Proceedings of ISAP'04, Sendai, JAPAN

Feed through an Aperture to a Post-Wall Waveguide with Step Structure

Takafumi Kai, Jiro Hirokawa, Makoto Ando
Department of Electrical and Electronic Engineering, Tokyo Institute of Technology
2-12-1, O-okayama, Meguro-ku, Tokyo, 152-8552, Japan
t-kai@antenna.ee.titech.ac.jp

1. Introduction

A post-wall waveguide is formed in a dielectric substrate by arraying metalized posts densely [1]. It is a kind of closed waveguides free of radiation loss and is an attractive candidate for low loss transmission lines in millimeter-wave bands [1]-[4]. The waveguide is easy to fabricate by making holes and plating their walls. Conventionally, it has an interface to a metal-wall waveguide through a rectangular aperture cut on one side of its broadwalls as is shown in Fig.1 (a) [1]-[3]. For matching, the post-wall waveguide is shorted at one end by additional posts.

As for the analysis of the structure, the post-wall waveguide is replaced with a metal-wall waveguide with equal guided wavelength [1]. Since the periphery of the aperture was close to the posts composing the short or side walls in the part [1]-[3], the accuracy of the analysis based upon the above replacement was not high enough; experimental adjustment was indispensable. Furthermore, the reflection and transmission are sensitive to position errors in the fabrication.

This paper proposes a step structure as is shown in Fig.1 (b), which is tolerant of the position errors. In this structure, the posts are sufficiently separated from the aperture so that the analysis based upon the replacement seems to be reliable. The reflection characteristics as well as the mechanical tolerance of the proposed structure are discussed theoretically and confirmed experimentally.

2. Structure and design

Fig.1 (b) shows the proposed structure with a step. An aperture is cut on one of the broadwalls as the interface to an external waveguide. The post-wall waveguide has a step and the width is wider around the aperture than at the other parts of the waveguide. The waveguide is shorted at the end by some posts. All the structure is symmetric about the central axis of the waveguide.

In the analysis, the post-walls are replaced with metal-walls in the equivalent position for which the waveguides have the equal guide wavelength [1]. A TE_{10} mode of unit amplitude is incident from the external waveguide. The analysis region is divided into three canonical regions according to the field equivalence theorem as shown in Fig.2. The apertures at the boundaries between adjacent regions are replaced with equivalent magnetic currents backed with perfect electric conductors. Integral equations are derived for the continuity of magnetic fields on the apertures and are solved for the unknown magnetic currents by Galerkin's method of moments (MoM). The scattering matrix for the transformer is calculated in terms of the obtained magnetic currents.

The transformer is designed at 61.25GHz to suppress the reflection for given dimensions of the post-wall and the standard waveguides. The thickness of the substrate is 1.2mm, the dielectric constant εr is 2.17 and the loss is $\tan \delta = 0.00085$ (specified at 10GHz). The post diameter is 0.5mm and the post spacing is typically 1.0mm. The parameter ai is fixed as 3.078mm, while the width of the post-wall waveguide ac is wider near the aperture. Generally, larger value of ac results in narrower bandwidth. On the other hand, some preliminary studies of tolerance of fabrication errors indicate that the spacing between the posts and the aperture edge should be larger than 1.0mm. Under the above conditions, the width ac is set to be 4.7mm for which the step width equals to typically one post-spacing or twice the post diameter (1.0mm) as in Fig.1 (b). The shorted position s and the cavity length c from the center of the aperture, and the aperture length z are determined in turns in a few iterations for given aperture length x. Figure 3 shows the parameters of s, z and c thus determined for various widths of the aperture x. When the aperture width increases, the shorted position and the aperture length become larger and the cavity length from the aperture becomes smaller.

Here, x is chosen to be small, 2.1mm or 0.6-0.7$\lambda\varepsilon$ ($=\lambda/\sqrt{\varepsilon_r}$) so that enough spacing is left on both sides of the aperture. We have calculated the frequency dependence of a transformer for $x =$

ISBN: 4-88552-206-4 C3055©IEICE

2.1mm, s = 3.49mm, z = 1.43mm and c = 2.61mm. Figure 4 (b) presents the frequency characteristics of the reflection. The black area indicated by “cal.” shows the reflection including with the errors. The bandwidth with the reflection below −25dB is approximately 12.4%.

3. Experiments and Estimation of fabrication error

In millimeter-wave applications, manufacturing errors may degrade the performance of the transformer. We assess the effects of various mechanical misalignments upon the frequency characteristics of the reflection. The proposed step structure has a larger separation between the aperture and the posts as compared with a conventional straight structure, so that it is expected to be more tolerant of fabrication errors. Another benefit of the step structure is that the larger separation enhances the reliability of the analysis based upon the replacement of metal-walls. The above two advantages, that is, the robustness of the fabrication errors and the accuracy of the analysis are verified by measurement in detail, where two kinds of misalignments are considered the side-wall and shorted posts position. In Figs 4 and 5, the dark bar indicates predicted results while the black bar indicates experiments. Figure (a) shows the reflection for the conventional straight structure while Figure (b) does for the proposed step structures.

Figure 4 shows the frequency characteristics when the side-wall position is shifted from the design by ±0.1mm. Figure (a) shows the measured and the predicted reflection for the conventional straight structure whose width of the waveguide is $ac = ai$ = 3.078mm. The change in the performance due to the side-wall position errors is not negligible. The measured reflection grows up to the level of −17dB and the change is no less than 10dB. As for the accuracy of the analysis, we recognize that large discrepancy between measurement and analysis is observed for the conventional straight structure, especially in a higher frequency bands. On the contrary in Figure (b), the measured bandwidth as well as frequency shifts for the proposed step structure is more stable for changes in the position, though the bandwidth becomes narrower by about 1.0GHz in the higher frequency bands. The measured reflection is −29.5dB at 61.25GHz and the frequency bandwidth with the reflection lower than −25dB is 11.4%. These behaviors are well predicted by the analysis for the proposed step structure.

Figs.5 (a) and (b) present the measured reflection of the straight and the step structures for the ±0.1mm error in the shorted-post position. In Figure (a) for the conventional structure, the error of −0.1mm causes a serious increase of reflection; the reflection is larger than −10dB in a range of 57.8-68.3GHz. Degradation due to the short-position error is serious. On the other hand in Figure (b) for the step structure, the degradation is much smaller than that for the conventional structure. The frequency range below −15dB in the reflection is 56.6-63.4GHz when the short position is varied. When the short position becomes smaller, the frequency bandwidth becomes narrower. The return loss degrades from −29.5dB to −20.1dB for the mechanical misalignment. As for the agreement with the prediction, higher accuracy is observed for the new step structure as is expected. The analysis results predict well the measured bandwidth broadening in lower frequencies with the short position shifts. The difference between the analysis and the experimental results are smaller than that of the conventional structure.

4. Conclusion

We have proposed an aperture coupling E-bend with step structure for the post-wall waveguide interface to an external waveguide in which the posts are separated away from the aperture. A 61.25GHz model transformer gives 11.4% bandwidth for the reflection below −25dB by using a 1.2mm-height dielectric substrate. The analysis results predict well the measured bandwidth for the reflection less than −15dB though the frequency shift of about 1.5GHz is observed. We have compared mechanical tolerances of both a conventional straight and the proposed step structures. The step structure is more robust against the mechanical errors than the conventional one. Another advantage is that the accuracy of the analysis model using the replacement by metal walls is enhanced for this step structure since the spacing between the aperture edge and the posts is larger.

Reference

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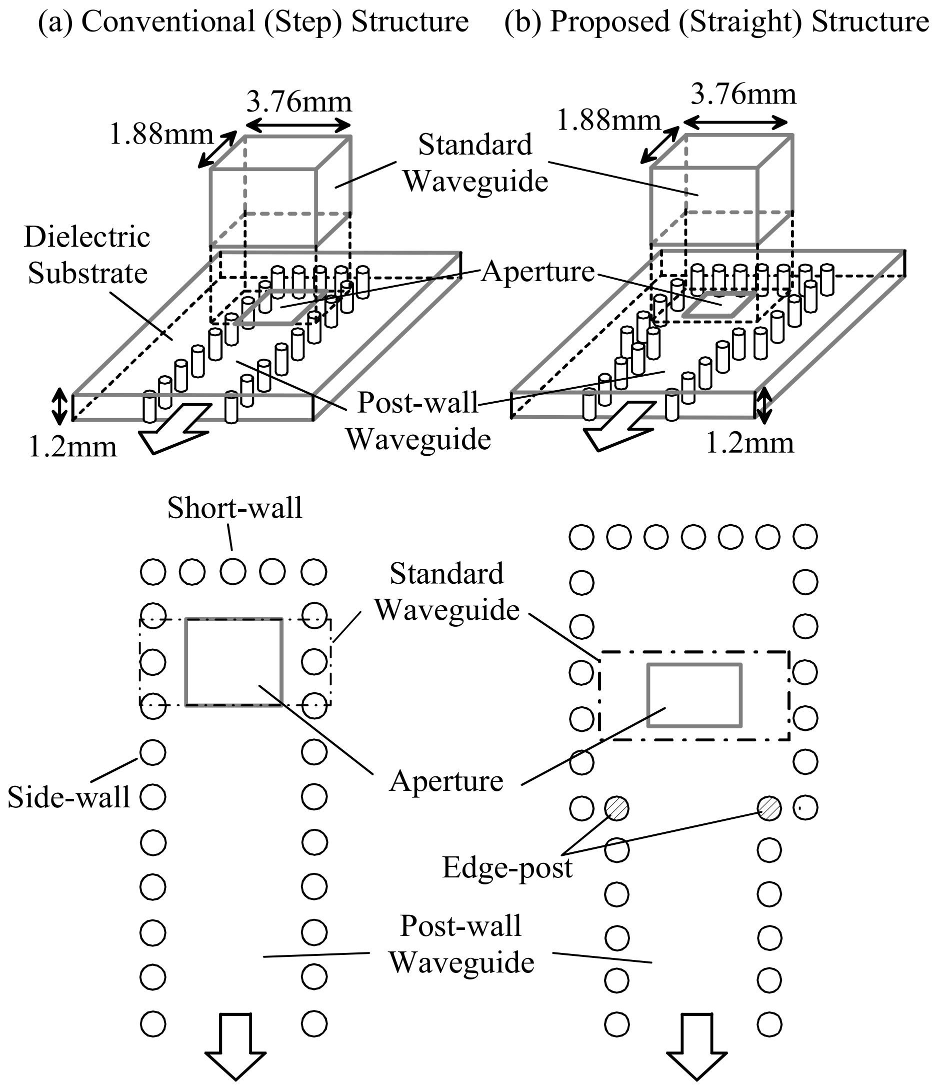

Fig.1 Feeding structure.

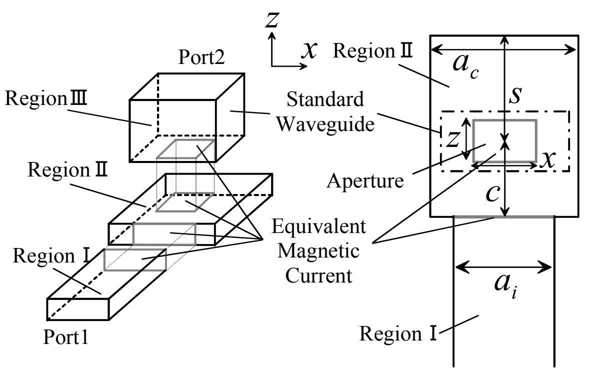

Fig.2 Analysis model of the transformer.

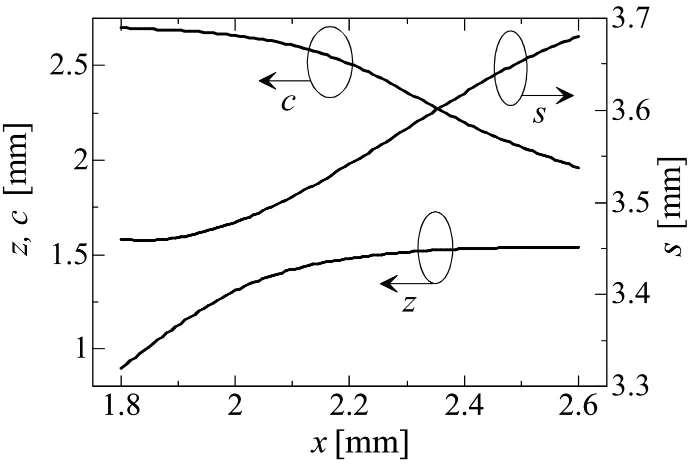

Fig.3 Short position s, aperture height z, and cavity length c as a function of aperture width x.

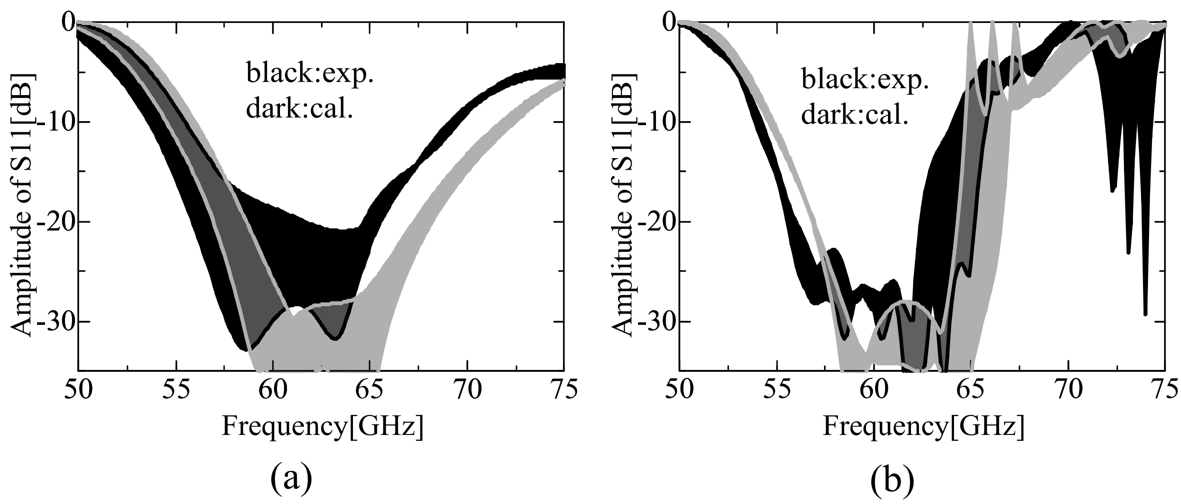

Fig.4 Side-wall position error.

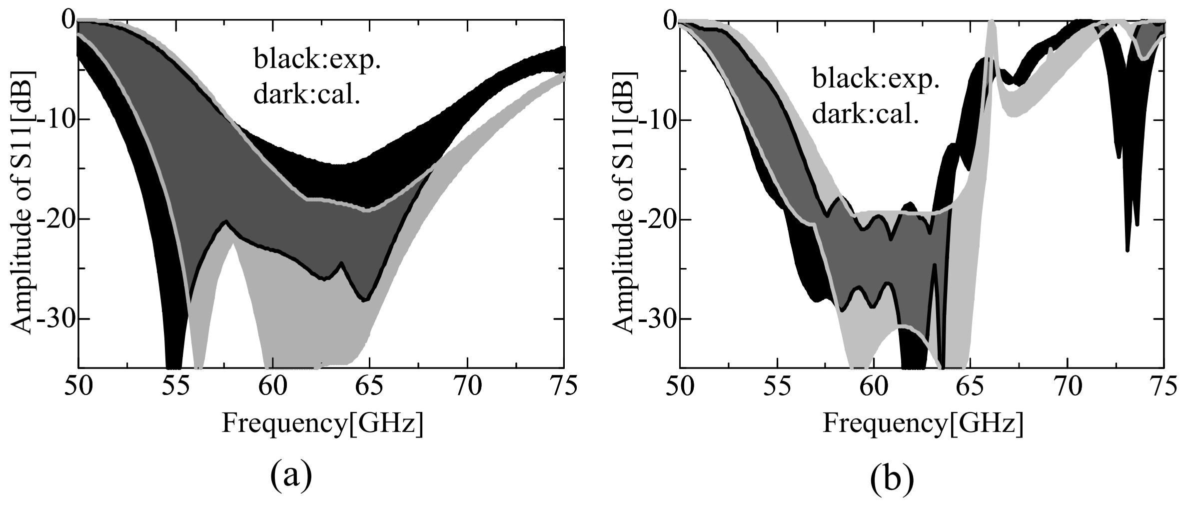

Fig.5 Shorted posts position error.