COMPUTER-AIDED DESIGN OF ARBITRARILY TERMINATED, SYNCHRONOUSLY OR ASYNCHRONOUSLY TUNED MULTI-CAVITY FILTERS

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Abstract

This paper presents a general optimization approach to the design, modelling and optimization of multi-cavity narrow-band microwave filters. Structures considered may be arbitrarily terminated, synchronously or asynchronously tuned. An exact sensitivity evaluation theory is applied to efficient simulation of responses, including group delay. Non-ideal effects such as junctions and losses are readily taken into account.

Introduction

An unterminated narrow-band multi-cavity filter [1,2] can be described by its coupling matrix **M**. Traditionally the filter is designed by choosing the transducer function of a singly- or doubly-terminated model, and constructing the coupling matrix accordingly.

Recently we have developed efficient approaches to the simulation and exact sensitivity evaluation of multi-cavity filters, treating all the couplings directly as possible variables, including the diagonal elements of **M**, which may represent deviations from synchronous tuning, and the input and output couplings which allow the filter to be embedded into a microwave system.

These approaches have been successfully implemented to develop a computer software system for the simulation, optimal design, efficient prediction of dispersive, junction and dissipation effects and parameter estimation from measured data of the filter network, accommodating various types of specifications and arbitrary terminations.

Basic Simulation Method

An exact and computationally efficient approach has been derived, based on the input-impedance analysis of the filter with an arbitrary load in place.

At each frequency point, the computational effort for gain, reflection coefficient responses, their sensitivities w.r.t. design variables and gain-slope evaluation is only one real matrix LU factorization and one real forward-backward substitution (FBS), an additional FBS for group delay and sensitivities of gain-slope. The sensitivities of group delay will require another two additional FBS.

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Filter Design by Optimization

The design problem can be formulated as an optimization problem [3] of minimizing the errors between the response and specification at user specified frequency points. The efficient and exact evaluation of the sensitivities allows us to employ a powerful minimax technique [4] to achieve the optimal design.

Usually the error functions are calculated at a large number of fixed points spaced along the frequency axis, thus the optimization package faces a large number of minimax error functions and the solution is not guaranteed to be optimal in the continuous sense since some error peaks may still be missed. To overcome this problem, we have introduced the gradient-based cubic interpolation technique to automatically detect and locate the extrema of the continuous error function using exact derivatives of response w.r.t. frequency. The frequency band of interest is divided into subintervals according to different required specifications. The extremum points located in each subinterval, the edge points and, to stabilize the algorithm, a few fixed points are used in constructing the minimax functions. In this way the dimension of the problem is significantly reduced, and a continuous minimax solution results.

Prediction and Estimation

The sensitivities are used not only in design optimization, but also in the efficient prediction of nonideal effects such as dispersion and dissipation, based on the designed nominal model, as well as in the estimation of parameter deviations from the nominal values, using measured data. In this way we can locate out of tolerance parameters as well as evaluate nonideal or parasitic equivalent circuit effects.

Small parameter deviations could be linearly approximated by least-squares estimation using the sensitivity matrix. For better accuracy, they can be identified and estimated by employing appropriate optimization techniques, e.g., the minimax technique or the conjugate gradient method, in an attempt to best reproduce the measured response, taking the deviated parameters and/or non-ideal factors as variables.

The Interactive Computer Program

The main program of the software system implementing the algorithms presented is designed to be user-oriented. The user is allowed the maximum freedom to specify his problem, e.g., to choose the coupling pattern and response type, to impose constraints on the variables, etc., while no external subroutine needs to be supplied by the user. The interactive feature of the program facilitates easy user monitoring and direction of the procedure and having the problem redefined conveniently.

Computational Experience

A large number of examples have been tried on the CDC 170/730 computer to verify our theory and the algorithm. Three examples are selected for this summary. Example 1: The nominal design of a six cavity filter with 4000 MHz center frequency and 1% bandwidth (Fig. 1), terminated by normalized load R_N = 1.0 Ω and source impedance Z_1 = 1.0 + j0.1. (The reactance could represent an adjacent network.) Typically, the computer time required for a nominal design varies from 20 ∿ 150 CPU seconds, depending on the starting point and the complexity of the requirement and variables involved. Example 2: The prediction of the dissipation effects, compared with the results of the exact simulation of the lossy network. See Fig. 2. Note that the exact and estimated responses are indistinguishable. Example 3: Tolerances on the couplings are introduced, and the parameters successfully identified and estimated from the corresponding deteriorated noisy response by using the minimax technique and starting from the nominal values. See Fig. 3.

References

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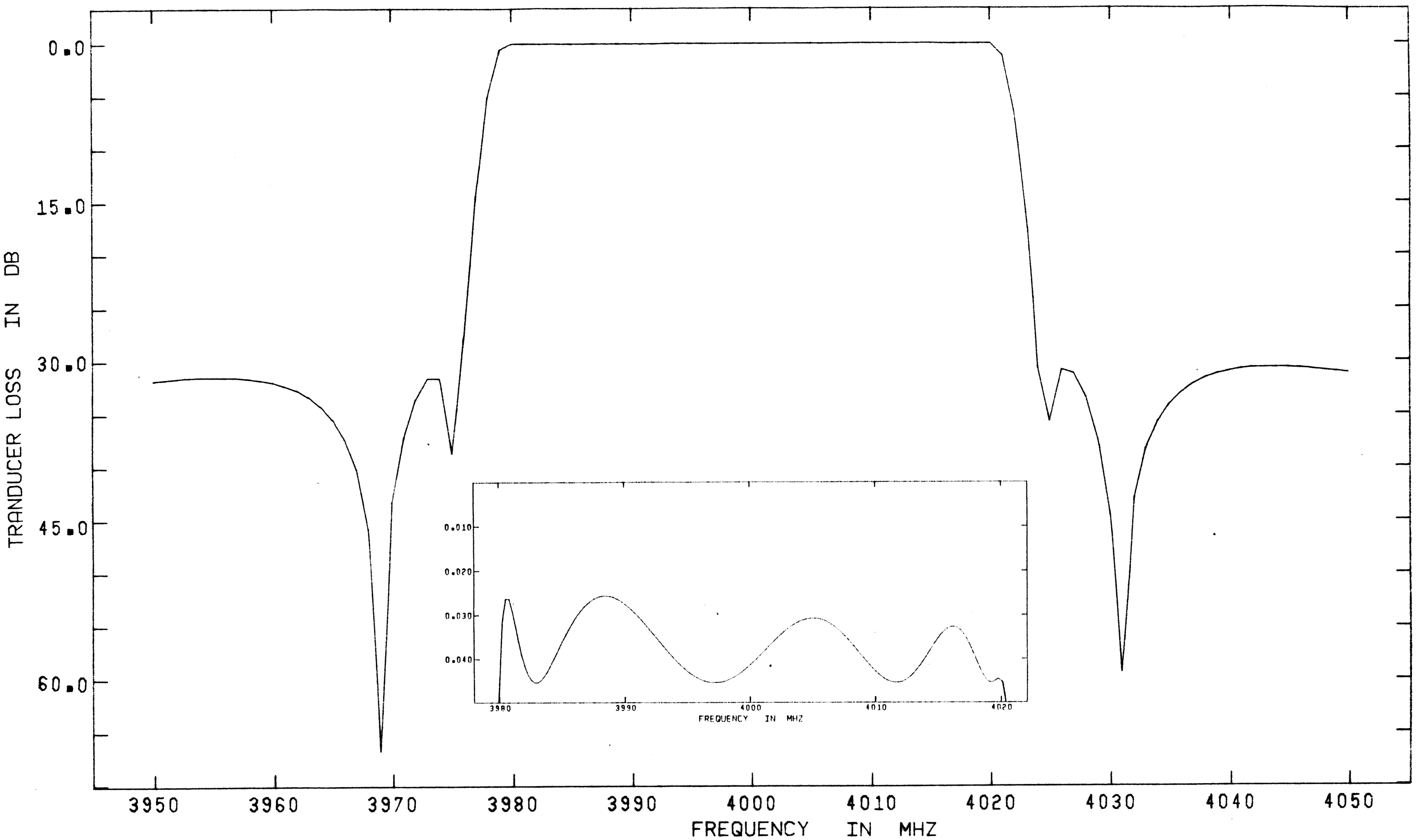

Fig. 1 Transducer loss response of an optimal design: center frequency 4000 MHz, bandwidth 40 MHz, mismatched terminations. All 7 cavity couplings as well as input and output couplings and bandwidth parameter have been optimized in 0.5 min CPU.

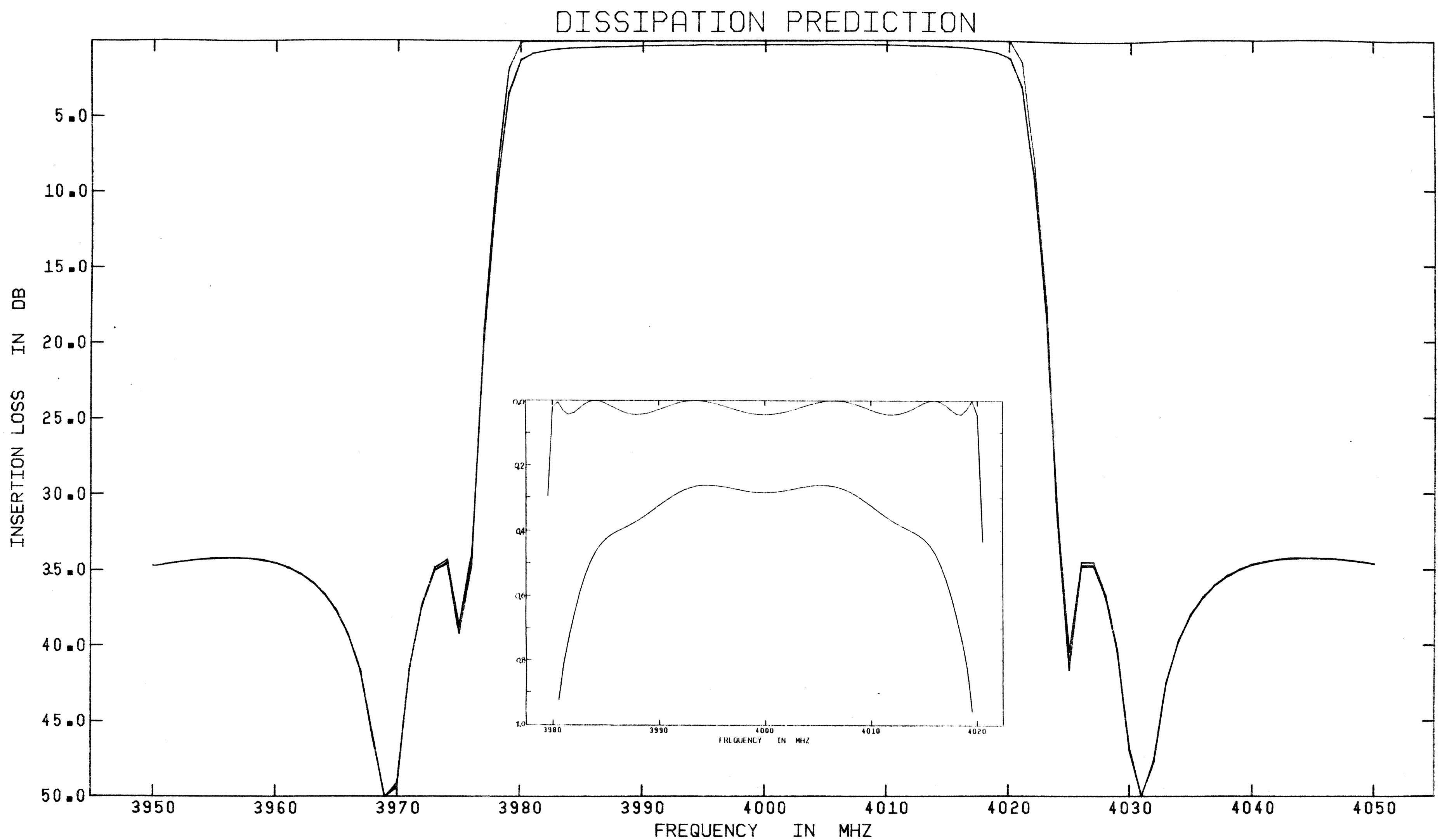

Fig. 2 Predicted response taking the dissipation effects into account using exact sensitivities. Unloaded Q = 12,000. The result is indistinguishable from the exact simulation of the lossy filter.

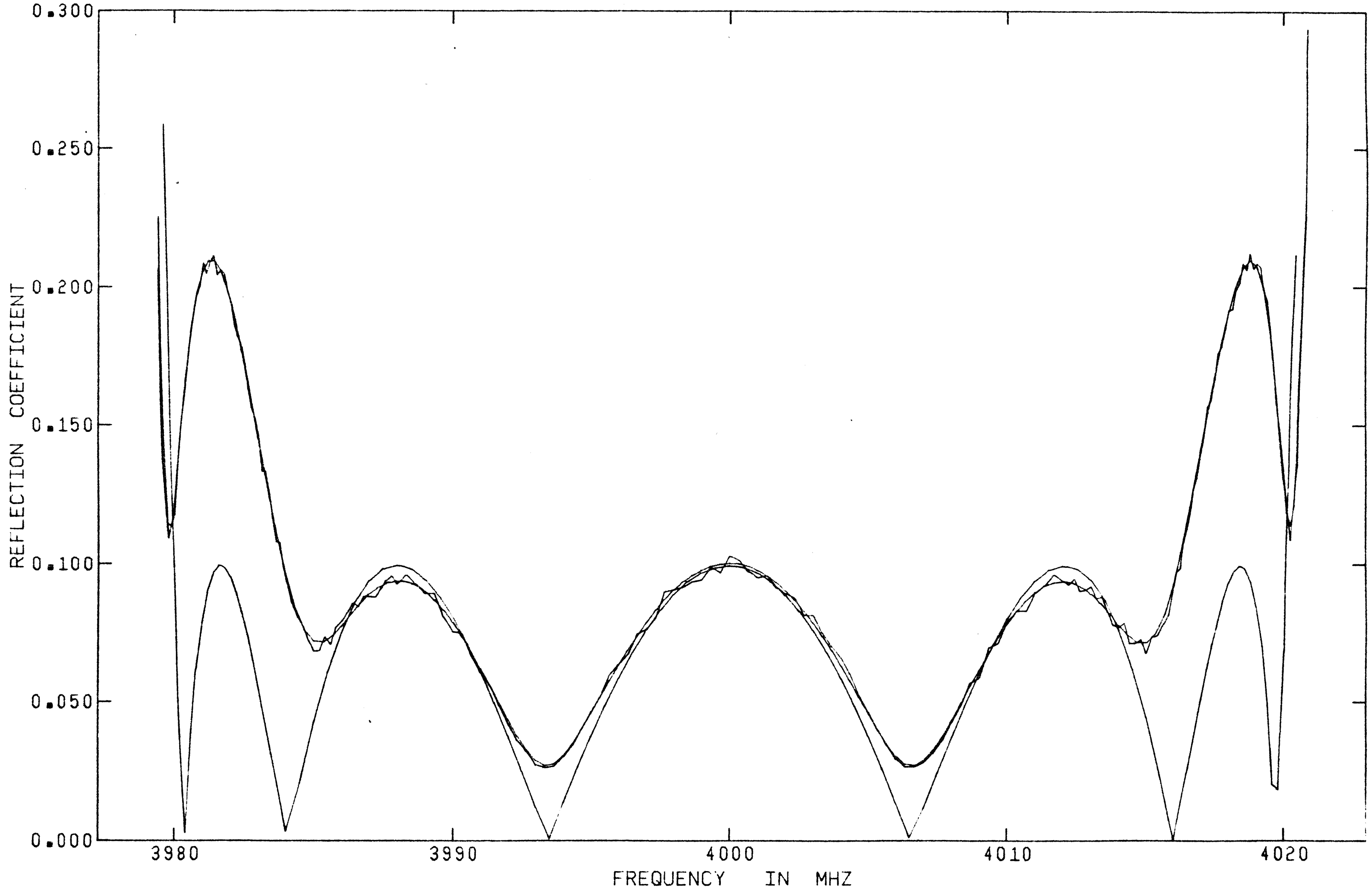

Fig. 3 Tolerances on the 7 couplings of a six cavity filter are introduced, the corresponding response data is distorted by measurement noise (noise level = 5 percent). The parameter deviations are identified and estimated in 0.25 min CPU and the simulated response of the estimated couplings matches the measured data excellently as shown.