MODE-SELECTIVE NEGATIVE COUPLING FOR IMPLEMENTING MULTIPLE ATTENUATION POLES IN EVANESCENT-MODE WAVEGUIDE FILTERS

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Abstract

This paper presents interesting improvements on evanescent-mode-waveguide bandpass filters which was reported by us at the 1994 IEEE International Microwave Symposium. Those improvements are now successful for newly introducing both the mode-selective negative coupling and the L-angled corner coupling scheme. Experimental results that we took prove the effectiveness of our improvements.

I. INTRODUCTION AND BACKGROUND

At the 1985 International Microwave Symposium we presented an idea [1], not previously published, to construct evanescent-mode-waveguide bandpass filters. The filter is constructed by the H-plane bifurcation of a standard rectangular waveguide to realize mechanically two paths which are utilized to produce the negative coupling in the off-passband regions. The great significance of this idea is that the passband characteristic can be basically synthesized independent of the stopband characteristic. This means that we can apply the impedance-inverter method to synthesize the passband characteristic prior to the synthesis of the overall characteristic. In practical synthesis tool, the inverter parameters are, of course, obtained by the full-wave analysis method described in [2]. Then, we have developed an efficient synthesis method [1][2] supported by both the conventional ***impedance-inverter method*** and the full-wave analysis based on the ***mode-matching method***.

We investigated theoretically and experimentally the possible characteristics of this type of filters, although some improvement was admittedly remained to remove a spurious dip in the insertion loss. In fact, in the paper [3], we state: "Such an improved filter has already been developed and is now under test, and will be reported in the other paper."

At the 1994 International Microwave Symposium we presented the results [4] of an improved filter and its synthesis method. In this filter, the two paths are realized not mechanically, but electrically by using the interference between the TE_{10} and TE_{20} modes in one cavity. The similar idea was discussed in [5], in which a full computer-aided synthesis method was used until the calculated overall insertion-loss characteristic corresponds to an expected one. However, this approach seems to be of time consuming and also gives us poor outlook on the final result. These drawbacks will be moderated if the impedance-inverter method is incorporated into the numerical synthesis method. However, it is impossible to apply the impedance-inverter method directly to the synthesis of the passband because its characteristic now should be essentially explained in terms of two modes.

To circumvent this difficulty, we initiated a new technique that we call "***the Q-curve-fitting approach***," which is used to develop an approximate impedance-inverter method. Also, to make numerical calculations efficiently, the modal-admittance-matrix method [6] has been substituted for the mode-matching method in the full-wave analysis. It was proved that these improvements on the structure and the numerical analysis were really effective to realize the bandpass filter with an expected electrical performance including no spurious dips in the insertion loss in the stopband range. However, there has still remained a basic problem to be solved. It is the almost zero insertion loss in the far-out-of-passband where the operating frequency approaches the cutoff frequency f_{c20} of TE_{20} mode in the input and output waveguides. An example of filter characteristic is shown in Fig.1, where the

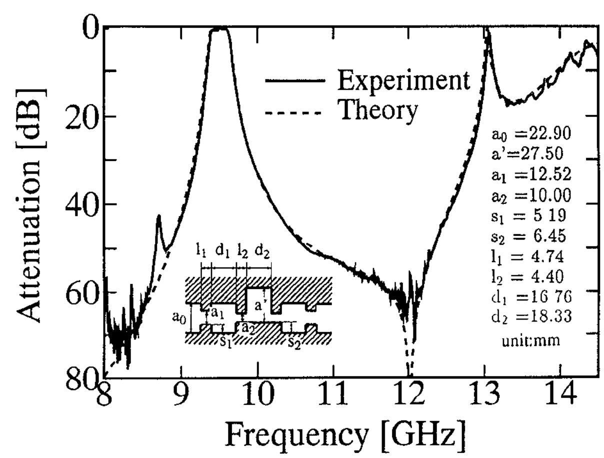

Fig.1. Theoretical and experimantal insertion-loss characteristics of the bandpass filter published in [4], where the TE_{10} and TE_{20} modes in the oversized central cavity are used to emerge an attenuation pole.

synthesized configuration is shown in the inset with the dimensions. It is clear that the zero insertion loss is seen at the cutoff frequency f_{c20} = 13.09GHz. Such a feature is peculiar to evanescent-mode bandpass filters, and will become a disadvantage in practical use, especially, in satellite-communication use.

During this past year, we have investigated a breakthrough to the decreased insertion loss in the far-out-of-passband much more thoroughly, and an idea that is presented in this paper has now emerged[7]. (It was a surprise for us that the similar investigation was also carried out by another research group[8].) This idea includes the following two improvements;

(a) The production of the electrically ***equivalent multipaths*** in a simple structural configuration to realize the "***mode-selective negative coupling***."

(b) A technique to control the coupling coefficients between the input/output waveguides and each equivalent path independently.

According to the item (a), it is easy to produce ***multiple attenuation poles*** in the far-out-of-passband to remove spurious dips in the insertion loss when such poles are arranged properly in the stopband region. On the other hand, since the electrical multipaths are realized here in one structural path, it is often necessary to move the attenuation poles while fixing the resonant frequencies of the cavity modes. Thus, it is shown that the ***L-angled corner-coupling*** scheme is quite effective for the item (b). This coupling scheme is also effective to realize a very sharp roll-off characteristic at the higher edge of the passband.

We present here that measured results for a test filter at X-band show an expected electrical performance, and prove the effectiveness of our idea.

II. PHYSICS OF OPERATION OF NEW BANDPASS FILTER

Figure 2 (the top view from the H-plane of a rectangular waveguide) shows a prototype configuration of the new type of filter with three cavities. All three cavities are oversized appropriately so that both the TE_{10} and TE_{20} waveguide modes play a dominant role on the filter response in the frequency range to be discussed here. If each cavity is isolated from neighboring cavities and/or waveguides, the resonant modes in the cavity 1 may be presumed as the TE_{101} and TE_{201} modes, while the TE_{101}, TE_{201} and TE_{102} modes in the main cavity 2. Since the main cavity 2 is the square configuration, the TE_{201} and TE_{102} modes are degenerate.

To discuss the filter characteristic of the present structure, we assume here that the cutoff frequency f_c for the TE_{20} waveguide mode in the cavity 1 is set a bit higher than the passband center frequency f_0. For such a structure, we may basically presume the following parallel three electrical paths between the input and output waveguides: The first equivalent path (the ***main path***) is realized by the mode coupling among the TE_{101} - TE_{101} - TE_{101} modes in the cavities 1 - 2 - 1, respectively. The second path (the ***subsidiary path 1***) is realized by the mode coupling among the TE_{101} - (TE_{101} and TE_{201}) - TE_{101} modes in the cavities 1 - 2 - 1, respectively, and the third path (the ***subsidiary path 2***) is realized by the mode coupling among the (TE_{101} and TE_{201}) - TE_{201} - (TE_{101} and TE_{201}) modes in the cavities 1 - 2 - 1, respectively.

The main path mentioned above, of course, contributes to realize the 3-pole-passband response, and its center frequency f_0 is related to the resonant frequency of the cavities 1 and 2.

For the subsidiary path 1, there exists such a frequency as the TE_{101} mode in the cavity 1 couples ***simultaneously*** with both the TE_{101} and TE_{201} modes in the ***cavity 2*** under the nonresonant situation. Then these two types of mode in the cavity 2 couple with the TE_{101} mode in the cavity 1 at the output side with the identical amplitude, but just π radians out of phase, and produce the negative coupling to realize an attenuation pole at $f = f_{\infty 1}$ that is in between f_0 and f_c.

For the subsidiary path 2, there exists such a frequency as the TE_{10} mode from the input waveguide excites ***simultaneously*** both the TE_{101} and TE_{201} modes in the ***cavity 1*** at the input side under the nonresonant situation. Therefore, we can expect the emergence of ***one more*** attenuation pole due to the negative coupling at $f = f_{\infty 2}$ that is in between f_c and f_0', the resonant frequency of the TE_{201} mode in the cavity 1. At $f_{\infty 2}$, such a negative coupling occurs simultaneous in two identical cavities 1 at both the input and output sides which are now coupled loosely each other through the

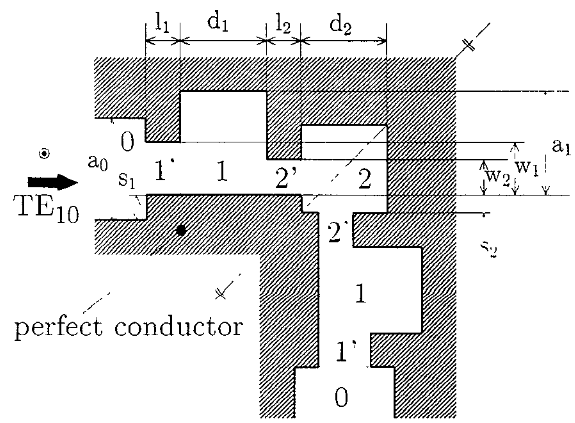

Fig.2. Improved type of evanescent-mode bandpass filter viewed from the H-plane of a rectangular waveguide, with the definition of constituting regions and structural dimensions.

off-resonant TE_{201} mode in the cavity 2. This results in a very sharp attenuation pole at $f_{\infty 2}$.

The two types of the negative coupling mentioned above now play an important role in improving the far-out-of-passband at the higher frequency range. Thus, we call a series of such negative-coupling mechanisms "***the mode-selective negative coupling***."

Now, to improve the insertion characteristic at the far-out-of-passband, let us move the attenuation pole $f_{\infty 2}$ beyond the cutoff frequency f_{c20}, while $f_{\infty 1}$ close to the high-frequency edge of the passband. For this purpose, it is absolutely necessary to realize a ***large*** coupling coefficient between the TE_{101} mode in the cavity 1 and the TE_{201} mode in the cavity 2, while keeping the coupling coefficient between the TE_{101} mode in the cavities 1 and 2. From a simple physical consideration, it is found that this problem will be satisfactorily solved by the ***L-angled corner-coupling*** scheme shown in Fig.2.

III. DESIGN APPROACH AND EXPERIMENTS

Although the simultaneous presence of both the TE_{101} and TE_{201} (TE_{102}) modes in each cavity plays a dominant role in the present filter, we want to still apply the conventional impedance-inverter method at least to design the passband response. To this end, we have developed an effective approximate method which we call the "Q-curve fitting approach." Its detail is omitted here due to the limited available space, and is found in [4] and also will be explained briefly at the talk.

For the design of the off-passband response, we apply the full-wave synthesis method, in which the fields in each cavity are expanded into a finite series of the resonant-cavity modes[9], while, in the cutoff-waveguide regions, a large number of higher modes are taken into account. This method is applied to the optimization under the constraint conditions for the emergence of the attenuation poles at the specified frequencies $f = f_{\infty 1}$ and $f_{\infty 2}$, correspondingly, for the settlement of the expected stopband width.

An example design is performed for the bandpass filter with the 3-poles, 0.1 dB Chebyshev-ripple passband response (f_0 = 9.5GHz and f_w = 200MHz). In this synthesis example, the attenuation poles are automatically implemented so that the insertion loss larger than 50dB should be realized in the off passband between 10.5GHz and 13.09GHz (the cutoff frequency f_{c20}). Our full-wave analysis took account of 40 cavity modes in each cavity and 50 modes at each cutoff waveguide, and the synthesized-structural dimensions are shown in the inset of Fig.3.

The broken curve shown in Fig.3 indicates the synthesized theoretical insertion-loss characteristic, while the solid curve shows the experimental result. Fig.4 shows the passband characteristic with the greatly enlarged scale, while Fig.5 is the corresponding return-loss characteristic. Also, Fig.6 shows the phase characteristic. Although there are some small discrepancies between the theoretical and experimental results in these figures, these results are enough to confirm the validity of our new idea for constructing a bandpass filter.

IV. CONCLUSIONS

We have shown here a new idea, the mode-selective negative coupling, for implementing multiple attenuation poles in the far-out-of-passband, which is effective to remove the spurious transmission and to widen the stopband width for evanescent-waveguide filters. Although the structure is constructed with several number of oversized waveguide cavities connected in cascade, we have shown an effective synthesis method supported by both the modified impedance-inverter method and the modal-admittance-matrix method. Although our idea has been discussed by using a simple filter configuration, its development into practical configurations has no difficulty.

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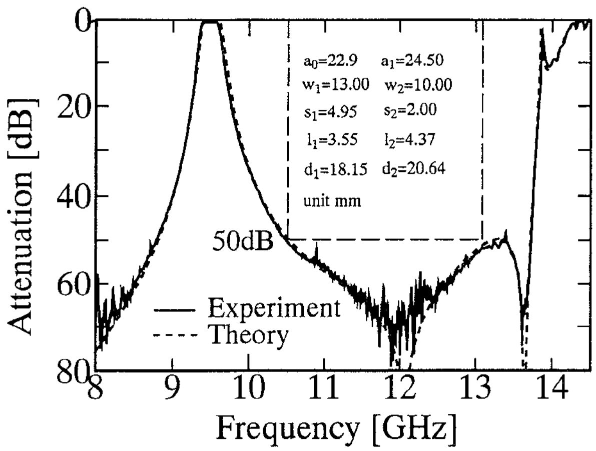

Fig.3. Theoretical and measured insertion-loss characteristics of an improved filter, of which structural configuration is shown in Fig.2 and the dimensional results are shown in the figure.

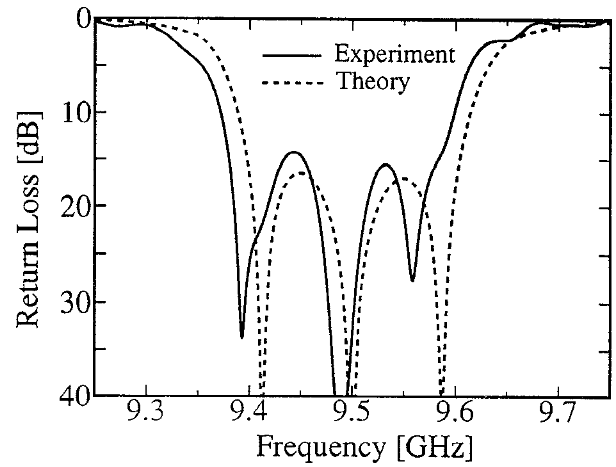

Fig.5. Theoretical and measured return-loss characteristics of an improved filter.

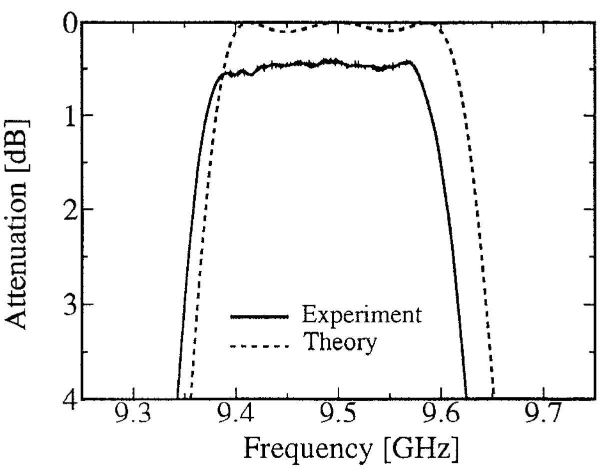

Fig.4. Passband characteristics with an enlarged scale. The experimental result shows a slightly large insertion loss, with a shifting to the low frequency.

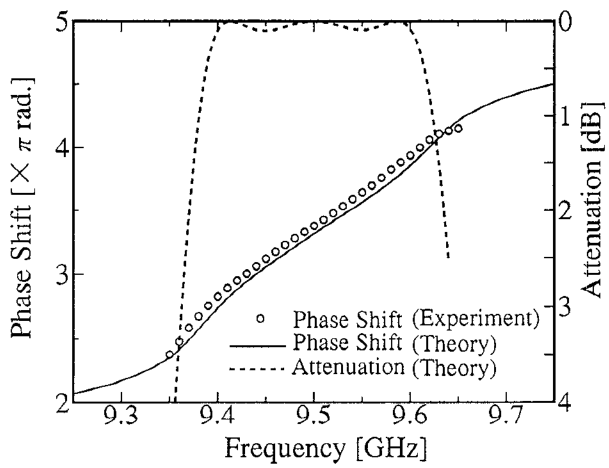

Fig.6. Theoretical and measured phase characteristics in the passband of an improved filter.