Design of Multiband MIMO Antenna for 5G Millimeter-wave Application

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Abstract. In this paper, design of multiband MIMO antenna by using patch and slot modification is proposed. The MIMO multiband antenna design uses the addition and modification of patch and slot shapes to obtain antenna performance in several frequency bands. In a previous study, the multiband antenna design only used the method of adding patches or slots separately. In this research, we tried to combine the addition of patches and slots together. The antenna design uses the substrate material Rogers RT5880 with a dielectric constant ($\varepsilon_r$) 2.2 and height 0.787 mm. The dimensions of the MIMO multiband antenna developed by this study are 42.90 × 14.89 mm. Simulation and measurement results show that this MIMO antenna can work on several millimeter-wave frequency bands, 24 GHz, 28 GHz and 38 GHz. These results prove that the development of design techniques by adding patches and slots to microstrip antennas can produce antennas that work in several frequency bands.

1. Introduction

The aim of this study is to prove the MIMO (Multiple Input Multiple Output) multiband antenna design technique. Multiband antennas are needed in today's wireless communication systems, because the frequency allocation determined is in several different frequency bands and far apart. This is not able to be accommodated by a single band antenna even though it has a wide bandwidth. Moreover, the type of microstrip antenna that has limitations in terms of bandwidth, multiband frequency design can be a solution of bandwidth limitations to support the frequency range requirements of wireless communication systems.

In the development of cellular communication systems, especially cellular communication systems, the requirement for antennas that have a range of frequency bands becomes a challenge in antenna development. MIMO system capability and millimeter-wave frequency range are the main requirements in the future Wireless communication system [1]. Cellular communication technology is currently in the development of fifth generation technology (5G) which is planned to have a spectrum in several millimeter-wave frequency bands [2], thus demanding the availability of antennas capable of supporting these frequency ranges [3]. In Indonesia, the 5G technology development plan is also planned in several different frequency bands, 3.5 GHz band, 24 GHz band, and 26-28 GHz band [4]. Thus it is necessary to anticipate the development of antennas that operate in several frequency bands for the 5G technology requirements that will be released soon. In this study the development of design techniques will be investigated to obtain MIMO multiband antennas operating in the millimeter-wave frequency range for 5G technology applications.

In several studies of multiband antennas previously it has been examined the development of several design methods to obtain MIMO antennas and multiband antennas such as the addition of patches [5-8], using the multislot rectangular patch [9] method, using the MIMO technique by adding slit [10], using the addition of slots [11] and other method studies. Thus the state of the art of this study is to develop a combination design of patch and slot addition on a microstrip antenna to get a better multiband antenna performance compared to the method of adding patches and slots separately in previous studies.
2. Research Methodology

2.1. Microstrip Antenna Design Method

The multiband MIMO antenna design method proposed in this study uses an approach reactively loaded multifrequency technique and the multipatch multifrequency technique [12] with a patch antenna modification through addition of patch and U-slot. Reactively loaded or also called as miscellaneous loaded by adding a reactive load on the antenna, such as stubs, slots, pins, and capacitors. Multi-frequency multipatch is used to produce more than one frequency band through arranged multiple patch antennas.

The design method used to produce this multiband antenna is as shown in Figure 1. This process starts from the design of patch antennas that work at a frequency of 28 GHz, then continues with the addition of patches to obtain a working frequency of 38 GHz and then modifies the patch by adding slots to produce antennas that work at a frequency of 24 GHz.

![Figure 1. Multiband Antenna Design Method](image)

In this study CST Microwave Studio 2016 simulation software is used to obtain design simulation results and to measure antenna fabrication results using vector network analyzer (VNA). The basic structure of the microstrip patch antenna consists of substrate material, radiating elements and groundplane as shown in Figure 2.
Figure 2. Microstrip Antenna Layer Structure [13]

To determine the design parameters of the patch antenna microstrip following the equations [13-14]:

\[
W_p = \frac{c}{2f_r \sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}
\]

\[
f_r = \frac{f_1 + f_2}{2} \tag{2}
\]

\[
L = L_{eff} - 2\Delta L \tag{3}
\]

\[
\Delta L = 0.412 h \left(\frac{(\varepsilon_{eff}+0.3)+\frac{W_p}{h}+0.264}{(\varepsilon_{eff}-0.258)+\frac{W_p}{h}+0.8}\right) \tag{4}
\]

\[
\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \sqrt{\frac{1}{1 + \frac{12h}{W_p}}} \tag{5}
\]

\[
L_{eff} = \frac{c}{2f_r \sqrt{\varepsilon_{eff}}} \tag{6}
\]

where \(W_p\) is width of patch antenna, \(c = 3 \times 10^8\) m/s, \(f_r\) is frequency resonant, \(\varepsilon_r\) is permittivity relative, \(L_p\) is length of patch antenna, \(h\) is height of patch antenna, \(\varepsilon_{eff}\) is permittivity effective of antenna and \(L_{eff}\) is length effective of patch antenna.

To determine the width and length of the ground plane and substrate following the equations [15-16]:

\[
W_s = 6h + W_p \tag{7}
\]

\[
L = 6h + L_p \tag{8}
\]

\(W_s\) is width of substrate antenna and \(L_s\) is length of substrate antenna.
2.2. MIMO Antenna Design

MIMO multiband antenna designs are designed following the specifications in Table 1.

| Parameter       | Specification |
|-----------------|--------------|
| Return Loss     | ≤ -10 dB     |
| VSWR            | ≤ 2          |
| Bandwidth       | ≥ 1000 MHz   |
| Frequency Band  | 24 GHz, 28 GHz, 38 GHz |

The substrate material used in this multiband MIMO antenna design is Duroid RT5880 with permittivity ($\varepsilon_r$) 2.2 and thickness 0.787 mm.

Based on the proposed design method, the multiband antenna design that works in the millimeter-wave region in this study is shown in Figure 3.

Furthermore, to obtain better beamwidth performance and is needed by 5G technology applications, the multiband antenna was developed in a 4 element linear array configuration and a 2T2R MIMO configuration (2 Transmits, 2 Receive) as shown in Figure 4.
Figure 4. MIMO Multiband Antenna: (a) Multiband Antenna Array 4x1 Element; (b) MIMO 2T2R Multiband Antenna

3. Results and discussion

The simulation result of the return loss at the frequency 24 GHz, 28 GHz and 38 GHz and the radiation pattern of the proposed multiband array antenna are shown in Figure 5 and Figure 6.

Figure 5. S-parameter of the proposed multiband antenna

Simulation results show that the antenna produces 3 working frequencies of 24 GHz, 28 GHz and 38 GHz. In the frequency 24.6 GHz frequency, the return loss value is -20.65 dB and the bandwidth value is 1.219 GHz. In the frequency 28.3 GHz it produces a return loss value of -20.30 dB and a bandwidth value of 1.305 GHz. Then on frequency of 37.5 GHz it produces a return loss value of -19.19 dB and a bandwidth value of 1.199 GHz.
Figure 6. The radiation pattern of the proposed multiband antenna

Figure 7. Fabrication of multiband antenna

Figure 8. Simulation and Measurement Comparison
The simulation results show that the performance of the multiband antennas produced is better than the results of previous studies, especially on the bandwidth performance of each frequency band around 1.2 GHz. In previous studies, the bandwidth is average 300 MHz for each band [7-11].

To obtain verification from the simulation results, fabrication and measurement of multiband antennas is carried out as shown in Figure 7. There is a slight difference between the simulation and measurement results as shown in Figure 8. However, this is not significant and shows better bandwidth performance in measurement. These results prove that the method of adding patches and slots used in this study is able to produce better bandwidth performance than the results of previous studies which were only around 300 MHz in each frequency band.

4. Conclusion
The design of multiband MIMO antennas at millimeter-wave frequencies for 5G technology applications has been described. The results of this design show that the design process and the proposed method are proven to be able to produce multiband antennas that work on the 24 GHz, 28 GHz and 38 GHz millimeter-wave bands. The design results also show a pretty good bandwidth performance in several frequency bands. Furthermore, these results can be used as a basis for further development of multiband MIMO antennas in accordance with the requirements of various communication systems.

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6. References
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