A TECHNIQUE FOR THE REALIZATION OF OPTIMUM BANDPASS FILTERS

by

A. Kent Johnson

Bell Telephone Laboratories, Incorporated
Whippany, New Jersey 07981

Summary

A technique for the planar realization of optimum bandpass filters is presented. This design method results in a coupled-line filter which can be realized by printed circuit techniques. A design example is given and the relative advantages and disadvantages of this approach are discussed.

Introduction

In their paper[1] on the design of optimum filters, Horton and Wenzel outline a general procedure for the design of optimum filters and discuss the relative merits of optimum filters as contrasted with redundant filters. They define an optimum filter as a nonredundant two-port network, and define a nonredundant network as one in which each element contributes a complex-plane pole that can be used to augment the filter skirt response. In a given filter, the filtering properties are realized by two different type elements: the stub-type element and the quarter-wave line spacer elements which are placed between the stubs. Horton and Wenzel compare the filtering properties of these two type elements and show that the stub types are always superior in filtering ability and increasingly so for wider bandwidths.

The work of Horton and Wenzel shows that there is a distinct advantage in including as many nonredundant stub-type elements as possible in the design of a filter. They outline a technique for realizing such a filter, but it results in a nonplanar structure. In the design of planar bandpass filters (such as with printed circuit techniques) the design methods generally available result in redundant networks with filters containing only 1 or 3 nonredundant stub-type elements. Whatever additional filtering is necessary is accomplished by quarter-wave line spacers. This situation arises because of the general difficulty in realizing series stubs in a planar structure. The redundant realization is generally satisfactory, but a technique for the planar realization of the nonredundant or optimum filter would clearly be useful. Such a technique will be presented here.

Realization Technique

Using the terminology of Horton and Wenzel, a general representation of the desired filter type is shown in Figure 1. This is a bandpass filter having only nonredundant reactive elements separated by nonredundant unit elements. Techniques for the realization of a shunt inductor next to a

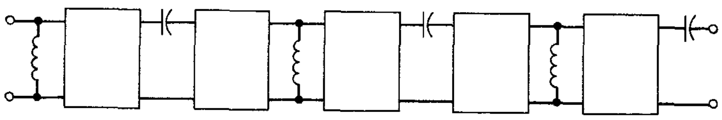

FIGURE 1

unit element or between two unit elements and for a series capacitor next to a unit element are available in the literature.[2] The only difficulty in Figure 1 is the planar realization of a series capacitor between two unit elements.

To demonstrate a technique for accomplishing this, consider a simpler example as shown in Figure 2A.

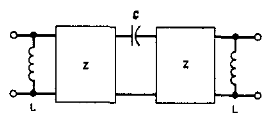

FIGURE 2A

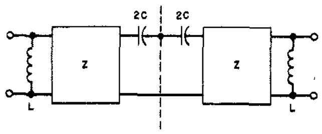

FIGURE 2B

FIGURE 2

The method for realizing the filter of Figure 2A consists simply of bisecting the filter into two networks for which planar realization techniques are available. The result of this bisection is shown in Figure 2B. Each of these networks can be realized separately and then combined in series at the bisection point to yield the overall filter. Figure 3A shows the network to the right of the bisection line and the equivalent planar (interdigital) realization. The techniques for accomplishing this interdigital realization are outlined in great detail in Reference 2 and will not be repeated here. Once the two halves of the bisected network have been realized they can be combined in series, with the final planar realization (of the Figure 2A filter) shown in Figure 3B.

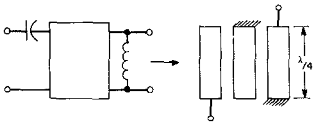

FIGURE 3A

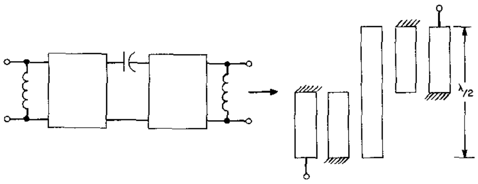

FIGURE 3B

FIGURE 3

Example

In this example, a simple bandpass filter of the configuration shown in Figure 3B will be realized. Following the procedures which are outlined by Horton and Wenzel this filter is recognized as having m = 3 (3 nonredundant reactive elements) and n = 2 (2 nonredundant unit elements). Using these values and the appropriate equations from their work one finds that

$$\rho = \frac{10260}{S^5+20.625S^4+211.7S^3+1340.8S^2+5245.4S+10260} \quad (1)$$

Then since $Z = \frac{1-\rho}{1+\rho}$ for the filter of Figure 3B:

$$Z = \frac{S^5+20.625S^4+211.7S^3+1340.8S^2+5245.4S}{S^5+20.625S^4+211.7S^3+1340.8S^2+5245.4S+20520} \quad (2)$$

Now using this value of Z and carrying out the exact network synthesis procedure yields the network values shown in Figure 4. When this network is bisected as shown in Figure 2B the right half of the bisected network is as shown in Figure 5. The

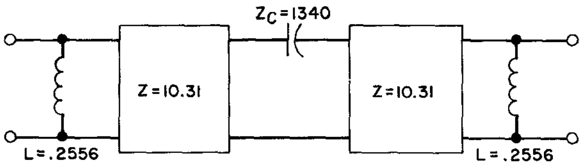

FIGURE 4

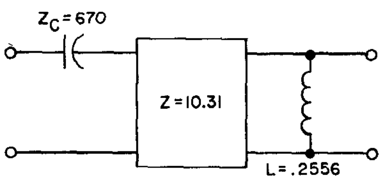

FIGURE 5

next step in the realization of this network is to set up a capacitance network and a corresponding capacitance matrix as described in Reference 2.

The capacitance matrix is next adjusted by multiplying various rows and columns by arbitrary constants which can be chosen to yield a physically realizable network. Wenzel[2] points out that only internal rows and columns can be multiplied by these arbitrary constants and that holds true in this case also, but it is important to recognize that the row and column of the capacitance matrix which are associated with the bisected capacitor are internal with respect to the overall filter and can be adjusted in this case. After some trial and error it is possible to arrive at a physically realizable capacitance network. An experimental model was constructed on microwave printed circuit boards and the experimental results were in agreement with theory.

Through the use of this technique for the realization of a capacitor between two unit elements and through use of the interdigital techniques already described in the literature,[2] it is now a simple matter to realize as a planar structure the general filter type shown in Figure 1.

The possible improvement gained by using the nonredundant filter can be seen dramatically by considering the three stub filter already discussed when designed for a 100% bandwidth. If both the redundant and nonredundant filters are designed for this 100% 3 dB bandwidth it is found that the theoretical frequency for a 40 dB loss in the redundant filter corresponds to a 90 dB loss in the nonredundant filter. This theoretical 50 dB improvement is a dramatic demonstration of the possible value of the technique outlined in this paper.

Conclusions

A technique for the planar realization of optimum bandpass filters has been described and illustrated. There are possible advantages and certain disadvantages to this approach. One clear advantage is the improvement in filter response as a result of incorporating reactive elements (with their better filtering properties) in place of unit elements. Another advantage is the introduction of flexibility. It may be possible to physically realize a filter in this configuration which it is not possible to realize as an interdigital filter. This technique has the disadvantages of requiring a printed circuit realization and of requiring a half wavelength dimension in place of the quarter wavelength dimension of the interdigital filter. It would seem, however, a worthwhile technique for the filter designer to have at his command.

References

[1] M. C. Horton and R. J. Wenzel, "General Theory and Design of Optimum Quarter-Wave TEM Filters," IEEE Trans. on Microwave Theory and Techniques, vol. MTT-13, pp. 316-327, May 1965.

[2] R. J. Wenzel, "Exact Theory of Interdigital Bandpass Filters and Related Coupled Structures," IEEE Trans. on Microwave Theory and Techniques, vol. MTT-13, pp. 559-575, September 1965.