Research Report

Millimeter-Wave Microstrip Line to Waveguide Transition Fabricated on a Single Layer Dielectric Substrate

Hideo Iizuka, Toshiaki Watanabe, Kazuo Sato, Kunitoshi Nishikawa

Abstract

A new type of microstrip line to waveguide transition fabricated on a single layer dielectric substrate is proposed. As a result of experiments, low transmission loss of 0.4 dB was realized at the design frequency of 76.5 GHz. Bandwidth of the transition was numerically investigated by the finite element method. It was clarified that the bandwidth of the transition became wider as the cross section of the waveguide became smaller and twice as wide as that of a conventional microstrip patch antenna element fabricated on a dielectric substrate with the same parameters. In addition, the effect of error in the relative position between the dielectric substrate and the waveguide was also investigated. It became clear that degradation of transmission characteristics was less than 0.1 dB for a manufacturing accuracy within ±0.1 mm.

Keywords Millimeter-wave, Transition, Microstrip line, Waveguide, Finite element method

1. Introduction

The millimeter-wave front-end module for an automotive radar sensor is generally composed of an antenna placed on the front surface of the sensor head and a millimeter-wave circuit inside it. As the antenna for the radar sensor, several types of antennas, a slotted waveguide antenna[1)], a triplate antenna[2)], a dielectric lens antenna[3)], a dielectric leaky wave antenna[4)] and a microstrip antenna[5)], have been studied. The microstrip antenna is still a candidate in order to realize low cost and low profile millimeter-wave front-end module for the radar sensor. The microstrip antenna is usually connected to the millimeter-wave circuit through a waveguide. Thus a microstrip line to waveguide transition is required to connect them.

Since high SNR (Signal to Noise Ratio) for automotive radar is required to detect a target at a long distance of 150 m, not only the millimeter-wave components but also the transitions used to connect them are desired to be low loss. In addition, assembling tolerance becomes important for actual manufacturing, particularly in the millimeter-wave band, and has to be considered[6]. The transition is also desired to have a simple structure composed of the least number of parts and robustness for assembling errors even when assembling errors occur.

Several kinds of microstrip line to waveguide transitions have been studied. These include a ridge waveguide type[7], a probe fed type[8, 9], a slot coupled type[10, 11] and a quasi-yagi antenna type[12]. They have low transmission loss characteristics even in the millimeter-wave band, but their structures are not well suited for millimeter-wave applications.

In this paper, we propose a new type of microstrip line to waveguide transition fabricated on a single layer dielectric substrate[13,14]. The proposed transition has features of low loss characteristic, a simple structure and robustness for assembling errors. In **Chapter 2**, a configuration of the proposed microstrip line to waveguide transition is described. Performance of the transition is presented in **Chapter 3**. This paper is concluded in **Chapter 4**.

2. Configuration of proposed microstrip line to waveguide transition

We propose the microstrip line to waveguide transition shown **Fig. 1**. Conductor patterns on both surfaces of a dielectric substrate are separately illustrated in Fig. 1. The conductor pattern with a notch (it is named a waveguide short pattern because of its function) and the microstrip line located at the notch are printed on one side of the dielectric substrate. In addition that, a rectangular conductor pattern (it is named a matching element because of its function) and a ground plane fixed to the waveguide cross section are printed on the another side of it. Some via holes are arranged around the waveguide short pattern to connect electrically to the ground plane. The proposed microstrip line to waveguide transition can be easily fabricated on a single layer dielectric substrate.

Parameters and coordinate systems of the transition are shown in **Fig. 2**. Parameters of a calculated model are presented in **Table 1**. Numerical investigation was carried out by using the finite element method.

Figure 3 shows electric field distribution of each mode in the *yz* plane. In the proposed transition, low transmission loss is realized by exchanging the quasi

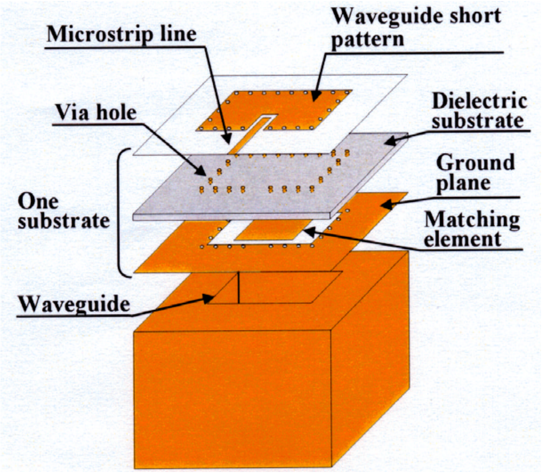


Fig. 1 Configuration of proposed microstrip line to waveguide transition.

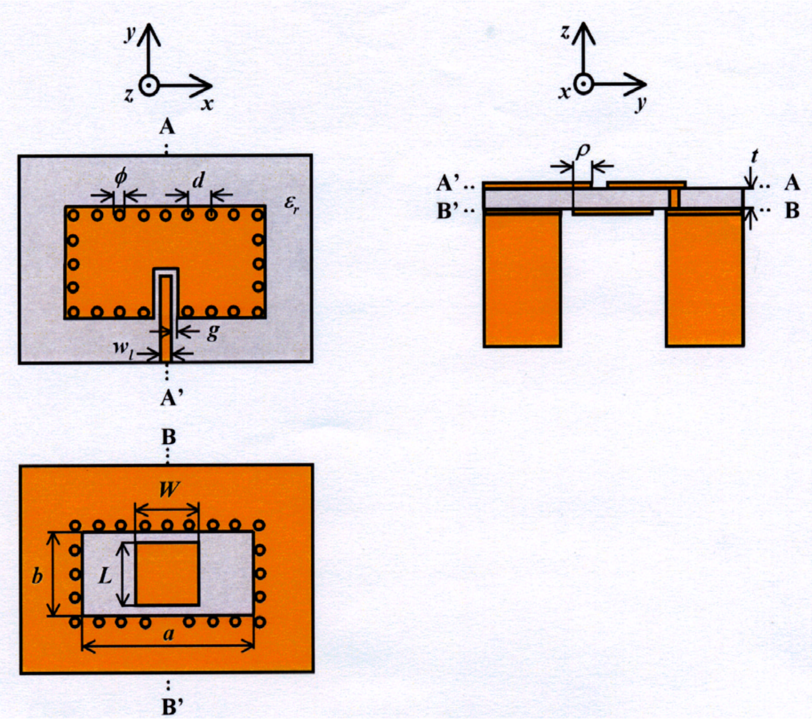


Fig. 2 Parameters and coordinate systems of proposed microstrip line to waveguide transition.

TEM transmission mode of the microstrip line and the TE_{10} fundamental transmission mode of the waveguide with high efficiency utilizing the TM_{01} fundamental resonant mode of the matching element. **Figure 4** shows calculated electric field intensity distribution in the xy plane including the BB'-line. The electric field intensity E includes x, y and z components of the electric field. We observed that the matching element is resonated in the TM_{01} mode in which the length L of the matching element is a half resonant wavelength.

Table 1 Parameters of calculated model. (Parameters of fabricated transition are represented in ( ).)

Length L of matching element	1.085 mm (1.12 mm)
Width W of matching element	1.085 mm (1.12 mm)
Length ρ of inserted microstrip line	0.195 mm (0.28 mm)
Width w_l of microstrip line	0.27 mm
Width g of gap	0.1 mm
Thickness t of dielectric substrate	0.127 mm
Relative dielectric constant ε_r	2.2
Broad wall length a of waveguide	3.1 mm
Narrow wall length b of waveguide	1.55 mm
Diameter ϕ of via hole	0.2 mm
Spacing d between via holes	0.5 mm

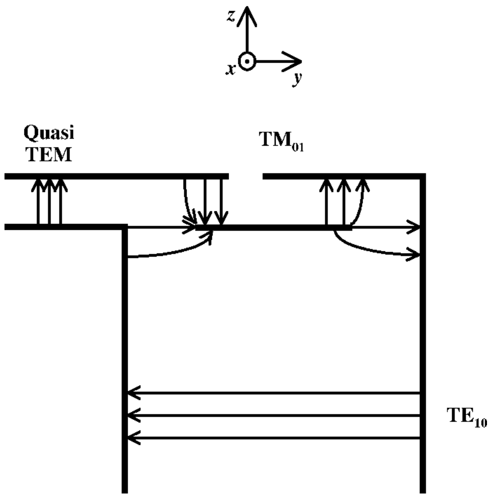


Fig. 3 Electric field distribution of each mode in yz plane. (Electric field: $\longrightarrow$)

3. Performance of proposed microstrip line to waveguide transition

3. 1 Reflection and transmission characteristics

Reflection and transmission characteristics of the transition are shown in **Fig. 5** (a) and (b), respectively. Calculated and measured results are represented by a dotted line and a solid line, respectively. The calculated results demonstrate good performance with low loss that reflection coefficient and transmission loss at 76.5 GHz are below –40 dB and 0.3 dB, respectively. Furthermore, wideband characteristic is achieved such that bandwidth below –14 dB (VSWR < 1.5) is 4.53 GHz (5.9 %). In this calculation, loss tangent $\tan\delta = 0.001$ and conductivity $\sigma = 5.8 \times 10^7$ S/m are used as loss factors. Transmission loss of 0.3 dB is separated to three kinds of losses : conductivity loss of 0.2 dB, dielectric loss of 0.05 dB and radiation loss of 0.05 dB.

As a result of the experiments shown in Fig. 5 (a) and (b), low transmission loss characteristics are realized such that measured reflection coefficient and transmission loss at 76.5 GHz are –28.0 dB and 0.4 dB, respectively. Moreover, a wideband characteristic is obtained such that bandwidth below –14 dB (VSWR < 1.5) is 5.22 GHz (6.8 %).

In the fabricated transition, three parameters such as the length L of the matching element, the width W of it and the length ρ of the inserted microstrip line are compensated to be 1.12 mm, 1.12 mm and 0.25

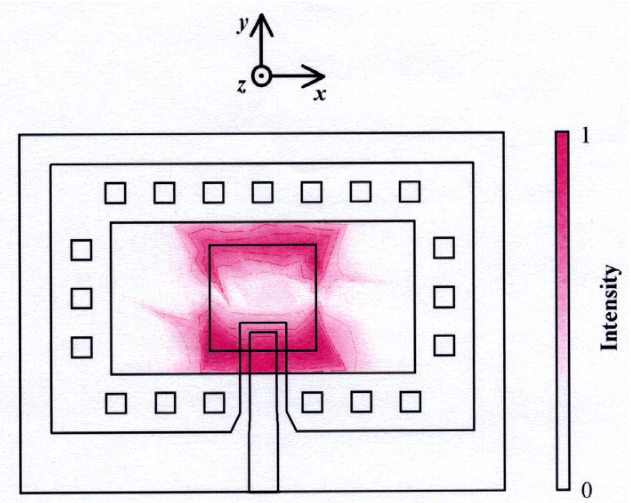
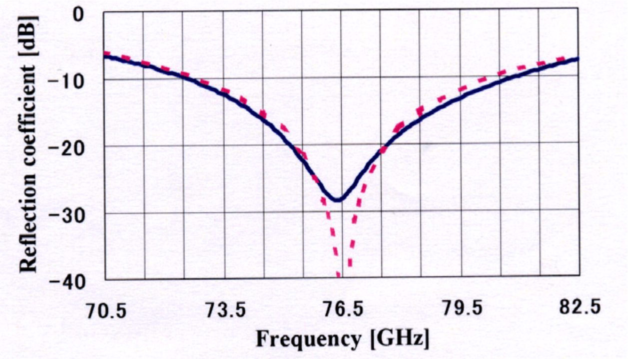


Fig. 4 Electric field intensity distribution in xy plane.

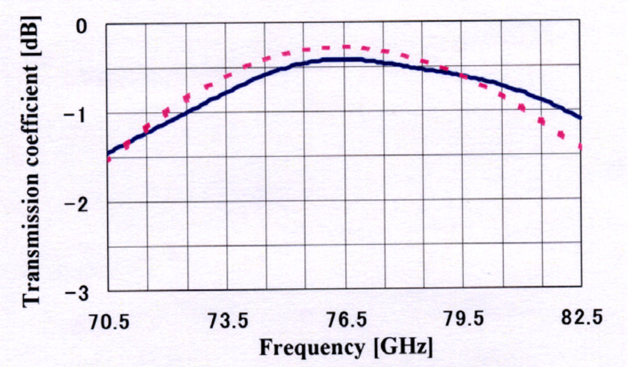
L listed in ( ) of the Table 1, which are 3 %, 3 % and 7 % longer than those of the calculated model. The compensation for the three parameters of the fabricated transition is needed and led experimentally because numerical analysis is carried out assuming that the conductor thickness of the calculation model is zero and that the shape of the corners of the matching element in the model is a right angle although the shape of the corners of actual matching element in the fabricated transition is rounded. Since the aim of this paper is mainly to clarify the relations between the parameters and the characteristics, details of the compensation are not discussed here. The assumptions are also used in **Section 3. 2** and **3. 3** in order to reduce calculation time.

3. 2 Bandwidth characteristic

Figure 6 shows the bandwidth (VSWR < 1.5) with variation of the dimensions of the waveguide. Calculation is carried out in case that the ratio of the broad wall to the narrow wall of the waveguide is constant as $a = 2b$. Bandwidth of the transition is represented by a solid line and that of the conventional microstrip patch antenna element fabricated on a dielectric substrate with the same parameters is represented by a dotted line as a reference. The conventional microstrip patch antenna element has a structure subtracting the waveguide from the structure of the transition shown in Fig. 1. As shown in Fig. 6, the bandwidth of the transition becomes wider as the dimensions *a* and *b* of the waveguide become smaller and maximum value of 6.5 %, which is twice as wide as that of the conventional microstrip patch antenna element, in case that the broad wall length *a* of the waveguide is set from 2.5 mm to 2.8 mm. Calculated transmission loss keeps a constant value of 0.3 dB at 76.5 GHz, which is independent on the dimensions *a* and *b* of the waveguide.



(a) Reflection characteristic



(b) Transmission characteristic

Fig. 5 Reflection and transmission characteristics of calculated model and fabricated transition.
(Calculated: - - - , Measured: ———)

Since not only numerical analysis but also fabrication and evaluation of the transition are goals of this paper, the dimensions of the waveguide are chosen to be the same dimensions as a network analyzer interface (WR – 12), which are 3.1 mm and 1.55 mm listed in the Table 1, in order to make an actual measurement.

3. 3 Assembling tolerance

Variation of transmission loss against the error in relative position between the dielectric substrate and the waveguide is shown in **Fig. 7**. The error in relative position is defined as the difference between the center of the matching element patterned on the

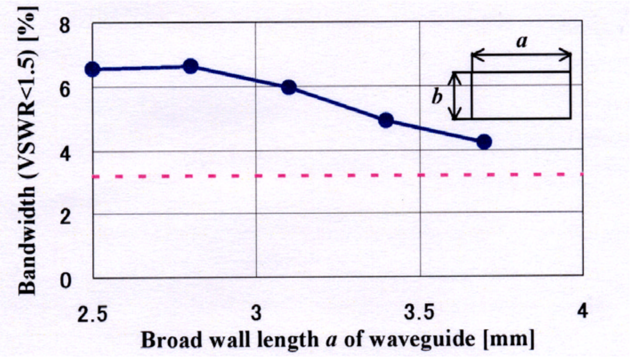


Fig. 6 Bandwidth (VSWR<1.5) of transition versus broad wall length *a* of waveguide in case of $a = 2b$. Bandwidth (VSWR<1.5) of conventional patch antenna is also presented as a reference.
(Transition: - - - , Antenna : ———)

dielectric substrate and the center of the waveguide cross section. The vertical axis represents the relative transmission loss normalized by transmission loss in case that there is no error in relative position, while the horizontal axis represents positional error Δx in the x direction and Δy in the y direction, respectively. Calculated results are shown by a circle in Fig. 7 (a) for positional error Δx and a rectangle in Fig. 7 (b) for positional error Δy. As shown in Fig. 7 (a), there is no increase of transmission loss and its value stays almost constant in case that positional error Δx in the x direction varies within ±0.2 mm. On the other hand, it can be seen from Fig. 7 (b) that transmission loss is remarkably degraded in case that positional error Δy in the y direction is out of the range from –0.08 mm to 0.14 mm. As a result of this investigation, we clarified that the minimum effect of positional error to degradation of transmission characteristics is realized when the center of the matching element is designed as 0.03 mm offset in the + y direction against the center of the waveguide cross section and that manufacturing accuracy has to be within ±0.1 mm in order to keep transmission loss less than 0.1 dB.

4. Conclusion

A new type of microstrip line to waveguide transition in the millimeter-wave band has been proposed. The proposed transition with a simple structure, low loss characteristic and robustness for assembling errors is suitable for connection between millimeter-wave components such as an antenna, an amplifier and a switch having an interface of a microstrip line or a waveguide. The millimeter-wave front-end module must have components that are suitable in cost, performance, size and reliability for the systems. The proposed transition with the above advantages is very useful to realize low cost, low profile and high SNR millimeter-wave front-end module for the radar sensor.

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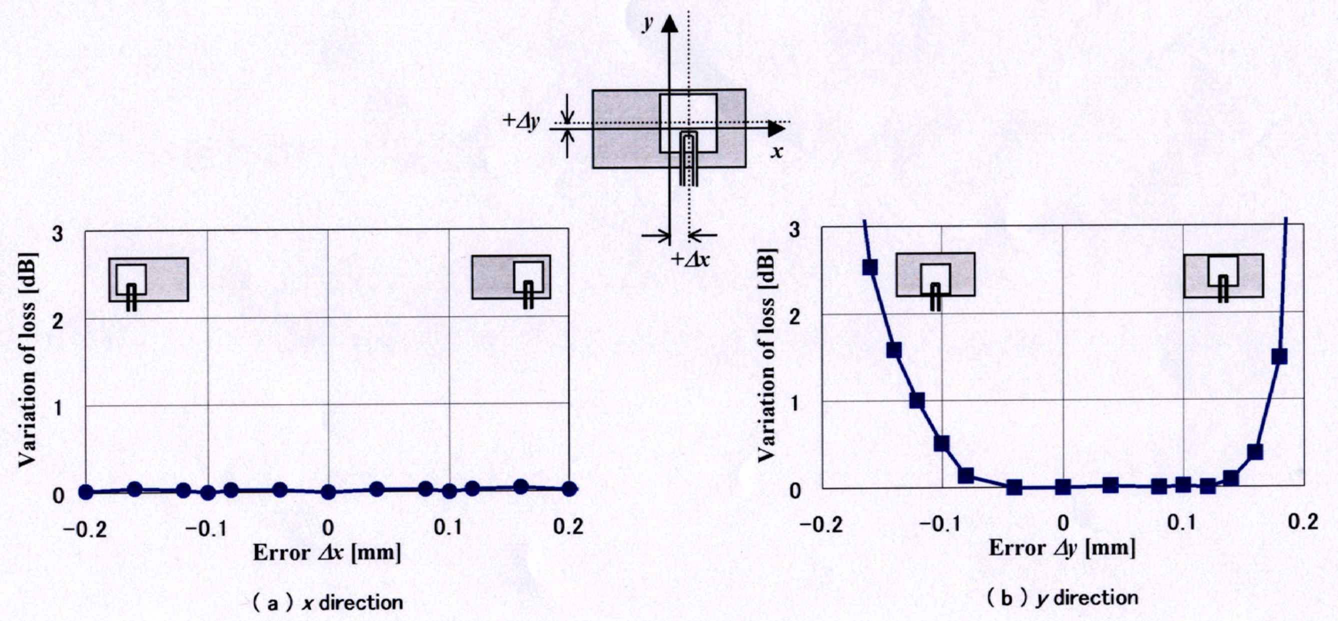

(a) x direction

(b) y direction

Fig. 7 Variation of loss versus error in relative position between dielectric substrate and waveguide.

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