MIMO 4×4 hexagonal microstrip array antenna for 15 GHz application

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Abstract. Recently 15 GHz has been a frequency candidate for fifth generation (5G) mobile communication technology. Minimum bandwidth has to provide for 5G application is 1 GHz. In this paper we proposed antenna design to fulfill those requirement. We use microstrip patch antenna which has narrow bandwidth. To improve the bandwidth, we use proximity couple and observe the hexagonal patch antenna frequency response. We design a 4×4 MIMO antenna with less than -15 dB return loss and -20 dB mutual coupling to each ports. From the realization we have maximum bandwidth 1.34 GHz with lower frequency 14.42 GHz and upper frequency 15.76 GHz.

1. Introduction

NTT DoCoMo and Ericson proposed 15 GHz as one of frequency candidates for fifth generation mobile communication (5G) [1]. Some advantages of 15 GHz than the other higher frequency candidates e.g. 28 GHz and 60 GHz, are less rain attenuation, less propagation loss, and the system is less complex [2]. Using high frequency related to smaller wavelength so the propagation signal has higher probability to get multipath fading. In that case, we can use Multiple Input Multiple Output (MIMO) system to compensate the multiple fading. Multipath fading can be occur because of reflection, diffraction and scattering.

In MIMO system, antenna is important device. Antenna microstrip can be used in MIMO system. It works in high frequency that has small dimension and easy to fabricated, but it has disadvantages. One of the disadvantage is, it has narrow bandwidth so its need to be developed with specific technique to make the antenna suitable with the bandwidth of 5G [3][4]. By adding a slot to increase the bandwidth. The T-Slot will increase the bandwidth of a rectangular microstrip antenna 25.23% in 2.4GHz with -10 dB return loss [5]. Besides T-Slot, it can used U-Slot for increasing the bandwidth [6]. Another technique is proximity couple, a technique to improve antenna bandwidth by making the dielectric wider [7].

Microstrip antenna patch can be rectangular or circular. It has its own bandwidth characteristic. At 15 GHz, the circular patch has wider bandwidth than the rectangular patch using T-Slot [8]. In this paper, as antenna development from the previous research [6][8], use MIMO hexagonal patch with proximity couple to design antenna characteristic that suitable for 5G.
2. Antenna Design

Hexagonal microstrip patch antenna is designed with initial dimension of circular patch. To calculate the circular patch use [9].

\[ F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \]  
\[ R = \frac{F}{\left[1 + \frac{2h}{\pi \varepsilon_r \ln \left(\frac{\pi F}{2h} + 1.7726\right)}\right]^2} \]

\( F \) is logarithmic function of radiating antenna element, \( f_r \) is resonant frequency, \( \varepsilon_r \) is dielectric permittivity and \( R \) is circular patch radius.

Antenna feeder use inset microstrip feed line. This method is used because the simplicity for MIMO antenna system. To calculate the width and length of feed line use [9]

\[ W_f = \frac{2h}{\pi} \left\{ B - 1 - \ln (2B - 1) + \frac{\varepsilon_r - 1}{2 \varepsilon_r} \left[ \ln (B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right] \right\} \]  
\[ L_f = \frac{\lambda}{4 \sqrt{\varepsilon_{eff}}} \]

with \( B \) and \( Z_0 \) are

\[ B = \frac{60 \pi^2}{Z_0 \sqrt{\varepsilon_r}} \]
\[ Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln \left[ \frac{8h}{W} + \frac{W}{4h} \right] \]

![Figure 1](image)

*Figure 1.* (a) Circular Patch Antenna as Initial Design (b) Hexagonal Patch Antenna Transformed from Circular Patch

| Parameter       | Symbol | Value (mm) |
|-----------------|--------|------------|
| Dielectric Thickness | h      | 1.57       |
| Conductor Thickness | h_c   | 0.035      |
| Feed Length      | l_f    | 3.64       |
| Feed Width       | w_f    | 5.44       |
| Patch Radius     | R      | 3.58       |
Based on those equation and defined parameter, it can be obtained the initial dimension or single circular patch microstrip antenna in Table 1. The initial circular patch antenna is transformed into hexagonal patch antenna. It is shown in Figure 1. The hexagonal patch is optimized to achieve 5G in 15 GHz bandwidth requirement. The hexagonal patch antenna dimension is shown in Table 2.

The bandwidth antenna for 5G application at 15 GHz allocated from 14.4 GHz until 15.4 GHz.

**Figure 2. Single Antenna Design Return Loss**

| Parameter   | Initial Value (mm) | Optimization Value (mm) |
|-------------|--------------------|-------------------------|
| R           | 3.58               | 2.8                     |
| Lf          | 3.64               | 2.6                     |
| Wf          | 5.44               | 1.4                     |
| Lg          | 10                 | 13                      |
| Wg          | 10                 | 13                      |

**Table 2. Hexagonal Patch Antenna Dimension**

**Table 3. Array 1 × 2 Patch Antenna Dimension**
with center frequency is 14.9 GHz [1][3][4]. It can be seen in Figure 2, the initial circular patch antenna has return loss bigger than -5 dB, likewise the initial hexagonal design. It is better than the circular, but the return loss is bigger than -10 dB. After optimization, for single hexagonal antenna design has better performance. Return loss for all the frequency range are below -15 dB. This optimal design is designed using proximity couple to achieve wider bandwidth.

After design the optimal single hexagonal patch antenna, it is designed the array 1×2 antenna. By using the dual array, the feed impedance is set to 100 Ohm. The array antenna design is shown in Figure 3 and Figure 3.(a). The frequency response between simulation and optimization array antenna is shown by Figure 4.

Based on simulation result, minimum return loss is -48.18 dB at frequency 14.338 GHz and return loss at center frequency 14.9 GHz is -14.35 dB. We optimize the dimension and the result is better. At the center frequency, 14.9 GHz, the return loss is -22.56 with the return loss of lower frequency is -16.17 and upper frequency is -16.95 dB.

The array antenna 1×2 design transform into MIMO 4×4 antenna with antenna spasing S. As shown in Figure 3.(b). Antenna dimension is shown in Table 5. The S-Parameters is observed only in port 2 because in simulation, it has same response among another ports. The return loss at the center frequency, lower frequency and upper frequency for antenna 2 respectively are -20.57 dB, -15.52 dB and -20.89 dB. It can be concluded that the design has meet the 5G bandwidth requirement.
Figure 5. Port 2 S-Parameters for MIMO 4x4 Antenna Design

Figure 6. MIMO 4x4 Antenna Realization

Table 4. MIMO 4x4 Antenna Dimension

| Parameter               | Symbol      | Design(mm) | Optimization(mm) |
|-------------------------|-------------|------------|------------------|
| Patch Radius            | R           | 2.7        | 2.7              |
| 50 Ohm Feed Width       | W f1        | 1.6        | 1.6              |
| 50 Ohm Feed Length      | Lf 1        | 3.1        | 3.1              |
| 100 Ohm Feed Width      | W f2        | 1.4        | 1.4              |
| 100 Ohm Feed Length     | Lf 2        | 3.55       | 3.55             |
| T Junction Width        | W junction  | 9.5        | 9.5              |
| Groundplane Length      | Lg          | 19         | 19               |
| Groundplane Width       | W g         | 45         | 85               |
| Antenna Spacing         | S           | 3          | 3                |

Table 5. Antenna Bandwidth

| Antenna   | Simulation Bandwidth (GHz) | Realization Bandwidth (GHz) |
|-----------|----------------------------|-----------------------------|
| 1         | 1.23 (14.28 - 15.51)       | 1.30 (14.44 - 15.74)        |
Table 6. Mutual Coupling Comparison

| Parameter | Optimization (dB) | Realization (dB) |
|-----------|-------------------|------------------|
| S21       | -28.95            | -22.25           |
| S31       | -39.08            | -26.33           |
| S41       | -42.30            | -32.06           |
| S12       | -29.08            | -21.87           |
| S32       | -30.12            | -24.72           |
| S42       | -39.08            | -26.53           |
| S13       | -39.15            | -26.32           |
| S23       | -30.12            | -21.84           |
| S43       | -29.09            | -25.09           |
| S14       | -43.27            | -33.74           |
| S24       | -39.01            | -28.92           |
| S34       | -28.96            | -25.56           |

![Graphs a, b, c, d](image)
3. Design Analysis
In this section we verify the design and analyze the MIMO performance. Figure 6 is the printed antenna. First we observe the return loss all the ports. It is shown by Figure 7. To achieve this graph, we measure the return loss and the mutual coupling between antenna 1 and 2 using Virtual Network Analyzer (VNA). We measure the port 1 and port 2, and connected the port 3 and 4 with 50 ohm dummy load.

Based on Figure 7, it can be concluded that all return loss for the frequency range expected are below -15 dB. Minimum 1 GHz bandwidth has been achieved. Antenna bandwidth is shown in Table 5. Minimum realization bandwidth is in port 1 and 2 with 1.3 GHz. It has same lower and upper frequency. The maximum bandwidth in port 4, it is 1.34 GHz.

Besides the return loss and bandwidth, we observe the mutual coupling among the ports. Table 6 shows the mutual coupling for port 1, 2, 3 and 4. It show the mutual coupling for center frequency 14.9 GHz. All of mutual coupling, for optimization and realization, are below -20 dB. For the realization mutual coupling, the maximum mutual coupling is -21.84 dB from port 3 into port 2. The minimum mutual coupling is between port 4 and port 1 with its value is -33.74.

4. Conclusion
In this paper has been designed and verified 4×4 antenna for 15 GHz which is proposed for 5G application. Using proximity couple and array antenna, it has meet for the bandwidth requirement. Maximum simulation bandwidth is 1.23 GHz and maximum realization bandwidth is 1.34 GHz.

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