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TWO PATH CUTOFF WAVEGUIDE RESONATOR FILTERS WITH ATTENUATION POLES

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ABSTRACT

We propose here a new idea to design filters which consist of low permittivity dielectric resonators placed in the two paths which are realized by a partial H-plane bifurcation in a rectangular waveguide. This type of filters is regarded as the parallel connection of two evanescent-mode waveguide filters.

This paper will try to design such a filter with the Chebyshev's passband response and also with the stopband response with attenuation poles at desired frequencies, and practical performance aspects of this type of filters will be discussed from the view points of both analytical methods and experiments in the X-band.

INTRODUCTION

Microwave bandpass filters employing dielectric resonators in a cutoff waveguide were discussed in [1] and more recently in [2],[3]. 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 is set sufficiently below the cutoff f_c. However, the band width of a filter and the insertion loss in the passband respectively decreases and increases as the passband center frequency f_0 is set lower than the cutoff frequency f_c. Thus, for most purposes, it will be usual to set the center frequency f_0 at the frequency not so far from the cutoff frequency f_c. In such a design, a high attenuation cutoff rate can be still obtained in the frequency band lower than the passband center frequency f_0, but it is difficult to keep a sufficiently large insertion loss in the frequency band between the frequencies f_0 and f_c [2].

On the other hand, in connection with satellite broadcasting applications, there is a need to develop a filter which has a rather wide passband at around the frequency f_0 and also has a rather wide stopband with large attenuation in the frequency range higher than the passband center frequency f_0. To this end, it is effective to put attenuation poles in the stopband, and we have proposed a new type of cutoff waveguide dielectric resonator filters[4]. Unlike usual evanescent-mode waveguide filters, our filter consists of low permittivity dielectric resonators placed in the two paths which are realized by a partial H-plane bifurcation in a rectangular waveguide. In short, this type of filters is simply regarded as the parallel connection of two evanescent-mode waveguide dielectric resonator filters.

The constituent filters have one or a number of dielectric resonators, and the resonant frequencies f_0 and f_r are usually set at the different frequencies each other. This means that, at around the passband center frequency f_0 of one (main path) of constituent filters, the output wave from another constituent filter (subsidiary path) has negligible effect on the over-all transmission characteristics of the filter because the wave through the subsidiary path attenuates largely by the cutoff nature of the bifurcated section. Therefore, it is expected that the resonant transmission of the main path provides the passband of the filter with the center frequency f_0, while at least one attenuation pole can be produced at another frequency f_∞ (where $f_0 < f_r < f_\infty < f_c$) by the interference of waves from both paths at the output terminal (namely, equal amplitude and out of phase between both waves).

This paper will try to design a filter with the Chebyshev's passband response and also with the stopband response with attenuation poles at the desired frequencies, and practical performance aspects of this type of filters will be discussed from the view points of an approximated and a more rigorous analytical methods and also from the experimental results.

DESIGN PROCEDURE

The structure under considerations is shown in Fig.1. We consider here the structure that contains three dielectric resonators in one (main path) of bifurcated guides. Each of constituent resonators in the main path is directly coupled through the cutoff waveguide sections so as to exhibit a desired characteristics in the specified passband frequency centered at the frequency f_0, while another subsidiary path (including an additional dielectric resonator as shown in Fig.1) is used to produce attenuation poles at the desired frequencies. Assuming that the only mode existing in each bifurcated guide is an evanescent TE_{10} mode, the simple transmission line equivalent circuit of Fig.2 is applicable, in which the susceptances at discontinuity planes are neglected. For a better understanding of the function of this type of filters, let us first consider the filter of Fig.1, but assume only one resonator in each path. Thus the basic function of this type of filter is understood from the parallel connection of two

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bandpass filters with different resonant frequencies f_0 and f_r (where $f_0 < fr < f_c$). Therefore, it is easy to realize a filter having such a characteristic that the vector sum of currents I_{10} and I_{20} of both paths at the output terminal makes the insertion loss zero at the passband center frequency , while both currents mentioned above, but identical in the amplitude and out of phase, produce the infinite insertion loss at a frequency f_∞. Especially, the later feature is quite effective to realize a sufficiently large insertion loss even in the frequency range $f_0 < f < f_c$ as already shown in [4]. To design such a new type of filters, we have already developed a 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.

The developed CAD program is based on the circuit description in terms of the scattering matrices as shown in Fig.3, where a few number of higher order modes (for example, two or three), interacting between neighboring discontinuities, are taken into account as " accessible modes " in each bifurcated guide and the rests of the port are terminated with their own characteristic impedances. The main part of the program, of which detail is omitted here (see [4]), needs some laborious calculations for decomposing the matrix element S_{21} into a main and subsidiary path contribution $S_{21} = S^a_{21} + S^b_{21}$ and to define several kinds of estimation function for entering the optimization routine.

It is difficult to apply the approach mentioned above to the two path filter of which main path consists of a number of dielectric resonator as shown in Fig.1 because the matrix element S_{21} becomes too complicate to fit its response to a given specification (for example, a Chebyshev ripple filter discussed below) in the entire frequency range of specification by the same methodology as that of our CAD program.

Then we assume first that the passband response can be determined almost by the response of the main path itself because the subsidiary path under cutoff is off-resonant at around the frequency f_0 and has no significant effect on the passband response. Therefore, we may design the main path so as to have a passband response of the given filter specification almost independent of the effect of the subsidiary path. If this makes sense, the structure of the main path can be synthesized by applying the design approach developed by Williams et al.,[5], though the calculations for the coupling sections should be modified because of the use of an evanescent-mode waveguide structure, instead of their gap-coupled coplanar waveguide. Also, a significant difference of the present structure from that of [1] is to realize the required lump elements by the dielectric resonators.

The cutoff waveguide sections in the main path are represented by the impedance inverters with the transmission lines connected on both sides as shown in Fig.4. The inverter parameter K and the electrical line length ϕ can be easily calculated from the equivalent T section circuit of a cutoff waveguide of the length l . The obtained results are shown in Fig.5, as a function of l , and the indicated parameters in the figure are assumed for later use.

NUMERICAL CALCULATIONS AND EXPERIMENTS

By using Fig.5, a 3-pole, 0.05dB Chebyshev ripple bandpass response with 3.2% band width at the center frequency f_0= 9.5GHz is first designed for the main path by using the fused quartz as dielectric material (ε_r = 3.78). Fig.6(a) shows the main path response (along with the phase characteristic) designed with the structural dimensions put on the figure.

On the other hand, Fig.6(b) shows the frequency characteristics of only the subsidiary path that consists of one dielectric resonator made of the fused quartz, of which resonant frequency is set at f_r = 10.75GHz in this example. It should be noted that we are able to have the phase difference of π radians between the output waves from both paths in the frequency range above f_r. Therefore, at least one attenuation pole can be realized at a desired frequency higher than f_r by controlling the resonant characteristic of the subsidiary path.

An example of the designed over-all response of a two-path filter is shown by the dotted curve in Fig.7. To this example, our simple CAD program is used to provide two attenuation poles at f_∞ = 11GHz and 13GHz (our CAD program is still available to this purpose, because the frequncy range is limited). The degraded response seen in the passband is due to a weak but non-negligible effect suffered from the subsidiary path. However, the introduction of attenuation poles in this fashion is effective to guarantee the insertion loss higher than about 50dB in the frequency band from 10.9GHz to 13.2GHz. The solid curve in Fig.7 indicates the experimental result, which shows the characteristic similar to the designed one, but there are some significant differences, especially in the passband, which result from the poor approximation of the design approach based on the equivalent network of Figs.2 and 4. So, a more rigorous characteristic is calculated by the analytical approach based on the circuit description of Fig.3, where 80 and 40 modes respectively in the input or the output waveguide and each bifurcated guide are taken into account for the analysis. The result obtained is shown by the broken curve which shows a good agreement with the experimental result. The main cause of the difference between these curves will be a small air gap existing between dielectric material and waveguide walls.

These results will be effective as a scaled model for the satellite broadcasting applications. However, for the practical uses, it is necessary to improve the over-all passband characteristic. This point is currently investigating from the view point of the optimal functional approximation of the over-all filter response.

Although important discussions on improving the passband characteristic are left here, but the experimental result and the investigations presented here are sufficient to make clear the idea itself of new type of filters.

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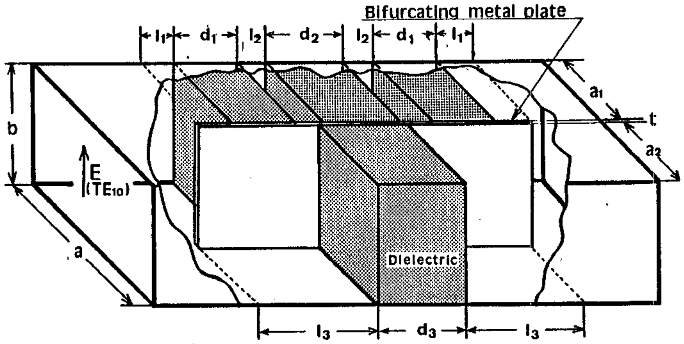

Fig.1. Sketch of two-path cutoff-waveguide dielectric resonator filter.
This example consusts of three resonators and one resonator in the mainpath and the subsidiary path, respectivery.

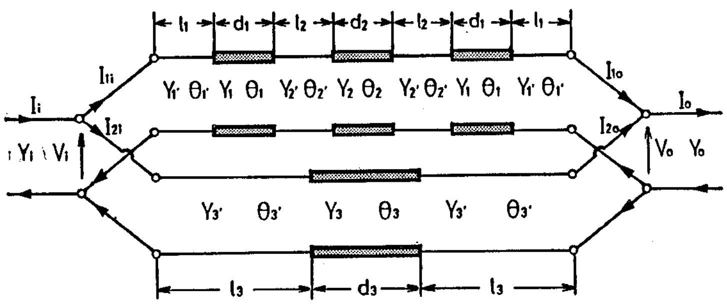

Fig.2. A simple transmission line equivalent circuit for the filter of Fig.1, where the only mode existing in each bifurcated guide is assumed to be an evanescent TE_{10} mode and the susceptances at discontinuity planes are neglected.

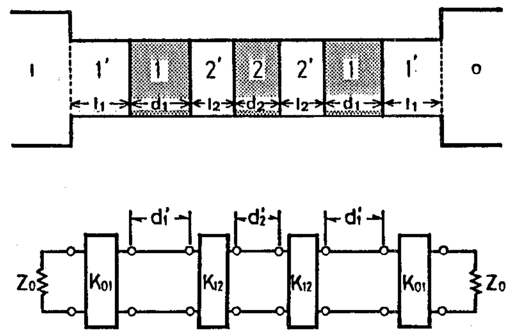

Fig.4. Equivalent circuit for the main path of Fig.1, represented by the impedance inverters with the transmission lines connected on both sides.

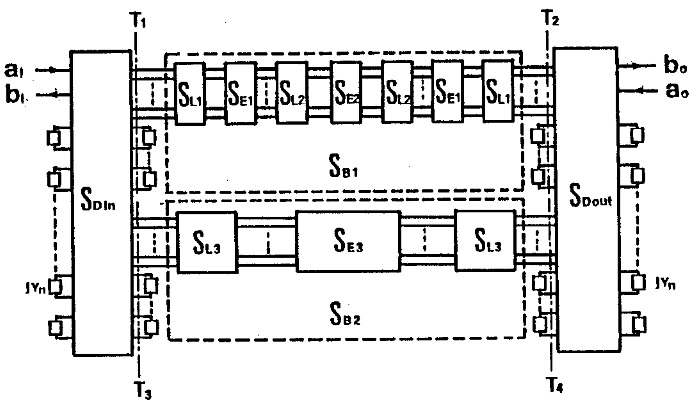

Fig.3. An equivalent circuit in terms of the generalized scattering matrices.

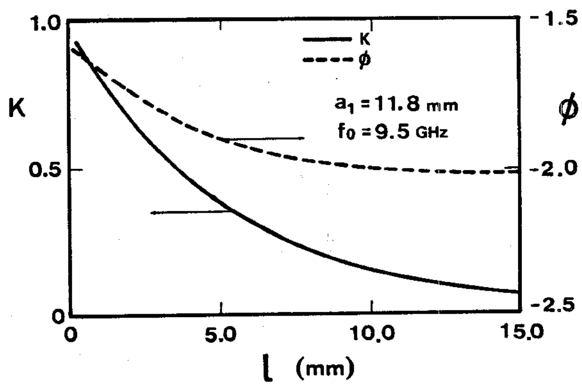

Fig.5. Calculated invereter parameter K and the electrical line length ϕ in case of f = 9.5 GHz and ε_r = 2.56 , as a function of the length l of cutoff waveguide section.

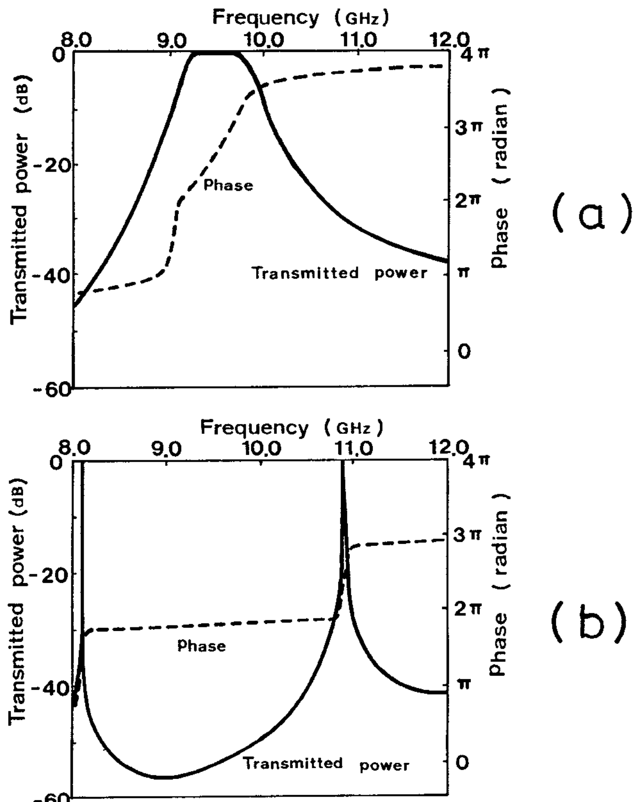

Fig.6. Chebyshev ripple bandpass response designed for the main path (a) and the frequency response of the subsidiary path, in which the second axial higher mode produces zero insertion at 10.75GHz so as to set the insertion pole at 11 GHz (b).

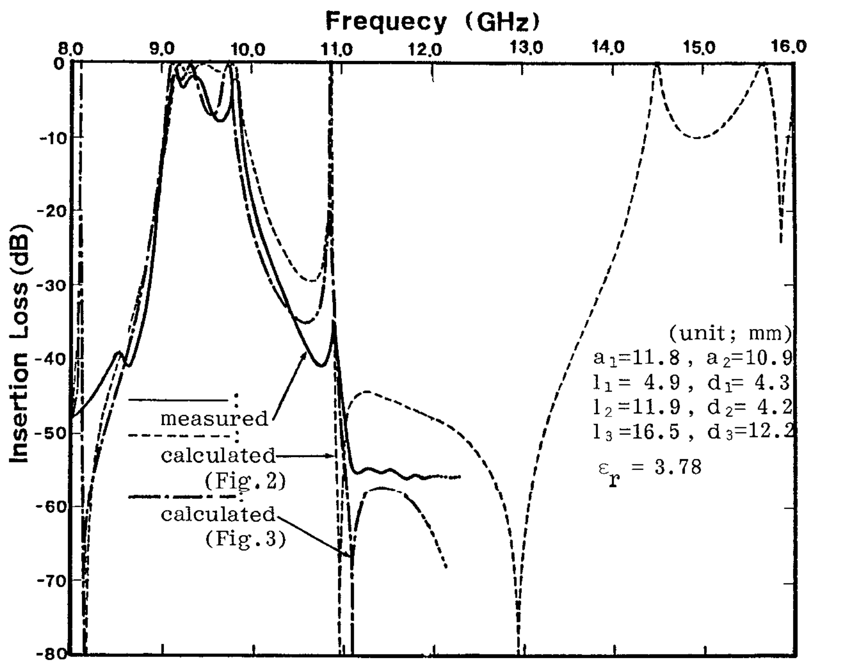

Fig.7. Measured and calculated responcses of designed Chebyshev ripple two-path cutoff-waveguide dielectric resonator filter.
Dielectric material is the fused quatz with dielectric constant 3.78 and the waveguide is a standard WRJ-10 with the length about 3cm.