1C5-2

Design of Broadband Microstrip-to-Waveguide Transition in Multi-Layer Substrate

Masato HIRONO, Kunio SAKAKIBARA, Nobuyoshi KIKUMA, Hiroshi HIRAYAMA
Nagoya Institute of Technology
Gokiso-cho, Showa-ku, Nagoya, 466-8555, Japan
E-mail sakaki@nitech.ac.jp

1. Introduction

Millimeter-wave technologies have been developed for applications such as broadband high-speed wireless communication systems, automotive radar systems and high angular resolution microwave sensors. Microstrip antennas are more advantageous than other millimeter-wave antennas at the viewpoints of low profile and low cost. The antenna is connected to the backed RF circuits through the waveguide in the millimeter-wave module as shown in Fig. 1. Therefore, microstrip-to-waveguide transition (MSL-WG transition) is required at the connection between the waveguide and RF circuits [1]. We have already reported broadband transition composed of an open-ended waveguide, a single-layer substrate and metal block with back-short waveguide [2]. Multi-layer substrate such as LTCC configuration is well known to integrate many RF-circuits into small substrate [3].

Back-short waveguide of the transition can be replaced by multi-layer substrate with metal plate and surrounding via holes. In this case, additional metal block for the back-short waveguide is not necessary. A novel transition in multi-layer substrate is proposed to operate over broad frequency bandwidth. The configuration and simulated performance are presented in this paper.

2. Structure of the Proposed Transition

Structure of the novel transition in multi-layer substrate is shown in Fig. 2. Multi-layer substrate is on the aperture of open-ended metal waveguide. This substrate is composed of three layers. Top and bottom layers are Teflon based substrates ($\epsilon_r = 3.48$, tan$\delta = 0.0035$). They are sticked by adhesive layer ($\epsilon_r = 3.54$, tan$\delta = 0.004$) on the middle. Figure 3 shows printed patterns of the metal planes. Upper back-short waveguide is composed of vertical walls of via holes and a metal plate in AA'-plane. Surrounding via holes reduce leakage of parallel plate mode transmitting into the substrates. The signal microstrip line on CC'-plane is perpendicular to the waveguide. The probe at the end of the signal line is inserted into the waveguide. Since dielectric is filled in the upper waveguide, the wavelength in the waveguide is shorter than that of a metal waveguide and cut-off frequency of higher order mode becomes lower. Therefore, higher order mode exists in the upper waveguide when the dimensions of the waveguide is the same with that of the open-ended metal waveguide (WR-10 : a=2.54 mm, b=1.27 mm). So, the dimensions of the upper waveguide are designed to be small as shown in Fig. 3 in order to suppress the higher order mode. Dimensions of the substrate aperture in DD'-plane connected to the lower metal waveguide is defined as a' and b'. Design parameters of proposed transition is length l of the probe inserted into the waveguide, length p of the extended ground from the center line of the via holes and thickness t_1 of top layer in dielectric substrate. Thickness t_1 of the top substrate is very important parameter which dominates resonant frequency. However, it is difficult to optimize the substrate thickness at the manufacturing point of view. So, we chose one of the thickness from standard substrates. Fine frequency tuning is implemented by other parameters l and p in the printed pattern. Major parameters are optimized at the design frequency 76.5 GHz by using an electromagnetic simulator of finite element method.

ISBN: 978-4-88552-223-9 C3055©IEICE

3. Simulated Performance

As a result of the parameter optimization under the condition of thickness $t_1 = 0.25$ mm of top layer [2], length l of the probe inserted into the waveguide is determined as 0.31 mm and length p of the extended ground is 0.41 mm. Figure 4(a) shows reflection S_{11} and transmission S_{21} of the proposed transition. It can be seen that S_{21} is 0.79 dB at 76.5 GHz and bandwidth of S_{11} lower than −20 dB is 6.8 GHz. Therefore, low loss and broad frequency bandwidth is confirmed although the back-short waveguide is composed of dielectric material and it is relatively high permittivity. In order to evaluate the effects of the small dimensions of upper waveguide width, the characteristics of the transition whose upper waveguide is the same dimensions with the lower metal waveguide is shown in Fig. 4(b). S_{21} drops at 72 GHz due to higher order mode. Therefore, return loss at 76.5 GHz increases significantly. By reducing the width of the upper waveguide, frequency where S_{21} drops shifts to higher frequency 83 GHz. Consequently, transmission S_{21} is improved at 76.5 GHz and the bandwidth of reflection is extended as shown in Fig. 4(a). Figure 5 shows RMS value of electric field on BB'-plane at 76.5 GHz. The red color is strong field and the blue color is weak field. It can be seen that the electric field concentrates at the center of the waveguide when waveguide width is small. On the other hand, when waveguide width is large, electric field distributes not only at the edge of the probe but also and at the other side of the waveguide. Thus, the higher order mode is observed when the width of waveguide is large. Figure 6 shows reflection S_{11} and transmission S_{21} depending on the broad-wall width a' and narrow-wall width b'. It can be seen that the frequency where S_{21} drops shifts to higher frequency by reducing the width a' and b'. For the design of broadband matching characteristics, Figure 7 shows reflection S_{11} and transmission S_{21} depending on the extended ground p and the probe length l. The electromagnetic coupling between microstrip line and waveguide is changed when length l is varied. Therefore, the level of reflection S_{11} is changed. On the other hand, length p decreases, resonant frequency shifts to higher frequency. Thus, the resonant frequency can be controlled by changing p without optimizing substrate thickness t_1.

4. Conclusion

A novel transition composed of multi-layer substrate is proposed in this paper. Wide bandwidth 6.8 GHz of reflection and low insertion loss 0.79 dB are obtained by simulations in the millimeter-wave band. Future study is to apply this transition to the substrate with high permittivity.

Acknowledgments

We express our gratitude to DENSO CORPORATION for fabrication of the transition.

References

[1] H.Iizuka, T.Watanabe, K.Kato, K.Nishikawa, "Millimeter wave microstrip line to waveguide transition fabricated on a single layer dielectric substrate," IEICE Trans., vol.E85-B, pp.1169-1177, 2002.

[2] Y.Deguchi, K.Sakakibara, N.Kikuma, H.Hirayama, "Design and optimization of millimeter-wave microstrip-to-waveguide transition operating over broad frequency bandwidth," IEICE Trans., vol.E90-C, No.1, pp.157-164, 2007.

[3] G.Strauss, W.Menzel, "A novel concept for mm-wave MMIC interconnects and packaging," Proc. IEEE MTT-S Int. Symp. Dig., pp.1141-1144, 1994.

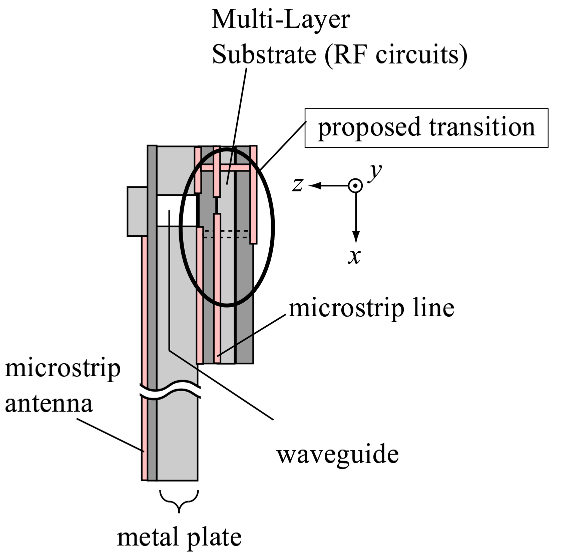


Figure 1: Connection between the Antenna and RF curcuits

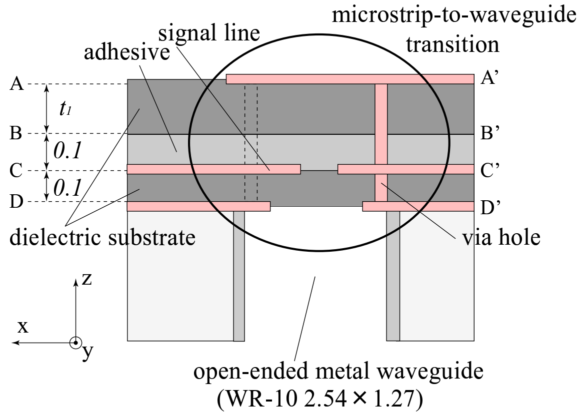


Figure 2: Cross Sectional View of the MSL-WG Transition in Multi-Layer Substrate

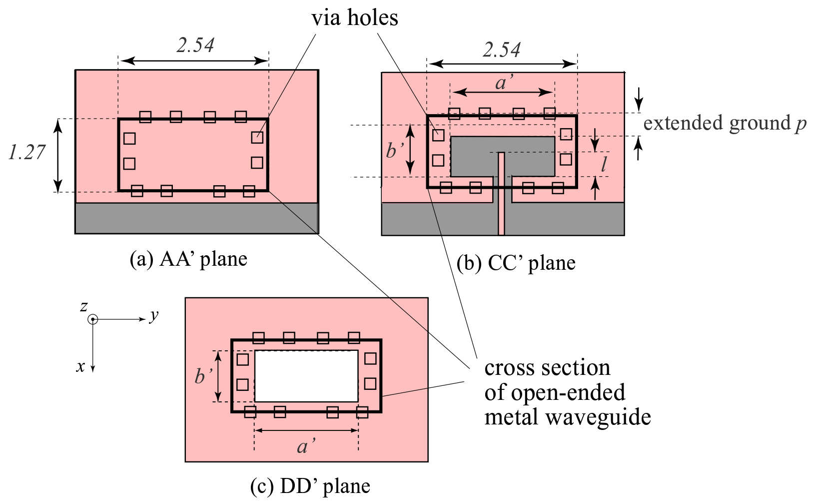
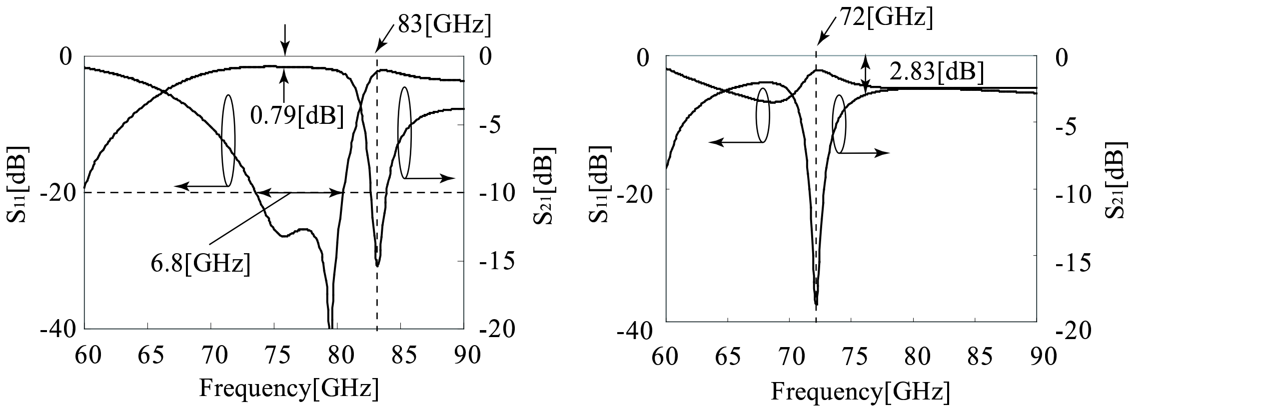


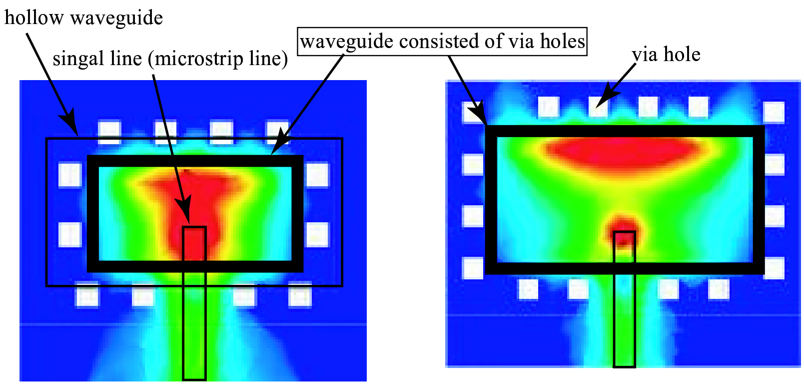
Figure 3: Printed Pattern of the Metal Plates of the Proposed Transition



(a)Waveguide Width is Narrow

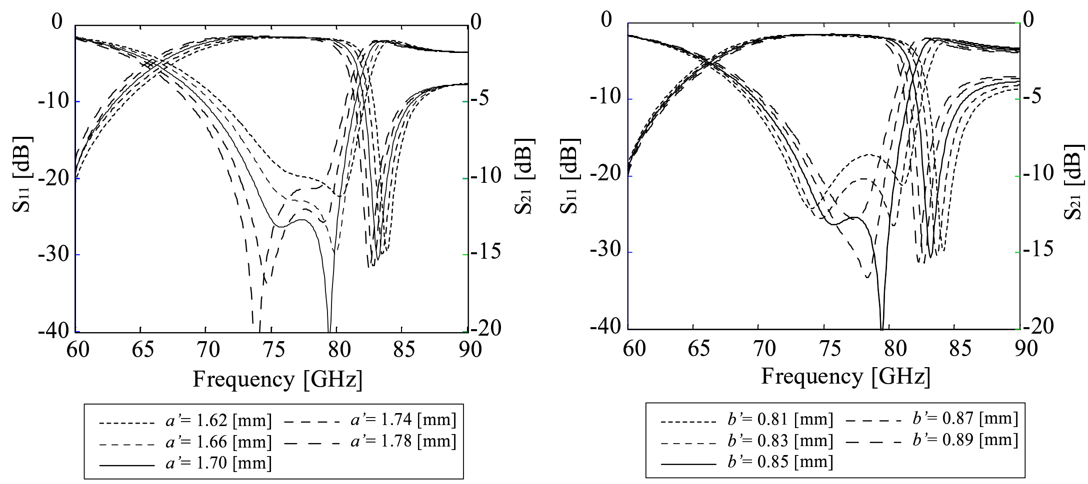
(b)Waveguide Width is the Same with that of Standard Waveguide

Figure 4: Simulated S_{11} and S_{21} of Transition



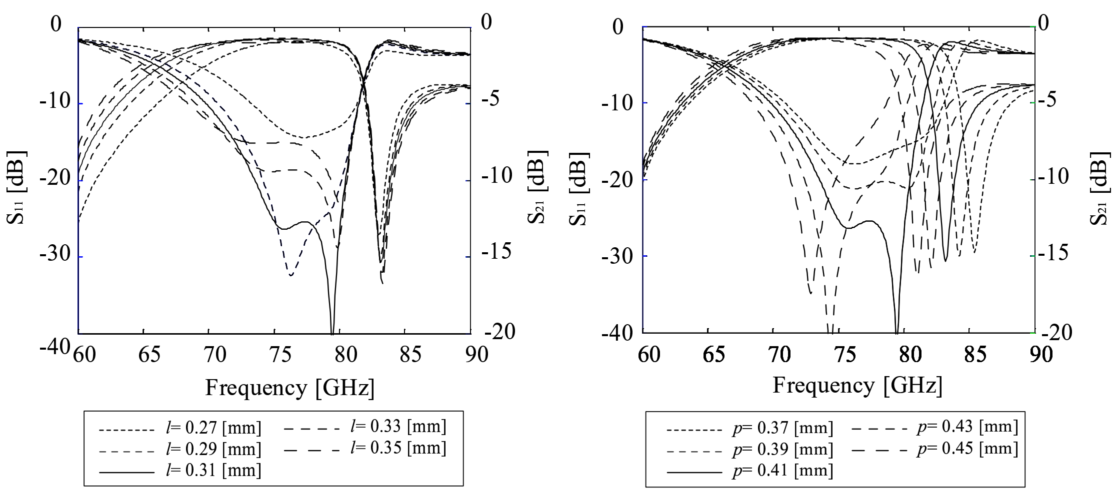
(a)Narrow waveguide width (b)Wide waveguide width

Figure 5: RMS Value of Electric Field with the Narrow Waveguide Width and Wide Waveguide Width



(a) Variation of Wide Waveguide Width a' (b) Variation of Narrow Waveguide Width b'

Figure 6: Simulated S-Parameter with Variation of a' and b'



(a) Variation of Inserted Length *l* (b) Variation of Extended Length *p*

Figure 7: Simulated S-Parameters with Variation of l and p