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# 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*



## 1. Introduction

Millimeter wave (Mm wave) technology has been presented in the last decade as a new innovative solution to allow searching for an optimal answer to the increasing demand of traffic capacity users, higher gain, higher data rates, and power efficiency especially in the proposed fifth generation (5G) [1]. The backbone of the proposed 5G technology will be changed from using optical fiber to mm-wave wireless connection, allowed a more using of greater spectrum at mm-wave frequencies [2], another adventurous of mm-wave technology over 5G is allowing a rapid development and connection with cooperation between the base stations [3-5].

Traditionally, mm-wave spectrum has been addressed for outdoor point to point backhaul link due to high path loss at higher frequencies, cost effective components, and other related factors. However, a promised utilization for this spectrum in mobile system has been introduced in [6-7]. Mm-wave technology on other hand suffers from severe challenges, including large propagation loss, signal absorbing, low gain of the proposed antenna, and low transmitted power. Low gain for antenna at base station (BS) in mm-wave can be solved by designing a suitable antenna using one of the available transmission lines theory such as waveguide, slotted antenna, and microstrip antenna.

In mm-wave BS infrastructure, a high-density base station will be used. Connecting these BS via wired structure will be costly, one solution is to connect mm-wave base station with backhaul link [8] and use a type of antenna array with higher gain and transmitting the power in two directions, to reduce the cost of the components, and increase the capacity of the traffic users. At Base Station side, an array of antenna or beamforming technique which combined the power transmitted and increase the gain of the antennas in a directional beam has been presented in [8-9].

Antennas with outstanding design can improve the performance of communication system, which is one of some challenges in 5G systems. Various types of antenna designs are considered suitable for 28 and 38 GHz respectively, in which applications due to the requirement for small size, light weight, and low cost has been demanded. [10]. Recently, the technology of waveguide slotted antenna [11-13] has been developed for mm-wave applications [13] due to the tradeoff integration in radio frequency front-end circuits and systems. As the demand of mm-wave increases, the delivery of gigabits per second service for

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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

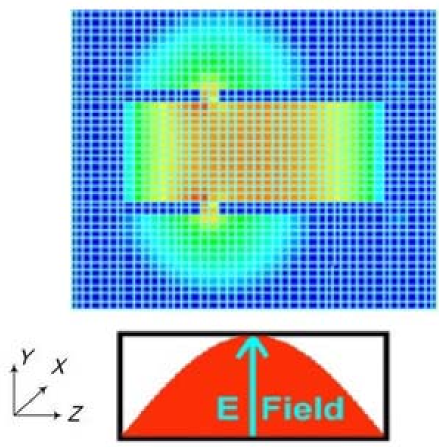



Figure 1. The Slot Cross-Section View of Waveguide [12]

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 [13]:

$$\lambda_g = 1 \Big/ \sqrt{\left(\frac{1}{\lambda_o}\right)^2 - \left(\frac{1}{\lambda c}\right)^2} \quad (1)$$

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]:

$$\text{Gain} = 10 \times \log_{10}\left(\frac{N \,.\, Slot\ Spacing}{\lambda_o}\right) \text{ dB} \quad (2)$$

$$\text{Beamwidth} = 50.7 \times \frac{\lambda_o}{N/_2 \,.\, Slot\ Spacing} \text{ Degrees} \quad (3)$$

where N is the total number of slots.

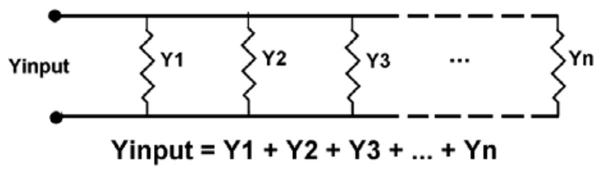



Figure 2. The Schematic of Waveguide Slotted Antenna [12]

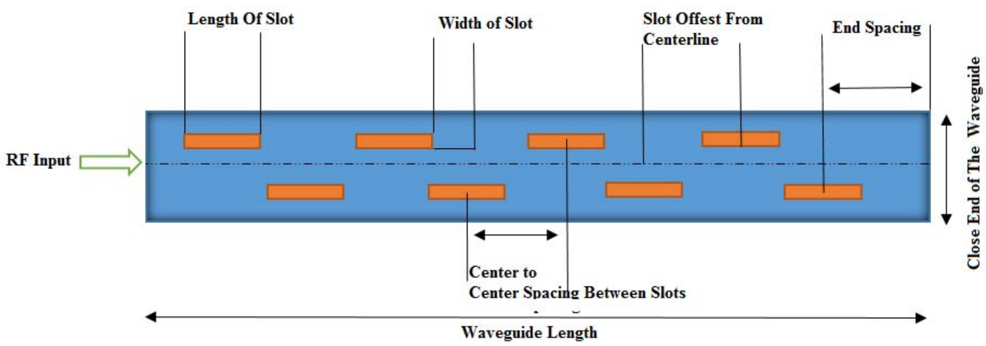



Figure 3. The Waveguide Slotted Antenna Structure [15]

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.

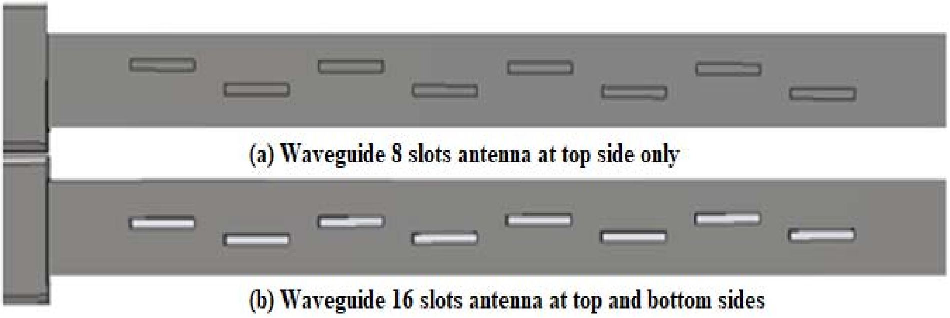



Figure 4. The Proposed Waveguide Slotted Antenna for This Work, (a) Antenna 1, (b) Antenna 2

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.

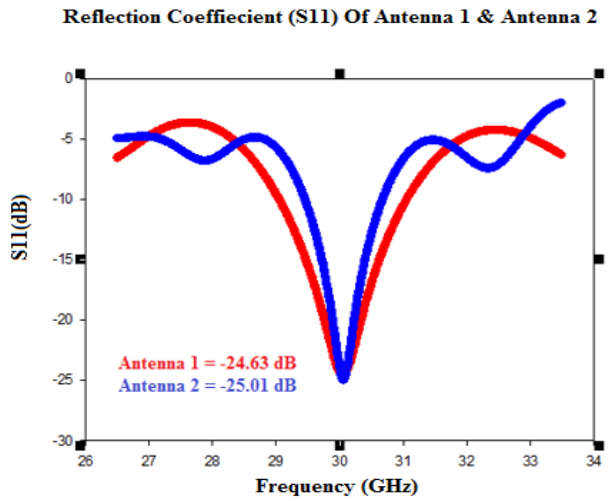
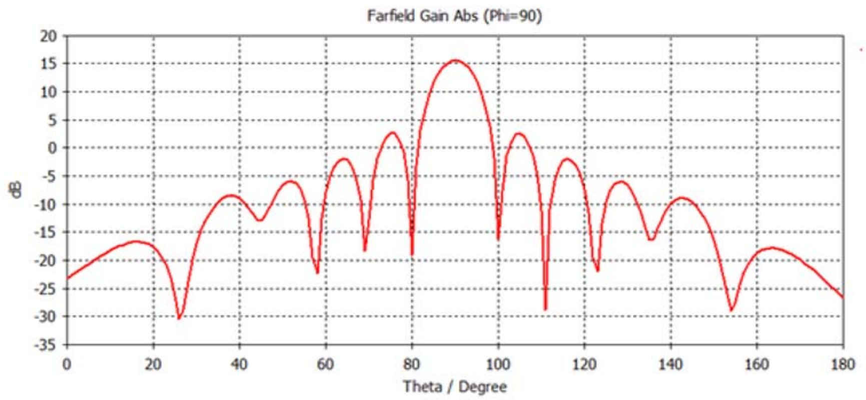
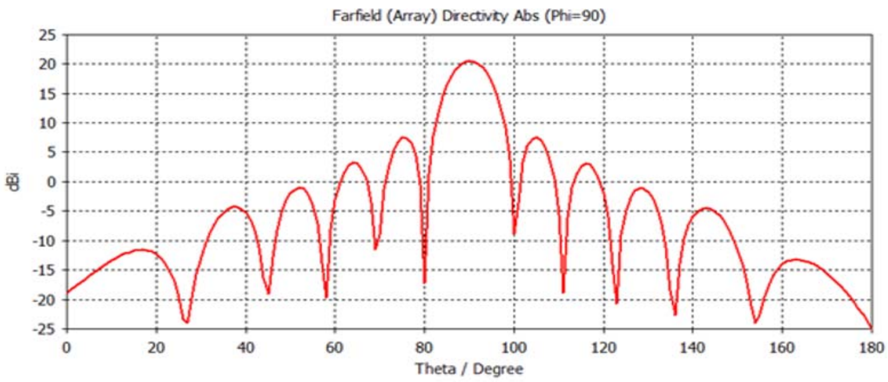



Figure 5. Simulation Results for Both Antenna 1 and 2

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.

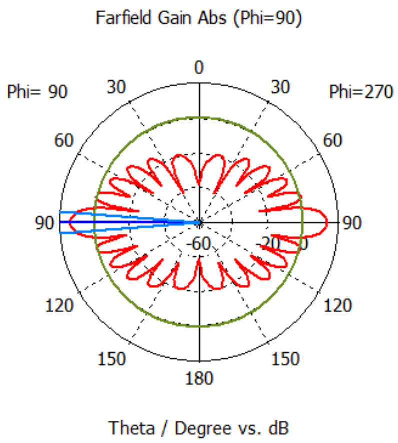



(a) Single elememnt

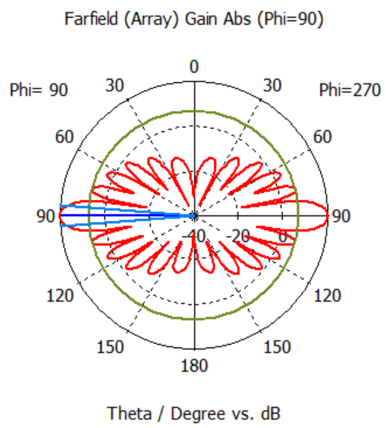



(b) Array element

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




(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 S11 (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 |

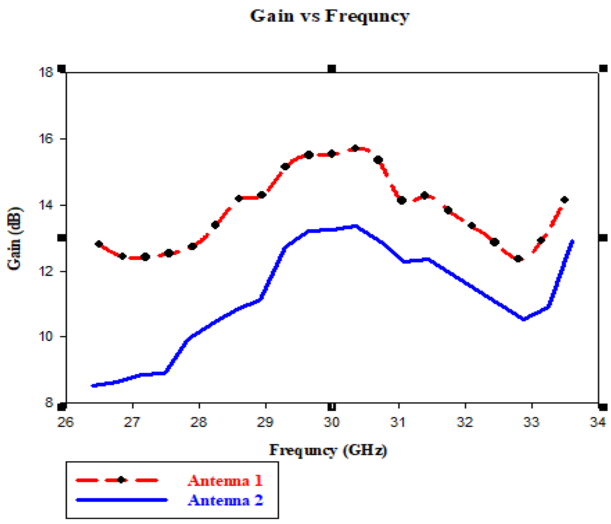



Figure 8. Gain vs Frequency for Antenna 1 & Antenna 2

## 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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