shown in ?? and Table 2 is the antenna dimension. We transform the design of single antenna into 4x4 MIMO antenna by adding antenna spacing d. We use the same shape from single dualband antenna and duplicate the single dual band antenna 4 times. We design the antenna based on specification of WiFi device [6].

### Table 1. Antenna Dimension

| Parameter | 2.441 GHz (mm) | 5.8 GHz (mm) | Dual-Band (mm) | MIMO (mm) |
|-----------|----------------|--------------|----------------|-----------|
| W         | 44.99          | 22.47        | 69.77          | 69.77     |
| L         | 27.59          | 11.26        | 47.75          | 47.74     |
| h         | 1.60           | 1.60         | 1.60           | 1.60      |
| t         | 0.035          | 0.0035       | 0.035          | 0.035     |
| Lf        | 15.33          | 7.17         | 13.53          | 13.53     |
| Wf        | 2.50           | 2.90         | 2.70           | 2.70      |
| Wg        | 54.59          | 32.07        | 79.37          | 79.37     |
| Lg        | 47.72          | 23.23        | 66.08          | 66.08     |
| Ws        | -              | -            | 49.15          | 49.15     |
| Ls        | -              | -            | 27.83          | 27.83     |
| S         | -              | -            | 3.00           | 3.00      |
| d         | -              | -            | -              | 33.87     |

#### 3. Analysis

In this section we compare the simulation and realization result. We print the optimal dual band MIMO antenna design and figure out it performance. We observe the antenna frequency response including S-Parameters and antenna bandwidth. As the objective of our research, to design an access point antenna, we observe the antenna radiation pattern.

### Table 2. S-Parameter for Simulation and Measurement.

| Parameters | 2.441 GHz Simulation (dB) | 2.441 GHz Measurement (dB) | 5.8 GHz Simulation (dB) | 5.8 GHz Measurement (dB) |
|------------|---------------------------|---------------------------|------------------------|------------------------|
| S11        | -19.14                    | -15.28                    | -20.63                 | -13.68                 |
| S21        | -47.67                    | -36.42                    | -37.49                 | -30.49                 |
| S31        | -42.86                    | -42.55                    | -31.75                 | -34.93                 |
| S41        | -42.18                    | -36.81                    | -36.55                 | -30.1                  |
| S22        | -19.14                    | -15.13                    | -20.63                 | -14.91                 |
| S12        | -42.18                    | -36.61                    | -36.55                 | -34.93                 |
| S32        | -44.67                    | -36.63                    | -37.49                 | -34.75                 |
We analyze the antenna design performance, the design of 2.441 GHz and 5.8 GHz single antenna, the performance is shown in Fig. 2. There are several resonant frequency as we design for the 2.441 GHz, but the other frequency resonant above 2.441 GHz is not suitable with the 5.8 GHz frequency allocation. From the design of frequency 5.8 Ghz, there is not frequency resonant below the frequency 5.8 GHz. With the design of dual band antenna, the frequency response has many resonant frequency. We notice the return loss level below -15 dB. There are in 2.4 GHz, 2.8 GHz, 4.8GHz and 5.8GHz. Based on the frequency response, the antenna can works in multiband frequency, but it is can be defined well in 2.441 and 5.8GHz for the WiFi application.
We transform the dualband single antenna into MIMO 4×4 antenna with defined antenna spacing d. The dimension of MIMO 4×4 antenna is shown in Table. 1 and the S-Parameter for antenna is in Fig. 3. Fig. 3a is return loss and and Fig. 3b, Fig. 3c and Fig. 3d are mutual coupling for antenna 1. All the S-parameters performances for 2.441 GHz and 5.8 GHz are shown by Table 2. Fig. 1d is the printed antenna. We observe the antenna bandwidth for 2.441 GHz and 5.8 GHz which is the larger bandwidth is in 5.8 GHz. The maximum bandwidth in 2.441 GHz is 108.2 GHz for antenna 2, and in 5.8 GHz is 229.2 GHz for antenna 1. All respected antenna bandwidth for simulation and measurement are shown in Table 3.

Based on Table 2, minimum return loss for 2.441 GHz is antenna 1 with -15.28 dB for the measurement. It is slightly different with the simulation which is -19.14 dB for all antenna. At the 5.8 GHz, the minimum return loss measured is -13.68 dB for antenna 1 compared to -10.63 dB at its simulation. Maximum mutual coupling are -36.13 dB between antenna 3 and antenna 4 for 2.441 GHz and -30.1 dB between antenna 4 and antenna 3 for 5.8 GHz. Antenna MIMO 4×4 defined with different antenna orientation each other. It has different polarization, so it will compensate the mutual coupling between sided by sided antenna.
Figure 4. Antenna Radiation Pattern (a) 2.441 GHz 3D (b) 5.8 GHz 3D (c) 2.441 GHz Elevation (d) 5.8 GHz Elevation (e) 2.441 GHz Azimuth (f) 5.8 GHz Azimuth.

We design dual band 4×4 MIMO for WiFi access point. It should have an omnidirectional radiation pattern. Fig. 4a and Fig. 4b are the simulation of 3D radiation pattern. The figures show that antenna design has a directional pattern with wide half power beamwidth. It is not omnidirectional, but it can be implemented as access point antenna because the radiation pattern spread in all area. We can locate the antenna in the top of ceiling. The 2D of antenna radiation pattern in Fig. 4c - Fig. 4f, it is compared the simulation and measurement.

4. Conclusion

In this paper rectangular slot microstrip MIMO 4×4 antenna has designed, simulated and realized that has been printed for WiFi access point 2.441 GHz and 5.8 GHz using hybrid slot. The printed antenna work in the frequency range 2.38-2.454 GHz and 5.643-5.87 GHz with a return loss ≤ -10 dB, bandwidth are ≥ 40 MHz for the frequency of 2.441 GHz and ≥ 100 MHz for the frequency of 5.8 GHz and Mutual coupling values is ≤ -20 dB. The antenna radiation pattern is directional with wide power beamwidth so it can be a WiFi Access Point antenna.

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