Bandwidth of Multi-Port Microstrip-to-Waveguide Transitions in Millimeter-Wave Band

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1. Introduction

Various types of microstrip-to-waveguide transitions are developed for feeding microstrip antennas and for connection of RF circuits in the millimeter-wave band. Ordinary transitions are composed of a microstrip line on the substrate inserted into the back-shorted waveguide with spacing of a quarter wavelengths from the microstrip line to the short circuit. Broad frequency bandwidth is achieved by using a back-shorted waveguide with the novel metal pattern on the substrate [1]. However, the metal block for the back-shorted waveguide causes performance degradation due to shift of the metal block from the waveguide center. Requirement of the additional part of the metal block causes further disadvantage for cost reduction.

Two types of transitions are developed to prevent using the metal block. One is a transition with the back-shorted waveguide in a multi-layer substrate [2]. A microstrip line is located on the lower substrate attached over the open-ended waveguide. The back-shorted waveguide is formed in the upper layer of the additional substrate. Consequently, the transition is composed in the double layer substrate. In this case, bandwidth is narrower than the previous transition with a metal block but is still broader than the next transition of the single layer substrate. Another solution is a transition with a single layer substrate [3]. The waveguide is shorted by the upper metal ground plane on the substrate. A microstrip line is inserted into the ground plane, which results in the coplanar line. The electromagnetic wave from the waveguide excites the microstrip patch at the center of the waveguide aperture on the lower plane of the substrate. The electric current on the patch couples to the coplanar line and transmits to the microstrip line port. Mode transformation is achieved from the waveguide to the microstrip line.

Transitions with multi microstrip-line ports are useful for feeding array antennas. Therefore, the transition with a single-layer substrate is applied to the multi-port transitions with one, two and four microstrip lines in this study. Multi microstrip-lines are inserted into the upper ground plane on the substrate. Electric current on the patch couples to the multi coplanar lines and equal power transmits to all microstrip-line ports simultaneously.

Three types of transitions are introduced as transitions with a metal block for the back-shorted waveguide, single and double layer substrates. Bandwidths of these transitions are compared in Sec. 2. Transitions with multi microstrip-line ports are designed and bandwidths are compared in Sec. 3.

2. Bandwidth and Configuration of Transitions

Three types of microstrip-to-waveguide transitions are developed for variety of bandwidth and structure complexity. One is a transition with a metal block for the back-shorted waveguide as is shown in Fig. 1 (a). A substrate with metal pattern is set on the open-ended waveguide. The aperture on the substrate is covered by a back-shorted waveguide. The novel pattern with an extended ground and a probe offset, shown in Fig. 1 (b), is proposed for double resonance to extend bandwidth. To prevent using the metal block, a transition in a double layer substrate is proposed. The structure is shown in Fig. 2 (a). A back-shorted waveguide is embedded in the top layer of the double substrate. To prevent generating higher order mode in the dielectric filled waveguide, the dimensions of the waveguide fixed by via holes are designed to be smaller than the standard waveguide as shown in Fig. 2 (b). The simplest structure is allowed for the transition in the single layer substrate. The total structure is completed only by a substrate on the open-ended waveguide as shown in Fig. 3 (a). The microstrip line is inserted into the metal short on the upper plane of the substrate. Electric current on the patch at the lower plane of the substrate, shown in Fig. 3(b), couples to the coplanar line. A low profile transition is realized. Reflection S_{11} and transmission S_{21} are simulated and measured to compare the bandwidths as shown in Fig. 4. Simulated bandwidths for S_{11} lower than –20 dB of the transitions with back-shorted waveguide (a), with double-layer substrate (b) and with single-layer substrate (c) are 32.5, 9.2 and 2.0 %, respectively.

3. Multi-Port Single-Layer Transitions

Multi microstrip-line port transitions from a waveguide are useful to feed array antennas. Microstrip-to-waveguide transitions with one, two and four microstrip-line ports are developed by using a single layer substrate. Variety of the printed patterns on the upper plane of the substrate is shown in Fig. 5. Three types of two-port transitions are compared in bandwidth. Transition (a) is only a combination of a one-port transition and a power divider independently designed. Transition (b) is a similar in structure with (a) but all dimensions are optimized by electromagnetic simulation of whole structure including mutual coupling effect between the transition and the closely located divider to reduce the total size. The most compact transition is composed of two microstrip lines independently inserted into the metal ground plane. To couple the currents on the patch and multi coplanar lines, width of the patch is designed to be large. Transitions with multi microstrip-line ports from both waveguide broad walls are also designed as well, shown in Figs. 6 (a) and (b).

Reflection S_{11} and Transmission S_{21} are simulated to compare the bandwidths in both two-port and four-port transitions as shown in Figs. 7 and 8, respectively. In Fig. 7, simulated bandwidths for S_{11} lower than –20 dB of the transition connected with Y-junction (a), Y-junction integrated transition (b) and two-line inserted transition (c) are 3.0, 3.0 and 3.8 %, respectively. In Fig. 8, simulated bandwidths for S_{11} lower than –20 dB of the Y-junction integrated transition (a) and four-line inserted transition (b) are 3.4 and 4.7 %, respectively. Bandwidths for microstrip-line-inserted transitions indicated in Figs. 5 (c) and 6 (b) are broad because the patches are wide to couple the patch to the multi coplanar-lines.

4. Conclusion

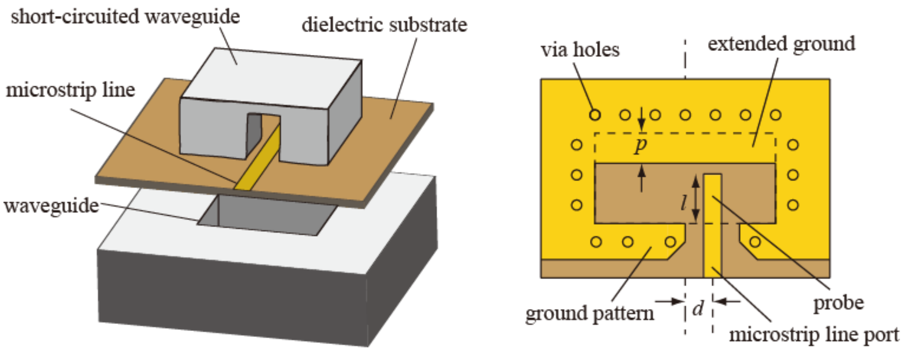
Three types of microstrip-to-waveguide transitions are developed. One is a transition composed of a substrate on the open-ended waveguide and a metal block for short-circuited waveguide. The metal block is required but bandwidth is broad. Other transitions with single and double layer substrate are narrower bandwidth but a metal block is not necessary. Multi port transitions are developed by using a single layer substrate. Almost the same bandwidths are obtained independently for one, two and four microstrip line ports. Bandwidths for transitions of microstrip line inserted into the upper metal ground plane are broad because the patches are wide to couple the patch to the multi coplanar-lines.

References

[1] 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. on Electronics, Vol.E90-C, No.1, pp.157-164, Jan. 2007

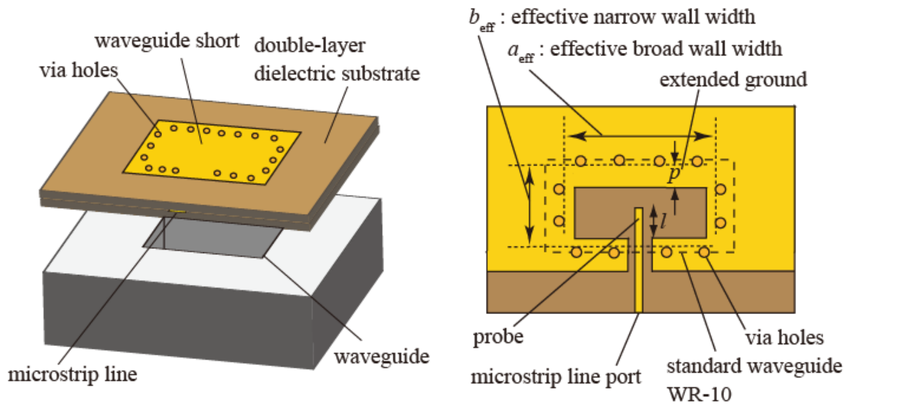
[2] M. Hirono, K. Sakakibara, N. Kikuma, H. Hirayama, “Design of broadband microstrip-to-waveguide transition in multi-layer substrate,” International Symposium on Antennas and Propagation, ISAP2007, 1C5-2, pp. 125-128, Niigata, 2007

[3] H. Iizuka, T. Watanabe, K. Sato and K. Nishikawa, “Millimeter-Wave Microstrip Line to Waveguide Transition Fabricated on a Single Layer Dielectric Substrate,” IEICE Trans. on Commun., Vol.E85-B No.6 pp.1169-1177, June 2002



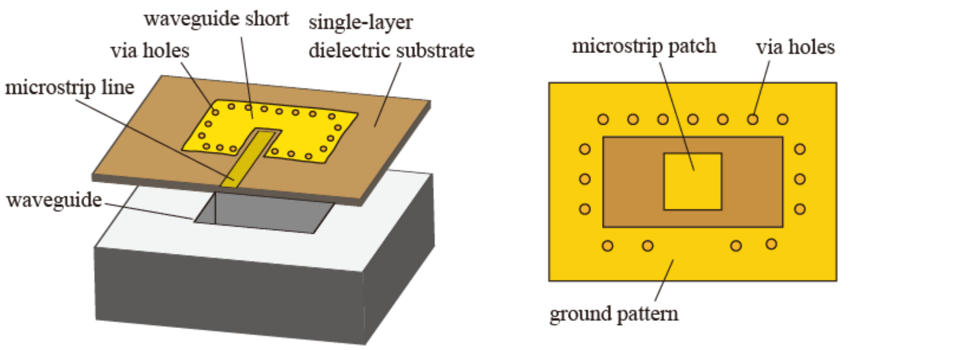
(a) Configuration of the transition (b) Printed pattern on the upper plane of the substrate

Figure 1: Transition with short-circuited waveguide



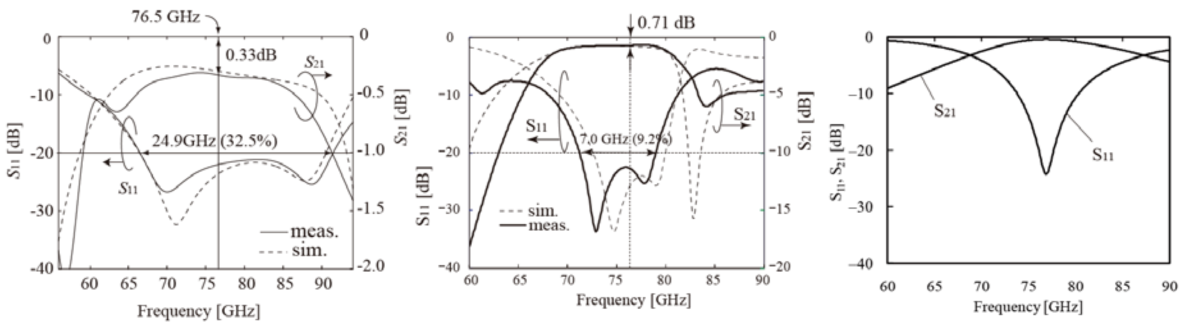
(a) Configuration of the transition (b) Printed pattern on the inner plane of the substrate

Figure 2: Planar transition in multi-layer substrate



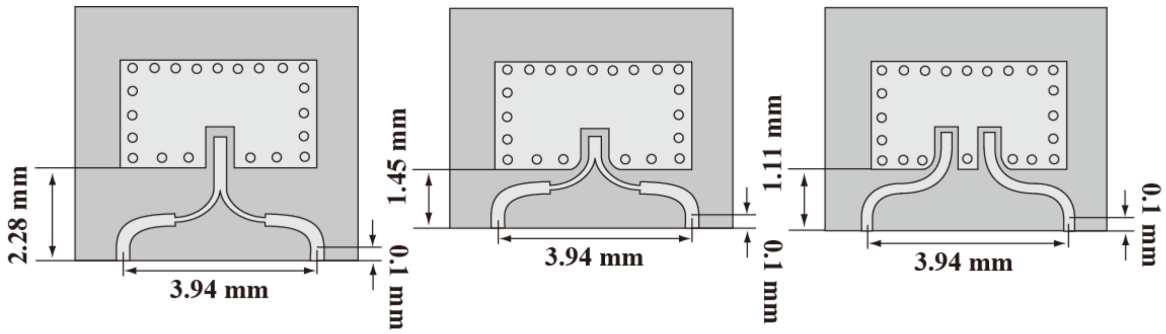
(a) Configuration of the transition (b) Printed pattern on the lower plane of the substrate

Figure 3: Planar transition in single-layer substrate



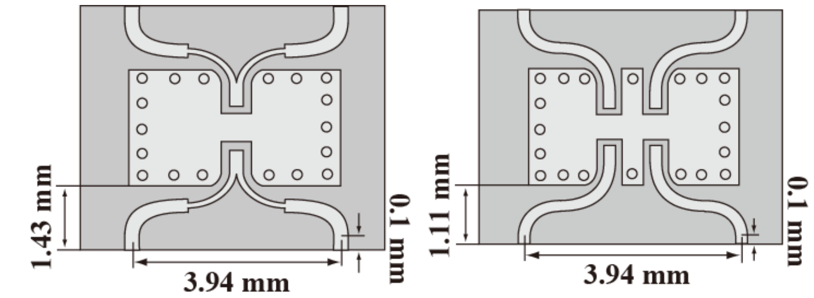
(a)Transition with metal block (b) Transition with double layer substrate (c) Transition with single layer substrate

Figure 4: Scattering parameters S_{11} and S_{21} of transitions



(a) Transition connected with Y-junction (b) Y-junction integrated transition (c) Two-line inserted transition

Figure 5: Three types of two-port transition with single-layer substrate



(a) Y-junction integrated transition (b) Four-line inserted transition

Figure 6: Two types of four-port transition with single-layer substrate

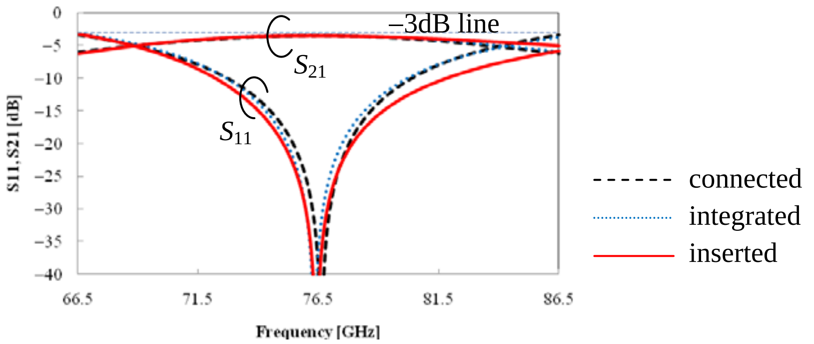


Figure 7: Scattering parameters of two-port transitions

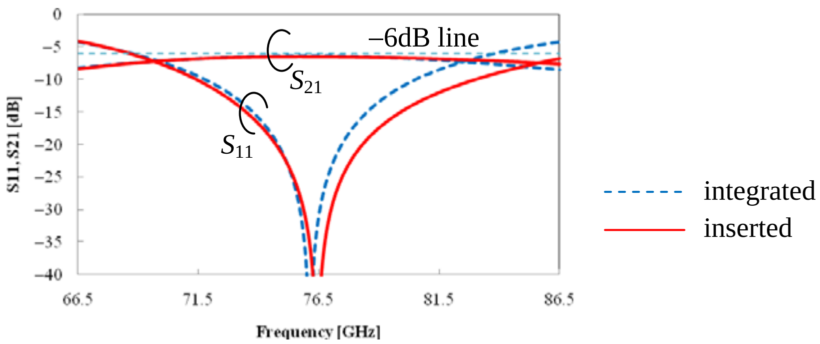


Figure 8: Scattering parameters of four-port transitions