CAD OF MICROWAVE JUNCTIONS BY POLYNOMIAL CURVE FITTING

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ABSTRACT

A circuit representation of lossless reciprocal microwave junctions is presented. Exact scattering parameters of the junction are determined by solving the electromagnetic boundary value problem at few frequencies and for few dimensions. Curve fitting is used to characterize the parameters continuously. This model can be used in any CAD or optimization program, reducing the computation time by several orders of magnitude, while preserving the high accuracy. Application of this model is demonstrated by designs of a low VSWR cavity filter and a broad band diplxer. Experimental data on the diplexer optimized by this method are included.

I. INTRODUCTION

Precise characterization of microwave discontinuities in various transmission media (e.g. microstrip lines, coaxial lines, waveguides of various cross section ...etc) are achievable by modern numerical analysis techniques (e.g. spectral domain, mode matching, integral equation, finite element, ..etc) [1]-[4]. These characterizations, although very accurate, are in most cases not practical to use directly in the CAD of microwave components, primarily due to the enumerous amount of computer time required in the design. For example, mode matching characterization of a step discontinuity in a waveguide typically takes about 15 seconds of CPU time per frequency point on a SUN sparc station. In optimizing a filter consisting of six resonators, at 100 frequency points, one analysis cycle needs about 150 minutes of CPU. Optimization of a filter of this type might require several hundred analysis cycles, or several hundred hours.

This paper develops a general circuit representation for microwave lossless reciprocal two port junctions. A polynomial is used to curve-fit the results of the element values of the circuit representation, which are obtained by rigorous numerical techniques at few points. Based on the curve-fitted approximation, the time required to optimize the response of a practical microwave network is drastically reduced (by at least two orders of magnitudes). The technique is presented for the case of inductive windows in rectangular waveguides, and is used for the optimization of a difficult to design moderate bandwidth 8-pole, .01 dB ripple band pass filter and a broad band diplexer. The results obtained are verified by the experimental diplexer which was fabricated and tested. The results were very close to the optimized response with absolutely no tuning.

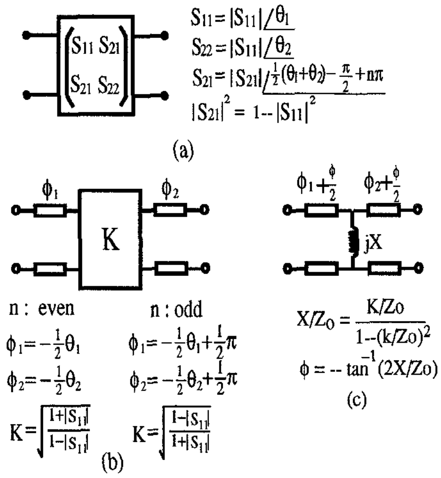


Fig.1 (a) Scattering matrix of a lossless, reciprocal junction
(b) A circuit representation of (a)
(c) Alternative circuit representation

II. EQUIVALENT CIRCUIT REPRESENTATION

A lossless reciprocal junction with a scattering matrix as shown in Fig.1(a), has a circuit representation at a single frequency, as a cascade of an ideal inverter and two sections of transmission lines and is shown in Fig.1(b). The choice of this model rather than T network shown in Fig. 1(c) [5] is preferable because it is directly related to the scattering matrix of the junction, which can be determined from numerical solution of the electromagnetic boundary value problem. Based on the unitary (lossless) and reciprocity ($S_{21} = S_{12}$) conditions of the scattering matrix, the parameters of the equivalent circuit K, ϕ_1 and ϕ_2 are expressed in terms of the scattering matrix and are shown in Fig.1(b). The validity of the two-port scattering matrix and equivalent circuit rely on the fact that the distance between adjacent discontinuities is large enough so that the field components of higher order modes have decayed sufficiently.

If all the physical dimensions of the junction are properly chosen and normalized to only one (denoted as ξ) , then each parameter in Fig.1.(b) is a function of the adjustable normalized dimension (ξ) and frequency (f). For example, for an inductive window, as shown in Fig.2.(a), if the window thickness (t) is fixed, the window width (W) is the only adjustable dimension. The numerical results of the elements' values of the equivalent circuit, which are obtained by mode-matching technique [6] are shown in Fig.2.(b).

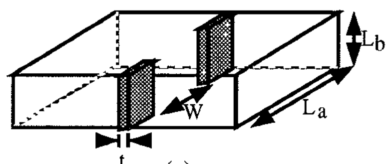
III. CURVE-FITTING OF THE ELEMENTS' VALUES

Curve-fitting of the results obtained from rigorous analysis method (e.g. mode matching) to a two-dimensional polynomial function is possible. For a parameter y (e.g. K, or ϕ), a two dimensional polynomial approximation is:

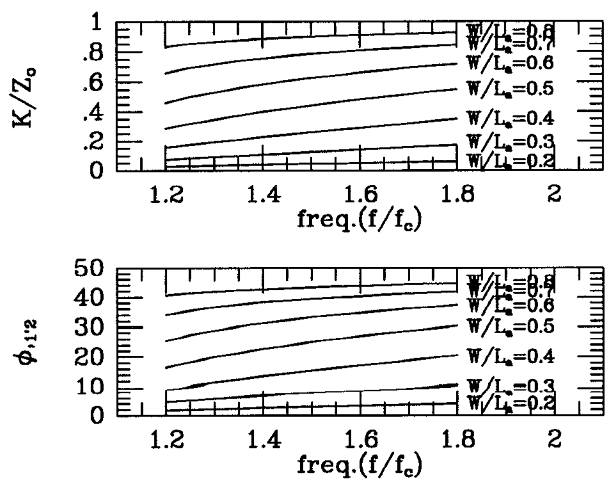
$$y(\xi, f) = \sum_{n=0}^{N} \sum_{m=0}^{M} k_{mn} f^m \xi^n \qquad (1)$$

where M and N are the maximum order of f and ξ . Equation (1) can also be written in matrix form as:

$$y(\xi, f) = \begin{bmatrix} 1 & \xi & \xi^2 & . & . & \xi^i & . & \xi^N \end{bmatrix} \begin{bmatrix} k_{01} & k_{02} & k_{03} & . & . & k_{0i} & . & k_{0M} \\ k_{11} & k_{12} & k_{13} & . & . & k_{1i} & . & k_{1M} \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ k_{N1} & k_{N2} & k_{N3} & . & . & k_{Ni} & . & k_{NM} \end{bmatrix} \begin{bmatrix} 1 \\ f \\ f^2 \\ . \\ . \\ f^M \end{bmatrix} \qquad (2)$$



(a)



(b)

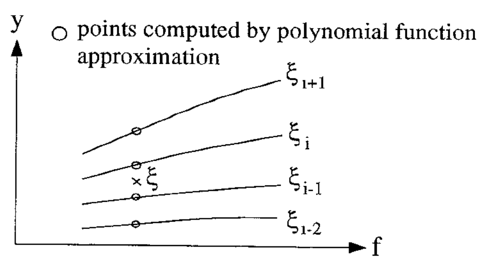
Fig.2 (a) Configuration of an inductive window
(b) The elements' values of the circuit representation computed by mode-matching.
$L_a = 2.0\, L_b$, $t = 0.135\, L_a$.

By applying curve-fitting technique, the coefficients of the polynomial function k_{mn} can be found if the results of some grid points of (ξ, f) are given.

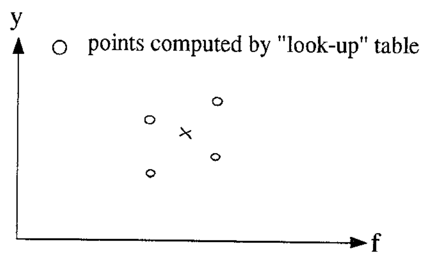
If the function $y(.,.)$ is not well-behaved in one of the variables, curve-fitting can still be applied to obtain the polynomial approximation of the well-behaved variable, and "interpolation" could be used to provide the dependence of the other variable, as shown in Fig.3(a). If the function is not well behaved in both the independent variables, a "look-up" table can be used to locate the closer points (around (f, ξ)) that exact solutions are given and interpolating these points to obtain the approximate solution for (f, ξ), as shown in Fig.3(b).

IV. APPLICATION TO MODERATE BANDWIDTH FILTER AND BROAD BAND DIPLEXER DESIGN

To illustrate the method, optimization of a moderate bandwidth filter is performed and a broad band diplexer is designed.



(a)



(b)

Fig.3 (a) Computation of y (f, ξ) by interpolating between points computed from polynomial approximation
(b) Computation of y(f,ξ) by interpolating among points computed from a "look-up" table

For an inductive window shown in Fig.2(a) and the electrical parameters shown in Fig.2(b), the two-dimensional polynomial function of eq.(1) or (2) is used to curve-fit the data in Fig.2(b). After the coefficients of the polynomial function (k_{mn}) are obtained, eq.(1) or (2) is used to compute the parameters (K/Z_o and $\phi_{1,2}$) in the range between $1.2f_c$ and $1.8f_c$ for f and $0.2L_a$ to $0.8L_a$ for window width. Fig.4 compares the results computed by eq.(1) or (2) and by mode-matching for points half-way between the curve-fitted points. Fig.5 shows the differences of the approximate model (i.e. computed by eq.(1) or (2)) and mode-matching of Fig.4. It is found that the maximum deviations are only 0.2° for $\phi_{1,2}$ and 0.004 for K/Z_o. These accuracies are quite sufficient for the designs of most practical filters.

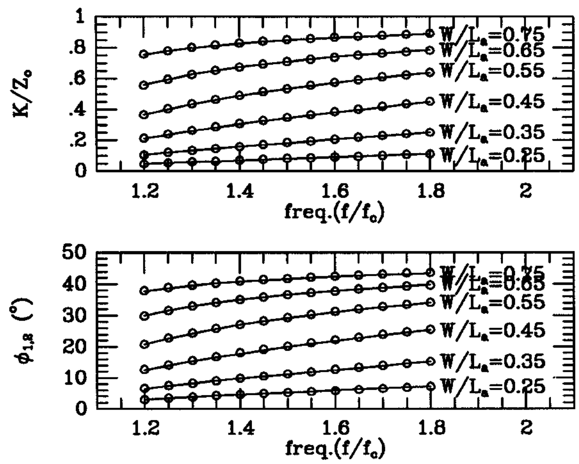


Fig.4 Circuit elements' values of the of the inductive window of Fig.2(a) computed by mode-matching (--) and curve-fitting (ooo).

The polynomial approximation model of the inductive window is applied to the design of an 8th order C band microwave filter as shown in Fig.6(a). The filter's dimensions as computed from references [7] and [8] and the dimesnsions after optimization are shown in Fig.6(b) while the frequency responses are shown in Fig.7. It is found that the band widths of all the designs are very accurate (about 14% bandwidth) but the pass band ripple degrades significantly. This is corrected by our design by optimizing the filter response. Fig.7 also shows the responses of the optimized design computed by both polynomial approximation model and mode-matching for the inductive windows. The ratio of computation time of the filter response is 1:800 for approximation model and mode-matching.

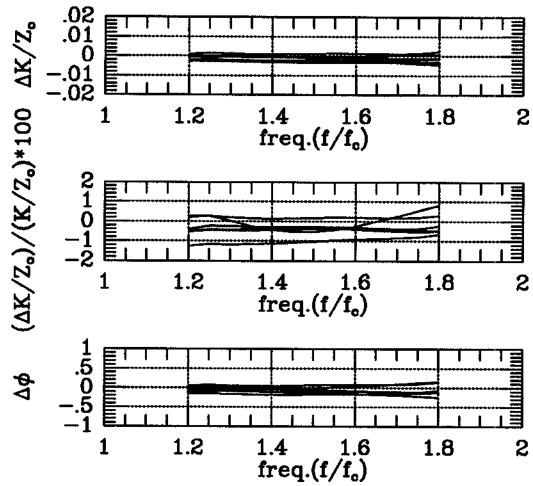
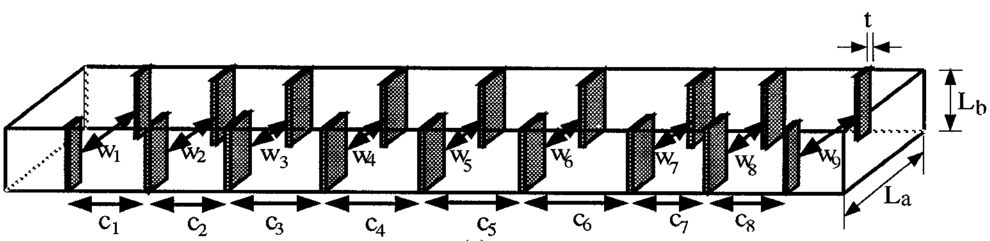


Fig.5 Differentce between the element values of the circuit representation of Fig.1(b) computed by mode-matching and by approximate model.



(a)

	W1	W2	W3	W4	W5	W6	W7	W8	W9
S B Cohn Design [7]	1.2947	0.9706	0.8194	0.7893	0.7827	0.7893	0.8194	0.9706	1.2947
R. Levy Design [8]	1.2957	0.9715	0.8202	0.7901	0.7835	0.7901	0.8202	0.9715	1.2957
Optimized Design	1.1929	0.9277	0.8246	0.7938	0.7868	0.7938	0.8246	0.9277	1.1929

La = 1.872"
Lb = 0.872"
t = 0.062" for I/O coupling
0.031" elsewhere

	C1	C2	C3	C4	C5	C6	C7	C8	
S B. Cohn Design [7]	1.1256	1.3317	1.4211	1.4382	1.4382	1.4211	1.3317	1.1256	
R Levy Design [8]	1.1263	1.3325	1.4221	1.4392	1.4392	1.4221	1.3325	1.1263	
Optimized Design	1.1774	1.3515	1.4209	1.4399	1.4399	1.4209	1.3515	1.1774	

Unit: inch

(b)

Fig.6 (a) Configuration of an 8-pole inductive-window filter
(b) Dimensions of the filter obtained by [7], [8] and from the optimized design

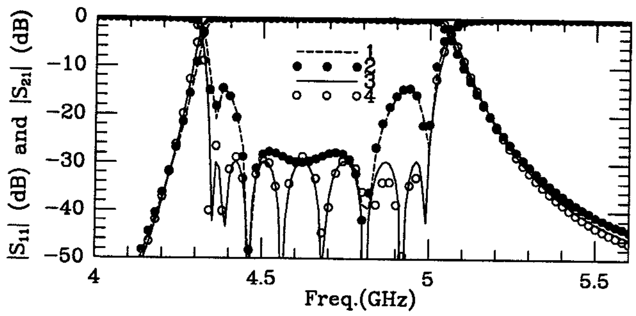


Fig.7 Filter responses of [7], [8] design and optimized design computed by approximate model and mode-matching.
1. Design [7, 8] (Approximate window's model)
2. Design [7, 8] (Exact mode-matching model)
3. Optimized design (Approximate window's model)
4. Optimized design (Exact mode-matching model)

Another example of the application of the model is for a broad band diplexer constructed by two inductive window filters and E-plane T-junction. To compensate for the frequency-dependent electrical behavior of the T-junction, all inductive window widths and cavity lengths of both filters are optimized to achieve the required diplexer response. The circuit model presented in this paper makes the diplexer optimization possible. The experimental data is very close to the predicted responses, as shown in Fig.8.

V. CONCLUSION

In this paper, curve-fitting a polynomial function to the electrical parameters of a lossless junction, which are computed by rigorous numerical method, are presented. Curve-fitting procedure requires much less effort than the numerical analysis of electromagnetic boundary value problems but fully-realize the potential of using the results of rigorous method to improve the component designs. The example of an inductive window shows that approximate model by a polynomial function for waveguide junction could be very accurate and greatly reduces computation time. The successful design of a moderate-band width , low VSWR filter and a broad band diplexer by optimization shows the powerfulness of the method in achieving practical filter and diplexer designs. Experimental data on the diplexer is presented and are shown to be very close to theory.

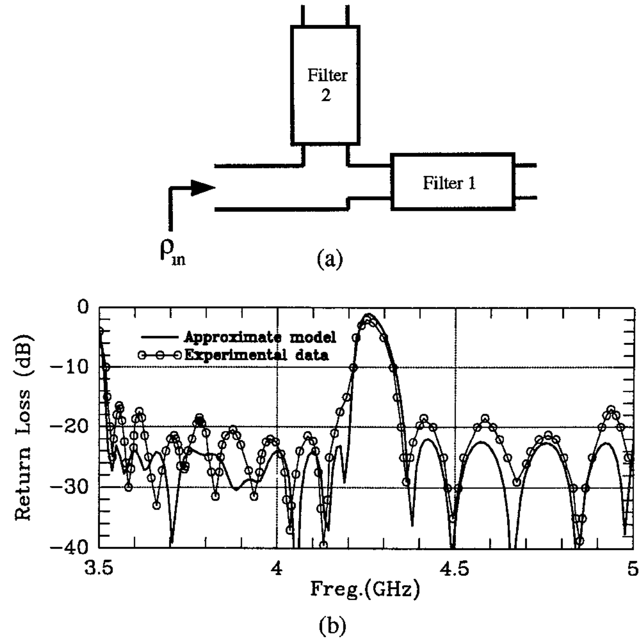


Fig. 8 (a) Diplexer configuration
(b) Diplexer input rerturn loss responses from the approximate inductive window model and experimental data.

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