Design of Millimeter-wave Slotted-Waveguide Planar Antenna for Sub-array of Beam-scanning Antenna

#Kunio Sakakibara, Akihiro Kawasaki, Nobuyoshi Kikuma, Hiroshi Hirayama
Nagoya Institute of Technology
Gokiso-cho, Showa-ku, Nagoya, 466-8555, Japan, sakaki@nitech.ac.jp

1. Introduction

Beam-scanning antennas are attractive for high-bit-rate data communication systems and high resolution sensing systems in millimeter-wave band. Waveguide antenna is one of the most attractive antennas for such millimeter-wave systems because of its low loss and high efficiency characteristics in high frequency band. Horizontally-beam-scanning antennas such as phased arrays and DBF (Digital Beam Forming) systems consist of multiple vertically-long sub-arrays arranged in horizontal direction as shown in Fig. 1. Beam scanning is achieved by giving individual phase to each sub-array from beamforming network. We developed a vertically-long slot-array antenna composed of two feeding waveguides in the millimeter-wave band. One of the solutions for grating lobe suppression is introduced in this paper. Feasibility of the proposed antenna is confirmed by experiments.

2. Structure of proposed antenna

The proposed sub-array antenna is composed of only two waveguides to form a vertically-long antenna as is shown in Fig. 2(a). We have already developed high-gain slotted waveguide rectangular planar array antenna in our past study [1]. Here, based on this technique, a two-line slotted-waveguide array antenna is developed in this work. Slots are cut on the narrow wall of the waveguide in order to assemble the waveguide at the center of the broad wall where current flows along longitudinal direction of the waveguide and is not cut by the plane. Consequently, transmission loss does not grow up significantly. Slot spacing for in-phase excitation of travelling-wave array is one guided-wavelength which is generally longer than the wavelength in free space. Grating lobe has been a significant problem in the travelling-wave slot array design. Following ideas are supplied to the developed antenna in order to solve the grating lobe problem.

(1) Interleave slot arrangement excites all slots in phase since the power divider feeds two waveguides with 180 degrees out of phase [2].
(2) In order to shorten the guided wavelength, the broad wall width of the waveguide is designed to be large.
(3) When the broad wall width is large, coupling power from the waveguide to the air through slot becomes small. In order to increase the coupling power to the air, a post is provided in the waveguide for each slot as is shown in Fig. 2(b).
(4) Reflection characteristic is generally improved by beam tilting from the broadside direction. Since one of the grating lobes moves toward the broadside when beam tilting, the grating lobe level increases significantly. Therefore, the post is designed to cancel the reflections from the slot and the post. Reflection characteristic improves without beam tilting.
(5) Grating lobe level is reduced by element radiation pattern of the cavity on the slot.

The dimensions of the radiating slot elements with post and cavity are optimized by using electromagnetic simulator of the finite element method. The design frequency is 76.5 GHz.

3. Fabricated antenna and measured performance

The designed antenna was fabricated and feasibility was confirmed by experiments. Photograph of the developed antenna is shown in Fig. 3. Two metal plates of aluminium alloy were screwed together. Posts were located in the waveguide to increase radiation from slots and to improve reflection characteristics. The cavity was set on each slot.

Figure 4 shows measured and simulated radiation patterns in the plane parallel to the waveguide at the design frequency 76.5 GHz. Beam direction was approximately 0 degree as was the same with the broadside beam design. Sidelobe level was around −20 dB as was almost the same level with the design of Taylor distribution for −20 dB sidelobe level. Some portion of the grating lobes were observed in ± 50 degrees which were about 7 dB higher than the simulation and still lower than −20 dB. Figure 5 shows measured and simulated radiation patterns at 76.5 GHz in the plane perpendicular to the waveguide. Almost symmetrical radiation pattern was obtained in the experiment. Sidelobe level was around −20 dB as was the same with the simulation. Figure 6 shows reflection characteristics. Since the resonant frequency corresponded to the design frequency 76.5 GHz, reflection level was lower than −20 dB at the frequency. Although the bandwidth was wider than 3 GHz for reflection lower than −10 dB, the center frequency of the bandwidth shifted by a few GHz lower than the design frequency. Figure 7 shows gain and antenna efficiency. Gain and antenna efficiency were 21.1 dBi and 51 %, respectively. They were degraded in the lower frequency band due to the return loss mentioned in the Fig. 6. However, the efficiency was relatively high compared with other millimeter-wave antennas.

4. Conclusion

A slotted waveguide array antenna was developed for sub-array of beam scanning antennas. The antenna was designed to realize high efficiency by reducing grating lobe level and return loss. As a result of the experiments of the fabricated antenna, the measured radiation patterns in both planes of parallel and perpendicular to the waveguide agreed well with simulated results at the point of beam direction and sidelobe level. Gain was 21.1 dB and relatively high antenna efficiency 51 % was obtained in the measurement of millimeter-wave band.

Acknowledgments

Authors are indebted to DENSO Cooperation for fabrication of antennas.

References

[1] A. Mizutani, K. Sakakibara, N. Kikuma, H. Hirayama, “Grating Lobe Suppression of Narrow-Wall Slotted Hollow Waveguide Millimeter-Wave Planar Antenna for Arbitrarily Linear Polarization,” IEEE Trans. on Antennas Propagation, Vol. 55, No. 2, pp. 313-320, Feb. 2007

[2] K. Sakakibara, T. Watanabe, K. Sato, K. Nishikawa and K. Seo, “Millimeter-Wave Slotted Waveguide Array Antenna Manufactured by Metal Injection Molding for Automotive Radar Systems,” IEICE Trans. Commun., Vol.E84-B, No.9, pp.2369-2376, Sep. 2001.

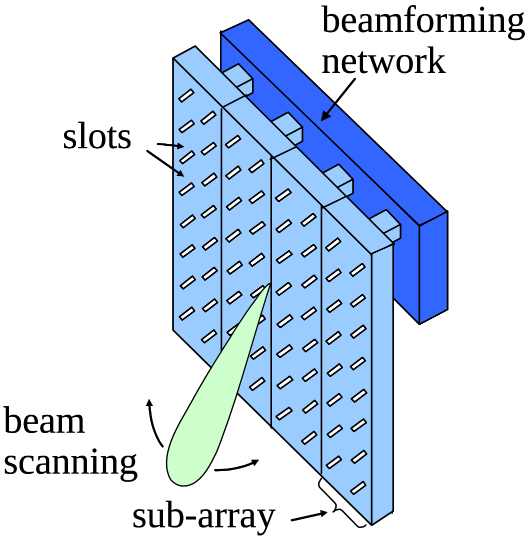
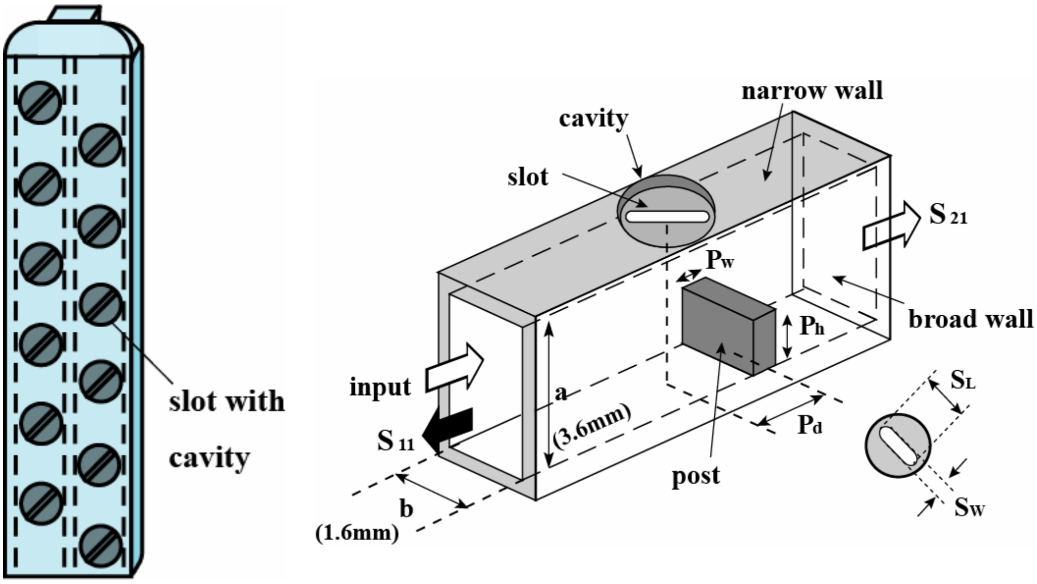


Figure 1. Horizontally-beam-scanning antenna



(a) Waveguide antenna for sub array (b) One unit of radiating slot with matching post and cavity

Figure 2. Structure of the developed antenna

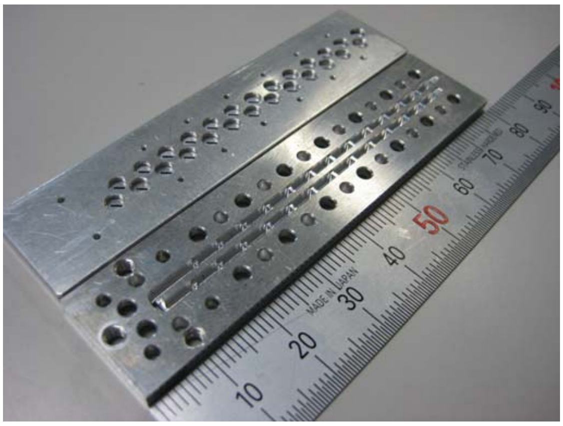


Figure 3. Photograph of the developed antenna

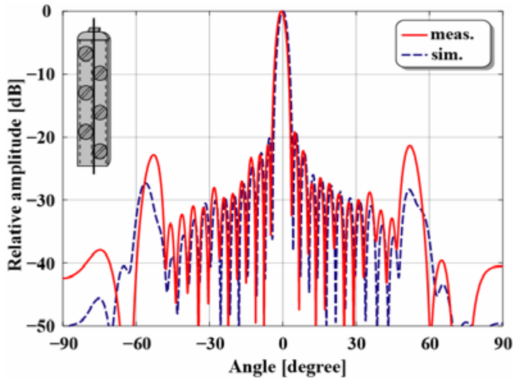


Figure 4. Radiation patterns in the plane parallel to the waveguide.

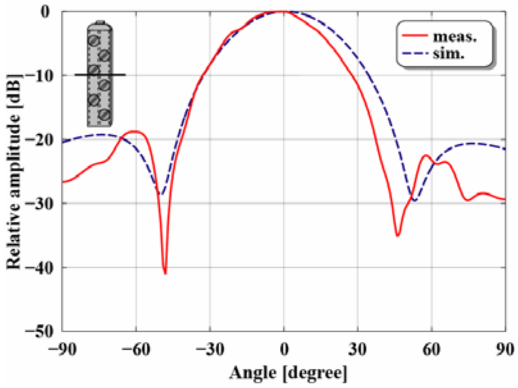


Figure 5. Radiation patterns in the plane perpendicular to the waveguide.

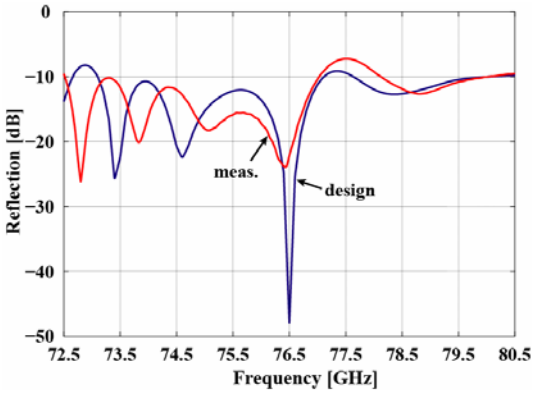


Figure 6. Reflection characteristics.

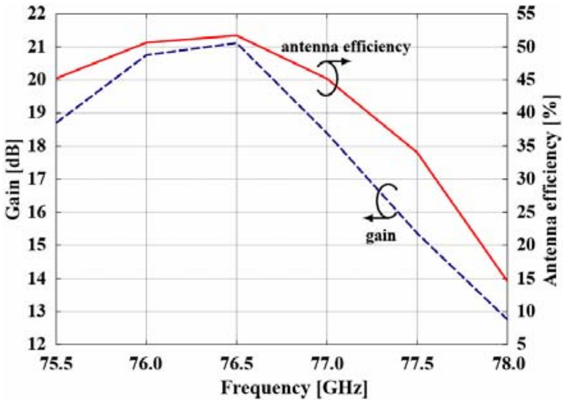


Figure 7. Gain and antenna efficiency.