Design of a Double-Layer Slotted Waveguide Array with a Partially Corporate Feed Circuit Installed in the Bottom Layer and its Fabrication by Diffusion Bonding of Laminated Thin Plates in 38GHz Band

[#]Miao Zhang, Jiro Hirokawa, Makoto Ando
Dept. of Electrical and Electronic Eng., Tokyo Institute of Technology
2-12-1- S3-19, O-okayama, Meguro-ku, Tokyo, 152-8552, Japan. miao@antenna.ee.titech.ac.jp

1. Introduction

This paper is to demonstrate the potential and realizability of a high-performance waveguide slot antenna. A double-layer slotted waveguide array with a partially corporate feed circuit installed in the bottom layer is proposed and designed in 38GHz band to realize broadband characteristics. For the antenna realization, a diffusion bonding of laminated thin plates is introduced as the fabrication technique of low-cost and high mass-productivity.

Previously, a single-layer slotted waveguide array [1, 2] has been developed for commercial use. It is an attractive candidate for high-efficiency and high-gain planar antennas because of its negligible transmission loss and simple structure. As show in Fig. 1 where the feed waveguide is placed at the end of antenna, the slot array cut in each radiating waveguide is fed in series. The bandwidth of antenna gain is restricted due to long line effect in radiating waveguide. And the mainbeam direction will also tilt a lot according to the frequency divergence of propagation coefficient in waveguide. In order to realize a wideband antenna in single-layer, the center feed [3] and the partially-corporate feed [4] structures have been investigated. The bandwidth is enhanced by reducing the long line effect to a certain fraction. However, the increase of blocking area with no radiating elements leads to the degradation of sidelobe level (SLL). Furthermore, the embedded feed circuits with more complexity than the series feed also lead to the difficulty in antenna realization using present fabrication technique.

In this study, a double-layer configuration is adopted: the partially-corporate feed circuit in the bottom layer and the radiating waveguides in the top layer. The etching of thin metal plates has high-precision and low-cost as a feature. The number of etching patterns for this double-layer antenna is only five. A proper number of etched metal plates are laminated together by diffusion bonding [5]. It is a process where the diffusion motions of atoms happen under the condition of high-temperature and high-pressure. In addition, a large number of antennas can be fabricated at one time for reduction in cost.

2. Design of a Double-Layer Antenna

Figure 3 shows the configuration of a double-layer antenna. By introducing the partially-corporate feed structure, the whole antenna is divided into 4x4 sub-arrays. Since the feed circuit is placed in the bottom layer below the radiating waveguides, the degradation of SLL due to blocking area is prevented. The whole antenna is fed at center through an input aperture. Four artificial feed points are fed in-phase, which is independent of frequency, via the E-plane T-junction, H-plane T-junction and H-plane bend in order. An in-phase feed type, which has regular slot arrangement and the advantage of suppressing the second-order beam [6] is adopted here, that is, all radiating waveguides are fed in-phase through slot couplers.

A 20x20 elements array is to be designed at the frequency of 38.7GHz. The widths of radiating and feed waveguides are 5.0mm and 5.4mm, respectively. And the height is 2mm in common. The thickness of metal plate and their number necessary in diffusion bonding are illustrated in Fig. 3 (c). Generally, it is enough to design only five elements in both feeding and radiating parts, because the 20x20 elements array is simplified into 4x4 sub-arrays. However, the mutual coupling including higher-order modes between the H-plane T-junction and its adjacent slot coupler should be taken into consideration during antenna design. Furthermore, the short position in the last slot coupler should also be shortened, in assembling separate couplers and dividers into a partially-corporate feed circuit.

To realize boresite radiation as well as reflection suppression, an inductive wall is introduced to each radiating slot [7]. Including the periodicity in external region, a method of moment (MoM) analysis is applied in the element design, and a FEM (Finite Element Method) based simulator HFSS is applied in the array analysis. By investigating frequency characteristics of reflection of each slot, it can be observed that the slot closer to the termination shows narrower bandwidth of reflection. The overall reflection of the 5-element linear array analyzed by HFSS is suppressed below -13dB over the frequency range from 38 to 39.5 GHz. A SLL of -13dB in H-plane as well as a good uniformity in excitation is also confirmed.

To realize travelling wave excitation in feed circuit as the similarity to radiating element, a reflection cancelling wall is newly introduced in each slot coupler compared to the original one [8]. As illustrated in Fig. 4, slot length l is tuned off from the resonant one to adjust the phase transmission in feed waveguide. The coupling is mainly controlled by the tiling angle θ. The position (p, q) of the inductive wall is optimized for each l and θ. The frequency characteristics of reflection for each slot coupler designed by MoM are also investigated. Similarly to the radiating element, the slot coupler closer to the termination also shows narrower bandwidth of reflection.

After the element and array design of both radiating elements, slot couplers and dividers, all of them are assembled together into a double-layer antenna. A full-structure analysis by HFSS is conducted to the designed whole antenna. The overall reflection as shown in Fig. 5 is suppressed below -20dB in the vicinity of center frequency. The antenna directivity including the effect of return loss is shown in Fig. 6. A maximum gain of 35.0dB and a high efficiency of 94% are achieved at the design frequency of 38.7GHz. Figure 7 shows the radiation patterns observed in several cut-planes. The SLLs are -11.5dB in E-plane (ϕ = 0 deg.) and -12.5dB in H-plane (ϕ = 90 deg.). Especially in the cut-plane of ϕ = 45 deg., all SLLs are sufficiently suppressed. That is also the advantage of in-phase fed array and contribute to the enhancement of antenna gain.

3. Antenna Fabrication and Measurement

The antenna designed above is fabricated by diffusion bonding of laminated copper plates. Figure 8 shows the photograph of test antenna. The antenna size is 140mm x 140mm and 8.6mm in thickness. The antenna is fed by a standard waveguide WR28 connected on the bottom. The measured reflection is included in Fig. 5, where a frequency shift of 500MHz from the design curve is observed. The aperture illuminations are measured under a near-field measurement system. The directivity calculated from the aperture illumination is also included in Fig. 6. A maximum directivity of 34.7dB is obtained at 39GHz, where a good uniformity in excitation is achieved. A high aperture efficiency of 87.5% is realized as the first trial fabrication.

A 25dBi Q-band standard horn is also measured in the near-field measurement system. Since the gain of the standard horn is known, the gain of test antenna is estimated as shown in Fig. 6. The peak gain of 33.9dBi and corresponding antenna efficiency of 73.2% are achieved at 38.5GHz. By excluding the effect of return loss, the conductor loss is estimated at about 1dB.

4. Conclusion

A 20x20 elements array with double-layer structure is designed in 38GHz band. A broadband antenna with 4x4 sub-arrays is to be realized by installing the partially-corporate feed circuit in the bottom layer below the radiating waveguides. The five-element sub-arrays in both feeding and radiating parts are designed first. As the design results, a maximum directivity of 35.0dB and a high efficiency of 94.0% are realized at 38.7GHz. The SLLs in E- and H-planes are -11.5dB and -12.5dB, respectively. For demonstration, the designed antenna is fabricated by diffusion bonding of thin copper plates. As the measurement results, a high aperture efficiency of 87.5% with the directivity of 34.7dB is realized in the first-time manufacture. The peak antenna gain of 33.9dBi is achieved at 38.5GHz, where the corresponding antenna efficiency is 73.2%.

References

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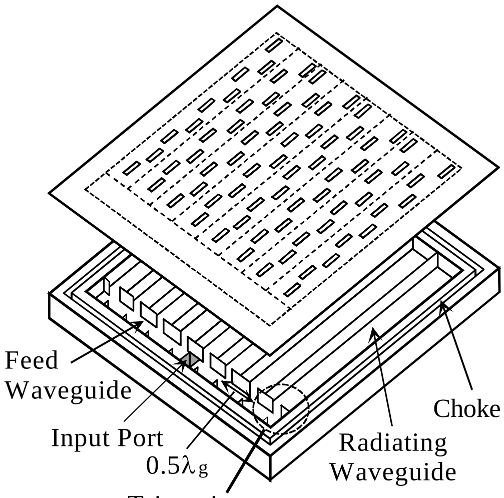
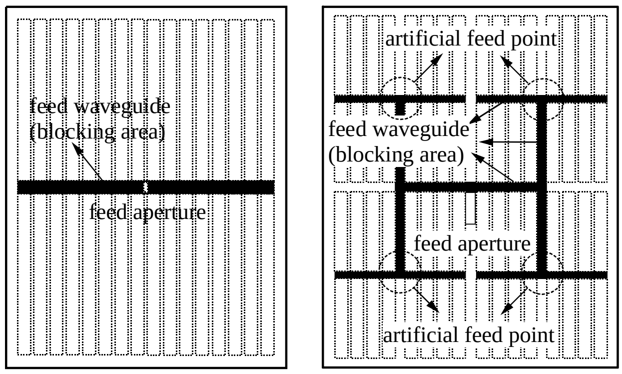


Figure 1: An Alternating-Phase Fed Single-Layer Slotted Waveguide Array



(a) center feed (b) corporate feed

Figure 2: Top View of the Center Feed and the Partially-Corporate Feed Antennas

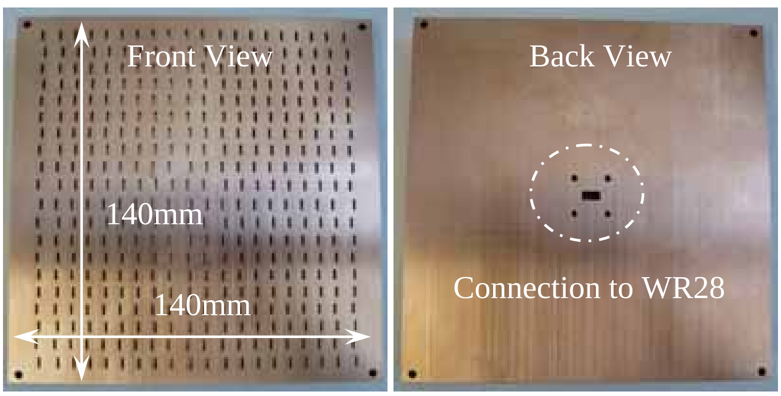


Figure 8: Fabricated Double-Layer Antenna Made of Copper

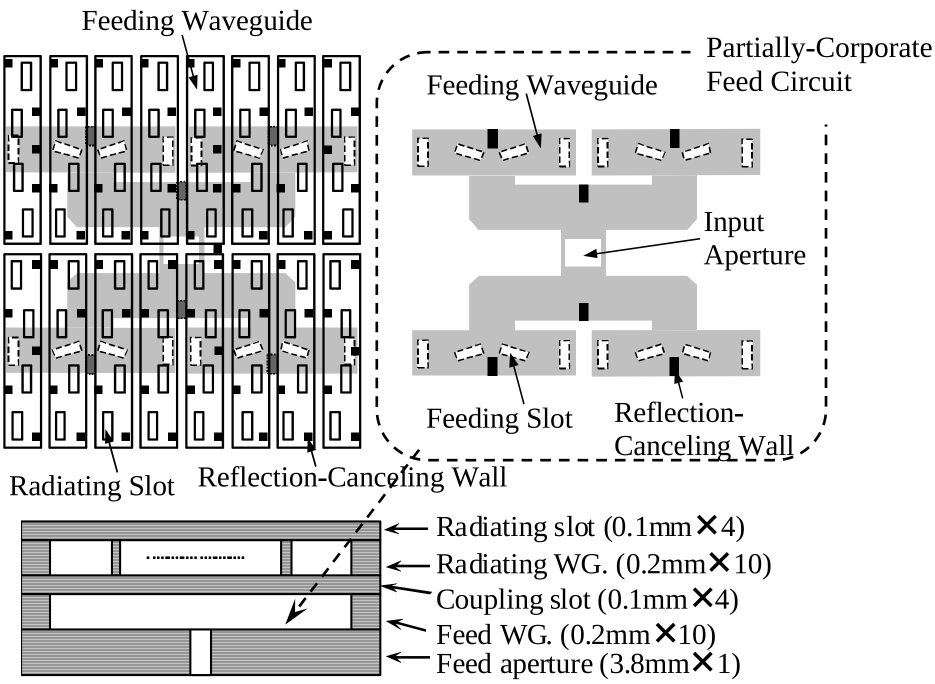


Figure 3: Structural Configuration of a Double-Layer Antenna with a Partially-Corporate Feed

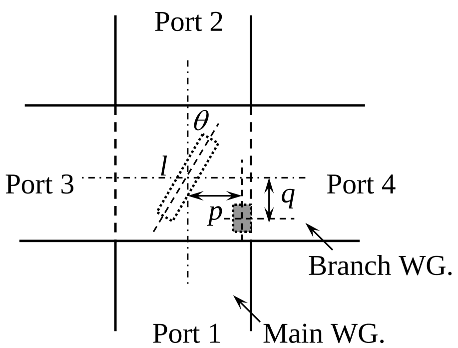


Figure 4: Structure and Parameters of a Slot Coupler with an Inductive Wall Figure

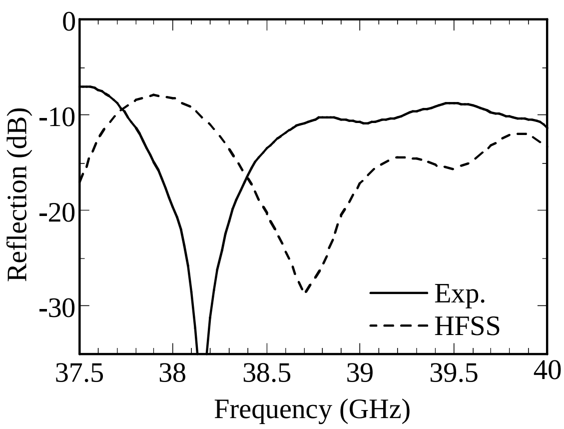


Figure 5: Overall Reflection of Design Antenna

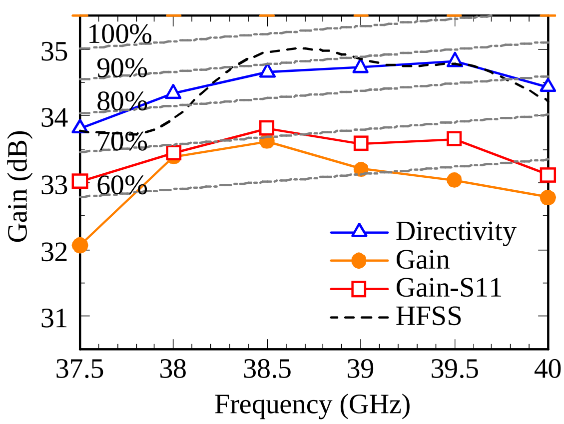


Figure 6: Antenna Gain and Directivity

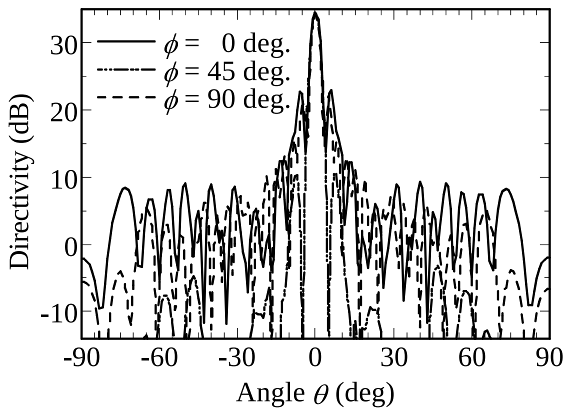


Figure 7: Radiation Patterns of Design Antenna