AN EXACT SOLUTION FOR A SIX-CAVITY DUAL-MODE ELLIPTIC BANDPASS FILTER

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Abstract

The paper treats the synthesis and realization of a six-cavity dual-TE_{101}-mode bandpass filter exhibiting all four theoretically possible attenuation poles at finite frequencies. A novel arrangement of the cavities in the dual-mode resonators effects the feasibility of an exact elliptic filter taking the place of the well known six-cavity pseudo-elliptic filter, which presents only two attenuation poles at finite frequencies. Measured curves of an example of implementation at 4 GHz show the results to be in good agreement with the theoretical responses.

Introduction

Dual-mode filters have in recent years assumed increasing importance at GHz frequencies because the utilization of orthogonal polarizations in cavity resonators allows a 50 % reduction in weight which is of particular interest for filters used in satellite repeaters. Williams and Atia have variously shown[1,2], that such filters also are able to exhibit attenuation poles at finite frequencies and at the same time a flattened group delay within the passband.
The present work will introduce a novel solution for the realization of dual-mode filters with additional couplings which, used in conjunction with symmetric and unsymmetric configurations, opens the way to a variety of hitherto unknown possibilities. A six-cavity elliptic bandpass filter of narrow relative bandwidth will be used as an example to illustrate the synthesis and realization of a filter of this type.

Definition of Problem

A six-pole elliptic bandpass filter exhibits two attenuation poles at finite frequencies both above and below the passband. Figure 1

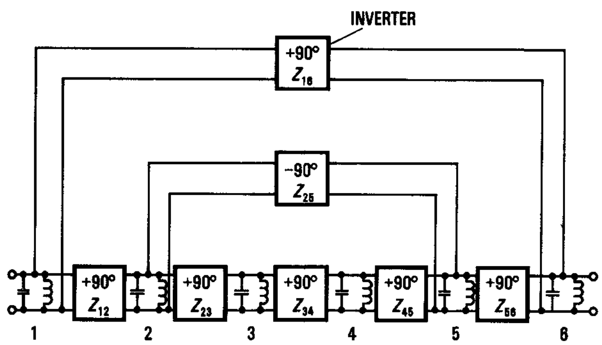

Fig.1: Equivalent circuit diagram of a six-pole elliptic bandpass filter.

shows a conventional symmetric equivalent circuit diagram comprising six shunt resonant circuits and interposed ideal inverters. The resonant circuits 1 and 6 as well as 2 and 5 are additionally coupled.

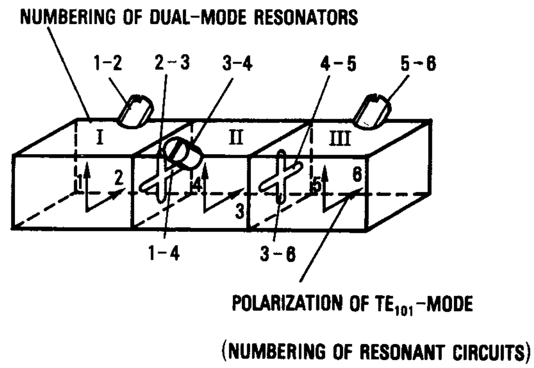

Fig.2: Conventional six-cavity dual-mode filter disallowing the realization of an elliptic filter.

Figure 2 is a schematic representation of a six-cavity dual-TE_{101}-mode bandpass filter in conventional technology. The vectors of the electric field strength are indicated by arrows and numbered in correspondence with the resonant circuits of the filter. The resonant circuits are accommodated in pairs in respective dual-mode resonators, each pair being coupled by way of a coupling screw oriented at an angle of 45° relative to the two polarization directions. The sign of the coupling is given by the setting of this screw. Cavities in physically separate resonators are coupled by way of slots in the common dividing wall, whereby the vectors of the electric field strength must be in parallel with each other, e.g. vectors 2 and 3 in dual-mode resonators I and II. As a result of this requirement, not all theoretically conceivable filter configurations can be realized in dual-mode technology.
The two possible additional couplings of resonant circuits 1 and 4 as well as 3 and 6 shown in the configuration in Figure 2 result in only one attenuation pole at a finite frequency above and below the passband, which leads to what is known in the literature as a pseudo-elliptic response.

As already noted, the realization of a six-cavity filter with an exact elliptic response requires the additional coupling of resonant circuits 1 and 6. Since however, as shown in Figure 2, the corresponding field strength vectors are normal to each other, the coupling of the two cavities and consequently the realization of the filter with this convential configuration is not possible. Thus far dual-mode filter implementations with TE_{101} or TE_{111} resonators have been reported for the six-cavity pseudo-elliptic filter, e.g.[3], but not for exact elliptic filters with all four theoretically possible attenuation poles at finite frequencies.

Comparison of Lowpass Filters of the Degree n = 6 with One and Two Attenuation Poles at Finite Frequencies

In order to show the advantage of an exact elliptic filter solution compared with the pseudo-elliptic solution it is convenient to look at the corresponding prototype lowpass filters of degree n = 6, the attenuation responses of which are given in Figure 3 for an example. Both lowpass filters exhibit an equiripple attenuation response $a_b \leq 0.011$ dB within the passband $0 \leq \Omega \leq 1$ as well as the

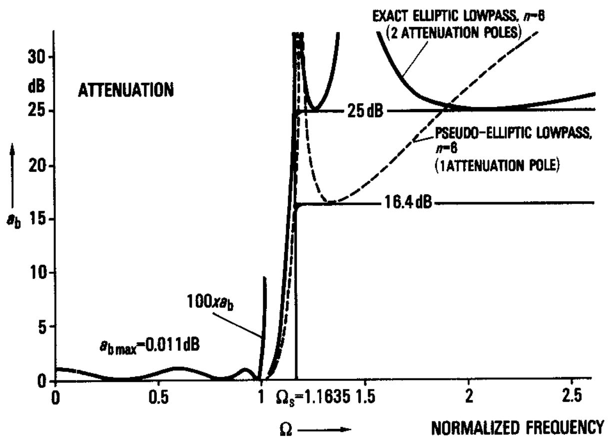

Fig.3: Attenuation responses of elliptic and pseudo-elliptic lowpass filter of degree n = 6.

same cut-off frequency $\Omega_s = 1.1635$. While the elliptic lowpass filter is good for a minimum attenuation of $a_b = 25$ dB in the stop band, the pseudo-elliptic lowpass filter guarantees only 16.4 dB. A proper description of the filters is given by their characteristic functions K(s):

Elliptic lowpass filter

$$K_E(s) = \frac{(s^2+0.112315)(s^2+0.650676)(s^2+0.964815)}{-0.4632\ (s^2+1.404932)(s^2+2.159188)}, \quad (1)$$

Pseudo-elliptic lowpass filter

$$K_{PE}(s) = \frac{(s^2+0.0910442)(s^2+0.597064)(s^2+0.957019)}{-0.7287\ (s^2+1.433881)}. \quad (2)$$

Attenuation depends on the characteristic function by the formula

$$\frac{a_b(\Omega)}{\mathrm{dB}} = 4.34 \ln\left(1 + |K(j\Omega)|^2\right). \quad (3)$$

Synthesis and Circuit Configuration of Reference Lowpass Filter

After illustrating the advantage of an exact elliptic solution for six-pole bandpass filters a proposal for the practical realization of an appropriate dual-mode filter will be outlined basing on the characteristic function (1) of the reference lowpass. The Hurwitz polynomial and the chain matrix polynomials are determined using the rules of insertion loss theory.

A lowpass configuration with bypasses is realized by the method described in[4], where the additional couplings are selectively extracted from the chain matrix of the lowpass filter as ideal bypassing transformers. Figure 4 presents the way of extraction. The flexi-

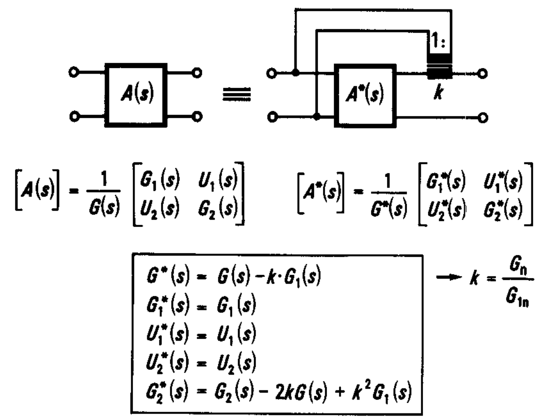

Fig.4: Decomposition of a bypassing ideal transformer from the chain matrix [A(s)].

bility of this method allows the synthesis of both symmetric and unsymmetric filter configurations with ease.
A lowpass filter configuration which is already suitable for the realization of the six-cavity elliptic filter with dual-TE_{101}-mode resonators is depicted in Figure 5a. Two ideal transformers serve for coupling the elements 1 and 6 as well as 1 and 4. Conversion yields the equivalent circuit shown in Figure 5b, consisting solely of shunt capacitances and inverters. Assuming all the inverters to have positive characteristic impedances and all the inverters of the basic configuration to have a phase b = +90°, the sign for the coupling of elements 1 and 6 will be positive and that for the coupling of elements 1 and 4 negative.

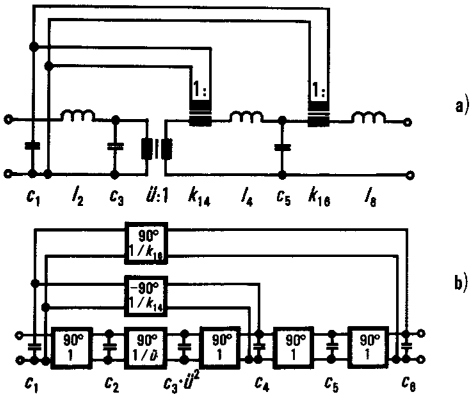

Fig.5: Equivalent circuits of prototype lowpass filter; a) with lumped elements, b) with inverters.

Realization of Six-Cavity Elliptic Filter in Dual-TE_{101}-Mode Technology

The realization of the filter in dual-mode technology with TE_{101} or TE_{111} resonators is made possible by a novel method of arranging cavities in the resonators. Whereas adjacent cavities, e.g. 1 and 2, 3 and 4 etc., are conventionally accommodated as a pair in a single resonator, the nonconsecutively numbered cavities 1 and 4 which have to be additionally coupled are here arranged in a single resonator. As seen from Figure 6, the arrangement of the resonators has the same outer appearance as that of the filter which cannot be realized.

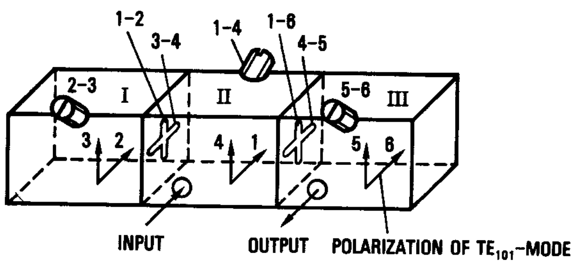

Fig.6: Cavity arrangement of a six-cavity dual-TE_{101}-mode elliptic bandpass filter.

The essential difference is that the middle resonator II accommodates cavities 1 and 4. The cavities within each resonator are coupled by the dual-mode coupling screw. The negative sign of the coupling 1 - 4 is realized by adjusting the setting of the appropriate coupling screw relative to the setting of the screws 2 - 3 and 5 - 6. Since the polarizations of the cavities 1 and 6 here run in parallel, coupling with the correct positive sign is possible through the slot 1 - 6 in the dividing wall between respective resonators. Cavities 1 and 2, 3 and 4 as well as 4 and 5 can be coupled in the same way.

The filter inputs are, e.g. SMA-connectors with their inner conductors running in parallel with the E-field polarizations of cavities 1 and 6.

According to the equivalent circuit in Figure 1 another arrangement of cavities is possible by accommodating cavities 1 and 6 as well as 2 and 5 in the same resonator, respectively. However this configuration appears rather unpractical because both filter inputs would concern the same resonator.

As an example of application a breadboard model was constructed and tested, using dual-TE_{101}-mode square waveguide resonators with the cross section 48 mm x 48 mm. The design goal was a six-cavity elliptic bandpass filter, centered at f_o = 4018 MHz and exhibiting a theoretical return loss of $a_e \geq 26$ dB ($a_b \leq 0.011$ dB) within the equiripple bandwidth of Δf_g = 40.36 MHz. In accordance with the previously mentioned reference lowpass design the theoretical stopband attenuation should not fall short of a_b = 25 dB for frequencies $|f - f_o| \geq 23.5$ MHz.

Measurements

As seen from the measured attenuation response curve in Figure 7, all four theoretically possible attenuation poles at finite frequencies are well defined and appear almost exactly at the predicted frequencies, so assuring close agreement between theory and practice for the entire response curve. The attenuation characteristic calculated from the equivalent circuit is indicated by a dashed line.

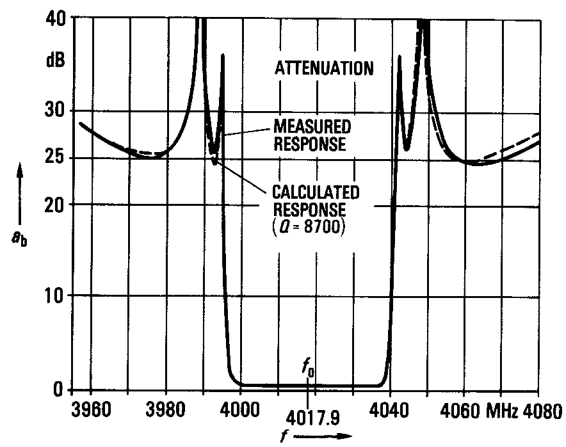

Fig.7: Measured and calculated attenuation response.

Measured values of return loss are grater than a_e = 21 dB within the frequency band $|f - f_o| \geq 20.19$ MHz, as Figure 8 shows.

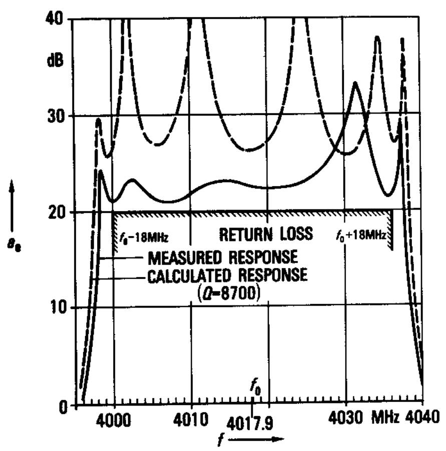

Fig.8: Measured and calculated return loss response.

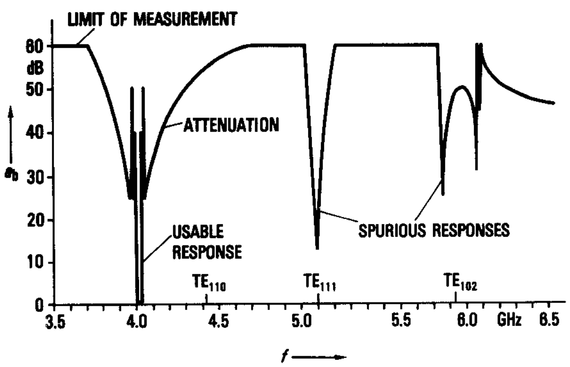

Fig.9: Measured out-of-band attenuation response.

Midband loss amounts to a_o = 0.3 dB according to a resonator Q of approximately 8700. Also the group delay characteristic agrees quite well with the calculated curve.
Figure 9 shows the out-of-band attenuation response.
If the described filter is implemented with carbon fibre epoxy material its weight will be less than 170 g.

Conclusion

It has been shown that a six-cavity elliptic bandpass filter can be realized in dual-mode technology with all four theoretically possible attenuation poles at finite frequencies if at least one resonator accommodates cavities without consecutive numbers.
This novel concept has general applicability and opens the way to a large variety of new options for the realization of dual-mode-filters.

References

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