Consideration on Undesired Radiation in Dielectric-Supported Tri-plate Line Filter

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Abstract

A dielectric-supported tri-plate transmission line is usually used in the centimeter wave band. It however suffers from undesired radiation in discontinuity parts, such as a band-pass filter, a junction, and so on, because it has any asymmetrical structures. In this paper, we could solve the problems by inserting the tri-plate transmission line filter into a cutoff waveguide and designed a three-pole 0.1dB ripple Chebychev band-pass filter

1. INTRODUCTION

Printed transmission lines such as a microstrip line and coplanar waveguide are often used at centimeter frequencies due to good mass productivity, but undesired radiation is excited at a curved section and discontinuities in their transmission lines [1], [2]. On the other hand, such undesired radiation is not excited in an ideal tri-plate transmission line. But undesired radiation actually occurs when a dielectric substrate, on which a center conductor is etched, is inserted in a parallel metal plate, since this structure is asymmetrical for the horizontal mid-plane. The undesired radiation causes an issue for a circuit element such as a band-pass filter having many discontinuities. In this paper, we tried to suppress the undesired radiation by inserting a tri-plate transmission line filter etched on the dielectric substrate into a cutoff waveguide. In addition equivalent circuit parameters such as an inverter parameter and a electrical line were calculated to design a filter using such tri-plate transmission line, and a band pass filter was designed by using these parameters.

2. Structure of Transmission Line

A. *Field Distribution and Structure of Tri-plate Transmission line*

Figure 1 shows a structure of the tri-plate transmission line. A copper foil etched on a dielectric substrate with a relative dielectric constant of 2.6 was inserted so as to be located at a symmetrical mid-plane in a rectangular waveguide with a height of a and a width of b. The dominant mode is a TEM wave as shown in Fig. 2. The height of a and the width of b were set to be less than half a wavelength to suppress higher modes such as TE_{10} and TE_{01} modes

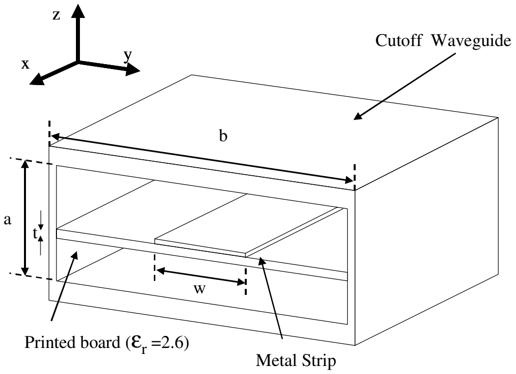


Fig.1: Structure of tri-plate transmission line

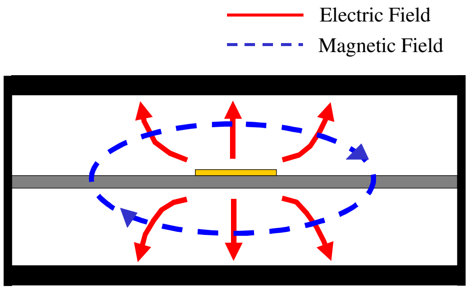


Fig.2: Electromagnetic field distribution

3. Design of Evanescent Type Band Pass Filter

A. *Equivalent Circuit of Evanescent Type BPF*

The band-pass filter was constructed by longitudinally coupling resonators with lengths of d_i through gaps with lengths of l_i as shown in Fig. 3. The gap was replaced with a K-inverter parameter with transmission lines of phase angles of ϕ_i, and then an equivalent circuit was obtained as shown in Fig. 4. The N-pole 0.1 dB ripple Chebychev filter could be represented by using this equivalent circuit as shown in Fig. 5 (b). Relationship between prototype element values of gi (i = 1, 2, …, N), a center frequency of f_0, a bandwidth of Δf, and the K-inverter parameter are given by [3]

$$\frac{K_{01}}{Z_O} = \sqrt{\frac{x}{g_0 g_1}\frac{\Delta f}{f_0}}, \quad (1\text{-a})$$

$$\left.\frac{K_{i,i+1}}{Z_O}\right|_{i=1\sim N-1} = \frac{\Delta f}{f_0}\frac{x}{\sqrt{g_i g_{i+1}}}, \quad (1\text{-b})$$

$$\frac{K_{N,N+1}}{Z_O}=\sqrt{\frac{x}{g_N g_{N+1}}\frac{\Delta f}{f_0}}\,, \qquad (1\text{-c})$$

where Z_o and x are a characteristic impedance of the tri-plate transmission line and a reactance slope parameter, respectively. The reactance slope parameter is given by

$$x=\frac{\pi}{2}\,. \qquad (2)$$

And finally we can obtain resonator lengths by requiring that the electrical line lengths d_i' between the adjacent inverters be π, that is to say,

$$d_i=\frac{1}{\beta}\left\{\pi+\frac{1}{2}\left(\phi_i+\phi_{i+1}\right)\right\}. \qquad (3)$$

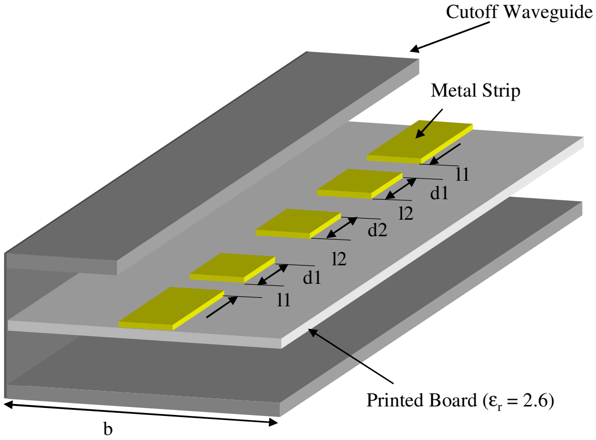


Fig. 3: Structure of tri-plate transmission line filter

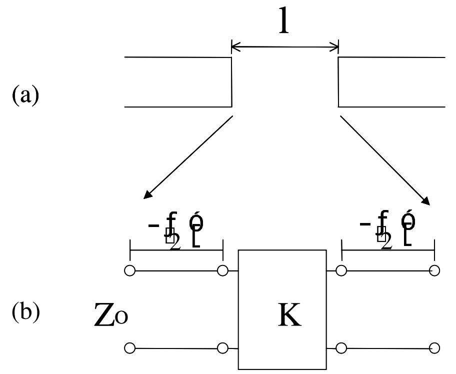


Fig. 4: A pair of gap-coupled tri-plate transmission line, (a) plane view and (b) equivalent inverter circuit with additional transmission line sections connected on both sides.

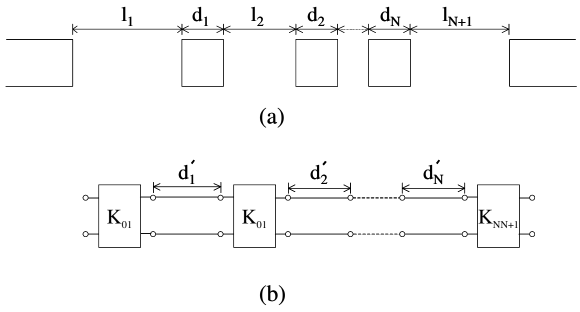


Fig.5: Gap-coupled filter, (a) plane view and (b) its equivalent circuits represented by inverters and transmission lines.

B. *Design of Evanescent Type Band Pass Filter*

We designed the 3-pole 0.1 dB ripple Chebychev band pass filter. The design specifications were a center frequency of 12.45 GHz and a relative bandwidth of 4 %. A thickness of a dielectric substrate with a relative dielectric constant of 2.6 was set to be 0.5 mm. A height, a, of the cutoff waveguide was set to be 4 mm so as to be less than half a wave length. A width of b was set to be 8 mm so as to cutoff the undesired TE_{10} mode. The K-inverter parameter and phase angle versus gap length were analyzed by using HFSS, and the analyzed results are shown in Fig. 6. The gap and resonator lengths were calculated by using the analyzed K-inverter parameter and phase angle. Scattering parameters of the BPF with these dimensions were analyzed, and the analyzed scattering parameters are shown in Fig. 7 as solid curves. From these results, the bandwidth and center frequency were similar to those of the design specifications. Next, scattering parameters of the filter are shown in Fig.7 as dashed curves where the width of the waveguide was enlarged to be from 8 mm to 20 mm to intentionally excite the TE_{10} mode for comparison. The insertion loss did not deteriorate at the pass band, but the characteristic at a stop band changed below –15 dB. From these results, the bandwidth and center frequency were not changed by such rectangular waveguide structures at centimeter frequencies.

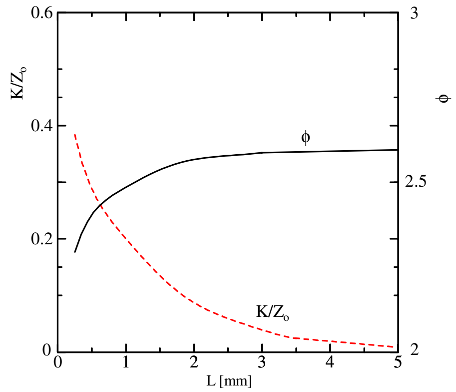
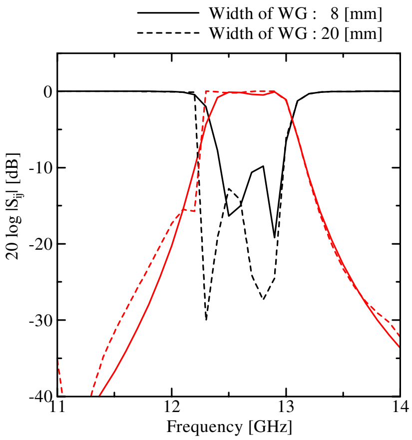
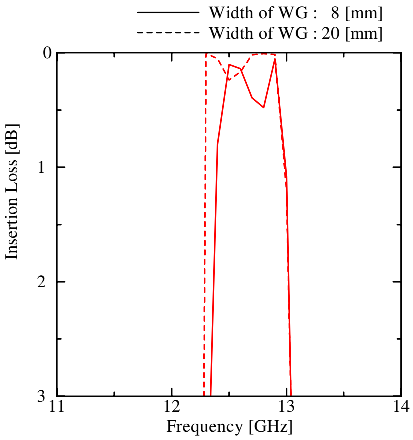


Fig.6: Normalized K-inverter parameter and phase angle



(a)



(b)

Fig.7: Tri-plate transmission line filter at centimeter frequencies, (a) transmission characteristics and (b) their insertion losses

Next, we designed the 3-pole 0.1 dB ripple Chebychev band-pass filter to investigate an effect of undesired radiation at millimeter frequencies. The design specifications were a center frequency of 60 GHz and a relative bandwidth of 4%. A thickness of a dielectric substrate with a dielectric constant of 2.6 was set to be 0.264 mm, and a height and a width of the cutoff waveguide were set to be 2 mm each so as to less than half a wavelength. The inverter parameter and the phase angle were analyzed for such dimensions by using HFSS, and the analytical result is shown in Fig.8. The gap and resonator lengths were calculated by using the analytical results. The calculated scattering parameters of the filter are shown in Fig. 9 as solid curves. From this result, the bandwidth and center frequency were similar to that of the design specifications. Next, scattering parameters of the filter are shown in Fig.9 as dashed curves where the width of the waveguide was enlarged to be from 2 mm to 10 mm to intentionally excite the TE_{10} mode for comparison. From these results, the skirt cutoff characteristic in the stop band and the insertion loss characteristic in the pass band deteriorated due to generation of the TE_{10} undesired mode, and thus it is obvious that the TE_{10} undesired mode increased by such an asymmetrical structure when the operational frequency was changed from centimeter frequencies to millimeter frequencies.

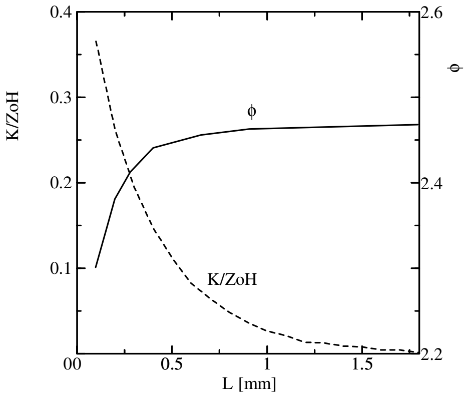
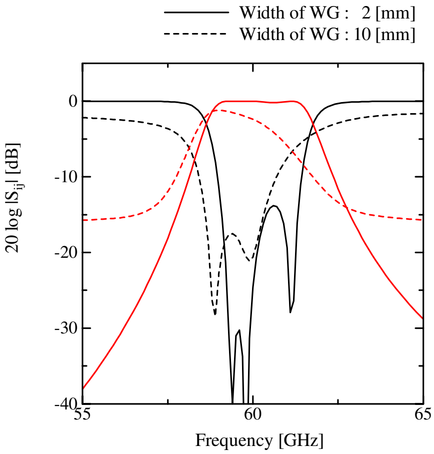
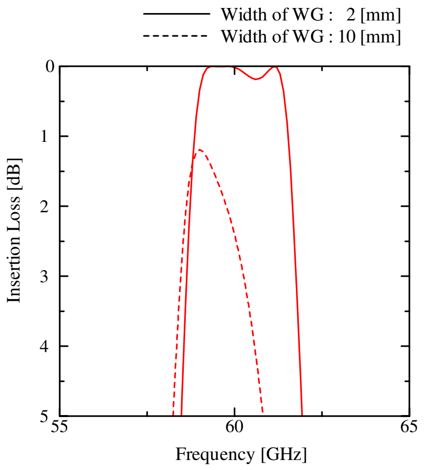


Fig. 8: Normalized K-inverter parameter and phase angle



(a)



(b)

Fig.9: Tri-plate transmission line filter at millimeter frequencies, (a) transmission characteristics and (b) its insertion losses

4. Conclusion

Since a dielectric-supported tri-plate transmission line suffers from undesired radiation in discontinuity parts such as a band-pass filter, we could solve the problems by inserting the tri-plate transmission line filter into a cutoff waveguide, and designed a three-pole 0.1dB ripple Chebychev band-pass filter in this paper. The scattering parameters of the filters were analyzed by using HFSS. The insertion loss increased as the frequencies went up from centimeter frequencies to millimeter frequencies because the undesired TE_{10} mode was excited by its asymmetrical structure. The undesired mode could be successfully suppressed by setting a width of the cutoff waveguide so as to be less than half a wavelength at millimeter frequencies.

References

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