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Omni-directional Slotted Waveguide Antenna with Low Omni Ripple at MM Wave

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ABSTRACT

The paper describes the design, simulation, and realisation of a slotted waveguide based horizontally polarized omni-directional antenna at millimeter wave frequency. This design has been optimised for minimum ripple in omni pattern and wide elevation coverage. It is based on radiating slots on both sides of waveguide for generating omni pattern and reduced height waveguide along with metallic wings on both sides used to obtain minimum omni pattern variation. The designed antenna has been simulated on finite element method-based ANSYS's HFSS EM Simulator software using proper boundary conditions. A metallic strip on both side of slot on upper face of antenna has been used to provide flatness as well as strength to antenna. The antenna has the advantages of being robust, low cost, and easy to fabricate being in waveguide configuration. Measured VSWR of antenna is less than 2.0 over the frequency band of 37-40 GHz and minimum omni gain of the antenna is 0 dBi over the frequency band.

Keywords: Millimeter wave, omni-directional, radiation pattern, slotted waveguide antennae

1. INTRODUCTION

A number of omni-directional antennae have been studied for the modern communication applications[1-3]. For reception of signal from any direction, an omni-directional radiation pattern is commonly required. Generally, omni-directional radiation pattern is obtained by quarter-wave monopole antennae, biconical antennae, discone antenna etc.[4]. In these, quarter-wave monopole antennae are generally used for narrow band and cone-shaped antennae are used for broadband applications. At millimeter wave frequencies, realisation of such type of antennae become critical as dimensions of antenna become very small.

To overcome this problem, various new approaches to design omni-directional antennae, have been reported[5-6]. One of the approaches for designing of such type of an antenna is to use slotted waveguide antenna. It uses wings or reduced height waveguide to obtain omni-directional pattern[7].

The paper describes the design, simulation, and realization of two-slots-based horizontally polarised omni-directional antenna at Ka-Band. Here, reduced height waveguide and side wings techniques are used to obtain uniform and smooth omni-directional patterns.

2. DESIGN APPROACH AND EM SIMULATION

To minimise fabrication criticalities at mm wave frequencies, a slotted waveguide configuration was selected. A slotted waveguide antenna with slot doublet on broad wall was used to produce omni-directional pattern. Metallic wings and reduced height waveguide have been used for high degree of circularity in radiation pattern. Slot doublet in omni-directional antenna is shown in Fig. 1.

A longitudinal slot cut on the broad wall of a waveguide radiates like a dipole antenna placed orthogonal to the slot. The position, shape, and orientation of the slot determine the radiation pattern. As offset of slot from the centreline (x) increases, the difference in the EM field intensity at the edges of slot becomes more. This leads to more current interruption and hence, more energy is coupled to the slot. The slot on the waveguide is assumed to have a narrow width, as larger width corresponds to higher degree of cross-polarization. Slot width (W) should be roughly one-twentieth of the wavelength. For vanishingly thin wall, the square-ended slot length (L) is approximately $0.464\,\lambda_0$, and for real wall thickness and rounded-ends, resonant length[8] of slot is approximately $0.483\,\lambda_0$.

Slots on both back and front walls are to be used to obtain omni pattern since a broadside slot in waveguide radiates only in the direction perpendicular to the axis of slot. This addition of slot on opposite wall helps in producing omni-directional pattern. Using this techniques, patterns show large variations in the azimuth radiation pattern as well as significant dips at four edges of the waveguide.

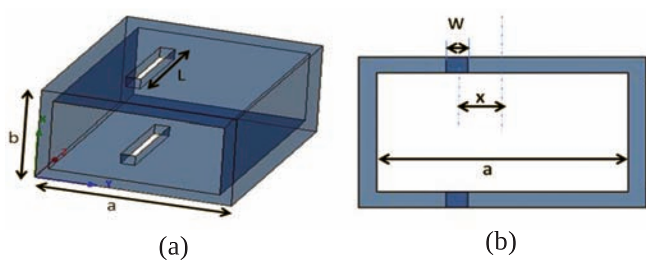

Figure 1. A slot doublet on the broad wall of a waveguide: (a) 3D view and (b) front view.

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A reduced-height waveguide is often used to achieve high degree of circularity in omni pattern. For a reduced-height waveguide, the external mutual coupling between slots in the upper wall and slots in the lower wall can no longer be ignored. For the full-height waveguide, the external mutual coupling is weak due to the small slot offsets and large height of waveguide. As the height of the waveguide was reduced, the distance between the upper and the lower slots becomes smaller, resulting in stronger mutual coupling between top and bottom slots. The height of the waveguide also changes the field distribution on the slot doublets and its resonant characteristics.

Further, variations in the radiation pattern can be minimized by adding side wings to the waveguide. Wings increase the size of ground plane for the slots and minimizes, the EM energy that wraps around the waveguide. Larger the wings, better these work. The wings extended up to approximately one wavelength on each side of waveguide provides omni pattern pretty well. The elevation pattern remains the same as that of without wings, wings affect the azimuth pattern only. HFSS model of reduced-height slotted waveguide antenna without wings is shown in Fig. 2. A comparison of simulated omnipattern of antenna with and without metallic wings is shown in Fig. 3. The simulated radiation pattern of antenna without wings shows four dips of -4.2 at each corner of the waveguide. By adding the wings to both sides of the waveguide, the dips reduce to 0.5 dB. In the first case peak-to-peak variation was 8dB while by adding the wings it was reduced to 4 dB . In this way, the addition of wings on both sides of the antenna improves the omni pattern and makes it more uniform and smooth.

In this design, slots were cut on 0.5mm thick reduced height waveguide (5.7 X 1mm^2) and a transition was used to feed antenna using conventional waveguide, i.e., WR-28 (7.11 X 3.56mm^2). To achieve wide elevation coverage, single pair of slot doublet was used. For better impedance matching, shorted wall was kept $\lambda g/4$ away from centre of slot. The designed antenna was modelled on finite element method-based ANSYS's HFSS software using proper boundary conditions. The antenna was excited by dominant mode of rectangular waveguide, i.e., TE_{10} and solved for desired frequency of operation. After initial simulation, the antenna was optimised for desired VSWR and radiation pattern. 3-D CAD model and photograph of developed antenna are shown in Fig. 4. The

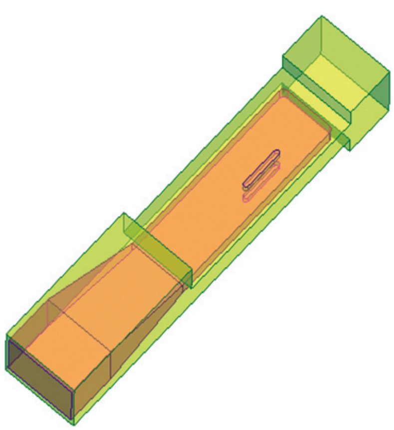

Figure 2. Antenna without wings.

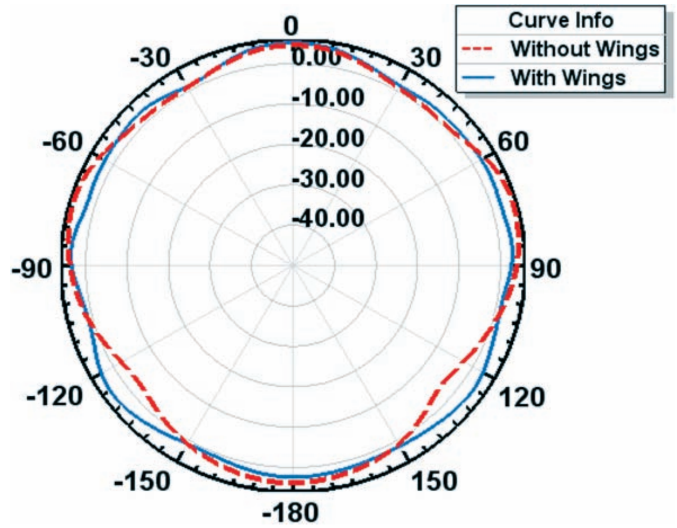

Figure 3. Comparison of Az pattern of antenna.

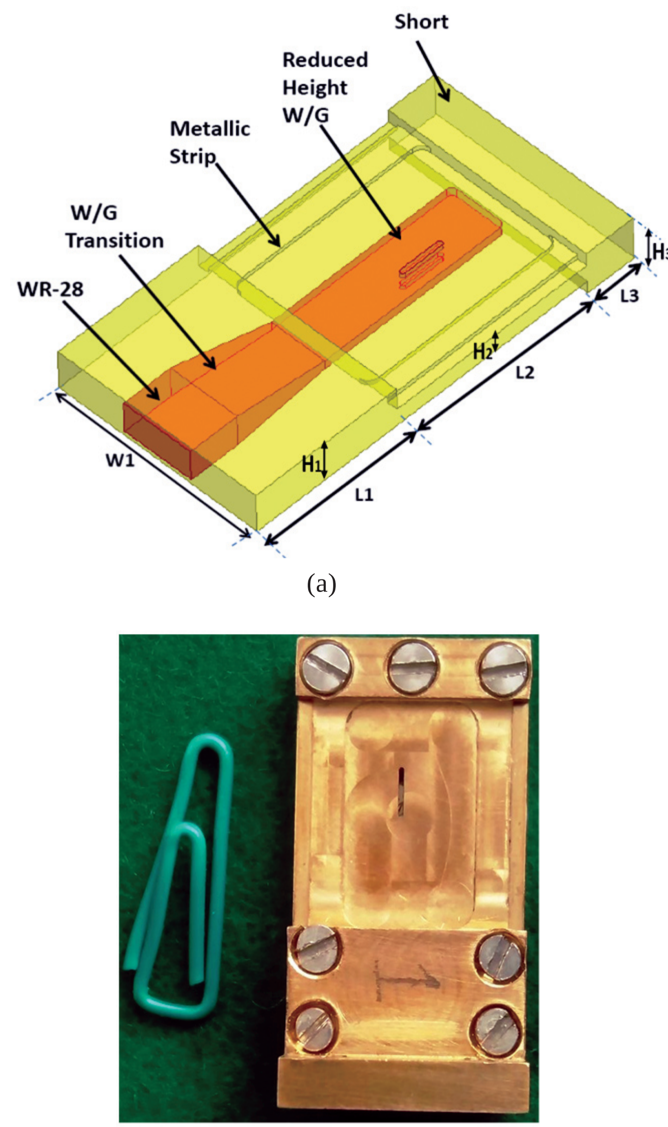

Figure 4. Slotted waveguide omni-directional antenna with wings: (a) 3D CAD model, and (b) developed antenna.

dimensions of designed antenna namely W1, L1, L2, and L3 were 2.67 λ_0, 1.9λ_0, 2.57λ_0, and 0.63λ_0, respectively. Height of different sections of antenna H_1, H_2, and H_3, were 6.2 mm, 2 mm and 5.8 mm, respectively. Optimised length, widths, and offset of rounded slot were 4.45 mm, 0.5 mm, and 0.7 mm, respectively. Optimised length of wings was 7.7 mm. The step close to slot was used as short and here thicker short was used to tighten the antenna perfectly. Short thickness was been optimised to get desired elevation coverage, which was -15° to +40°.

Designed antenna was fabricated in two parts using milling machine. As thickness of waveguide wall is very small, i.e., 0.5 mm, so there may be some chance of bending. To overcome this problem, 3 mm wide metallic strip on both sides of slot was used which provide extra mechanical strength to antenna and also maintains the flatness during integration of both parts. Although these strips are asymmetry to radiating slot but the order of asymmetry from centre of slot is approximately 0.064 λg and placed away apart from radiating slot, i.e., minimum λg/2 (where λg is guided wavelength). Hence, it does not affect the radiation pattern of antenna.

3. RESULTS AND DISCUSSION

VSWR of developed antenna was measured using Rohde and Schwarz Vector Network Analyzer. The simulated and measured VSWR of developed antenna is shown in Fig. 5. From the figure, it can be seen that measured VSWR closely follows simulated ones over the frequency band 37 GHz to 40 GHz. Simulated results cater for sharp rectangular waveguide while fabricated waveguide has some tool radius at the corner which modifies the VSWR of the antenna slightly. Developed antenna has been characterised for its radiation pattern at compact antenna test range. The effect of incorporating tool radius has been verified using EM simulation tool. Figure 6 shows the simulated peak azimuth gain of antenna over the frequency band of operation. It was observed that peak azimuth gain of antenna is greater than 3 dBi. Comparisons of measured and simulated radiation pattern of antenna are shown in Fig. 7. The measured gain of the antenna at 38 GHz is 4 dBi (Fig. 8). The measured azimuth pattern of antenna shows small variation (± 2.5 dBi) over the frequency band, as shown in Fig. 9.

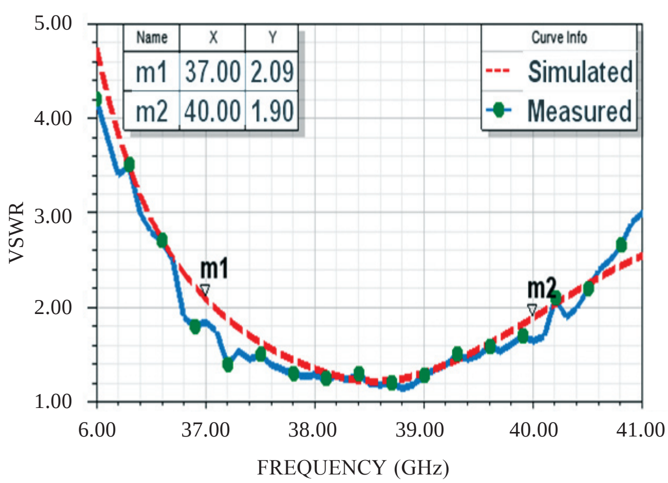

Figure 5. VSWR plot of antenna.

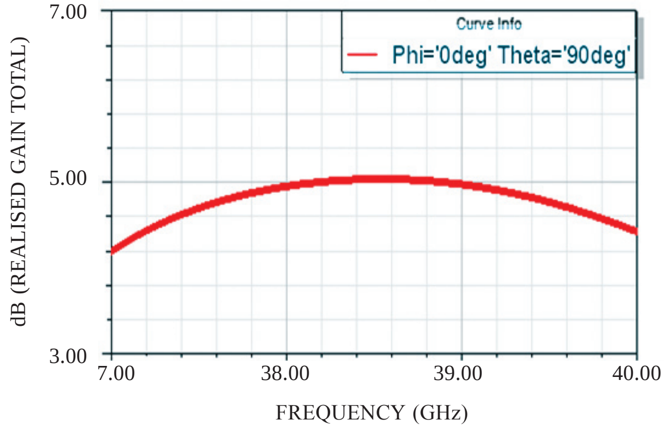

Figure 6. Peak gain plot of antenna.

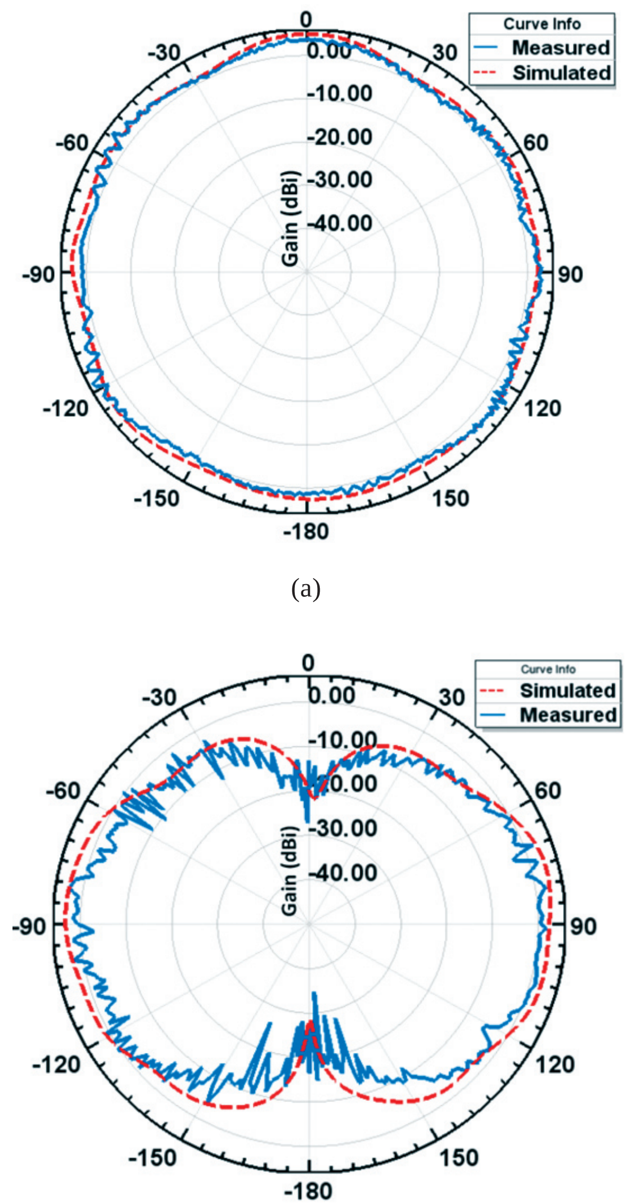

Figure 7. Radiation pattern of antenna at 38 GHz: (a) Azimuth pattern, and (b) elevation pattern.

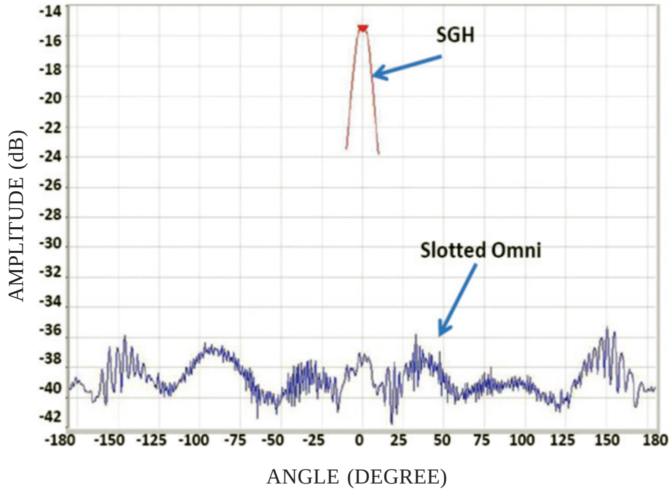

Figure 8. Gain measurement of antenna at 38 GHz.

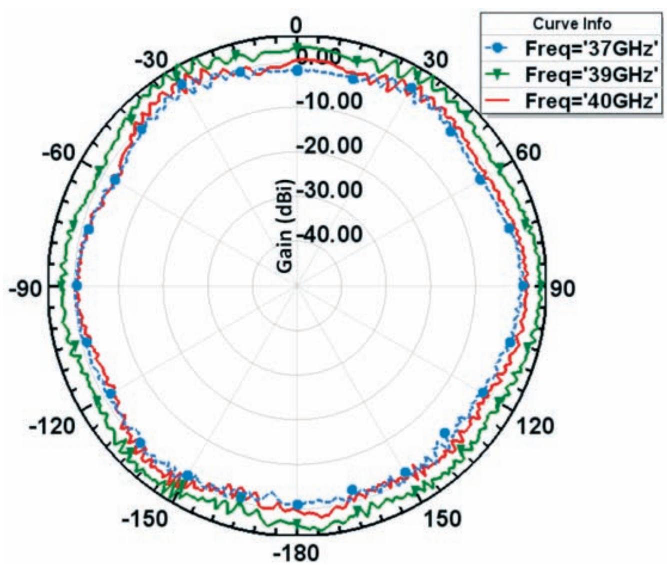

Figure 9. Measured Az pattern of antenna.

4. CONCLUSION

A slotted waveguide-based horizontally polarized omni-directional antenna has been designed, simulated, optimised, and developed at Ka -Band. The antenna has elevation coverage of -15 to 40 degree with omni azimuth coverage. The antenna is perfectly matched over the desired frequency band. Omni coverage of this antenna is excellent over the desired band (37-40 GHz). The measured radiation patterns of antenna show very good resemblance with the simulated results. The measured minimum gain of antenna is 0 dBi over the frequency band on the horizon plane. The slight deviation in radiation pattern and elevation coverage may be accorded due to the fabrication and integration tolerances and measurement inaccuracies. The robustness, simple structures, and simple manufacturing process, recommend the use of this antenna in the Ka-Band communication system.

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