Using Frequency-Dependent Coupling to Generate Finite Attenuation Poles in Direct-Coupled Resonator Bandpass Filters

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***Abstract*— Frequency-dependent coupling sections in direct-coupled resonator bandpass filters are used to generate attenuation poles at finite frequencies. The technique allows the prescription of attenuation poles on either side of the passband, symmetrically or asymmetrically, as opposed to overmoding the resonators where attenuation poles are generated only in the upper stop band. The frequency-dependent coupling sections are also used as inverters to determine the passband response. The classical inverter theory is used to obtain approximate designs which are subsequently optimized to fit the specifications. A third-order filter with four attenuation poles and a fifth-order with two attenuation poles are presented to illustrate the approach.**

***Index Terms*—Bandpass filters, computer-aided analysis, waveguide filters.**

I. Introduction

DIRECT-COUPLED resonator bandpass filters have been investigated and used for decades [1], [2]. Accurate synthesis and design techniques of this type of filters with equal-ripple passband have been known for almost as long.

In these design techniques, the frequency dependence of the coupling sections is seen rather as a hurdle to be overcome in order to achieve an accurate design, and appropriate methods were advanced to address this topic [2]. While these corrections deal well with the passband response, they affect the stop band only slightly.

With the increasing demand for filters with sharp cutoff skirts, and even asymmetric responses, direct-coupled resonator bandpass filters without finite attenuation poles are replaced by cross-coupled resonators with elliptic or pseudoelliptic responses. In dual- and multimode filters, additional couplings are established between the different resonances although the physical cavities are directly coupled. A few attempts have been made to generate finite transmission zeros without additional couplings between nonadjacent resonators, e.g., [3]–[5]. The mechanisms used to generate these poles consist in overmoding the resonators, thereby generating poles only in the upper stop band. Using this mechanism in H-plane filters results in all coupling sections being irises, e.g., [3]–[5].

In this letter, we present a new mechanism for generating finite attenuation poles in direct-coupled resonator bandpass filters. Instead of overmoding the resonators and using only one type of coupling sections (irises), we selectively use coupling sections which depend strongly on the frequency. For planar E- or H-plane filters, for example, both stubs and irises are used as coupling elements. The stubs are then used to provide the attenuation poles as well as the proper value of the inverters in connection with the remaining irises, e.g. [6]. (Note that the stubs are not external elements added for the purpose of providing the attenuation poles. On the contrary, their frequency dependence is an integral part of the filter function.) Weak coupling is implemented using irises and strong coupling using stubs. The dimensions of the stubs are adjusted to give attenuation poles on either side of the passband, either symmetrically or asymmetrically. Using this approach it is possible to generate more attenuation poles than allowed by cross-coupled resonators with *constant* coupling coefficients where n resonators can generate a maximum of $n-2$ attenuation poles [7].

Another alternative proposed in [8] consists of extracting series or shunt resonators at each end of the filter. The method presented here is, however, simpler with respect to the synthesis procedure, although the final design requires optimization. In addition, the transmission zeros in our design can, in principle, be generated by frequency dependent coupling elements which are not necessarily placed at each end of the filter.

II. Approximate Synthesis

In order to keep the discussion simple, we consider a third order E-plane filter as shown in Fig. 1. In its standard form, a bandpass filter is designed using capacitive irises as coupling sections between the three resonators. Such an arrangement cannot generate finite attenuation poles without "overmoding" the resonators as mentioned above.

To introduce these poles, we therefore change some irises into E-plane stubs. By suitably adjusting the width (in axial direction) and the height of the stubs, it is possible to introduce finite attenuation poles on either side of the passband. It is not, however, efficient to limit the role of the stubs exclusively to the introduction of the poles. In our method, they are also used to provide the correct coupling (inverters) at the center of the passband [6].

Using the classical inverter approach of synthesis of direct-coupled waveguide cavity filters [9], the dimensions of the stubs are adjusted to give the correct value of the inverter

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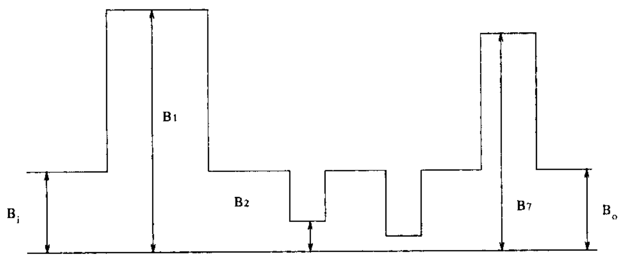

Fig. 1. Side view of a third-order stub-iris E-plane filter. The two stubs generate attenuation poles and act as inverters.

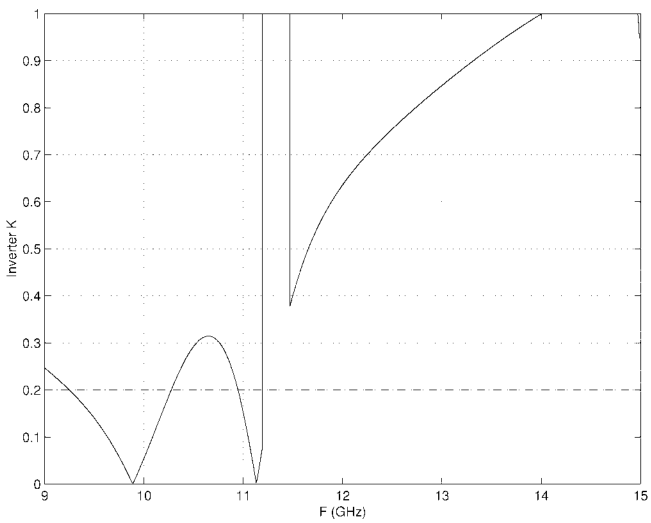

Fig. 2. Dependence of the inverter impedance of an E-plane stub on frequency. The dashed line is the target value obtained from the prototype.

at the center frequency of the passband and the location of the attenuation poles. The frequency dependence of an inverter's impedance, which corresponds to an E-plane stub, is shown in Fig. 2. Note the presence of frequencies at which this impedance vanishes, thereby providing attenuation poles. For a given target value of an inverter's impedance, a number of solutions are possible as shown, for example, in Fig. 2 where this number equals four. By varying the dimensions of the stub, the curve in Fig. 2 can be shifted toward higher or lower frequencies, thus allowing the positions of the attenuation poles to be located on either side of the passband. Moreover, the stub dimensions influence the number of attenuation poles that can be generated. The in-band return loss is, however, affected by the attenuation poles. How close they can be placed to the passband depends on the return-loss specifications and the filter order, i.e., the number of resonators. The two prototypes presented in the next section provide some guidelines for three- and five-resonator filters with 20-dB return loss.

III. Results

The approach outlined above was used to design E-plane and H-plane filters of varying orders with attenuation poles. Here, we present two examples to illustrate the kind of results that can be achieved.

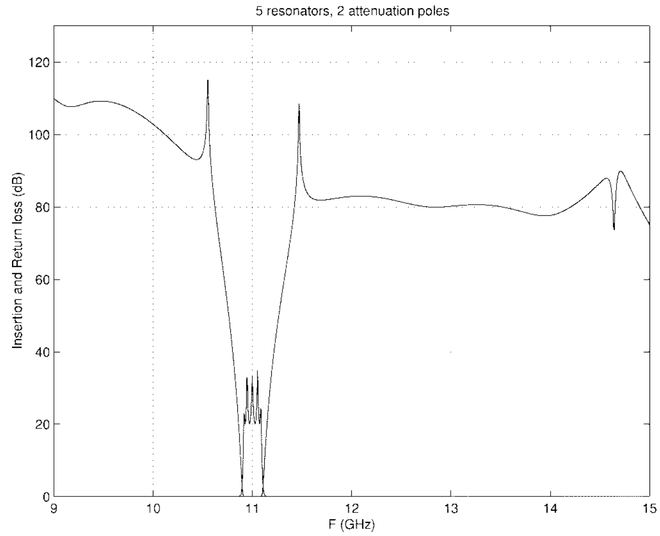

Fig. 3. Insertion and return loss (decibels) of the final fifth-order H-plane filter with two finite attenuation poles.

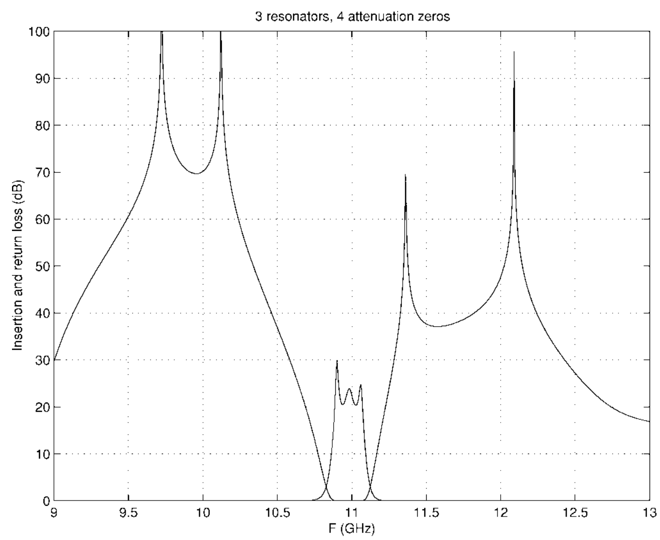

Fig. 4. Insertion and return loss (decibels) of a third-order E-plane filter with four finite attenuation poles.

The first example is a fifth-order H-plane filter with one attenuation pole on each side of the passband. The approximate design was carried out as outlined above. The first and last coupling sections consist of H-plane stubs and all the remaining ones are asymmetric inductive irises of thickness 1 mm. Although the passband return loss of the initial design does not satisfy the 20-dB minimum originally specified, both attenuation poles as well as the edges of the passband are well accounted for. To finalize the design, the dimensions obtained from this initial design are used as start values in an optimization algorithm. The response of the optimized filter is shown in Fig. 3. The presence of the two attenuation poles as well as the 20-dB minimum passband return loss are now achieved.

The second example is a third-order E-plane filter with two transmission zeros on each side of the pass band. As in the previous case, only the first and last coupling sections are implemented using E-plane stubs, capacitive corrugations are used for the remaining ones. We first allow the two stubs to be wide enough (in axial direction) to generate two attenuation poles each. The position of the attenuation poles is controlled as illustrated in Fig. 2.

For lack of space, we only present the response of the final filter which is obtained by optimization using the initial design as starting guess. The insertion and return loss of this filter is shown in Fig. 4 where the presence of the four attenuation poles is obvious.

The data in Figs. 3 and 4 have been obtained using the coupled-integral-equations technique (CIET) which has been proven to provide results in excellent agreement with mode-matching (e.g., [10]) and finite-element (e.g., [11]) techniques.

IV. Conclusions

Frequency-dependent coupling sections are used to introduce finite attenuation poles in direct-coupled resonator band-pass filters. A mixture of irises and stubs are used in the same filter to generate finite attenuation poles on either side of the passband. Two filters illustrating the approach are presented.

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