DIELECTRIC WAVEGUIDE BAND-PASS FILTERS WITH BROAD STOP BANDS*

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SUMMARY

Techniques for the design of band-pass filters using dielectric waveguide gratings are discussed. Direct-coupled-resonator filter theory is applied to synthesize a prescribed pass band having a Chebyshev or maximally flat characteristic, and at the same time a broad, absorptive stop band is provided through the use of parallel-coupled gratings. Experimental results are also presented which show good agreement between theoretical and measured results.

INTRODUCTION

In the past a variety of types of dielectric waveguide (DW) have been proposed and investigated, but relatively little research has been done on the design of filters in DW. Since the energy guided by a DW is loosely bound in most cases, quite different techniques are needed than are used in conventional microwave filters. One type of DW band-pass filter that has been used is the ring-resonator filter (1). However, to avoid excessive radiation losses, the ring resonator must be many wavelengths in circumference, and this results in numerous, closely spaced pass bands. Filters in "nonradiative guide" have been proposed (2). But here again, nonradiative guide is nonradiative only below a critical frequency and such filters can be expected to have a poor stop band above that frequency. The object of this work has been to obtain DW band-pass filters which have a good pass band along with broad, strong stop bands as are generally needed for system applications. Such filters appear to have potential application for integrated circuits particularly for the higher mm-wave, infrared, and optical ranges.

CONFIGURATION AND MODELING OF DW GRATINGS

We have been working with DW gratings formed by cutting notches in the sides of an "image guide" which is operated using the lowest-order mode which has its electric field predominantly vertically polarized (normal to the ground plane). We have found that such gratings, pictured schematically in Fig. 1(a), can be modelled with a transmission-line equivalent circuit, Fig. 1(b), where each section has equal electrical length (3). Then the grating is conveniently described in terms of only two parameters, the impedance ratio $r = Z_1/Z_0$ and the center frequency f_0 at which all the line segments are a quarter-wavelength long. These parameters can be derived from experimental data (3).

Two parallel gratings, close to each other, as shown in Fig. 2(a), can be modelled as a coupled transmission-line circuit shown in Fig. 2(b). The circuit can be described in terms of its even- and odd-modes. From experiments, we have found that the effect of the coupling is to alter the wave velocities of the even- and odd-modes but the impedance ratio remains almost unaltered except for very tight couplings. If both the even- and odd-modes are in their respective stop bands, the coupled gratings behave as a lossless circuit (line losses neglected). Stop band is here defined as the "image" stop band where the "image" impedance (i.e. impedance one would see looking into a grating of infinite length) is imaginary (4, Ch.3). If either the even- or the odd-mode or both of the coupled gratings are not in their respective stop bands some of the power sent into, say, port A, will not emerge at port B but will instead just travel down the guides. If the gratings were infinitely long, for frequencies away from the stop bands high attenuation would exist between ports A and B. Finite length gratings would behave exactly as being infinite if we could terminate them in their image impedances. This is impossible to achieve at all frequencies but we have found that a gradually introduced loss makes a good load for the gratings as our experimental results show.

The circuit of Fig. 2(b) exhibits a trasmission-resonance type behaviour at frequencies where it acts as a lossless circuit, and close to the resonant frequency it can be further modelled as an impedance inverter with associated resonators as in Fig. 2(c). A derivation of the parameters of the circuit in Fig. 2(c) from the parameters of the circuit in Fig. 2(b) can be found in (3). A similar equivalent circuit can be shown to apply as well between ports A and B

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of the single, uncoupled grating in Figs. 1(a) and (b). This property has been derived in (5). These equivalent circuits are very useful in the design of band-pass filters.

For an accurate model of the DW gratings, effects of dispersion need to be taken into account in the equivalent circuits of Figs. 1(b) and 2(b). Our approach has been to use a measured wave velocity at the center frequency f_0, but the velocity is made to vary linearly around this value with a slope of velocity versus frequency predicted by the so-called effective dielectric constant method (6).

BAND-PASS FILTER CONFIGURATIONS

The simplest form of DW band-pass filter we have found consists of a pair of parallel-coupled gratings such as shown in Fig. 2(a) with distributed loads at the right ends of the gratings. It can give useful band-pass characteristics but has a drawback in that the shape of the pass band cannot be controlled as there are not enough degrees of freedom (for given gratings only the spacing between the guides can be adjusted). Equations for the design of this class of filters along with experimental results are discussed in (3).

The shape of the pass band can be better controlled if resonators are formed by use of gratings. A sort of Fabry-Perot resonator is formed if two gratings are placed on a DW and separated a multiple of half guide wavelength apart at the center frequency of the grating stop bands. Figures 3(a) and (b) show two- and four-resonator filters that use this type of resonators. Thus in Fig. 3(a) the first resonator is formed from gratings G_{01} and G spaced apart on the upper guide, and the second resonator from gratings G_{23} and G spaced apart on the lower guide. When the gratings are in their stop band the structure operates as a conventional two-resonator reflection type filter and the pass band of the filter can be designed to have a prescribed shape (such as Chebyshev or maximally flat). The design proceeds by the use of the equivalent circuit of Fig. 2(c) defined as in Ref. (3) for parallel-coupled gratings and in Ref. (5) for the single-grating case. One can see that using equivalent circuits as in Fig. 2(c) the structure of Fig. 3(a) reduces to the standard form of Fig. 4 to which direct-coupled-filter theory (4, Ch. 8) is readily applied. The reactance slope of each resonator in Fig. 4 is the sum of the reactance slopes of each constituent. In this model the role of the connecting waveguide between the gratings is to add $m_s \frac{\pi}{2} Z_0$ to the total reactance slope where m_s is the number of half wavelengths in the connecting guide. Notice that the resonators to the right of K_{23} and to the left of K_{01} in Fig. 4 can be neglected because their slope parameter is comparatively small.

When the gratings are in their pass band (which is the stop band of the filter), the coupled gratings behave as a lossy circuit and e.g. in Fig. 3(a) power entering at the upper left is passed on to the distributed loads on the right. In this manner a broad, absorptive stop band is introduced with respect to transmission between the input and output ports on the left. Since this class of filters are absorptive in their stop bands, such filters can be cascaded to yield high stop-band attenuations without harmful interactions. In the four-resonator filter in Fig. 3(b) there are two sets of parallel-coupled gratings so its potential stop-band attenuation is very high.

EXPERIMENTAL RESULTS

The solid line in Fig. 5 shows a measured response for a two-resonator filter of the sort in Fig. 3(a), and the dashed line shows its computed response. This filter was designed to have a 0.5-dB ripple Chebyshev pass band. For the most part the agreement is very good. The filter was constructed using image guide made of Rexolite 1422 that has a relative dielectric constants of 2.55. It has been found to be desirable to separate the gratings G_{01} and G_{23} in Fig. 3(a) as rapidly as possible without causing excessive radiation due to sharp bends. The response as shown used a metal dividing wall between gratings G_{01} and G_{23}. Without this wall the stop-band attenuation below the pass band was not as good (i.e. around 30 dB). The measured attenuation in Fig. 5 includes the loss of the mode launchers and some connecting DW. The midband loss of the filter alone is believed to be 1.5 dB or less.

Figure 6 shows the computed response for a four-resonator filter of the type shown in Fig. 3(b). The dashed line shows the response for the case of infinitely long parallel-coupled gratings and the solid line shows the corresponding response for the case of the parallel-coupled gratings having distributed loads at their outer ends. It was designed to have a 0.5-dB ripple Chebyshev pass band with an equal-ripple bandwidth of 1.3 percent. The computations were made assuming a Q of 1,200 for the DW (a loss of 0.0227 dB per guide wavelength). Figure 7 shows a corresponding measured response for a filter realized using image guide made of Rexolite 1422. The dashed line in Fig. 7 shows the approximate attenuation contributed by the mode launchers and quite long sections of input and output guide. The net midband loss of the filter alone is about 3.1 dB which is somewhat higher than expected. We believe this is due to radiation from some relatively sharp bends used in this filter. The filter was tuned a slight amount by inserting small pieces of dielectric near the center of the resonators.

Measurements were made up as far as 26.5 GHz. In the range 12 to 18 GHz, except for two frequencies, the attenuation was in excess of 55 dB provided that metal or absorbing dividers were put between the input and output guides and the adjacent gratings to suppress stray coupling. At the two frequencies mentioned, the attenuation dropped to 37 or 45 dB. It was found experimentally that these two weak points could be dropped down below 55 dB if several pieces of fine metal wire were placed transverse to the guide axis on top of the G_{23} grating in Fig. 3(b). These wires did not affect the rest of the response. We believe the observed weak points and their disappearance with the wires is due to higher-order modes of the DW. In the 18 to 26.5 GHz range attenuation was in excess of 55 dB except for one frequency where it dropped to 47 dB, again provided that the dividers were in place. This 47 dB could not be further suppressed with the wires. Even if no dividing walls or wires were used the typical attenuation was 50 dB in the 12 to 18 GHz range, 40 dB in the 18 to 26.5 GHz range, with a 37 dB minimum attenuation in the full 12 to 26.5 GHz range.

REFERENCES

(1) R.M. Knox, "Dielectric waveguide microwave integrated circuits - An overview," IEEE Trans. MTT, Vol. MTT-24, pp. 806-814, Nov. 1976.

(2) T. Yoneyama, F. Kuroki, S. Nishida, "Design of nonradiative dielectric waveguide filter," 1984 IEEE MTT-S International Microwave Symposium Digest, pp. 243-244.

(3) G.L. Matthaei, D.C. Park, Y.M. Kim, D.L. Johnson, "A study of the filter properties of single and parallel-coupled dielectric waveguide gratings," IEEE Trans. MTT, Vol. MTT-31, pp. 825-835, Oct. 1983.

(4) G.L. Matthaei, L. Young, E.M.T. Jones, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, New York: McGraw-Hill, 1964. Dedham, MA: Artech House, 1980.

(5) G.L. Matthaei, E.B. Savage, F. Barman, "Synthesis of acoustic-surface-wave-resonator filters using any of various coupling mechanisms," IEEE Trans. SU, Vol. SU-25, pp. 72-84, March 1978.

(6) W.V. McLevige, T. Itoh, R. Mittra, "New waveguide structures for millimeter-wave and optical integrated circuits," IEEE Trans. MTT., Vol. MTT-23, pp. 788-794, Oct. 1975.

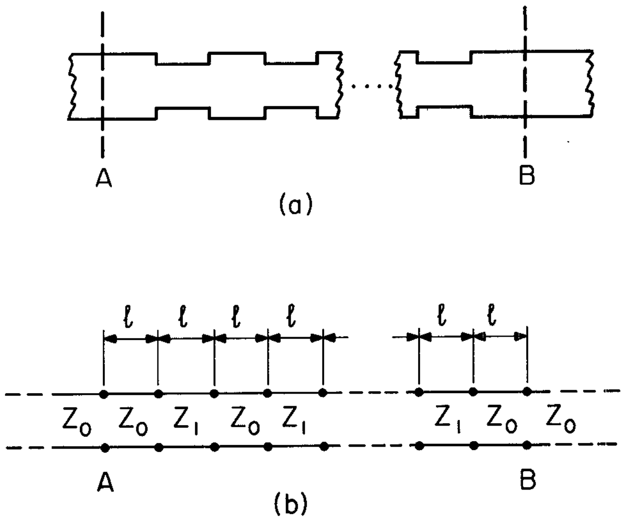

Fig. 1. At (a) a DW grating is shown schematically and at (b) is shown its equal-line-length equivalent circuit.

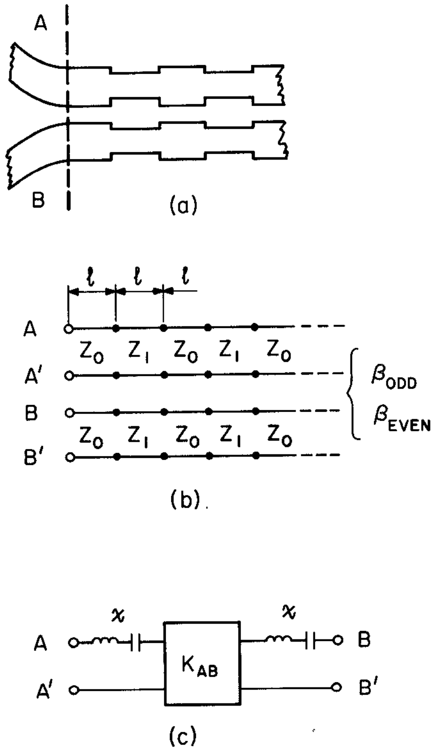

Fig.2. At (a) is shown a parallel-coupled DW grating and at (b) is shown its equivalent circuit. (c) An equivalent circuit which applies to the circuit shown at (b) as well as to the circuit shown in Fig. 1(b) at frequencies for which the gratings are in their stop band.

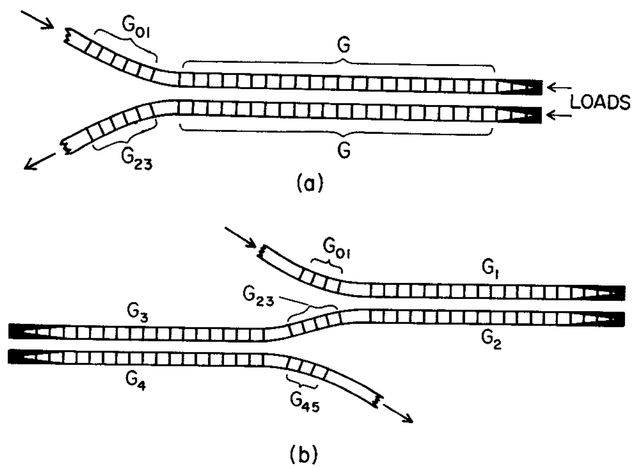

Fig. 3. Two, grating-type DW band-pass filter configurations. The gratings were actually of the form in Fig. 1(a).

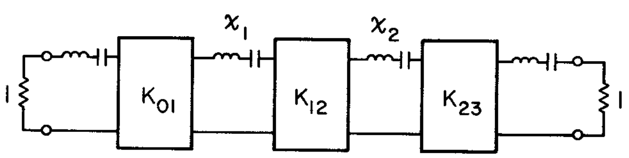

Fig. 4. An equivalent circuit for the filter in Fig. 3(a) for frequencies in and near the pass band.

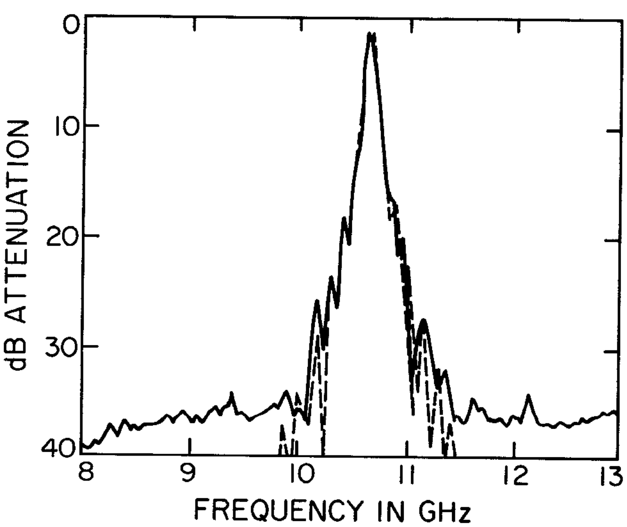

Fig. 5. The solid line shows a measured response for a two-resonator DW band-pass filter as shown in Fig. 3(a), and the dashed line shows its computed response.

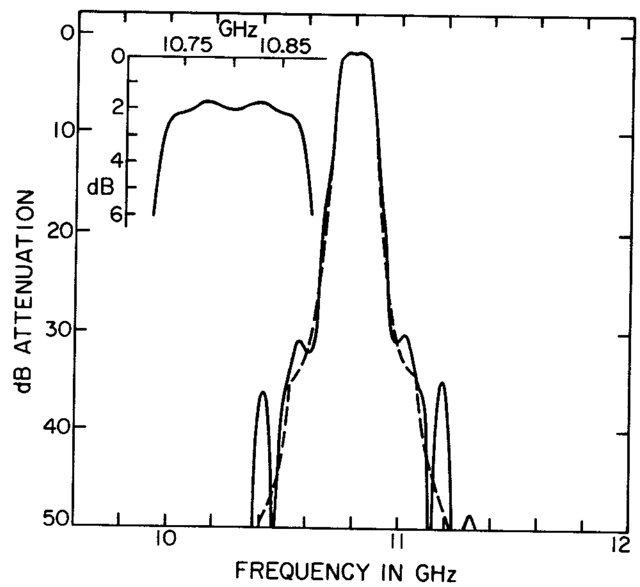

Fig. 6. The solid line shows a computed response for a four-resonator DW filter as shown in Fig. 3(b) with distributed loads at the outer ends of the parallel-coupled gratings while the dashed line shows the corresponding response with infinite, parallel-coupled gratings.

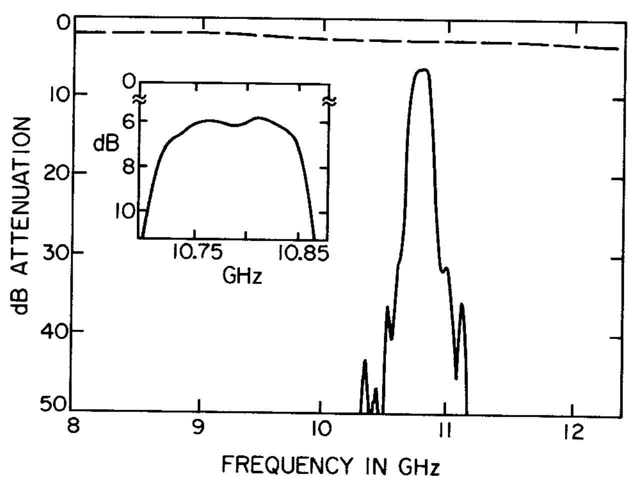

Fig. 7. A measured response for a four-resonator filter as in Fig. 3(b) and Fig. 6. The dashed line indicates the loss due to the mode launchers and the lengthy input and output guides that were used.