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AN OPTIMIZATION TECHNIQUE FOR LUMPED - DISTRIBUTED TWO PORTS

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ABSTRACT

A frequency domain direct efficient analysis and optimization technique of a large class of lumped - distributed networks containing active elements is presented. Sensitivity and Hessian matrix calculations are performed using truncated Taylor series expansion of two port parameters of subnetworks. An interactive computer program was developed to demonstrate the application of the method. An example of network optimization is included to illustrate the powerfullness of the technique.

I. INTRODUCTION

Most microwave integrated circuit designs require a significant amount of computer aided analysis and optimization. In the past decade, techniques for network sensitivity and optimization have received considerable attention. These techniques generally belonged to two broad categories: the indirect approach which utilizes the concepts of the adjoint networks[1,2] and other direct approaches that utilize the inverse of a nodal admittance matrix[3,4].

This paper presents a new direct efficient approach to the analysis and optimization of a large classs of lumped - distributed networks containing active elements. The class of networks under consideration includes microwave integrated circuits and other networks that possess sparse nodal admittance matrices. Although it is well known that such class of networks is more efficiently analyzed as an interconnection of subnetwork m-ports[5,6] little has been done to extend this direct analysis approach to the computation of network sensitivities. The development of such an approach for the frequency-domain analysis and optimization of lumped - distributed two port networks using the Hessian matrix is the subject of this paper. In this approach, a two port network is analyzed as the interconnection of several subnetworks expanded in a truncated nth-order Taylor series of their two-port parameters. Direct analysis of the two port network is performed by converting each subnetwork to an appropriate domain for interconnection, then linearly combining their Taylor series terms. The number of terms used in the series determines the highest order of network sensitivity available for optimization.

This direct approach to network sensitivity analysis is more efficient than conventional adjoint and inverse nodal admittance matrix approaches because it does not require complex nodal admittance matrix inversion, nor repeated analyses. A comparison of these three basic approaches to network sensitivity analysis shows that computations for second-order direct analysis increase linearly with the number of interconnected subnetworks and as the square of the number of variable network elements. For the adjoint and inverse nodal admittance analysis, the required computations increase with the cube of the number of nodes.

To demonstrate the powerfullness of this new approach, an interactive computer program was developed for the analysis and optimization of lumped - distributed two ports containing active elements in the frequency domain. The program accepts any set of eighteen lumped - distributed two port subnetwork types including: uniform transmission lines, RLC subnetworks, controlled sources, ideal transformers, mutually coupled coils, gyrators and negative converters. Permissible interconnections include: series, parallel, cascade and hybrid interconnections in the impedance, admittance, hybrid, transmission and scattering parameter domain.

Section II describes briefly the technique used in the program for the computation of the various sensitivities and the optimization strategy of the demonstration program. An example of the optimization of a wide band microwave amplifier which demonstrates the powerfullness of the new approach is given in Section III.

II. OPTIMIZATION OF INTERCONNECTED 2-PORT NETWORKS

The class of networks under consideration is that of 2-port networks which can be described as a combination of cascaded, series, shunt or hybrid connection of several subnetworks. Optimization is performed by minimizing the least pth error between desired and actual two port frequency responses of the network with respect to the natural log of variable elements. The optimization algorithms used included: an initial non-sequential grid search, the method of steepest descent, Newton's method, a modified Newton method of handling non-positive definite Hessian matrices, a cubic line search and an algorithm for eliminating insensitive variable network elements. In all of these algorithms, the error function is expressed as a truncated 2nd order Taylor series expansion. This expansion involves only subnetwork two-port parameters and their partial derivatives. For a cascaded network the required partial derivatives are calculated from the transmission matrix of the subnetworks that contain the variable element. To illustrate this procedure, consider a cascaded network of m subnetworks with an overall transmission matrix expressed as:

$$T(\underline{x}) = T_1 T_2 \cdots T_{k-1} T_k T_{k+1} \cdots T_n \qquad (1)$$

where T_k is the transmission matrix of the kth subnetwork of the cascade, $k=1,2, \ldots n$, $\underline{x}$ is a vector of the r variable network elements. If x_i belongs only to subnetwork ℓ, x_j belongs only to subnetwork m, then the partial derivatives of $T(\underline{x})$ with respect to x_i and x_j are given by:

$$\frac{\partial^P T}{\partial x_i^P} = T_1 T_2 \cdots T_{\ell-1} \frac{\partial^P T_\ell}{\partial x_i^P} T_{\ell+1} \cdots T_n; \; P = 1,2, \ldots$$

$$\frac{\partial^P T}{\partial x_j^P} = T_1 T_2 \cdots T_{m-1} \frac{\partial^P T_m}{\partial x_j^P} T_{m+1} \cdots T_n; \; P = 1,2, \ldots$$

$$\frac{\partial^2 T}{\partial x_i \partial x_j} = T_1 T_2 \cdots T_{\ell-1} \frac{\partial T_\ell}{\partial x_i} T_{\ell+1} \cdots T_{m-1} \frac{\partial T_m}{\partial x_j} T_{m+1} \cdots T_n; \quad i \neq j$$

This process is used to compute very effectively the required derivatives of the error function in the various algorithms used in the minimization. This same technique can be used to analyze any interconnected 2-port network not only cascaded networks. Details of this process is given in[7] using tensor notation to describe the interconnection of subnetwork 2-ports, including those requiring 2-port parameter domain conversion. The optimization strategy used in the program is shown in Figure 1.

III. EXAMPLE OF NETWORK OPTIMIZATION

An example network is chosen to demonstrate the powerfullness of the present optimization technique. This network is a wide band single stage FET amplifier consisting of an input and output matching networks each of which has three stubs and a single cascaded line as shown in Figure 2[8]. The FET is defined by Table 1 of scattering parameters at seven frequencies between 6 and 12 GHz. All the transmission lines and stubs have fixed characteristic impedances and variable lengths. The network was optimized for a constant 8 dB power gain over the frequency band 6 to 12 GHz. This network was optimized in 5 iterations using the present technique, compared with at least 10 iterations in Ref. 8. The solution obtained by the present technique indicated that the last stub can be removed. Initial and final values of the line lengths and amplifier response are given in Table 2 and Figure 3, respectively.

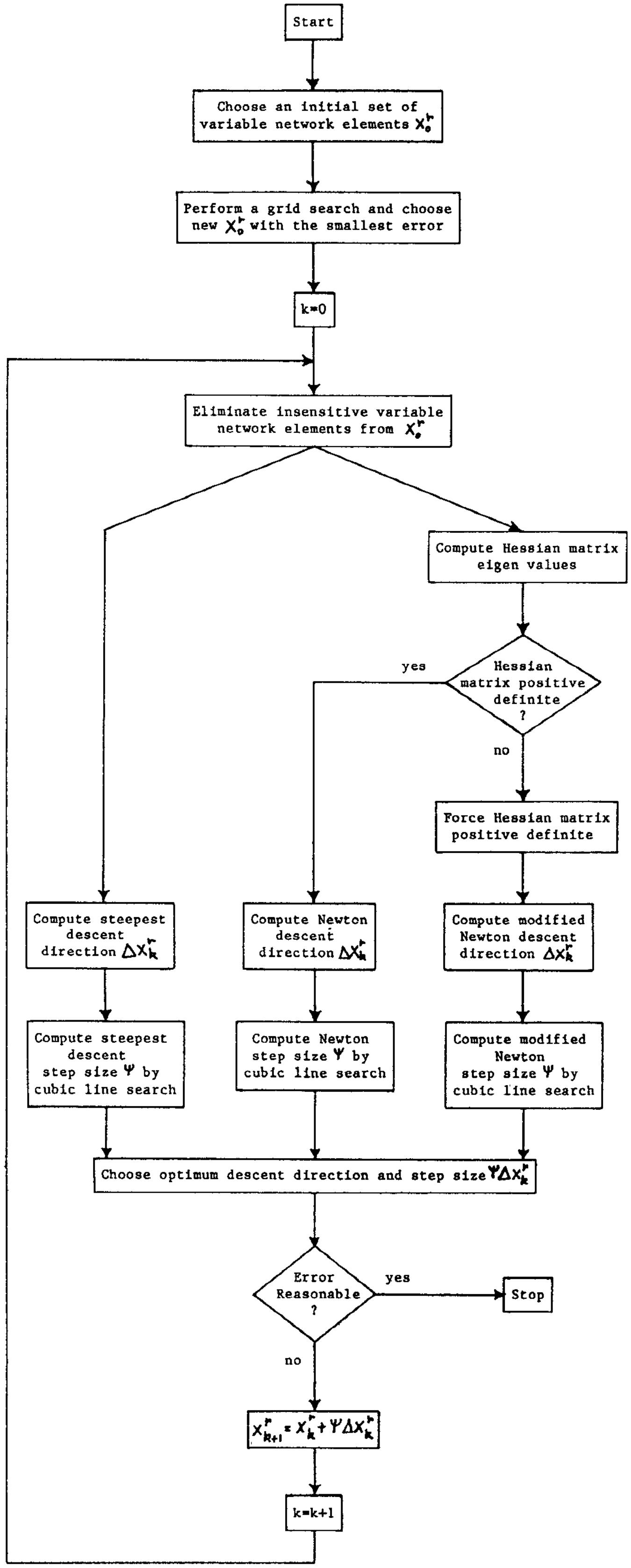
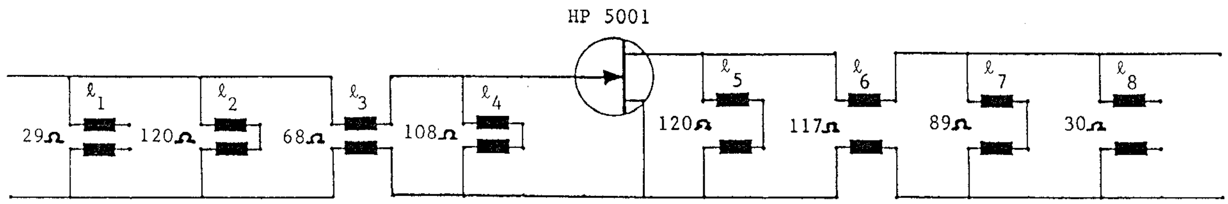


FIGURE 1. OPTIMIZATION STRATEGY



Desired Power Gain = $20 \log_{10}|S_{21}|$ = 8 db ; 6 GHz $\leq f \leq$ 12 GHz ; $v_p = 30 \times 10^{-8}$ cm/sec ; $\alpha = 0$

FIGURE 2. FET AMPLIFIER CIRCUIT

TABLE 1. FET SCATTERING PARAMETERS

f(GHz)	S_{11}	S_{12}	S_{21}	S_{22}
6	0.73/ -96°	0.051/ 69.8°	1.97/ 99.3°	0.64/ -26°
7	0.69/-110°	0.059/ 70.3°	1.84/ 88.2°	0.63/ -30°
8	0.67/-124°	0.066/ 73.2°	1.71/ 78.4°	0.62/ -35°
9	0.65/-136°	0.073/ 77.2°	1.56/ 69.8°	0.61/ -40°
10	0.62/-147°	0.081/ 82.7°	1.45/ 61.7°	0.60/ -45°
11	0.61/-155°	0.093/ 87.5°	1.38/ 53.7°	0.60/ -50°
12	0.62/-160°	0.108/ 90.7°	1.33/ 44.6°	0.60/ -58°

TABLE 2. VARIABLE LINE LENGTHS FOR FET AMPLIFIER EXAMPLE

	Initial	Final
ℓ_1	0.2986 cm	0.3247 cm
ℓ_2	0.2986	0.4074
ℓ_3	0.2986	0.2113
ℓ_4	0.2986	0.2740
ℓ_6	0.2986	0.3727
ℓ_7	0.2986	1.012
ℓ_8	0.2986	0.001198

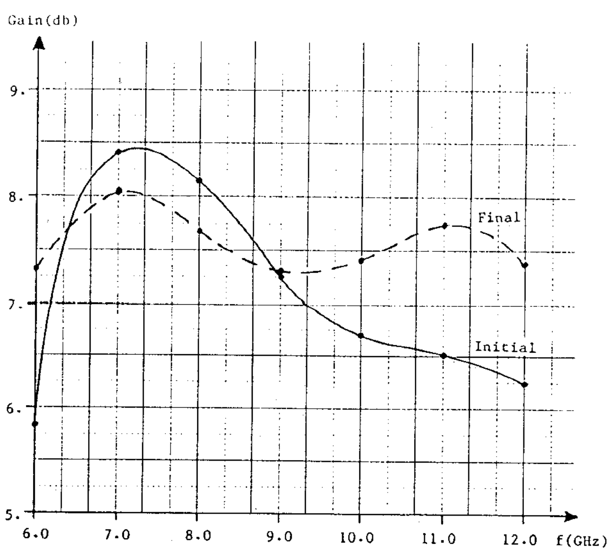


FIGURE 3. INITIAL AND FINAL RESPONSE OF FET AMPLIFIER EXAMPLE

IV. CONCLUSION

A technique is presented for the optimization of a large class of lumped - distributed microwave networks containing active elements. This technique computes the network sensitivities and the Hessian matrix directly using an efficient method which does not require repeated analysis nor the inversion of nodal admittance matrix. The optimization strategy used in a demonstration program is described and an example of a wide-band single stage FET amplifier was used as an illustration of the powerfullness of the process.

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