Loss Evaluation of a Plate-Laminated Rectangular Waveguide Fabricated by Pressure Bonding

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Abstract

The plate-laminated rectangular waveguide is newly realized by pressure bonding. Its transmission loss and phase are investigated in detail by changing the diameter, spacing and position of the concave-convex structures. The total loss at 38.75GHz is estimated at 0.03 dB/cm in HFSS and evaluated at 0.137 dB/cm by experiment.

Keywords: Rectangular Waveguide Loss Evaluation Pressure Bonding Concave-Convex Structure

1. Introduction

Instead of the conventional die-casting and milling process, the lamination of etched thin metal plates [1, 2] is introduced to the realization of multi-layer waveguide slot antennas as the new approach. The etching of thin metal plates exhibits the features of low cost and high precision even in the millimeter-wave band. These etched plates are to be assembled together by a suitable lamination technique, which is the key to realizing the multi-layer structure with good electric connection and high mass-productivity. In this study, the pressure bonding by applying a pressing at ambient temperature which has very higher mass-productivity than the diffusion bonding [1, 2] is supposed. Unfortunately, unlike the surface bonding technique the perfect electric contact between adjacent plates can only be realized at specific locations with pre-processed concave-convex structures. The electric contact in the rectangular waveguide is indispensable to realize the waveguide slot antenna with high-efficiency, and the corresponding etched plates have to be bonded with densely-arranged in the neighborhood of the waveguide’s periphery.

In this paper, the plate-laminated rectangular waveguide to be fabricated by pressure bonding with concave-convex structures are modeled first in the finite element method (FEM) based simulator ANSYS HFSS. The effects of gaps between the etched plates on the loss and equivalent guided wavelength are investigated. The transmission loss and phase are also estimated in detail by changing the diameter, spacing and position of the concave-convex structures. Finally, the waveguide is fabricated by pressure bonding in 39 GHz band, and evaluated experimentally.

2. Loss Estimation by Simulation

Figure 1 shows the plate-laminated rectangular waveguide consisting of several thin metal plates. The number of the etched waveguide plates is simply determined by the waveguide height associated with the single plate thickness. The dimension and relative location of the feeding aperture in the bottom plate is optimized for input matching. Four screw holes are introduced in all plates to connect the flange of a standard waveguide for feeding. In the process of pressure bonding, the concave-convex structures as illustrated in Fig. 2 are produced in a pre-process in the neighborhood of the waveguide’s periphery. After that, the etched plates with the concave-convex structures at the same locations are bonded together at by the pressing at ambient temperature. The bonded concave-convex structures function like the posts to prevent the leakage from waveguide. Unfortunately, unlike the surface bonding technique the electric contact can only be realized at specific locations of “posts”. Furthermore, there is a gap existing between different plates and the conductivity of the artificial “post” is unknown.

The analysis model for the plate-laminated waveguide to be simulated in HFSS is illustrated in Fig. 3. The electric field along the direction of waveguide height is uniform for the regular rectangular waveguide without perturbation. The gaps between each pair of the etched plates are accumulated on the top side of the waveguide and the total height of the gap is h. The concave-convex structures in each layer are modeled as the posts located on both sides of the waveguide and similarly the total height is h. The diameter and spacing of the posts are d and s, respectively. That is, the periodic of the posts are $d + s$. The distance between the edges of waveguide and the array of posts is g. A TE_{10} mode corresponding the rectangular waveguide with the cross-section of $a \times b$, is incident to this plate-laminated waveguide. The center frequency is 38.75 GHz and the dimension of the waveguide is 5×2 mm. Due to the fabrication limitations of pressure bonding, the minimum diameter d and spacing s are 1.5 mm, and the minimum distance g is 1.0 mm. The number of concave-convex structures directly determines the manufacture cost. A smaller number as well as lower loss is preferred in pressure bonding. The perfect electric conductor (PEC) is adopted in HFSS for simplicity.

The value of gap height h is uncertain. The effects of h on the transmission loss and phase are investigated first. The diameter d and spacing s are fixed at 1.5 mm, and the distance g is selected at 0.5, 1.0 and 1.5 mm. Figure 4 shows the transmission loss as a function of height h. The leakage is not sensitive to h and is no larger than 0.005 dB/cm even for a large $g = 300$ μm. Figure 5 shows the phase delay compared to the regular waveguide without gap as a function of height h. The phase delay is sensitive to h due to the change in guided wavelength and its value for a unit length of 1 cm is -13 degrees for $g = 1.0$ mm and $h = 100$ μm. The gap height h will be fixed at 100 μm for the rest simulation in this paper. The effect of spacing s on the transmission loss and phase is also investigated. The diameter d is fixed at 1.5 mm, and the distance g is selected at 0.5, 1.0 and 1.5 mm as before. Figure 6 shows the transmission loss as a function of spacing s. The losses at $s = 2.0$ mm are 0.01 dB/cm and 0.05 dB/cm for $g = 1.0$ mm and 1.5 mm, respectively. It is a similar conclusion with the post-wall waveguide [3, 4] that, the spacing no larger than the post diameter is preferred to reduce the leakage at a sufficient low level.

By keeping the spacing s and the diameter d at the identical values, the diameter d is changed from 1 mm to 3 mm at an interval of 0.5 mm. The distance g is fixed at the minimum of 1 mm. Figure 7 shows the transmission loss as a function of diameter d. A larger diameter $d = 2$ mm, where the leakage is 0.005 dB/cm, is also acceptable and can leads to the reduction in the number of concave-convex structures. Finally, the effects of distance g on the transmission loss and phase are investigated. Here, both the spacing s and the diameter d are fixed at 1.5 mm. Figure 8 shows the phase delay compared to the regular waveguide without gap as a function of distance g. There are drastic phase changes at the neighborhood of $g = 2.25$ and 7.75 mm, where the plate-laminated waveguide is cutoff and all the incident power is reflected to the input. One interesting result is that, the phase delay due to the gap can be cancelled out by enlarging the distance at $g = 4.75$ mm, where the leakage of 0.0005 dB/cm is be negligible. By adopting these parameters, it is possible to realize a plate-laminated rectangular waveguide without change in the guided wavelength.

3. Loss Evaluation by Experiment

The plate-laminated rectangular waveguides with different lengths are fabricated by pressure bonding in 39 GHz band. The dimension of the waveguide cross-section is 5×2 mm. The thickness of metal plates is 0.4 mm in common, and the total number of the etched plates with three types of etching patterns is seven. As the initial approach, the minimum diameter and spacing at $d = s = 1.5$ mm are accepted, and the distance g is also fixed at its minimum of 1.0 mm. The total loss with both the conductor loss and leakage at 38.75 GHz is estimated at 0.03 dB/cm by including the conductivity of copper (58.1×10^6 S/m) in HFSS.

Figure 9 is the photograph of plate-laminated rectangular waveguides, which to be fed by the standard waveguides WR-28. A full two ports measurement is conducted by using a network vector analyzer. The total losses including both the insertion and transmission losses at 8.75 GHz are summarized in Fig. 10 for three waveguides with different lengths. The transmission loss is evaluated by fitting the data linearly, and corresponds to the gradient of 0.137 dB/cm. This value is more than four times of the estimated one, and is as large as double compared to the post-wall waveguide [5]. Similarly, the frequency characteristics of transmission losses are obtained.

4. Conclusion

The plate-laminated rectangular waveguide is to be realized by pressure bonding with high mass-productivity. The etched plates with pre-processed concave-convex structures, where the electric contact can be realized only at those special points, are bonded together by applying a pressing at ambient temperature. The transmission loss and phase are estimated by simulating this plate-laminated waveguide with both the gap and two rows of posts in HFSS. The effects of gap height, diameter, spacing and position of the concave-convex structures on the leakage and phase delay are investigated in detail. The total loss at 38.75GHz is estimated at 0.03 dB/cm in HFSS and evaluated at 0.137 dB/cm by measurement.

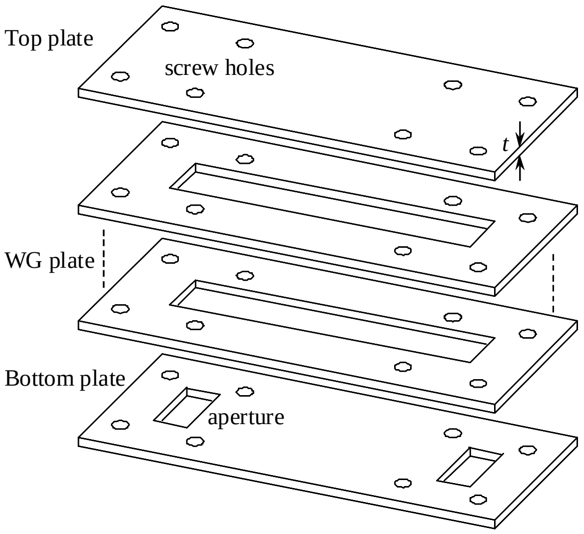

Figure 1: Plate-Laminated Rectangular Waveguide.

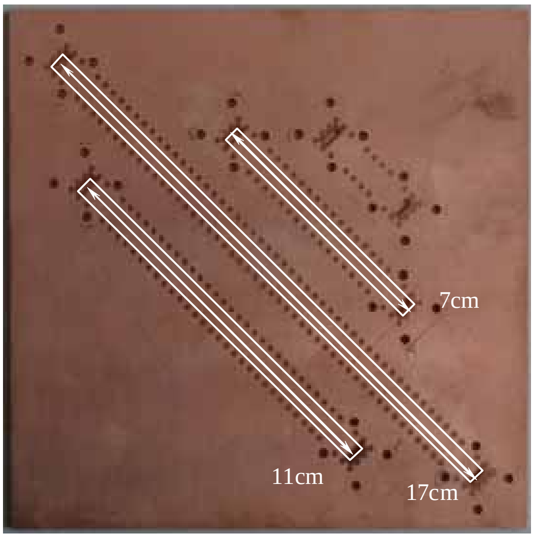

Figure 9: Photograph of Waveguide Fabricated by Pressure Bonding

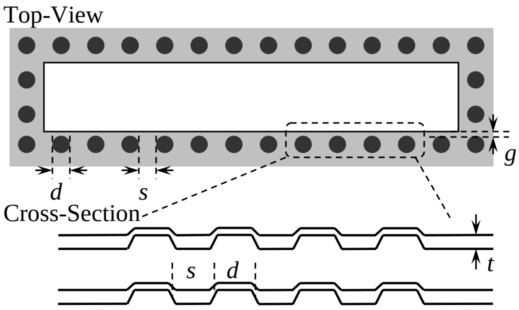

Figure 2: Rectangular Waveguide with Concave-Convex Structures on the Periphery

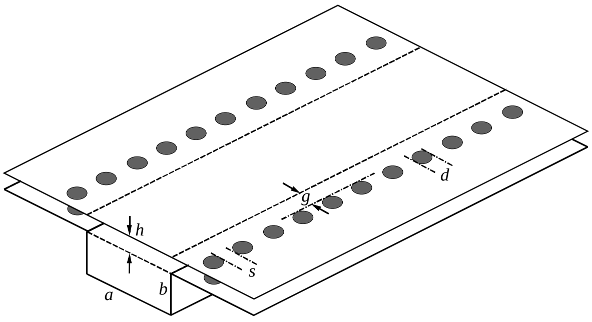

Figure 3: HFSS Simulation Model for the Plate-Laminated Waveguide

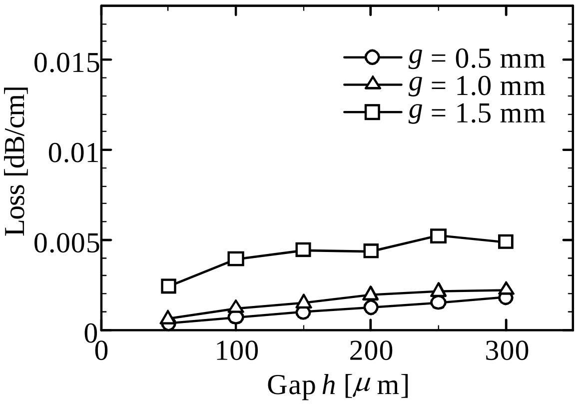

Figure 4: Transmission Loss as a Function of *h*.

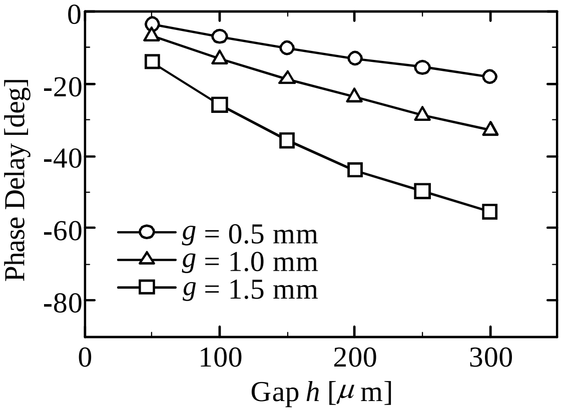

Figure 5: Phase Delay as a Function of *h*.

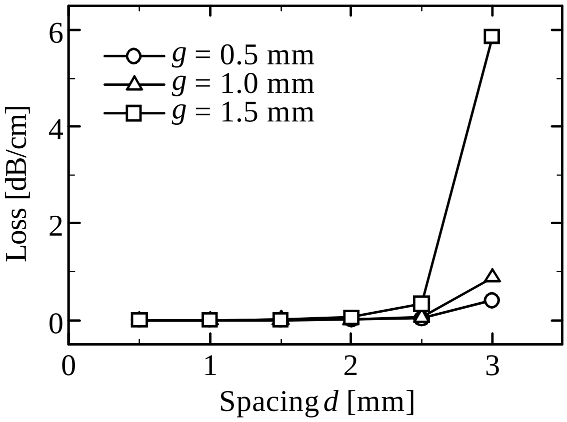

Figure 6: Transmission Loss as a Function of *s*.

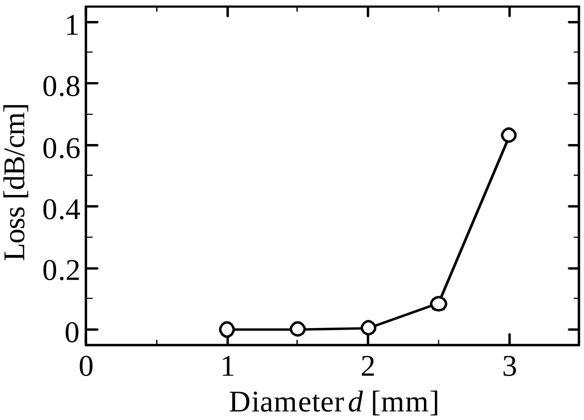

Figure 7: Transmission Loss as a Function of *d*.

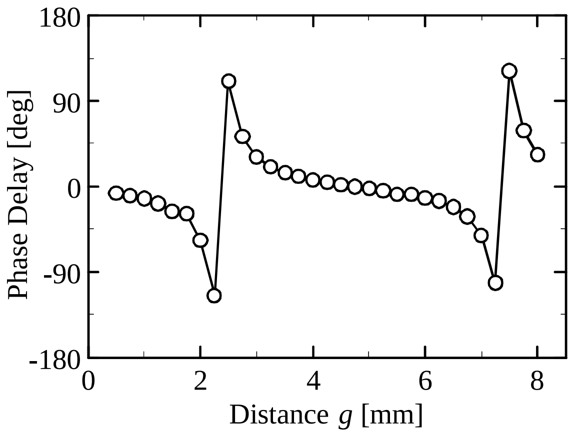

Figure 8: Phase Delay as a Function of *g*.

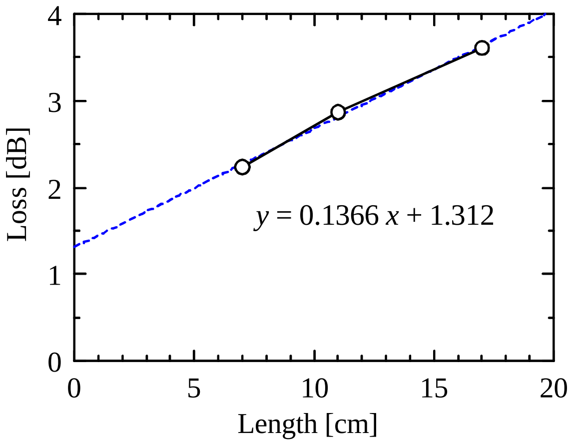

Figure 10: Transmission Loss of the Laminated Rectangular Waveguide @ 38.75 GHz.

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