TWO-PATH CUTOFF WAVEGUIDE DIELECTRIC RESONATOR FILTERS

H. Shigesawa, M. Tsuji and K. Takiyama

Department of Electronics, Doshisha University
Kamikyo-ku, Kyoto 602, Japan

ABSTRACT

We propose here a new idea to design filters for achieving new levels of performance. This type of filters is made of a rectangular waveguide with a partial H-plane bifurcation. Each bifurcated section finite in length operates as a cutoff waveguide, at the central part of which low permittivity dielectric resonators are loaded. An accurate CAD program is developed which is based on a procedure that takes into account the effect of not only the dominant, but also a large number of higher order modes generated at discontinuities. Experiments for X-band trial filters designed by a new program show good agreements with the theory.

INTRODUCTION

Microwave bandpass filters employing dielectric resonators in a cutoff waveguide have been discussed[1],[2]. Such filters are operated in the cutoff range of a waveguide and have their passband in it. Therefore, it is easy to realize a high attenuation cutoff rate in the filter response, if the passband center frequency f_0 is set sufficiently below cutoff fc. However, the bandwidth of a filter and the insertion loss in the passband respectively decreases and increases as f_0 becomes lower. Thus, for most purposes, it will be usual to set f_0 at the frequency being not so far from fc. In such a design, a high attenuation cutoff rate can be still obtained in the frequency band lower than f_0, but it is difficult to keep a sufficient large insertion loss (for example, 50 dB or more) in the frequency band between f_0 and fc [1].

On the other hand, in connection with satellite broadcasting applications [3], there is a need to develop a filter which has a passband at around f_0 and also has an attenuation pole at a given frequency f_∞ that is higher than f_0. For this purpose, we propose here a cutoff waveguide dielectric resonator filter. Unlike usual filters of this type, our filter (a prototype is shown in Fig.1 or Fig.2(a)) is made of a rectangular waveguide having a bifurcating metal plate placed parallel to the E-plane. Each bifurcated section finite in length operates as a cutoff waveguide, at the central part of which low permittivity (for example, $\varepsilon_r = 2 \sim 3$) dielectric resonators are loaded.

In short, this type of filters is considered as the parallel connection of two series resonant circuits (two paths) with different resonant frequencies. Therefore, it is expected that the resonance of one of two resonant circuits provides the zero insertion loss at a given frequency f_0, while the attenuation pole is produced at another frequency f_∞ by the interference of waves from both circuits at the output terminal (namely, equal amplitude and out of phase between both waves). At around the passband center frequency f_0, the output wave from the non-resonant path has negligible effect on the transmission characteristics of a filter because the wave throughout this path suffers from a large attenuation by the cutoff waveguide. This feature of this type of filters essentially differs from that of the multi-path transmission line filters already discussed by one of present authors (K.T [4]).

Besides the structure of Fig.2(a), a special case includes removing one of dielectric resonators as shown in Fig.2(b). This filter can be understood by the same physical meaning as before, but the characteristics to be expected differs from ones of Fig.2(a), especially around the attenuation pole as described later.

To design such a new type of filters, this paper uses a cost effective and yet accurate CAD program based on a procedure that follows the mode matching method in the sense of least squares in which a large number of higher order modes generated at discontinuities are taken into account. This program is supported by an efficient nonlinear optimization routine, cooperated with a good initial guess obtained from a simple equivalent transmission line model.

DESIGN PROCEDURES

For the structure shown in Fig.2(a), the most simple equivalent circuit representation is shown in Fig.3 which considers only the dominant mode, neglecting the

0149-645X/85/0000-0357 $01.00 © 1985 IEEE 1985 IEEE MTT-S Digest

susceptances at discontinuity planes. The lines 3 and 4 correspond to the dielectric resonators, while the lines 1 and 2 support the evanescent modes and serve as the coupling circuits between input or output line and the resonators. Thus the basic function of this filter is simply understood as that, at the frequency f_0 of zero insertion loss, the vector sum of currents I_{10} and I_{20} at the output terminal becomes maximum without reflection at the input terminal, while, at the frequency f_∞ of infinite insertion loss, both currents become identical in the amplitude and out of phase. This idea can produce an attenuation pole even in the frequency range $f_0 < f < f_c$ and a high attenuation cutoff rate at around f_∞ can be expected.

The accurate CAD program developed here for this type of filters is based on the circuit described in terms of the scattering matrix as shown in Fig.4 and can be split into three steps. In the first step, the generalized scattering matrices [5] S_{Din}, S_{Dout} at the discontinuity plane of bifurcated waveguide are calculated by the least-squares boundary residual method [6]. The second step is to derive generalized transmission matrices S_{Bi} (i =1 and 2) of bifurcated guides, which consist of cutoff sections, a dielectric resonator and the junction plane between them. The third step is to combine these S-matrices. By these steps we obtain the scattering matrix S of the entire filter structure of Fig.2. In our program, S_D-matrix is obtained by considering 80 modes in the input or the output guide and 40 modes in each bifurcated guide. When these matrices are connected in cascade, only a few higher order modes (for example, two to three), interacting between neighboring discontinuities, are used as " accessible modes " [5] in each bifurcated guide and the ports for the higher order modes are terminated with their own characteristic impedances. Following all the above steps, the element S_{21} of S can be easily calculated. Some manipulations lead that S_{21} can be split into S_{21}^{I} and S_{21}^{II}, corresponding respectively to the contributions of wave from each path.

Now, we provide a nonlinear optimization routine based on the Gauss-Marquardt method to meet with a given filter specification. A most simple example will be to specify two frequencies f_0 and f_∞ at which the insertion loss becomes zero and infinite, respectively, and the values d_1, d_2 and a_1 in Fig.2(a) are varied to meet with this specification with a given total length of the filter. To this end, we define the following error functions which ideally must be zero;

$$F_1(a_1,d_1,d_2) = |S_{21}(f_0)|^2 - 1$$

$$F_2(a_1,d_1,d_2) = |S_{21}^{I}(f_\infty)| - |S_{21}^{II}(f_\infty)|$$

$$F_3(a_1,d_1,d_2) = |\arg.S_{21}^{I}(f_\infty) - \arg.S_{21}^{II}(f_\infty)| - \pi.$$

For finding a good initial guess of the variables to be solved, a simple optimization problem to the equivalent circuit of Fig.3 is first solved to meet with the same specification. These values are often very close to the final values.

EXPERIMENTS

In the first example, two dielectric resonators are put in both of bifurcated guides, and f_0 = 9.5 GHz and f_∞ = 11.0 GHz are specified. In the second example, one of dielectric resonators is removed, and d_1 and a_1 are varied to meet with the specification with f_0= 10.3 GHz and f_∞ = 11.5 GHz.

Fig.5 shows the results obtained for the first example, where the solid curve indicates the measured response, while the broken curve means the theoretical one. Fig.6 shows the results obtained for the second example. It is found that experiments are in surprisingly good agreement with the theory. Fig.5 shows a keen attenuation pole. This is understood as the result of that the attenuation pole of this type of filters is expected by an interference of waves from two resonant circuits, and the phase difference between both waves changes with a large slope to the frequency. On the other hand, the attenuation pole in Fig.6 is the result of interference between the waves from an off-resonant circuit and from a cutoff waveguide itself, so that the variation of insertion loss around the pole becomes dull.

We proposed here a new idea to design filters for achieving new levels of performance, and explained the basic idea physically, numerically and experimentally. More sophisticated structures will be developed, but will not be discussed here.

Acknowledgements

The authors are indebted to Dr. Y.Konishi, the president of UNIDEN Satellite Technology Inc., for his encouragement in this work.

References

[1] Y.C.Shih et al., " Analysis and Design of Evanescent-Mode Waveguide Dielectric Resonator Filters," 1984 IEEE/MTT-S Inter'l Microwave Symposium Digest, 9-3, pp.238-239, May 1984.

[2] P.Guillon et al., " Dielectric Resonators Band Pass Filter with High Attenuation Rate," 1984 IEEE/MTT-S Inter'l Microwave Symposium Digest, 9-4, pp.240-242, May 1984.

[3] Y.Konishi, Private Communication.

[4] K.Takiyama, " A Study of Two-Path Transmission Line Filters," The Sci. Eng. Review Doshisha Univ., vol.1, pp.239-255, Dec. 1980.

[5] T.E.Rozzi et al., " Field and Network Analysis of Interacting Step Discontinuities in Planar Dielectric Waveguides," IEEE Trans.MTT, vol.MTT-27, pp.303-309, April 1979.

[6] M.Tsuji et al., " On the Complex Resonant Frequency of Open Dielectric Resonators," IEEE Trans. MTT, vol.MTT-31, pp.392-396, May 1983.

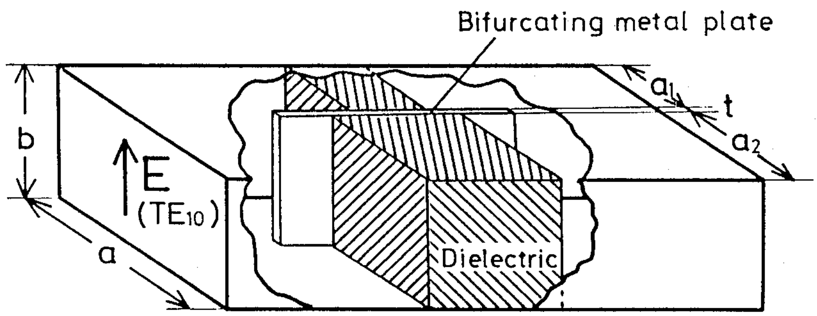
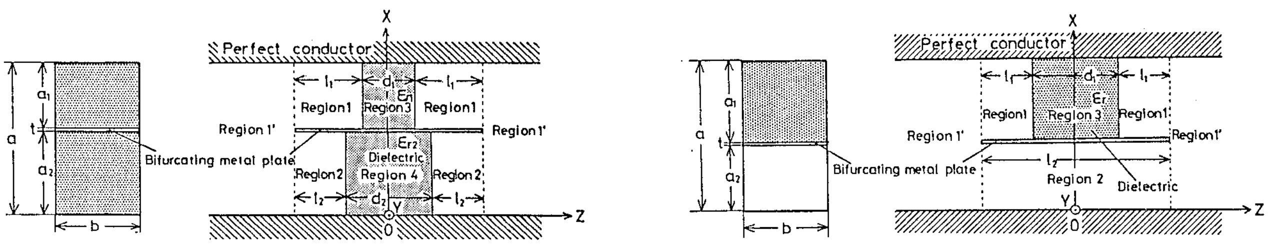


Fig.1. Sketch of two-path cutoff-waveguide dielectric resonator filter.



(a) (b)

Fig.2. Coordinates and dimensions of the filters consisting of two dielectric resonators (a) and single dielectric filter (b).

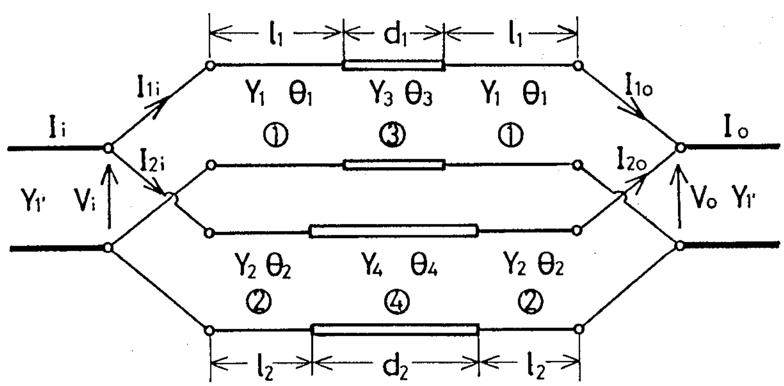


Fig.3. A most simple equivalent circuit in terms of only transmission lines for the filter of Fig.2(a).

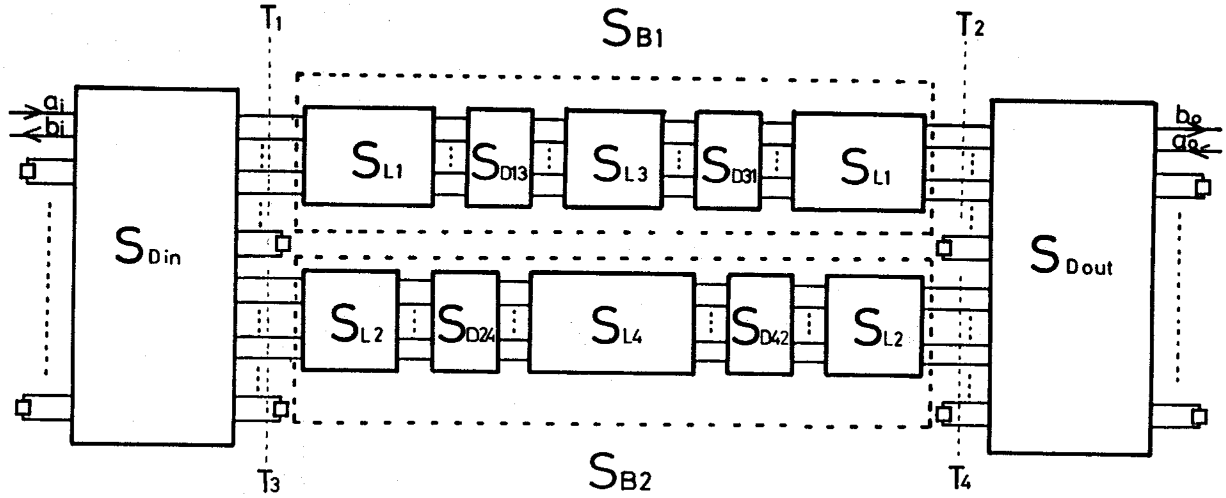


Fig.4. Equivalent circuit representation of the filter by means of the generalized scattering matrices.

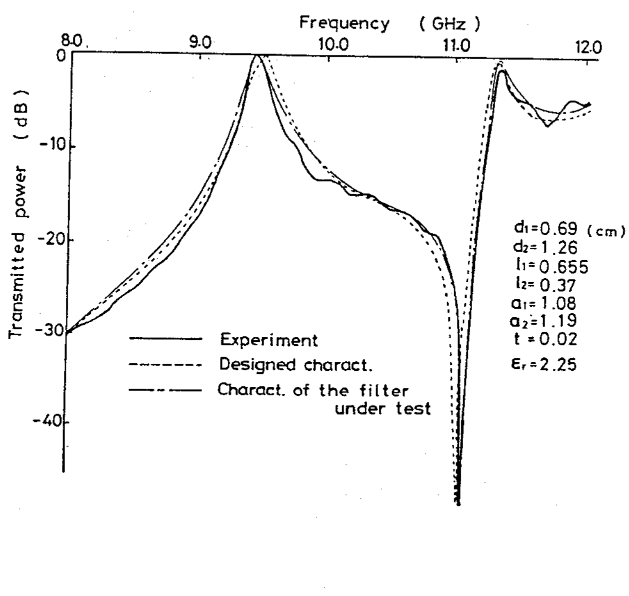


Fig.5. Measured and designed characteristics of the filter of Fig.2(a). The filter under test has slight difference in the dimensions from the specific parameters obtained by the CAD program which results in the frequency characteristic shown by the dashed-dotted curve.

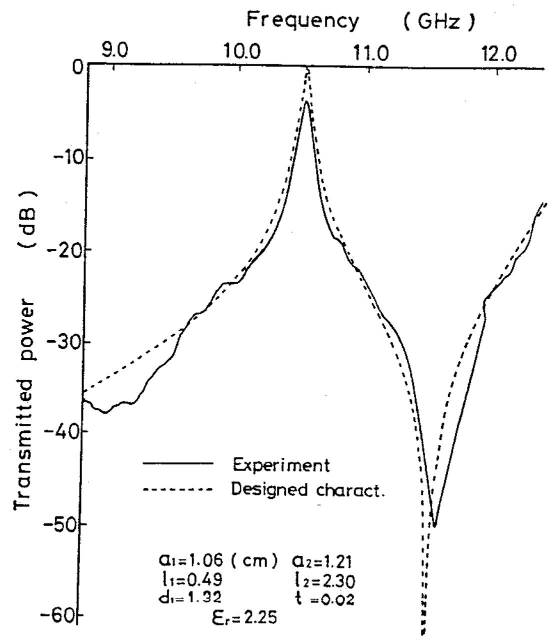


Fig.6. Measured and designed characteristics of the filter of Fig.2(b). The filter under test has almost the same dimensions with those defined by the CAD program, except for a slight warp of the birfurcation plate.