Design of substrate integrated waveguide to improve antenna performances for 5G mobile communication application

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Abstract. In this paper, a new design of substrate integrated waveguide was developed to improve the gain performance of microstrip antennas for 5G antenna applications. The antenna and substrate integrated waveguide were designed at the frequency 28 GHz millimeter-wave band. The design of substrate integrated waveguide was developed by design an H-slot structure without a gap in the substrate layer to provide better matching impedance and reduce the loss of surface wave microstrip antenna. This study was conducted with a research and development approach through the calculation of the H-slot structure on substrate integrated waveguide and simulated by using antenna design software simulation. The numerical result shows that the new design approach for the H-slot structure without gap model was improved antenna gain and antenna size. This result has shown significant improvement compared to the circular antenna design without substrate integrated waveguide.

1. Introduction

The development of cellular communication technology is currently in the stage of entering the 5th generation (5G) which has the challenge of achieving high speed, power efficiency and system reliability [1]. One important device in 5G technology is an antenna device that supports 5G technology network performance. 5G cellular technology requires antennas that have high performance, Multiple Input-Multiple Output (MIMO) and beamforming transmission systems [2]. 5G technology is recommended to work on the millimeter-wave frequency (24-28 GHz) and the 5G antenna must be designed to work on the millimeter-wave frequency band [2]. One type of antenna that has been developed by antenna researchers is a microstrip antenna. This type of antenna has advantages in terms of physical size, low profile and easily fabricated. But this type of antenna has disadvantages in a narrow bandwidth and low gain. Various studies have been developed to improve gain performance and antenna bandwidth, one of which is by adding substrate integrated waveguide (SIW) [3-8]. The addition of Cruciform Substrate Integrated Waveguide Couplers has proven to be able to increase bandwidth by 20% with return loss below -20 dB at frequency 21 GHz to 28.3 GHz [5]. Then the research with the addition of Circularly Polarized Slotted Substrate Integrated Waveguide cavity has been proven to increase bandwidth by 35% at frequencies 21 GHz to 28 GHz [6]. Furthermore, research with the development of the design method of SIW directional couplers proved to be able to increase bandwidth by 29.5% at frequencies below 20 GHz with return loss reaching -30 dB [7].

In this study, a further implementation of SIW will be developed to improve gain performance of microstrip antenna. The antenna was designed for 5G frequency applications at 28 GHz frequency. The
development of the SIW design was carried out by forming an H-slot on the structural configuration of SIW that expected to improve gain performances better than previous studies.

2. Theoretical foundations

2.1. Substrate Integrated Waveguide (SIW)

SIW is developed from the basic material of a dielectric substrate with \( h \) thickness and relative permittivity \( \varepsilon_r \). The top and bottom of the substrate are thick metal layers that have no effect. This structure is theoretically capable of passing signals at any frequency, even DC signals. The SIW structure adds two rows of metal cylinders (metal pole, metallic posts), which connect the upper metal layer with the lower metal layer (ground) [3]. The diameter of this metal cylinder \( d \) and the distance from the midpoint of two inline cylinders is \( p \) (pitch), while the distance from the midpoint of this parallel cylinder line is \( a \). The existence of these two rows of metal cylinders causes low-frequency signals that cannot propagate inside SIW, the SIW structure provides a certain cut-off frequency value, if the signal passed through it has a frequency lower than the cut-off frequency, the signal will be rejected [3]. The basic structure of SIW is shown in figure 1.

![Figure 1. Basic Structure of SIW [4].](image)

From figure 1, it can be seen that the width of the SIW waveguide is \( a \). However, the effective value used to determine the width of the SIW waveguide follows the following equation [9].

\[
a_e = a - \frac{d^2}{0.95p}
\]

(1)

Where \( a_e \) is the effective width of SIW. For large \( d \) values, the approach from equation (1) becomes the following equation [10].

\[
a_e = a - 1.08 \frac{d^2}{p} + 0.1 \frac{d^2}{p}
\]

(2)

2.2. Circular microstrip patch antenna

In this study used a circular microstrip antenna as the basis for antenna development with SIW. To determine the radius of the circular patch microstrip antenna follow the following equation [11].

\[
a = \frac{F}{\left\{ 1 + \frac{2h}{\pi \varepsilon_r F} \left[ \ln \left( \frac{\pi F}{2h} \right) + 1.7726 \right] \right\}^{\frac{1}{2}}}
\]

(3)

The value of \( F \) is obtained from the following approach [11].

\[
F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}
\]

(4)
2.3. Microstrip feed line
Microstrip feed lines are designed to obtain impedance matching with antenna radiating elements. The approach given to determine the width of the microstrip feed line is as follows [11].

\[
\frac{W_F}{h} = \frac{8e^A}{e^{2A-2}}
\]  
(5)

Where \( A \),
\[
A = \frac{Z_0}{100} \left[ \frac{\varepsilon_r + 1}{2} \right]^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left[ 0.23 + \frac{0.11}{\varepsilon_r - 1} \right]
\]  
(6)

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \left[ \frac{\varepsilon_r - 1}{2} \left( \frac{1}{1 + 12 \frac{h}{W_F}} \right) \right]
\]  
(7)

3. Antenna design method

3.1. Design of circular microstrip antenna 28 GHz
The circular microstrip patch antenna is designed using CST Microwave Studio 2016 at the frequency of 28 GHz. The substrate material using Rogers RT5880 with length and width 27.0 mm and thickness 0.787 mm. This antenna has a circular patch that has a radius of 5.65 mm with a thickness 0.035 mm. To get better performance, this antenna is designed in the array configuration 2x1 element as shown in figure 2.

![Figure 2. Circular microstrip patch array 2x1.](image)

3.2. Design of circular microstrip array with SIW addition
The circular microstrip patch antenna with the addition of SIW is designed using CST Microwave Studio 2016 which works at a frequency 28 GHz. The substrate material is designed has width and length 15.5 mm and thickness of 0.787 mm using Rogers RT5880 material. The circular patch has a radius of 4.5 mm with a thickness of 0.035mm. The SIW material used Alumina with a diameter 0.254 mm and a dielectric constant (\( \varepsilon_r \)) 9.9. The distance between the midpoint of SIW diameters is 1 mm with a thickness (\( h \)) 0.787 mm such as the size of the material for the substrate. The SIW design proposed in this study is the H-slot structure. This structure without a gap in the substrate layer to provide better matching impedance and reduce the loss of surface wave microstrip antenna. The antenna configuration is designed using MIMO with each port consisting of 2x1 arrays as shown in figure 3.
4. Result and discussion

The results of this study are comparing the design of circular microstrip antenna conventional with circular microstrip antenna using subtract integrated waveguide (SIW). The observation results show that the best distance between SIW elements is 1mm. Simulation and Comparison of radiation patterns far-fields between conventional circular microstrip antenna with a circular antenna using SIW addition as shown in figure 4 and figure 5.

The overall performance comparison between the circular MIMO antenna conventional with circular MIMO antenna using SIW addition as shown in Table 1. The results of this comparison show that the addition of SIW to the MIMO circular antenna can increase the antenna gain to 9.5 dB even though there is a slight decrease in antenna bandwidth. For this reason, further research will develop the addition of SIW with the addition of particle reflective surface (PRS).
Table 1. Overall comparison circular microstrip antenna with SIW Addition.

| Antenna                      | Antenna Dimension (mm) | Antenna Parameters          |
|------------------------------|------------------------|-----------------------------|
|                              | Length x Width         | Return Loss (dB) | VSWR | Bandwidth (MHz) | Gain (dB) |
| Conventional Antenna        | 27.0 x 27.0            | -23.0          | 1.10 | 2.60           | 7.5       |
| Antenna with SIW Addition   | 15.5 x 15.5            | -22.5          | 1.16 | 1.65           | 9.5       |

5. Conclusion
Numerical results and software simulations show that with the addition of SIW material to the design of the 5G MIMO antenna can significantly improve antenna gain and slightly reduce antenna bandwidth. The results of the study can be used as the basis for the development of further 5G antenna designs to achieve better performance and specifications.

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