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Coupling of a circularly polarized slot pair on a corrugated waveguide of finite length

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Abstract: We analyze a circularly-polarized slot pair on a hollow rectangular waveguide of finite length with corrugations on the bottom by the method of moments. The analysis is for designing a radial line slot antenna for high-power or space applications. The reflection from the end of the corrugation array gives ripples in the slot coupling for the relative position of the slot pair but the ripples are so small that averaging of the slot coupling is acceptable for practical design of the antenna.

Keywords: slot antenna, corrugated waveguide, method of moments

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

We analyze the coupling of a circularly-polarized slot pair on an infinitely-long corrugated waveguide by analyzing it on a finite-length corrugated waveguide as shown in Fig. 1 and eliminating the reflections at the both ends of the finite-length corrugated waveguide connecting regular waveguides, because we cannot analyze the slot pair on the infinitely-long corrugated waveguide

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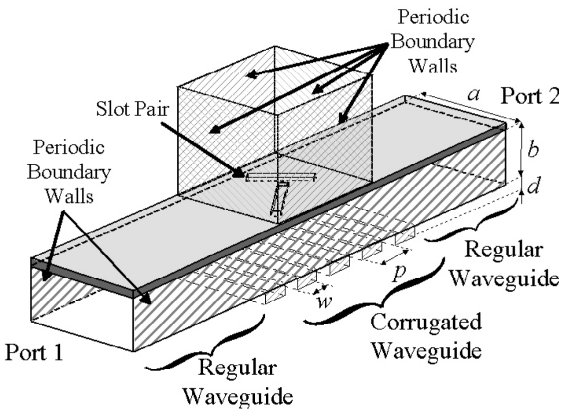

Fig. 1. Circularly-polarized slot pair on a corrugated waveguide of finite length

directly.

The analysis will be used for designing a radial line slot antenna [1] with corrugations [2] as slow-wave structure to suppress grating lobes. The radial line slot antenna is a slot array on a circular parallel plate waveguide. Slow-wave structure should be installed in a radial waveguide to suppress grating lobes because the element spacing is one guided wavelength. Generally dielectric is filled as the slow-wave structure. But dielectric could not be used in high-power or space applications. Metal corrugated waveguide is applicable especially for these applications. The slow-wave factor is defined as a ratio of guided wavelength over free-space wavelength [2]. The aperture efficiency degrades by grating lobes for larger slow-wave factor near one. The aperture efficiency increases for smaller slow-wave factor at some frequency. But the bandwidth becomes narrow for smaller slow-wave factor due to the long line effect in a series-fed array of elements. Slow-wave factor around 0.9 is good in terms of high efficiency and wide bandwidth [3]. The slow-wave factor can be controlled arbitrarily by the corrugation dimensions.

2 Analysis

Figure 1 shows the analysis model. A finite number of corrugations and a slot pair are cut on a rectangular waveguide with periodic boundary walls in the narrow walls to simulate uniform excitation of the slot pairs arrayed in the transverse direction in a parallel plate waveguide [4]. Another rectangular waveguide with two sets of periodic boundary walls is placed in the external region to simulate uniform excitation of a two-dimensional array of the slot pairs. The number of the corrugations should be large enough not to couple higher-order evanescent modes with the slot pair. The model includes not only the coupling of the slot pair but also the reflections at both ends of the corrugation array. The model is solved by the method of moments together with the modal-expansion and the field equivalence theorem [4]. We assume sinusoidal distribution over each slot and uniform distribution over each corrugation aperture for the magnetic currents. We derive integral equations for

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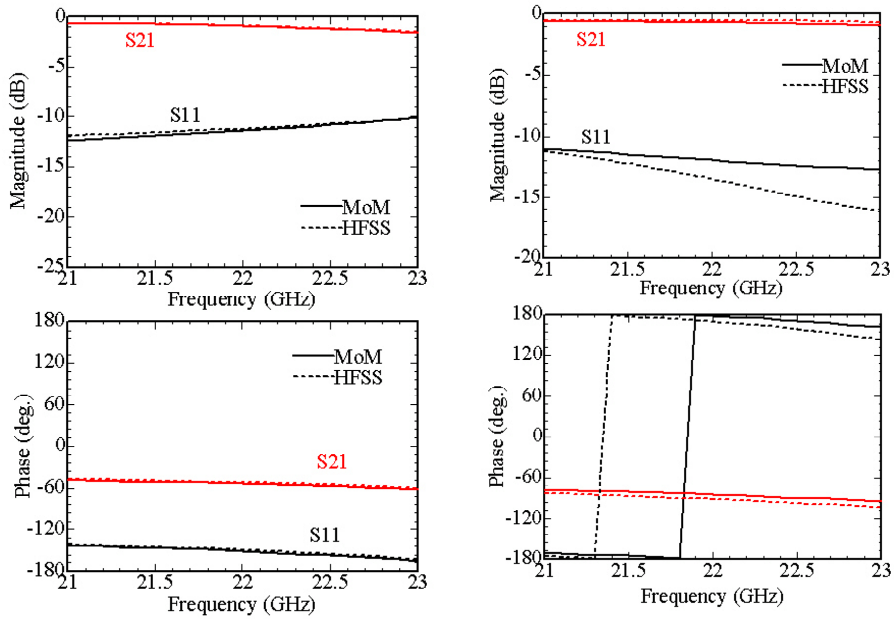
the continuity condition on the tangential component of the magnetic field in the slots and the corrugation apertures. Once we obtain the magnetic currents in the slots and the corrugation apertures, the scattering characteristics can be found.



(a) Shallow corrugations (b) Deep corrugations

Fig. 2. Scattering characteristics

Figure 2 (a) shows the scattering characteristic for shallow corrugations with the slow-wave factor of 0.88 in 22.0 GHz band. This value of the slow-wave factor is for only corrugations without slots. The waveguide width a is 8.0 mm and the slot width is 0.6 mm. The corrugation pitch p is 2.0 mm and the corrugation width w is 1.0 mm. In the shallow corrugations, their depth d is 1.1 mm and the waveguide height b is 2.0 mm. The slot length is 6.0 mm. We have good agreements between MoM and HFSS. The corrugation apertures are far enough from the slot apertures to assume the uniform distribution of the magnetic currents over the corrugation aperture. The effective slow-wave factor including the slot perturbation can be estimated from the phase of the S_{21}. The value is 0.86, which is a bit smaller than the unperturbed one, because we use non-resonant slot shorter than the resonant length to control the coupling.

Figure 2 (b) show the results for deep corrugations with the slow-wave factor of 0.77. In the deep corrugations, their depth d is 1.6 mm and the waveguide height b is 1.5 mm. The other parameters are the same to the shallow-corrugation case. In this case we have a discrepancy between MoM and HFSS. The corrugation apertures could be close to the slot aperture so that the assumption of the uniform distribution of the magnetic currents in the corrugation apertures would not be sufficient. However the slow wave factor seems to be too small a little from bandwidth point of view as men-

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tioned in the introduction, so that the shallow corrugations will be used in the following discussions.

3 Slot coupling

We analyze corrugated waveguide of finite length without slots at first so that we have reflections from the both ends. We should estimate effects of these reflections on slot coupling. The reflected power from the both ends is around 2% for the shallow corrugations. This suggests we have 1% reflection roughly from one end.

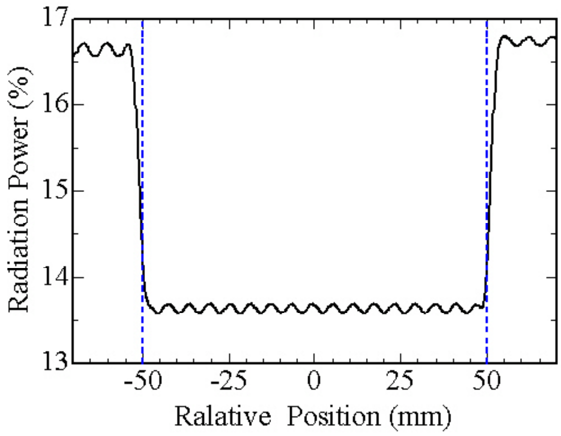

Fig. 3. Coupling for Relative Position of the Slot Pair against 51 Corrugations

Figure 3 shows the coupling for relative position of the slot pair against 51 corrugations. The relative position inside 50 mm corresponds to the case where the slots are within the corrugated region while the relative position outside 50 mm corresponds to the case where no slots are over the corrugations. The radiation power or the coupling has ripples against the relative position. The coupling is defined as the substraction of the reflected power and the transmitted power from the incident power. The period of the ripples in the corrugated region is about 6.0 mm, which is a half of the guided wavelength. This means the ripples are due to reflection from the end of the corrugation array. The ripple width is 0.13% and the averaged coupling is 13.6% for the slot length of 6.0 mm. When no slots are over the corrugations, the period of the ripples is about 6.8 mm, which is a half of free-space wavelength. This is different from the value in the corrugated region. In this region, the slot pair itself has small reflection because of the slot spacing in the pair of a quarter of the guided wavelength. Another type of ripples relating to this pitch would be possible. The pitch of the corrugations is one-sixth guided wavelength. But this type of ripples is negligible for the shallow corrugations where the corrugation apertures are far enough from the slot apertures.

The average coupling and the ripple width are calculated for various slot

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length, and then the ratio is also defined as the ripple width over the averaged coupling. The ratio is 1.0% for the slot length of 6.0 mm. It is 1.3% for the slot length of 5.5 mm, where the coupling is 3.9% and the ripple width is 0.05%. It is 1.1% for the slot length of 6.8 mm, where the coupling is 68.0% and the ripple width is 0.73%. We find the ratio is almost constant independent on the averaged coupling and it is almost equal to the ratio of reflected wave from the end of corrugations for an incident wave.

4 Conclusion

We adopt the method of moments for a slot pair with several corrugations. We evaluate quantitatively the slow-wave effect by metal corrugations and the coupling control for slot length. We find small ripples proportional to the coupling against the relative position by reflection of the end of the corrugation array. We suggest that the ripples are so small that averaging of the coupling is acceptable for practical design of the antenna.

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