TUNING PROCEDURE FOR SYMMETRIC COUPLED-RESONATOR FILTERS

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Abstract

A tuning procedure for symmetric coupled-resonator filters is presented that significantly reduces development and production tuning time. A method of analysis and application to a 12-resonator combline filter are described. The analysis method allows direct calculation of the loss slope and delay responses.

Introduction

One of the most important types of microwave bandpass filters is the coupled-resonator filter in a symmetric folded configuration (canonical form) with an even number of resonators (n). The lowpass prototype for such a filter, as shown in Figure 1, exhibits a frequency-symmetric response with n-2 finite-frequency loss poles that can be arbitrarily placed in the stopband for selectivity and in the complex-frequency domain for flat passband delay or linear phase. This flexibility in the response is possible because of the multiple paths through the network between the input and output ports. However a filter with such multiple paths is inherently a high sensitivity network and is much more difficult to tune than a filter with only a single path.

The total number of adjustable parameters in the filter of Figure 1, including input/output couplings, inter-resonator couplings and resonator tuning is 5n/2. Thus for a 12-resonator filter there are 30 possible adjustments. Even on a production unit which requires a minimum amount of adjustment, tuning the filter can be a frustrating task for the most experienced tuner. The situation is worse for an engineering model, which may require significant modification of couplings. A simple tuning procedure is described in this paper that is suitable for both development and production tuning. Applied to a 12-resonator combline filter, the procedure has resulted in a reduction of tuning time for an engineering model from several weeks to several days.

Procedure

The procedure begins with the symmetric two-resonator system consisting of resonators 1 and n, the coupling $K_{1,n}$ and the coupled terminations. This system constitutes an undercoupled filter whose theoretical loss response is calculated. In the actual filter with the other resonators decoupled, the two-resonator system is tuned to duplicate the theoretical response. Next a symmetric four-resonator system is formed by adding resonators 2 and n-1 and associated couplings, and is tuned to match the theoretical response. The procedure is repeated until all n resonators are in the circuit. At that point the filter will be ready for the final tuning stage in which fine adjustments are made to the return loss, delay and rejection responses.

For production tuning this procedure can be used for the initial coarse tuning stage. For filter development, this procedure would follow the theoretical or empirical determination of the required couplings. In some instances however the procedure itself may be the easiest method to determine the couplings, particularly for very small "bridge" couplings such as $K_{1,n}$, $K_{2,n-1}$, etc. in Figure 1.

Because several theoretical responses are required for this tuning procedure, an efficient and accurate analysis method is desirable. The following method can be used to directly calculate the network response parameters, including loss slope and delay.

Analysis

As in synthesis [1] , the analysis of a symmetric coupled-resonator filter (or one of its subnetworks) is most easily accomplished using bisection to obtain the singly-terminated even- and odd-mode networks. Let $S_{\pm}$ be the reflection coefficient for the even (+) or odd (-) mode. The two-port scattering parameters for the symmetric network are then:

$$S_{11} = S_{22} = (S_+ + S_-)/2 \quad (1a)$$

$$S_{12} = (S_+ - S_-)/2 \quad (1b)$$

Let $Z_{\pm}$ be the input impedance to the even/odd-mode network, including the termination shunting node 1. Then $S_{\pm} = 2GZ_{\pm} - 1$, and from (1)

$$S_{11} = G(Z_+ + Z_-) - 1 \quad (2a)$$

$$S_{12} = G(Z_+ - Z_-) \quad (2b)$$

For the canonical form of Figure 1, the analysis is further simplified because the even/odd-mode networks have no "bridge" couplings. Hence the nodal admittance matrix $\underset{\sim}{Y}_{\pm}$ is a tridiagonal matrix, and methods used to analyze ladder networks [2,3] can be adapted to this situation. For a tridiagonal matrix $\underset{\sim}{Y}$ of order m, whose elements are Y_{ij}, the following sequence is calculated in descending order:

$$D_{m+2} = 0 \quad (3a)$$

$$D_{m+1} = 1 \quad (3b)$$

$$D_i = Y_{ii} D_{i+1} - Y^2_{i,i+1} D_{i+2}, \quad m \quad i \quad 1 \quad (3c)$$

The desired element of $\underset{\sim}{Z} = \underset{\sim}{Y}^{-1}$ is

$$Z_{11} = D_2/D_1 \quad (4)$$

For the network of Figure 1, the non-zero elements of $\underset{\sim}{Y}_{\pm}$ are $Y_{11} = G + s + g \pm jK_{k,n}$, $Y_{12} = jK_{12}$, $Y_{22} = s + g \pm jK_{2,n-1}$, etc. (A small conductance term, g, accounts for the resonator unloaded Q.) Using these elements in the sequence (3), equation (4) gives the impedances $Z_{\pm}$ needed to calculate S_{11} and S_{12} in (2).

The loss slope and delay are the real and imaginary parts, respectively, of $d/d\omega(-\ln S_{12})$ from equation (2b). Thus by taking the derivatives of the sequence (3) and equation (4), the loss slope and delay can be calculated directly. The sensitivity of the response to any network parameter is also available with this method.

Example

The tuning procedure was applied to a 12-resonator combline filter at 4 GHz as shown in Figure 2. The lowpass prototype response of this filter has two pairs of stopband loss poles, one complex-frequency loss-pole quad, and a pair of loss poles on the real s-plane axis. Loss responses of symmetric subnetworks with two through ten resonators were calculated for tuning purposes, examples of which are shown in Figures 3 and 4. The theoretical and measured response of the filter (Figures 5 and 6) show reasonable correspondence. Based on this and subsequent filter development, the tuning procedure has proven to be a valuable resource at the laboratory bench.

References

[1] H. C. Bell, Jr., "Canonical lowpass prototype network for symmetric coupled-resonator bandpass filters," Electron. Lett., vol. 10, pp. 265, 266, June 27, 1974.

[2] T. R. Bashkow, "A note on ladder network analysis," IRE Trans. Circuit Theory, vol. CT-8, pp. 168, 169, June 1961.

[3] G. L. Matthaei, et al., Microwave Filters, Impedance-Matching Networks, and Coupling Structures, ch. 2. New York: McGraw-Hill, 1964.

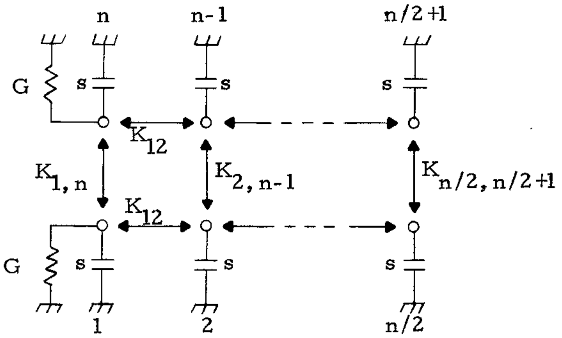

Figure 1. Lowpass prototype.

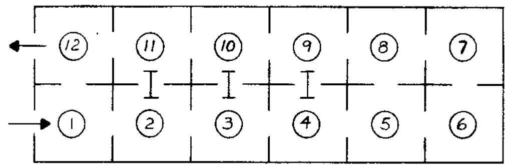

Figure 2. Combline filter.

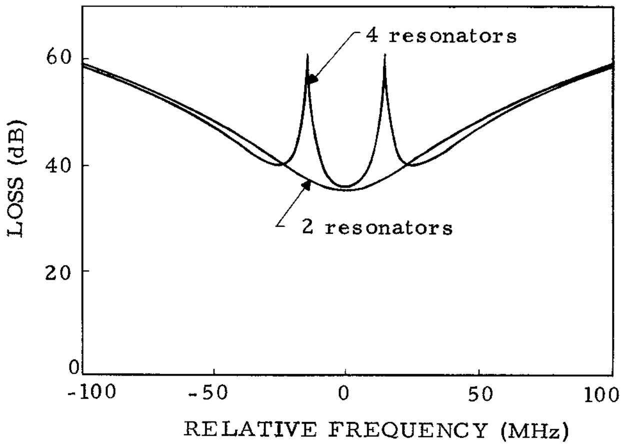

Figure 3. Loss response for 2 and 4 resonators.

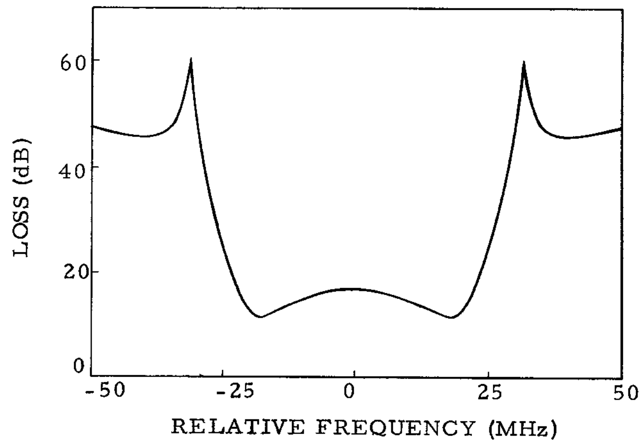

Figure 4. Loss response for 8 resonators.

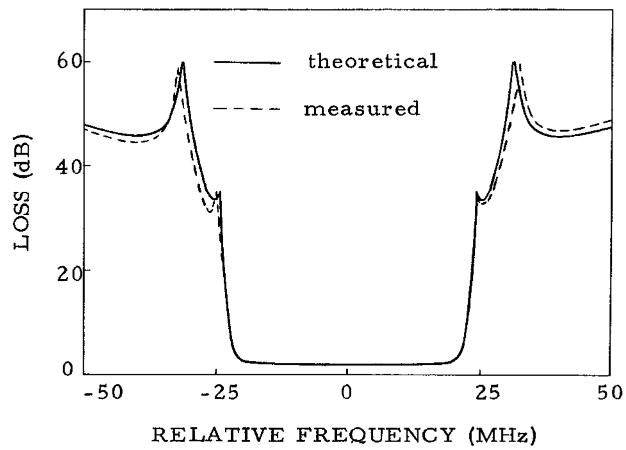

Figure 5. Loss response of filter.

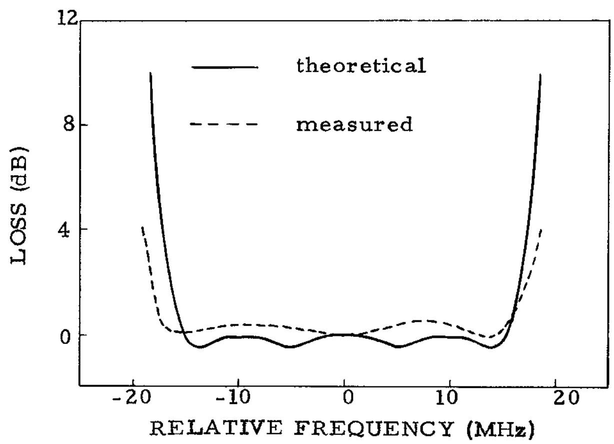

Figure 6. Delay response of filter.