Bi-directional Beams Waveguide Slotted Antenna at Millimeter Wave

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Abstract
This paper focused on designing a bi-directional beams waveguide slotted antenna at millimetre wave spectrum. Waveguide slotted antenna is known for its highly directional pattern. By having bi-directional pattern, the capacity of system coverage can be expanded. The design is implemented by using antenna slot theory on a waveguide structure. The slotted are made on two wall surfaces and the performance is compared to the slotted on single wall. The two models designs are simulated using Computer Simulation Technology (CST) microwave software. The simulation results show that both models operate at 30 GHz with minimum reflection coefficient of -24.63 and -25.01 dB respectively. The two models achieved a fair high gain at 15.5 dB and 13.3 dB with directional beamwidth of 8.9 degree. The proposed bi-directional beams structure achieved a comparable gain in both directions when compared to the single direction.

Keywords: Waveguide slotted antenna, Bi-directional beams, Mm-wave, 5G

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consumer devices increases. Therefore, an increasing demand of higher gain antenna and the desired antenna has to be compatible with integrated circuits, and own high gain and small side lobe.

Hence, this paper is focusing on designing the waveguide slotted antenna operating at 30 GHz, providing a high gain, low side lobes, and bi-directional beams. Two types of waveguide slotted antennas are investigated in this work. The first design implements 8 slots on one side of the waveguide structure, named as Antenna 1. The second design applies 8 slots each on two of the waveguide walls, make it 16 slots in overall, named as Antenna 2. The performance of the two types proposed antennas are simulated using Computer Simulation Technology (CST) software.

2. Design of Waveguide Slotted Antenna

In this work, our main goal is to design and develop a waveguide slotted antenna at mm-wave frequency and to achieve a high gain, low side lobe, and dual directional beam at 9 degrees at the same level of the one directional beam gain. A rectangular shape of slotted antenna and waveguide has been selected for this design, applied on top of the first waveguide, and top-bottom of the second one. The slot type of linear aperture distribution has been used in this work [10].

The position of the cutting slot is determined from the nature of current flow and field propagation in the waveguide. Hence, the position will determine the impedance of the slot, the amount of radiating power from slot, and the amount of the power coupled to the slot which can be controlled by the position of cutting slot. Figure 1 [12] shows a cross section view in the waveguide for a single slot. A slot in the centre position as seen in Figure 1, of broad wall of waveguide will not radiate, and when the slot is away from centre more current crosses through slot edges, then more energy coupled in the slot and that will increase the radiating power. The slot in the waveguide is consider as a shunt impedance across the transmission line or an equivalent admittance loading the transmission line [12,14]. Therefore, when the admittance of the waveguide equals the admittance of the slot, a matched transmission line condition is applied

![Figure 1. The Slot Cross-Section View of Waveguide [12]](image)

Slotted waveguide exhibits high gain antenna with highly directional on the antenna plane. This can be achieved by feeding all the slots in phase [16-18]. Figure 2 shows the schematic of waveguide slot antenna, where a half-wavelength of transmission line has been chosen of repeating admittance. As a result, the admittance of all the slots will be in parallel, where each parallel resistor represents one slot.
Figure 3 shows the proposed structure of the slots in the waveguide. Total 8 slots implemented on Antenna 1 and 16 slots on Antenna 2. The slots are in phase by shifting their centers at half guided wavelength along the waveguide. The guided wavelength can be determined from (1):

$$\lambda_g = \frac{\lambda_c}{\sqrt{(1)^2 - \left(\frac{1}{m}\right)^2}}$$  \hspace{1cm} (1)

where, $\lambda_c$ is the cutoff wavelength, and its two times the dimension of the waveguide. The gain of the slotted antenna can be considered as a gain of an antenna array, so when it doubles the number of element, the gain doubled. Therefore, to find the gain and the beam width of the slotted antenna the following equations are applied [14-15]:

$$\text{Gain} = 10 \times \log_{10} \left(\frac{N \cdot \text{Slot Spacing}}{\lambda_c}\right) \text{ dB}$$  \hspace{1cm} (2)

$$\text{Beamwidth} = 50.7 \times \frac{\lambda}{W/2 \cdot \text{Slot Spacing}} \text{ Degrees}$$  \hspace{1cm} (3)

where N is the total number of slots.

Figure 2. The Schematic of Waveguide Slotted Antenna [12]

Figure 3. The Waveguide Slotted Antenna Structure [15]

Figure 4 shows the proposed waveguide structure the first one has 8 slots on the top of the waveguide side, and the second antenna has 16 slots; 8 slots at each top and bottom side of the waveguide. The increasing number of slots lead to increase the power radiating and hence, increasing of the gain, while chosen the 16 and 8 slots are based on two factors; the size of the antenna structure, and the higher gain which can be achieved.

The waveguide dimension, including slots dimensions for both antennas can be found in Table 1. The antenna is designed to operate at 30 GHz millimeterwave frequency. Based from calculation, the half power beamwidth is 9 degrees. The performance of the antennas are simulated using CST software.
Figure 4. The Proposed Waveguide Slotted Antenna for This Work, (a) Antenna 1, (b) Antenna 2

Table 1. The Dimensions of the Proposed Design

| Parameters                  | Specification of proposed waveguide slotted antenna | Antenna 1 | Antenna 2 |
|-----------------------------|-----------------------------------------------------|-----------|-----------|
| Frequency (GHz)             |                                                     | 30        | 30        |
| Waveguide Dim (mm)          |                                                     | 7.112×3.556| 7.112×3.556|
| Min. Wavelength (mm)        |                                                     | 68.3      | 68.3      |
| Slot Length (mm)            |                                                     | 4.88      | 4.88      |
| Slot Width (mm)             |                                                     | 0.85      | 0.7       |
| Offset from Centerline (mm) |                                                     | 0.6       | 0.6       |
| Spacing between slots (mm)  |                                                     | 7.03      | 7.03      |
| Number of slots             |                                                     | 8         | 16        |
| Waveguide side              |                                                     | Top only  | Top and Bottom |

3. Results and Analysis

Computer Simulation Technology (CST) is used to simulate the proposed waveguide slotted antenna structure. The software used Finite-Difference Time Domain (FDTD) for 3D EM field analysis. Simulation results show that the proposed waveguide slotted antenna (Antenna 1 and Antenna 2) is operating at desired frequency with minimum reflection coefficient of -24.63 and -25.01 dB respectively, and the response for both antennas can be seen in Figure 5.

Figure 5. Simulation Results for Both Antenna 1 and 2
The main lobe gain of the Antenna 1 is about 15.5 dB, and for the Antenna 2 is about 13.3 dB. The beam width for both antennas showed a good value of 8.9 degree, with the direction of beam at 90 degrees. The simulation also includes on the array probation to estimate the increase in gain. Figure 6 shows the radiation pattern of Antenna 1 as single element antenna in part (a) and as an array element antenna (4 antennas) in part (b), where the gain is increased to be 20.5 dB. Figure 7 shows the radiation pattern of the Antenna 2 as same approached mentioned in Figure 6, where the gain has increased to 21.5 dB.

Figure 6. Simulation of Radiation Pattern for Antenna 1 (a) Single Element, (b) Array Elements

Figure 7. Simulation of Radiation Pattern for Antenna 2, (a) Single Element, (b) Array Elements
Figure 8 shows the gain distribution over the frequency range from 26 -34 GHz for both antennas. The gain at 30 GHz of Antenna 2 is less than Antenna 1 by 2 dB, the difference here as shown in Figure 7 is Antenna 2 transmitting the power in dual direction beams with same beam width and less gain compared to Antenna 1.

A comparison of the performance for both waveguide slotted antennas are summarized in Table 2, where Antenna 2 showed a promising performance compared with Antenna 1. Whereas with bi-directional beams radiation at 30 GHz, the responses were equal in both sides with same gain of 13.3 dB, and for Antenna 1 the radiation performance is in one direction with gain of 15.5 dB. Furthermore, both antennas showed a satisfactory performance when array elements of 4 were applied with gain of 20 and 21 dB respectively.

Table 2. Comparison of the Performance for the Two Proposed Waveguide Slotted Antennas

| Parameters       | Performance of proposed waveguide slotted antennas |
|------------------|----------------------------------------------------|
|                  | Antenna 1  | Antenna 2 |
| Number of Elements | 4          | 1          | 4          |
| Reflection Coefficient $S_{11}$ (dB) | 24.63      | -24.6      | -25.01     | -25.01 |
| Gain (dB)        | 5.5        | 0.5        | 13.3       | 21.5     |
| Side lobes (dB)  | 13         | 13         | -13        | -13      |
| Beam width (degree) | 8          | .9         | 8.9        | 6.4      |
| Angel (degree)   | 0          | 0          | 90         | 90       |
| Frequency (GHz)  | 0          | 0          | 30         | 30       |
| number of slots  | 8          | 2          | 16         | 64       |

4. Conclusion

A waveguide slotted antenna is discussed in this paper. Two model of waveguide slotted antenna were presented, one with one directional beam radiation power, and the second one with bi-directional beams radiation power. The simulated results show a good response at 30 GHz. The waveguide antenna with 8 slots on top side has a fair beamwidth up to 18 degrees and a high gain as array with 15.5 dB. The second waveguide antenna with 16 slots on top and bottom side has high gain in two directions with 13.3 dB, and a very good beam width of 8.9 degree. Future works related to this work will be developed an antenna beamforming system at mm-wave which can radiate at ± 90 degree, which can easily be adopted to the 5G cellular base stations networks, and an examination of optimal fabrication process for these model at mm-wave technology.
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