PROBLEMS IN MICROSTRIP FILTER DESIGN

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ABSTRACT

Accurate microstrip filter design is complicated by the presence of parasitic elements, physical constraints, and the inhomogeneous nature of the medium. This paper describes the design problem, surveys commonly used design methods, and shows typical errors obtained using these design approaches. A computer-aided design procedure is then described that yields precise bandwidth with exact equal ripple passband response.

Exact design procedures have been developed for many types of microwave filters. Approximate design approaches also exist in most cases and are often used to handle networks containing a mixture of non-commensurate and lumped elements. For the mixed element cases, if approximate design approaches are not sufficiently accurate, computer optimization can be used to achieve exact equal ripple designs.

The design techniques mentioned above have been applied almost exclusively to structures realized in a homogeneous medium. This restriction normally yields an equivalent circuit of a cascade form. The elements of the equivalent circuit are related (either analytically or experimentally) to the dimensions of the desired physical realization. The design problem is then reduced to a two stage process. First, circuit element values are found that yield the desired response. Second, dimensions are determined for the physical realization. If the resulting structure is not practical, new circuit values are obtained by re-design or by equivalent circuit transformations.

The convenient feature of the above process is that the circuit design and realization problems are not a constrained type of problem, and can be carried out essentially independent of each other. In effect, each element in the equivalent circuit is related to a specific part of the physical structure. The physical dimensions obtained for a given circuit design may not be desirable or practical, but in general they are uniquely determined by the above design process.

For microstrip circuits, transmission line characteristic impedances and propagation constants are functions of frequency. However, these variations are often ignored in the quasi-TEM approximation that has been found to be quite accurate if appropriate dimensional constraints are observed. For the case of coupled line microstrip circuits, even the quasi-TEM approximation does not allow the use of a simple cascade equivalent circuit.

Consider the edge-coupled structure in Fig. 1a and the quasi-TEM equivalent circuit shown in Fig. 1b.*[1] For simplicity, assume that both lines are of equal width so that the circuit is describable in terms of Z_{oe}, Z_{oo}, θ_e, and θ_o. The physical circuit has three independent parameters, line width W, gap width S, and line length L. Unfortunately, the equivalent circuit has four parameters (Z_{oe}, Z_{oo}, θ_e, θ_o) that are not independently specifiable. Thus the circuit design stage (if one is known) might determine values of Z_{oe}, Z_{oo}, θ_e and θ_o that would yield a precise filter design. However the resulting values may not be compatible with each other, and the paper design will not be realizable. In addition, an accurate design should include the lumped fringing capacitance that exists between the open-circuited ends of each coupled line and the ground plane as indicated in Fig. 1. These fringing capacitors further complicate the equivlent circuit of Fig. 1b. Accurate design procedures of the two step type described above are not available for equivalent circuits of the type shown in Fig. 1.

There are several possible ways to approach the design problem. The experimental design approach based on measured coupling coefficients completely eliminates any consideration of complex equivalent circuits, dispersion, mode velocities, and parasitic elements. A wide variety of resonator structures can be accomodated with excellent results.[2] Negative aspects of this approach are a dependance on the quality and expediency of the experimental measurements, and the difficulty of predicting stopband selectivity and spurious responses. In addition, each new frequency range and resonator construction may require additional experimental models and measurements. However, no microstrip filter designer should ignore this approach, as it may work where all else fails.

Many designers ignore the complexities of the microstrip medium, assume an average mode velocity, and design using available procedures developed for homogenous circuits. In general, bandwidth, VSWP, and center frequency are not as desired, but good results are achievable if the bandwidth is not too wide, and emperical correction factors are included in the design process. Designs of this type can be checked using the equivalent circuits discussed above, and some design corrections can be analytically determined. Examples of typical errors obtained using the above approach will be presented.

A precise design based on an equivalent circuit of the type given in Fig. 1 can be achieved using a computer aided optimization approach. Consider the typical symmetric edge coupled circuit shown in Fig. 2a. Input coupling is achieved by means of an edge coupled section, but other possible methods of input and internal coupling as shown in Fig. 2b and c are also useful. The specific circuits shown are usually designed to yield an N=7 resonator equal ripple passband response. For exact equal ripple passband response, a minimum of N+1 = 8 independently specifiable

*Note that the equivalent circuit of Fig. 1b does not contain the fringing capacitors shown in Fig. 1a and is thus incomplete.

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parameters are required. If four of these parameters are the lengths of each coupled section (call them $L_i = L_1$ thru L_4), we have but one free parameter to determine for each of the four coupled line sections (call them $X_i = X_1$ thru X_4). The four parameters of each coupled line section (Z_{oe}, Z_{oo}, θ_e, θ_o, must be analytically related to a single variable X. This can be accomplished by interpolation from available data.[3,4] Note that this interpolation process involves an arbitrary choice of physical constraints, and in addition, must be redone for differing geometries and substate materials. Thus one can determine $Z_{oe}(X)$, $Z_{oo}(X)$, $\theta_e(X)$, and $\theta_o(X)$ such that $Z_{oe}(X) + Z_{oo}(X)$ = constant, or $Z_{oe}(X) \cdot Z_{oo}(X)$ = constant, or any of an infinity of possible constraints. The resulting filters can all have precisely equal ripple response, but physical dimensions, stopband selectivity, spurious response characteristics, and practical realizability will vary significantly with constraint choice.

Once $Z_{oe}(X)$, $Z_{oo}(X)$, $\theta_e(X)$, and $\theta_o(X)$ have been chosen, the ABCD matrix of each coupled line section can be computed (including the effects of resonator fringing capacity) by starting with the basic matrix relationships given in Zysman and Johnson[1]. These matrices are then used in a computer optimization program, similar to those described by several authors [5,6,7] to determine the line lengths (L_i) and coupled line parameters X_i required for exact equal ripple performance.

The computed response for several forty percent bandwidth N=7 1.10:1 VSWR designs is shown in Fig. 3. The designs were carried out assuming a .025" alumina substrate. Curve A shows the response obtained using the original homogeneous design equations developed by Cohn[8], with resonator length adjusted to provide the desired center frequency. This design was used as the starting point for the optimization process. For reference, curve B gives the computed insertion loss response (including fringing capacity) after optimization to 1.10 equal ripple VSWR, assuming a homogeneous medium. Curves C and D give the computed responses for two optimized equal ripple designs with different types of input coupling. Skewing of the response is evident for all non-homogeneous designs, as is a significant deterioration of upper stopband performance. The precise type of input coupling used as well as the fundamental Z_{oe}, Z_{oo}, θ_e, θ_o constraint chosen, have substantial effects on stopband performance, as well as on practical realizability. Results for other designs of differing bandwidth and complexity have also been obtained and will be presented.

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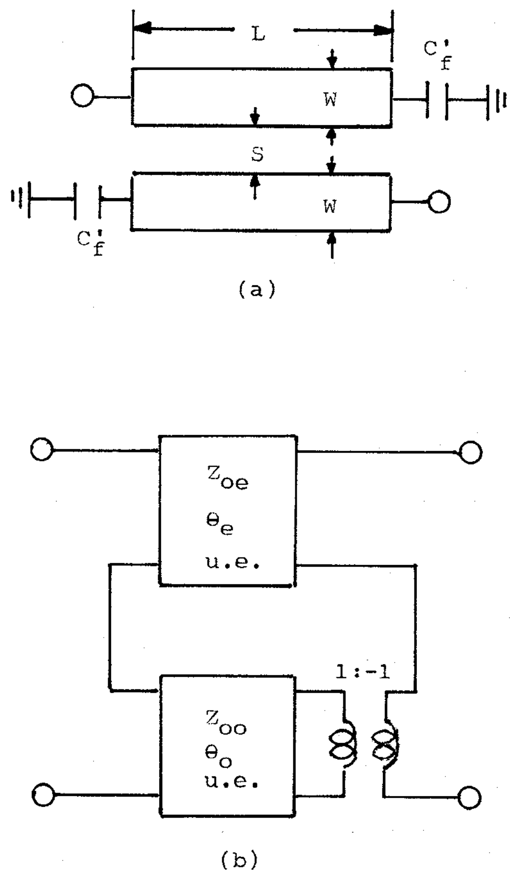

Figure 1. (a) Edge Coupled Microstrip Circuit
(b) Quasi-TEM Equivalent Circuit

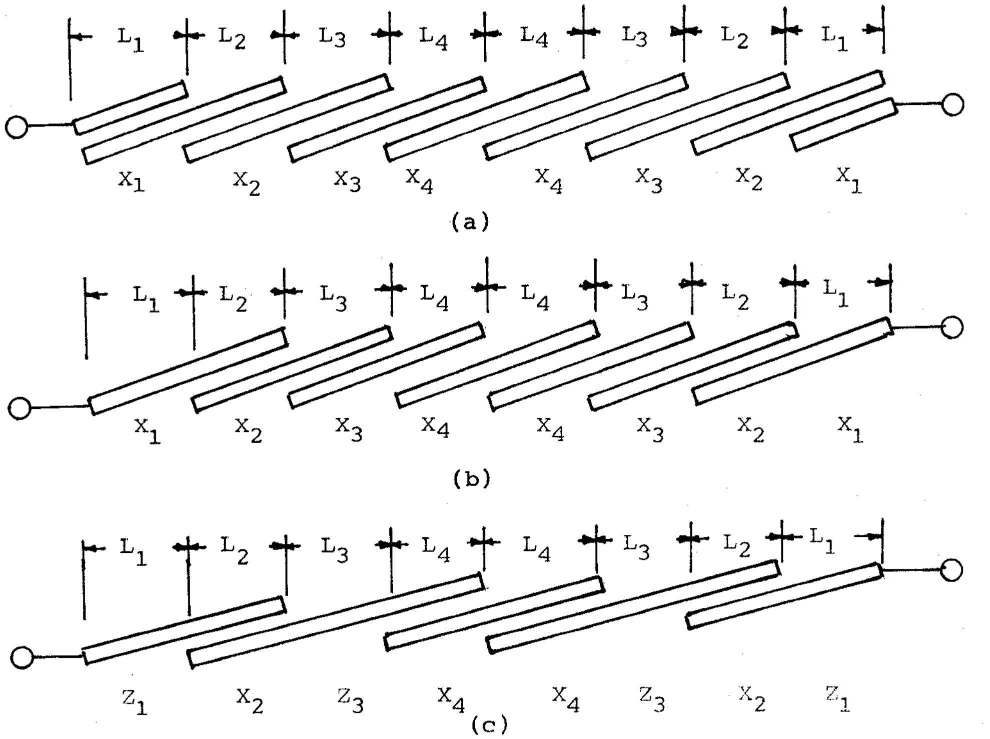

Figure 2. Several Forms of Edge-Coupled Filters Capable of Equal Ripple Performance with Differing Dimensions, Sensitivities, and Rejection Performance.

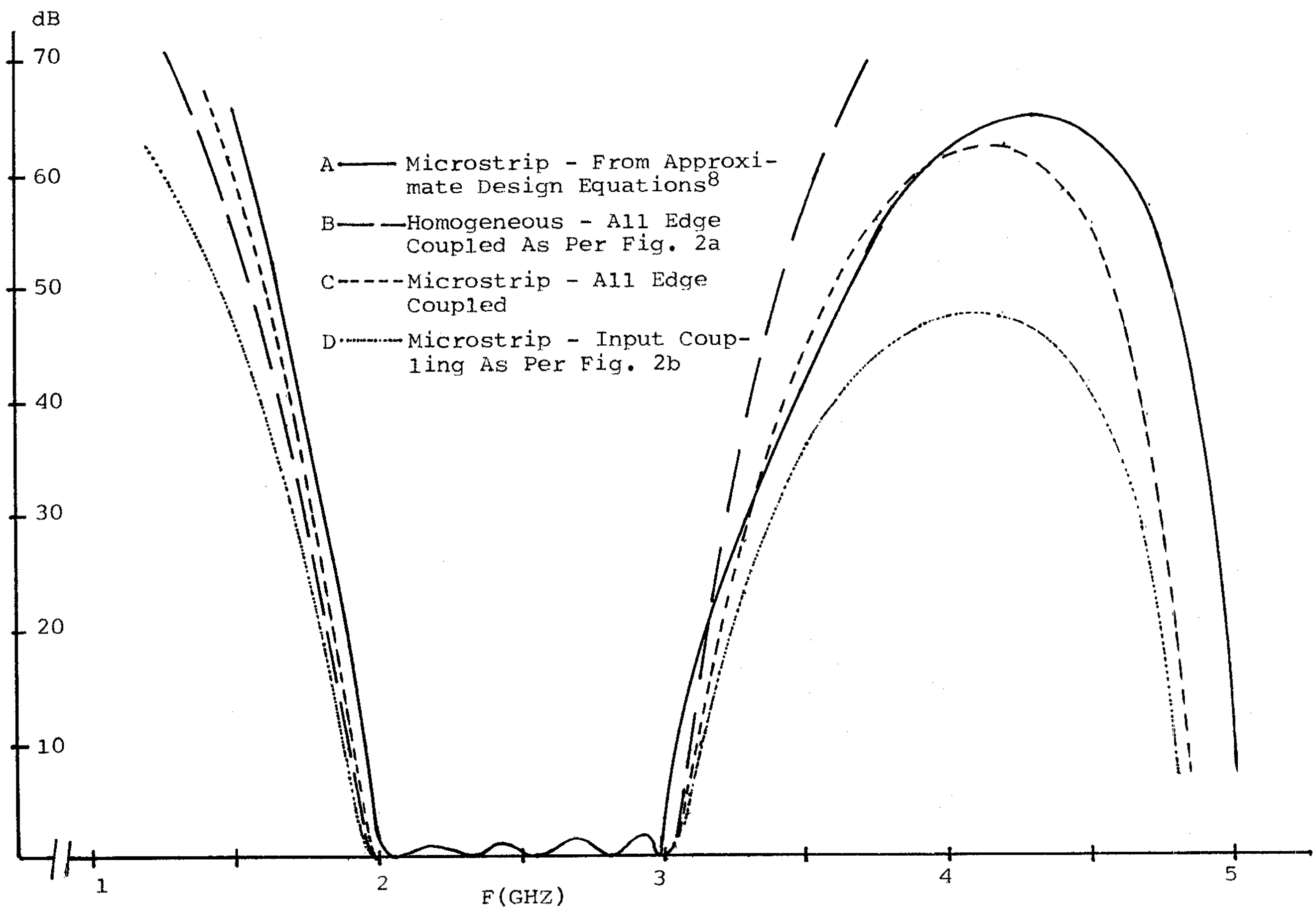

Figure 3. Computed Response of Microstrip Filter Designs