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DIELECTRIC WAVEGUIDE GRATING DESIGN FOR BANDSTOP AND BANDPASS FILTER APPLICATIONS*

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SUMMARY

Techniques have been obtained for the precision design of dielectric wavegude (DW) bandstop filters in the form of a grating in DW which utilizes notches of varying depth. The grating is designed from a transmission-line prototype which has a prescribed stop band and also prescribed Chebyshev pass bands. Two such grating structures used with loads on one end and a 3-dB coupler can be used to form a bandpass filter.

A. INTRODUCTION

The possible use of dielectric waveguide (DW) gratings consisting of uniformly periodic notches in DW as mm-wave or optical-frequency bandstop filters is well known(1),(2). Though such uniform gratings can give a strong stop band, their pass bands may have ripples of the order of two dB or so which is excessive for many applications. In order to obtain pass bands with prescribed low levels of ripple it is necessary to use designs with grating notches of varying depths. Precision bandstop grating designs of this sort also have potential application for use in bandpass filters. Figure 1 shows a bandpass filter made with a 3-dB coupler and two gratings with loads at their right ends. It can be shown that when the gratings are reflecting, power entering the coupler at port 1 will emerge at port 2 yielding a pass band. However, when the gratings are not reflecting, power entering at port 1 will pass through the gratings and be absorbed by the loads at the right, thus creating a stop band with respect to transmission from port 1 to port 2. Reference (2) discusses the fundamentals of a bandpass filter technique which uses parallel gratings with coupling between them. However, that technique appears to be most practical for filters having bandwidths of the order of one percent since when using that technique the pass-band width of the filter must be considerably less than the stop-band width of the gratings. It can be shown that the structure in Fig. 1 has potential application for bandwidths up into the 5 to 10 percent range. This is because for the structure in Fig. 1 the passband for transmission from port 1 to port 2 in Fig. 1 corresponds to the full width of the grating stopband.

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B. CHARACTERIZATION OF THE GRATINGS

The DW gratings we have used in our experimental work are of the image-guide type using the lowest-order mode which has its E field predominantly vertically polarized. We have found that for that mode best results (i.e., stonger stopband attenuation with no nearby spurious responses) are obtained with grating notches on the sides of the guide as shown in Fig. 2. (At the center of the grating stop band the length of each notched and unnotched region of the grating in Fig. 2 is approximately a quarter guide wavelength.) However, if the lowest-order horizontally polarized mode is used, notches on the top of the guide are most effective, and for some applications that arrangement may be desirable. We have also found that we can model gratings with good accuracy by use of an equal-line-length transmission-line equivalent circuit as is shown in Fig. 3(a) with a frequency-dependent velocity introduced to account for dispersion(2). It has been found that the equal-line-length transmission-line model with appropriate parameters represents a grating accurately over a wide band of frequencies even if the electrical lengths of the grating notched and unnotched sections are fairly unequal(2).

In order to carry out trial designs such as are described later in this paper it was necessary to have accurate data for the effective ratios of the impedances of the notched regions to that of the unnotched regions for a range of notch depths, and also data for the effective average wave velocity in the gratings for a range of notch depths. Design data was obtained by a combination of experimental methods(2) and approximate theoretical methods.

C. SYNTHESIS OF BANDSTOP FILTER PROTOTYPES

Our bandstop filter design procedure begins by first obtaining an appropriate transmission-line prototype circuit which uses equal-length-line sections. It can be shown that transmission-line bandstop filter circuits can be derived from related step-transformer circuits by roughly the same procedure that Young used for obtaining transmission-line prototype bandpass filters from step-transformer designs(3). Thus, existing methods for step-transformer design can be the starting basis

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for bandstop filter design methods. The design method we obtained is based on an approximate, transformer design procedure due to Cohn[4].

Figure 4(a) shows the computed attenuation (including approximate correction for dispersion) for a design having 93 line sections, 20-dB maximum stop-band attenuation, with 0.00087-dB pass-band Chebyshev ripple (which gives a minimum of 37-dB return loss in the pass bands, such as might be a desirable goal if filters like this are used as the gratings in a bandpass filter like that in Fig. 1). The initial circuit for this filter was of the form shown in Fig. 3(a), where the impedance values alternate up and down as one moves towards the right. The circuit was then converted to the more practical configuration for gratings shown in Fig. 3(b) where all of the even-numbered sections have been replaced by line sections of impedance Z_0, while the odd-numbered sections are all of impedance higher than Z_0. This configuration is then amenable to being realized as a uniform DW with notches cut in it to create the higher-impedance line sections. An approximate procedure for converting designs as in Fig. 3(a) to the form in Fig. 3(b) was obtained, and Fig. 4(b) shows how this approximation affected the computed pass-band ripples. Note this design has an 0.00087-dB ripple objective, and the ripples near cutoff are a little large but taper down to be less than the design objective at low frequencies. The approximation has virtually no effect on the stop band.

D. EXPERIMENTAL RESULTS

Using the design data for gratings obtained as was mentioned in Sec. B, a DW bandstop filter was fabricated to realize the design whose theoretical responses were computed in Figs. 4(a) and 4(b). The DW utilized Rexolite 1422 which has $\varepsilon_r = 2.55$, and the guide was 0.4 in. high by 0.5 in. wide with notches as in Fig. 2 ranging from 0.021-in. deep at the ends to 0.141-in. deep at the center of the grating. Figure 5 shows the measured attenuation response (including the loss of mode launchers at the ends), which is in excellent agreement with the theoretical response. The measured peak attenuation is almost exactly 20 dB above the dissipative attenuation floor, while the 3-dB stop-band width is about 6.05 percent as compared to a theoretical value of 5.93 percent. Figure 6 shows the measured return loss, which is of special interest for applications such as the filter in Fig. 1. The dashed line shows the return loss of a load on the dielectric waveguide without a grating and suggests the measurement limits of the test setup which included a mode transducer from metal guide to DW. The solid line shows the measured return loss of the filter, and it is seen to have stronger sidelobes than are desired, though the apparent height of the sidelobes is probably due in part to imperfections in the test setup. Computer studies indicate that higher sidelobes for a grating filter could easily be due to some lack of synchronism between the various parts of the grating having different notch depths.

E. CONCLUSIONS

Procedures have been obtained for the precision design of DW bandstop filters. The results of a trial design with extremely demanding design objectives yielded an attenuation characteristic in excellent agreement with the objective. The much more sensitive return-loss characteristic did not meet the objectives as well, but it is believed that by use of a DW coupler for the measurements (instead of a metal waveguide coupler plus a mode transducer to couple into DW), and perhaps by use of more precise velocity design data, appreciably better return-loss agreement should be possible.

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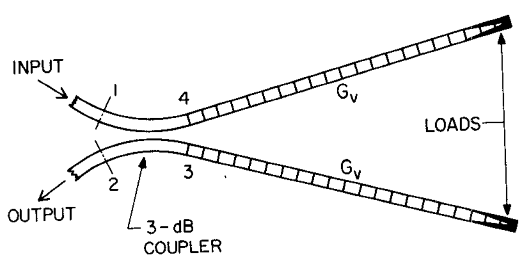

Fig. 1. A bandpass filter formed from two DW bandstop gratings plus a DW 3-dB coupler.

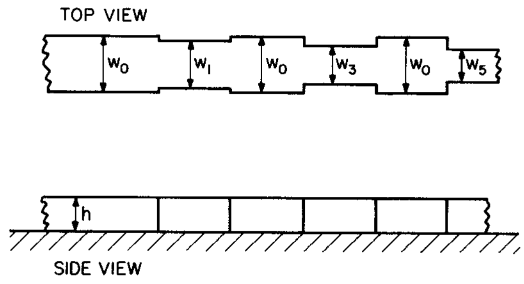

Fig. 2. An "image guide" DW grating.

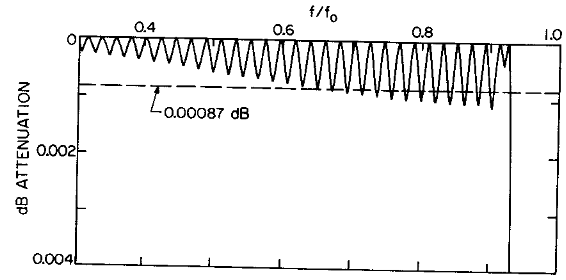

Fig. 4(b) The solid line shows the computed pass-band ripple characteristic for a design of the form in Fig. 3(b).

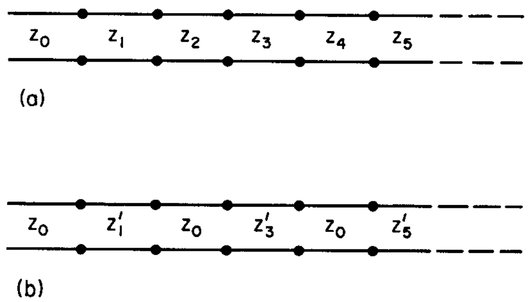

Fig. 3. Transmission-line equivalent circuit for gratings. The circuit at (b) relates to a uniform DW with notches in it.

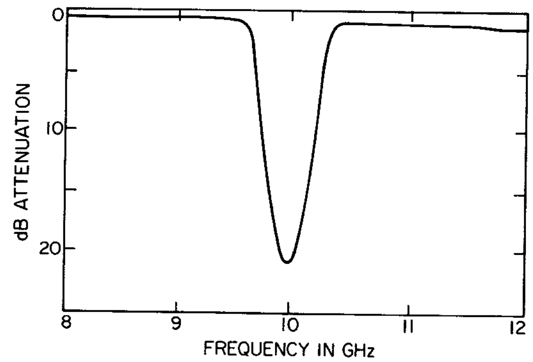

Fig. 5. The measured attenuation characteristic for the same design as in Figs. 4(a) and 4(b).

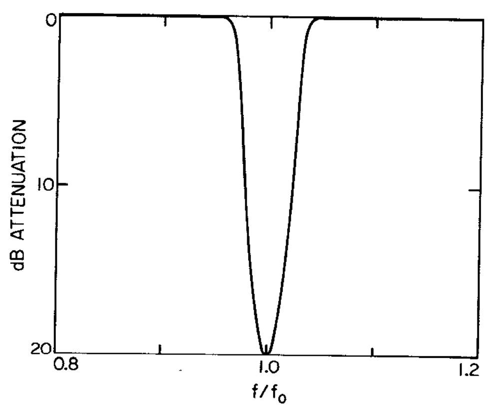

Fig. 4(a) The computed attenuation characteristics of a trial grating design including correction for dispersion.

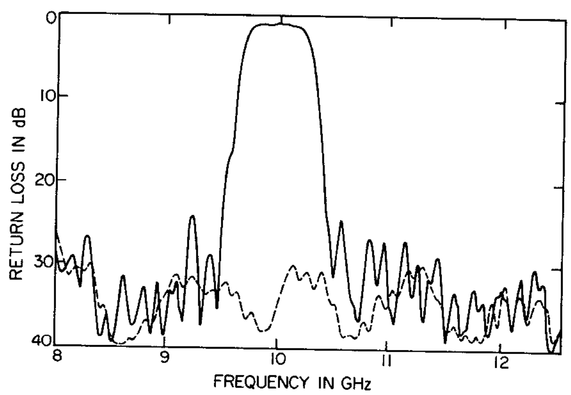

Fig. 6. The solid line shows the measured return-loss characteristic for the same bandstop grating as in Fig. 5. The dashed line suggests the limit of sensitivity of the measurement system.