Basic study of 79 GHz Band Resin Waffle-Iron Ridge Guide

Yutaka Aoki[#], Hiroshi Tanaka[#], Hiroyuki Kamo[#], Takashi Shimizu[*]
[#]Taiyo Yuden Co. Ltd., Japan
[*]Utsunomiya University, Japan
yutaka-aoki@jty.yuden.co.jp, tshimizu@cc.utsunomiya-u.ac.jp

***Abstract*— In this paper, a millimeter wave (mmWave) transmission technology applying a waffle-iron ridge guide (WRG) technology is described. A circuit layer is molded on an aluminum plate and an acrylonitrile butadiene styrene (ABS) plate using precision machine cutting technology. The ABS resin layer would be copper plated to get conductivity. Insertion loss (IL) in the 79 GHz band is approximately 0.4 to 0.6 dB (/30mm), the performance of the copper plated product is better. The skin effect (in consideration of surface roughness) is also mentioned using 3D EM simulator. The simulation results and the measurement results are in good agreement.**

***Keywords*— Waffle-iron Ridge Guide, transmission line, resin, waveguide, sub-THz, millimeter wave(mmWave), copper plating, ABS, aluminum plate.**

I. Introduction

The wireless data rate has been increasing at a faster pace. According to Edmonds law, the wireless data rates have doubled every eighteen months over the last three decades and it predicted that tera-bit-per-second (Tbps) link speed will even be achieved before 2030 [1], facilitating capacity well beyond current networks. To support the prediction, transmission line technology (namely. WRG) using mmWave to sub-THz waves is expected. The WRG is short for waffle-iron ridge wave guide that consists of a metal plate and metal plate with ridges and rods [2]-[4]. This was also known as a "Gap waveguide", which is published by P. -S. Kildal *et al* [5],[6].
Generally, the WRG and the Gap waveguide are fabricated from metal conductor plates and their weight are a little bit heavy. In order to resolve the problem, some 30 GHz band resin-based gap waveguide device has been reported using 3D printing technology and metallization technology [7]-[9]. However, there are few reports of a resin-based WRG technology in the W band.

In this paper, a 79 GHz WRG transmission by a resin material and a copper plating using a precise machining cutting processing technology is presented. The organization of this paper is as follows. Section II describes the basic principle of WRG, section III presents the prototype sample, and section IV presents the measurement results. Finally, conclusions are described in Section V.

II. Basic Principle of Waffle-Iron Ridge Guide

The operating frequency of the WRG is determined from a ridge part and rods part, which are shown in Fig.1. The ridge part operates a transmission line. And, the rod part operates as the artificial perfect magnetic conductor (PMC) wall. Thus, the height of ridge and rods and the distance between rod to rod are required to be nearly equal to λ/4. In this study, the dimension of the WRG is optimized from the initial value based on a quarter wavelength λ/4 by the eigen value calculation with periodical boundary condition by a commercially available FEM simulator.

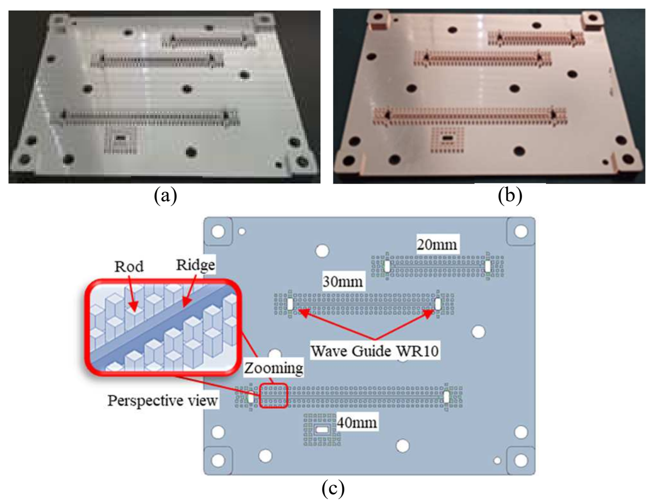

Fig.1. Prototype of the WRG (circuit layer). (a): made of aluminum, (b): made of ABS with copper plating and (c): design drawing. The copper plating thickness is almost 12 µm.

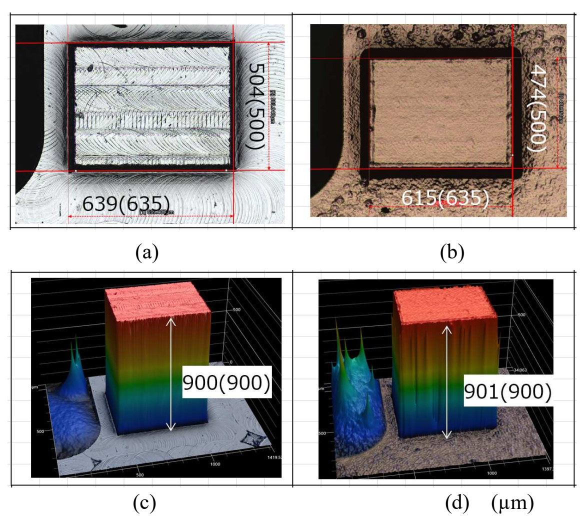

Fig.2. The precise shape measurement results of the rods. The numbers in () are design values. (a) is made of aluminum, (b) is made of resin (ABS) with copper plating. (c) and (d) show analysis images of the laser microscope, which image correspond to the above one. The surface roughness(rms) is (a):0.57µm and (b):1.89µm, respectively.

III. Resin Waffle-Iron Ridge Guide

A. Fabricated Resin and Aluminum Waffle-Iron Ridge Guide

An acrylonitrile butadiene styrene (ABS) was used to evaluate the performance of a resin WRG, also an aluminum one was fabricated in order to ensure the comparability as a reference model. The ABS type WRG was made by precise machining cutting technology. Then it was copper plated. In the plating process, after pre-treatment (degreasing → roughening → reduction), a seed layer is formed by electroless Cu plating, and a mirror surface is formed by electrolytic Cu plating.

The plating thickness is 12 μm. Fig.1 shows circuit layer of the WRG. The precise shape measurement result using laser microscope (VK-X3000, Keyence) shown in Fig.2. Regarding the precision machining cutting, the horizontal plane accuracy of the aluminum one is in the range of ±5 μm from the design value, and the resin one is in the range of ±25 μm.

IV. Results and Analysis

In order to analyze the WRG's performance, S-parameters were measured and simulated. A vector network analyzer (VNA) (N5247B, Keysight Technology) was used for the measurement, and 3D EM simulator (HFSS, ANSYS) was used for the simulation. The measurement set up is shown in Fig. 3. The measurement results of S-parameters are shown in Fig. 4, and the comparison data with the simulation are shown in Fig. 5, respectively.

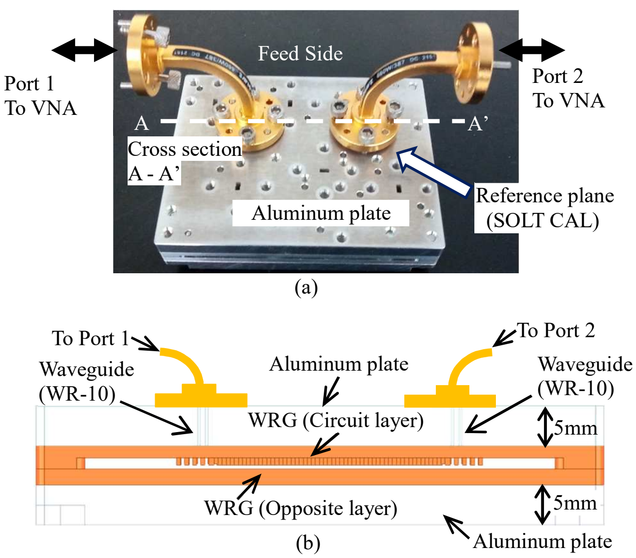

Fig. 3. (a): Photography of the measurement setup with 2 aluminum plates and two WR-10 waveguides (bends) mounted on the aluminum plate. The SOLT (short, open, load and thru) method was used for calibration. The reference plane is as same as the top aluminum surface. (b): Cross sectional (A–A') view of the measurement setup.

It was found that the insertion loss of the high precision copper plating product is smaller than the aluminum product from Fig.4. One of the reasons for this would consider to be the influence of the resistance value of the material. Simulation data for each material are shown in Fig. 5(a): (aluminum) and (b): (copper), respectively. From Fig. 4(c), it can be confirmed that both products are good matched at 79 GHz. In order to see the influence of the skin effect, a simulation considering the surface roughness was performed as well. Fig. 5 shows, it can be seen that these products obtained good result as simulated data. One of the reasons for the slight difference from the simulation data (0.1–0.2 dB) is considered to be the effect of surface roughness. The simulation data (blue dush line) is also calculated with the effect of roughness.

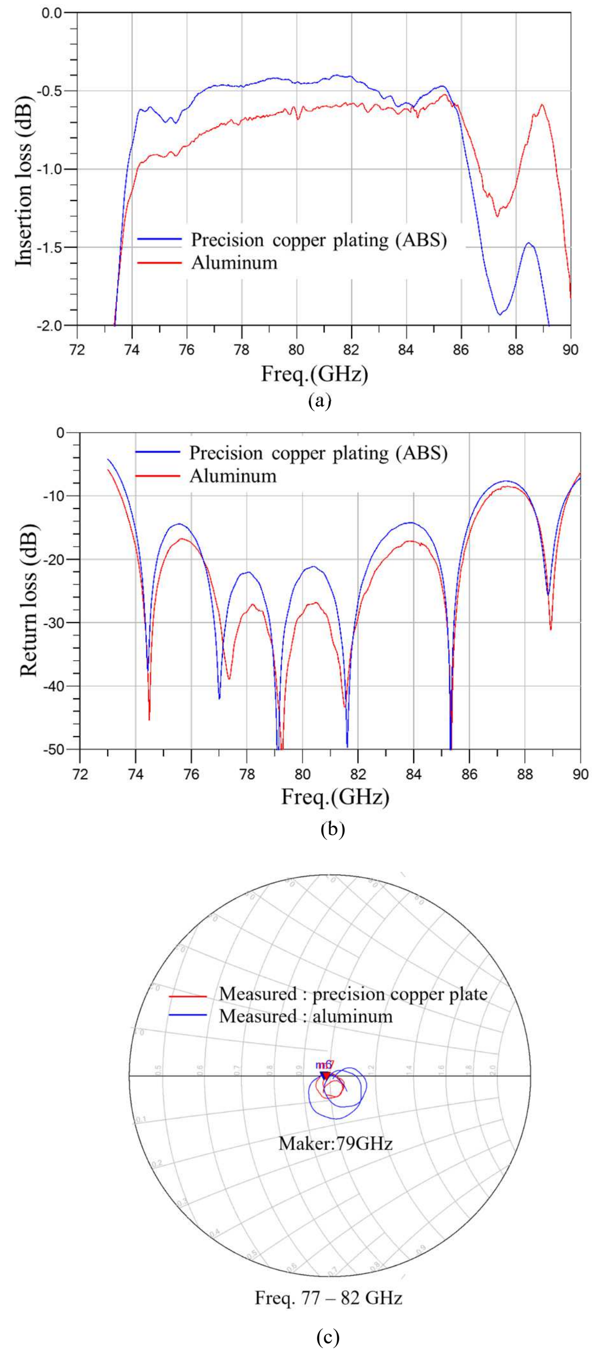

Fig.4. The results of measured S-parameters (including both the waveguide parts (WR-10)). (a): insertion loss, (b): return loss and (c): the smith chart indicates the reflection of measured S-parameter. It can be seen that they are good matched at 79 GHz.

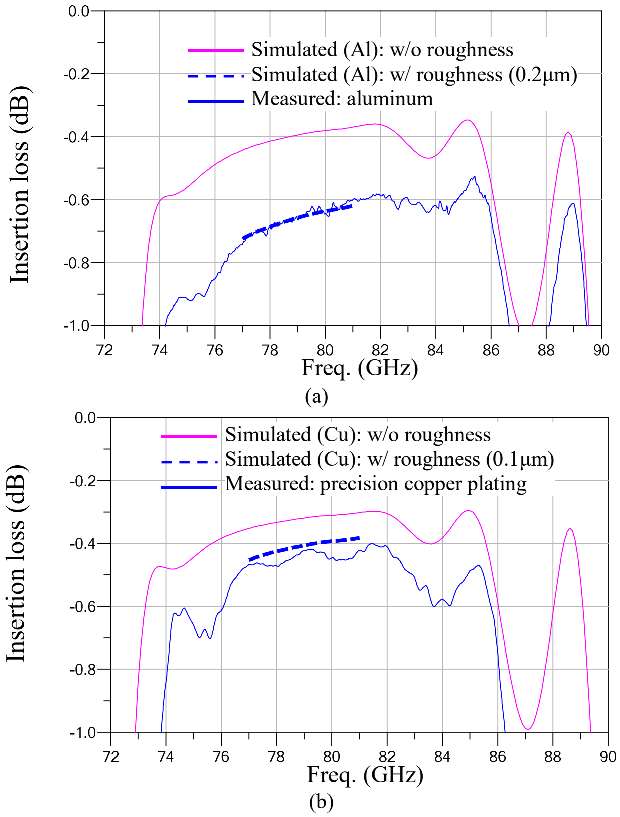

Fig.5. Comparison of measured and simulated insertion loss. The WRG line length is 30 mm. (a): aluminum, (b): copper plating. The simulation data is calculated with the effect of roughness, (a) w/o roughness and w/ roughness (0.2μm), (b) w/o roughness and w/ roughness (0.1μm). Simulated conductivity; aluminum (3.8×10^7 S/m), copper (5.8×10^7 S/m).

V. Conclusion

The millimeter wave (79GHz) transmission line applying WRG technology has been evaluated. The WRG circuit layer has been formed on aluminum plate and ABS plate using precision machine cutting technology, respectively. The ABS resin pattern would be copper plated to get conductivity. IL in the 79 GHz band is approximately 0.4 to 0.6 dB (/30mm), the performance of the copperplated product is better. The ability to realize high-frequency transmission lines with a combination of resin and plating is attractive in terms of cost and weight.

References

[1] T. Kürner and S. Priebe, “Towards THz Communications - Status in Research, Standardization and Regulation,” Journal of Infrared, Millimeter, and Terahertz Waves, vol. 35, no. 1, pp. 53-62, 2013.

[2] H. Kirino, K. Ogawa, and T. Ohno, “A variable phase shifter using a movable waffle iron metal and its applications to phased array antennas,” in Proc. IEICE ISAP Intl. Symp., Aug. 2007, vol. 4B3-2.

[3] H. Kirino, K. Ogawa, and T. Ohno, “A variable phase shifter using a movable waffle iron metal plate and its applications to phased array antennas,” IEICE Trans. Commun., vol. E91-B, no. 6, Jun. 2008.

[4] H. Kirino and K. Ogawa, “A 76GHz Multi-Layered Phased Array Antenna Using a Non-Metal Contact Metamaterial Waveguide,” IEEE Trans. Antennas Propag., vol.60, No.2, pp. 840-853, Feb. 2012.

[5] P.-S. Kildal, E. Alfonso, A. Valero, and E. Rajo, “Local metamaterial-based waveguides in gaps between parallel metal plates,” IEEE Trans. Antennas Propag. Lett., vol. 8, pp. 84–87, 9, Sep. 2009.

[6] P.-S. Kildal, E. Rajo, E. Alfonso, A. Valero, and A. U. Zaman, “Wideband, lowloss, low-cost, quasi-TEM metamaterial-based local waveguides in air gaps between parallel metal plates,” in ICEAA2009, Torino, Italy, Sep. 2009.

[7] A. Tamayo-Domínguez, J. -M. Fernández-González and M. Sierra-Pérez, "Groove Gap Waveguide in 3-D Printed Technology for Low Loss, Weight, and Cost Distribution Networks," IEEE Transactions on Microwave Theory and Techniques, vol. 65, no. 11, pp. 4138-4147, Nov. 2017

[8] B. Al-Juboori et al., "Lightweight and Low-Loss 3-D Printed Millimeter-Wave Bandpass Filter Based on Gap-Waveguide," IEEE Access, vol. 7, pp. 2624-2632, 2018

[9] Ferrando-Rocher, Miguel, et al. “Performance assessment of gap-waveguide array antennas: CNC milling versus three-dimensional printing,” IEEE Antennas and Wireless Propagation Letters 17.11 (2018): 2056-2060.