SOME DIELECTRIC-WAVEGUIDE FILTER STRUCTURES*

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Summary

Band-stop and band-pass filters utilizing dielectric-waveguide (DW) gratings are discussed and theoretical and measured responses are presented. The simplest band-pass filter of this class consists of two, parallel-coupled gratings with distributed loss added at their far ends. It is shown that using combinations of parallel-coupled and direct-coupled gratings Chebyshev or other pass-band characteristics can be obtained.

Introduction

The design of filters using dielectric waveguide (as may be desirable for millimeter-wave or optical integrated-circuit applications) poses special problems. Since the energy is relatively loosely bound to the guide, T-junctions and sharp bends cannot be used because of their tendency to radiate, and short circuits or open circuits are not available. This means that a quite different set of techniques are needed for dielectric-waveguide (DW) filter applications.

Grating Band-Stop Filters

As is well known, a simple form of DW band-stop filter can be obtained by cutting a grating in DW. In Fig. 1(a) is shown dielectric image guide with a grating formed using notches in the sides of the guide. Our results indicate that this configuration gives decidedly superior results over the more common case of notches in the top of the guide when using the fundamental mode having predominantly vertical E-field polarization[1] (By superior results we mean stronger attenuation and greater freedom from spurious stop bands.) On the other hand, when using the mode with predominantly horizontal polarization, the use of notches on the top of the guide as in Fig. 3(a) appears to be decidedly superior.

As is discussed in Ref. 2, we have found that the frequency response of DW gratings can be accurately predicted by the simple, equal-line-length transmission-line equivalent circuit in Fig. 1(b) after an appropriate impedance ratio Z_1/Z_0 and center-frequency average velocity have been determined from measurements on a test grating. (Note that the effects of the discontinuity reactances are included in these values.) The dispersion of the velocity away from the center-frequency value was obtained by use of the "effective dielectric constant" method.[3] The solid line in Fig. 2 shows the measured stop-band response for a grating as in Fig. 1(a) having 35 narrow sections, $\varepsilon_r = 2.55$, $w = 1.270$ cm, $h = 1.016$ cm, $w_1/w = 0.625$, $\ell_0 = 0.528$ cm, and $\ell_1 = 0.577$ cm. The dashed line shows the computed response obtained using the equivalent circuit in Fig. 1(b) as discussed above and in Ref. 2. The agreement is seen to be very good.

Parallel-Coupled Gratings as a Band-Pass Filter

A band-pass resonance can be obtained by using a pair of gratings appropriately spaced apart on the same guide so as to form a kind of Fabry-Perot resonator. A properly designed structure of this sort can give a good pass band in the middle of the grating stop band, and this resonance can be used for applications such as oscillator frequency control.[4] However, this structure is not very useful as a band-pass filter because of the very limited extent of the stop band. Until recently, the only true DW band-pass filter which has appeared in the literatue is the ring-resonator filter.[5] However, in order to avoid excessive radiation, the diameter of the ring must be quite large compared to a wavelength causing closely spaced bands which are unacceptable for many applications.

To avoid such spurious pass-band problems, we have been working on structures which utilize the resonance properties of gratings to give a pass band, but utilize the absorption of energy in internal loads within the filter structure in order to obtain a broad stop band.[2] To our knowledge, the simplest kind of band-pass filter structure which achieves these functions is that shown in Fig. 3. It can be shown that if this structure is properly designed, at the stop-band center frequency of the gratings all of the power entering the structure at A will be transmitted out of the structure at D. Meanwhile, when the gratings are in their pass bands the energy entering at A will be absorbed by one or the other of the loads on the right. In this way, broad, absorptive stop bands are achieved. In order to achieve high attenuation in the stop bands it is critical that the loads on the right give very little reflection. In this regard, we have obtained best results by gradually introducing lossy material into the DW grating structure so there is no abrupt transition between the gratings and the loads.[6,2] It is also important to have as little coupling as possible between the input lines to the left of A and D. This is because even in the grating pass bands there will be small reflections from the leading edges of the gratings. Thus, power from the input guide coupling across to the output guide can, to some extent, reflect from the grating edge at D and degrade the absorptive stop-band attenuation of the filter.

We have found that a relatively simple analysis of coupled gratings such as that in Fig. 3 can be achieved in terms of the odd-mode and even-mode <u>image</u> impedances for the coupled gratings. Besides simplicity, this approach has the great advantage that it views the gratings as being infinitely long so that there are, in theory, no reflections from waves once they have entered the gratings, and the optimum performance is computed. Because of the difference in velocity for the odd and even modes, the stop band for the odd mode is centered at a somewhat higher frequency than for the even mode. It is found that in order to obtain complete power transfer in the configuration in Fig. 3 the upper edge of the even-mode image stop band must coincide with the lower edge of the odd-mode image stop band. Then a typical computed response is as shown in Fig. 4. The highly unusual breaks in the response curve are possible because the structure is assumed to be infinite. The curve in Fig. 5 shows the measured results of a trial design using gratings as for Fig. 2 spaced 0.610 cm. The response includes the loss of the mode transducers and input and output guides,[6,2] and the mid-band loss of the filter alone is between 1 and 1.5 dB. Though this structure is finite in length, note that it has an approximately V-shaped pass band

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region just as in Fig. 4. The spikes in the attenuation characteristic are due to resonances caused by small reflections at the ends of the gratings.

Since the filter in Fig. 3 is absorptive in its stop bands, it should be possible to cascade such structures without any harmful interaction effects. Thus it should be possible to obtain quite high stop-band attenuation by cascaded structures of this type.

Grating Coupled-Resonator Band-Pass Filters

The filter structure in Fig. 3 with its response as in Fig. 5 should have practical applications, but there is not the flexibility in the pass-band shape that one has in coupled-resonator filters. It turns out that when coupled gratings have less coupling than is required for the responses in Figs. 4 and 5, so that the odd- and even-mode stop bands overlap, the coupled gratings can be modeled by two resonators coupled by an impedance-inverter for frequencies in the vicinity of resonance.[2] Thus, coupled gratings have potential utility in the realizing of coupled-resonator-type band-pass filters. A kind of coupled-resonator filter is shown in Fig. 6(a). This is a two-resonator structure, each resonator being formed by a grating G and an input or output grating G_{01} or G_{23}. It is desirable that gratings G_{01} and G_{23} not be coupled to each other so their coupling cannot cause energy to be scattered to the output port as discussed in connection with the input and output lines in Fig. 3. Figure 6(b) shows a three-resonator version of the same type of filter.

The dashed lines in Fig. 7 show the computed response of a two-resonator filter as in Fig. 6(a) with infinite gratings G, designed to have 0.5-dB Chebyshev pass-band ripple. The solid line shows the computed response when finite gratings are used with distributed loads (which were simulated by introducing a gradually increasing dielectric loss factor into the transmission-line model). The dashed line in Fig. 8 shows the measured response (including mode transducers and connecting DW guides) of a filter we constructed using this design. It has about 0.15-dB pass-band ripple, and is slightly mistuned as indicated by the slope in pass band. (We found tuning can be accomplished by placing dielectric material adjacent to the center of the resonators.) In order to reduce possible coupling between gratings G_{01} and G_{23}, a metal dividing wall was added between the input gratings, giving the response shown by the solid line in Fig. 8. Note that the stop band is enhanced at frequencies below the pass band, and that the resonators have slightly less coupling as evidenced by the disappearance of the Chebyshev ripple. The midband loss of the filter alone is less than 1.5 dB.

Conclusions

Structures using DW gratings can be useful for constructing both band-stop and band-pass filters[2]. The simple structure in Fig. 3 provides very limited control over the pass-band characteristic, but has adequate attenuation characteristics for many applications. It might prove useful as a filter for integrated optics. The filter types in Figs. 6(a),(b) provide greater flexiblity[2] and can be designed to have Chebyshev, maximally flat or other pass-band characteristics.

References

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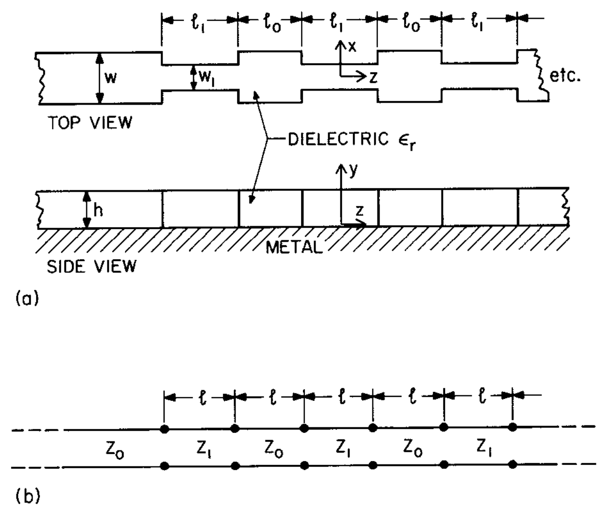

Fig. 1 (a) A DW grating. (b) A grating equivalent circuit.

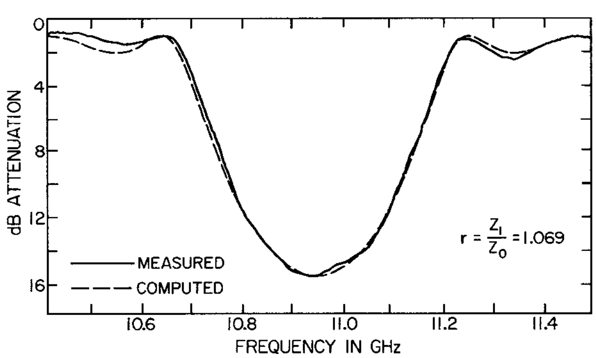

Fig. 2 Measured & computed responses for a grating.

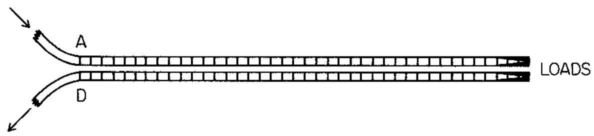

Fig. 3 A simple DW band-pass filter.

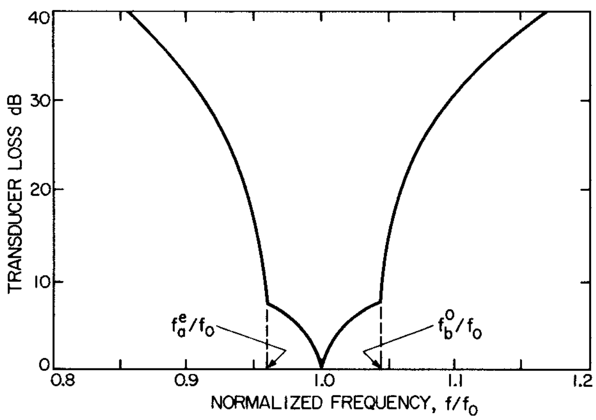

Fig. 4 A computed response for a filter as in Fig. 3 with infinitely long gratings.

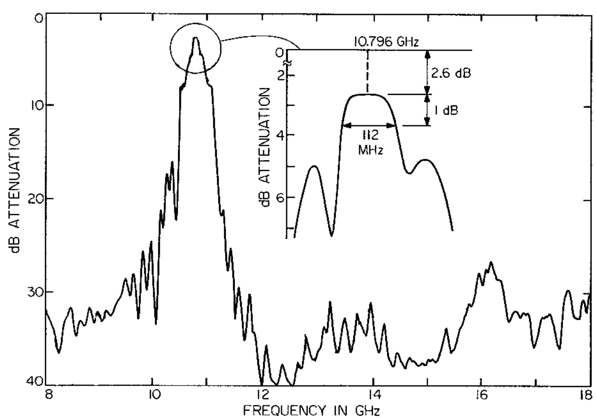

Fig. 5 Measured response for a filter as in Fig. 3 including mode transducers and connecting DW guides.

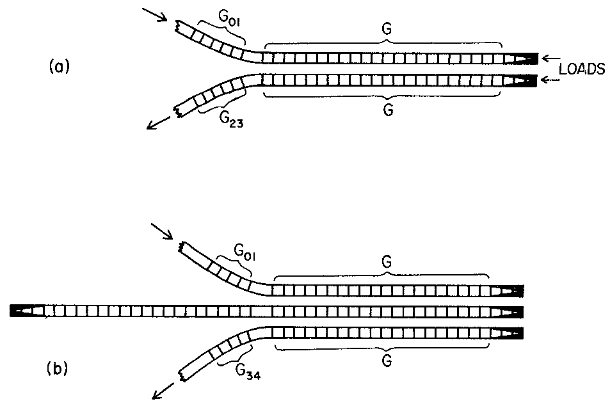

Fig. 6 At (a) is shown a 2-resonator filter while at (b) is shown a corresponding 3-resonator version.

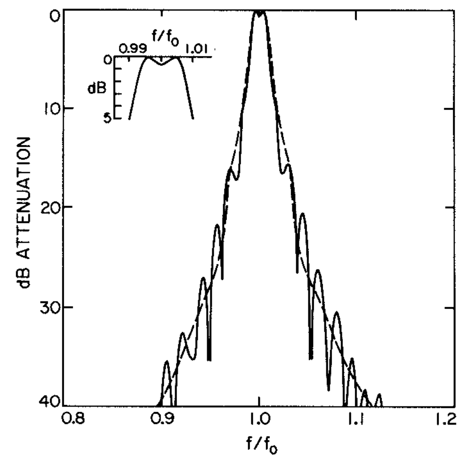

Fig 7 Computed responses for a filter as in Fig 6(a). The dashed line is for infinite G gratings while the solid line is for finite G gratings.

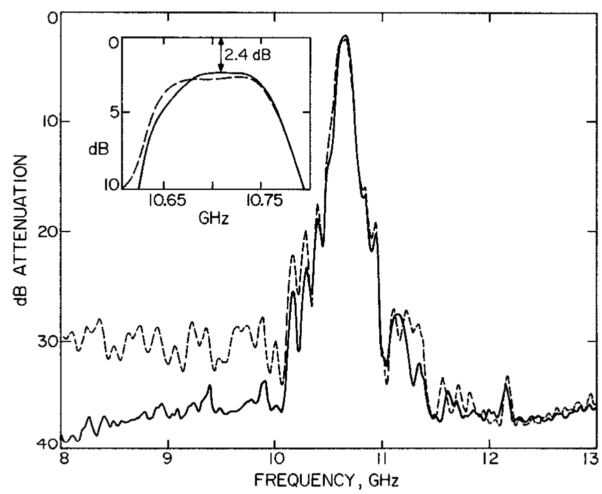

Fig. 8 Measured responses for a filter design as in Fig. 6(a) (including mode transducers and connecting DW guides). See text.