EXACT, EFFICIENT GRADIENT OPTIMIZATION OF PRACTICAL CONTIGUOUS-BAND MULTIPLEXERS

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Abstract

A general contiguous-band multiplexer optimization procedure exploiting exact network sensitivities is described. The structure under consideration consists of synchronously and asynchronously tuned coupled-cavity filters distributed along a waveguide manifold. All design parameters, e.g., filter spacings (section lengths), input-output and filter coupling parameters, can be directly optimized using a powerful gradient-based minimax algorithm. The computer implementation includes dissipation, dispersive effects and junction susceptance models.

Introduction

Practical design and manufacture of contiguous-band multiplexers consisting of coupled-cavity filters distributed along a waveguide manifold has been a problem of significant interest [1-4]. Recently, a general multiplexer design procedure using an extension of the normal least squares method has been described [5].

Here, we formulate the design of a contiguous-band multiplexer structure as an optimization problem using a recently developed minimax algorithm of Hald and Madsen [6]. All design parameters of interest, e.g., filter spacings, input-output and filter coupling parameters, can be directly optimized. A wide range of possible multiplexer optimization problems can be formulated and solved by appropriately defining specifications on common port return loss and individual channel insertion loss functions. The minimax error functions are created using those specifications, simulated, exact multiplexer responses and sensitivities and weighting factors.

The minimax optimization algorithm we use [7] requires functions and their first-order derivatives to be supplied. They are calculated using a new theory developed for multiplexer structures which is based on the method of forward and reverse analyses for cascaded structures developed by Bandler, Rizk and Abdel-Malek [8].

Formulation of the Problem

The objective function to be minimized is given by

$$F(\mathbf{x}) = \max_{j \in J} f_j(\mathbf{x}), \tag{1}$$

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where **x** is a vector of optimization variables (e.g., section or spacing lengths, channel input and output couplings and filter coupling parameters) and $J \triangleq \{1,2,...,m\}$ is an index set. The minimax functions $f_j(\mathbf{x})$, $j \in J$, can be of the form [9]

$$w_{Uk}^{1}(\omega_i)(F_k^1(\mathbf{x}, \omega_i) - S_{Uk}^1(\omega_i)), \tag{2}$$

$$-\, w_{Lk}^{1}(\omega_i)(F_k^1(\mathbf{x}, \omega_i) - S_{Lk}^1(\omega_i)), \tag{3}$$

$$w_{U}^{2}(\omega_i)(F^2(\mathbf{x}, \omega_i) - S_{U}^2(\omega_i)), \tag{4}$$

$$-\, w_{L}^{2}(\omega_i)(F^2(\mathbf{x}, \omega_i) - S_{L}^2(\omega_i)), \tag{5}$$

where $F_k^1(\mathbf{x},\omega_i)$ is the insertion loss for the kth channel at the ith frequency, $F^2(\mathbf{x},\omega_i)$ is the return loss at the common port at the ith frequency, $S_{Uk}^1(\omega_i)$ ($S_{Lk}^1(\omega_i)$) is the upper (lower) specification on insertion loss of the kth channel at the ith frequency, $S_U^2(\omega_i)$ ($S_L^2(\omega_i)$) is the upper (lower) specification on return loss at the ith frequency, and w_{Uk}^1, w_{Lk}^1, w_U^2, w_L^2 are the arbitrary user-chosen non-negative weighting factors.

Computer Implementation

A Fortran package has been developed for multiplexer simulation, sensitivity analysis and optimization. Functional blocks of the package are shown in Fig. 1. This package has been designed to reflect the requirements of ComDev Ltd. of Cambridge, Ontario, Canada. It has been tested in close cooperation with engineers involved in design and postproduction tuning. For details see the section on Computational Experience.

A. Options of the Package

The required mode of operation of the package is selected by the user by setting an indicator as follows:

1 - if only multiplexer simulation is required,
2 - if multiplexer sensitivity analysis is required (implies simulation),
3 - if multiplexer optimization is required (implies both simulation and sensitivity analysis).

B. Options of the Optimization Mode

If the multiplexer optimization option is selected three modes of optimization are allowed for, namely, only return loss optimization (suggested by Chen [4]), only insertion loss optimization, return loss and insertion loss optimization, all at user-defined sets of frequency points. A suitable and sophisticated coding scheme has been developed which creates a consecutively numbered set of minimax functions depending on whether we have only lower (upper) specifications, both or no specifications on a function of interest at a certain frequency point.

C. Options Related to the Selection of Optimization Variables

The coding scheme developed and employed in the package allows also a very flexible choice of optimization variables. In general, all parameters are candidates for optimization variables, however, with very little effort the user can declare any parameters to be optimization variables.

D. Options Related to the Microwave Model of a Multiplexer

The package can exploit three commonly used practical models of the multiplexer, depending on whether the junctions are ideal or nonideal (junction susceptance is included), whether the filters are lossless or lossy (dissipation is included) and whether the filters are modeled as dispersive or non-dispersive. (The waveguide manifold is always assumed dispersive.)

Computational Experience

Test 1 A 5-channel, 12 GHz multiplexer has been optimized using spacings, input-output transformer ratios as the optimization variables with specifications on channel insertion loss for the three middle channels. A lower specification of 20 dB on return loss at the two crossover frequencies has been imposed. The results of optimization are shown in Fig. 2. The problem involves 5 variables, 47 nonlinear minimax functions and the solution is reached in about 80 seconds of CPU time on the Cyber 170/815 system.

Test 2 Suppose we want to satisfy the above specifications on insertion loss for the 3 middle channels and a uniform specification of 18 dB on return loss without dummy channels 1 and 5. Additional optimization variables (coupling parameters and cavity resonant frequencies in filters 2, 3 and 4) have been released. The results of optimization are shown in Fig. 3. The problem involves 39 variables, 92 nonlinear minimax functions and the solution time is about 8 minutes.

Test 3 Fig. 4 shows the results for the problem as in test 2 but with input-output transformer ratios as additional variables.

Test 4 An 8-channel, 12 GHz multiplexer has been optimized using spacings as the only variables and specifications on channel insertion loss functions for the 6 middle channels. A lower specification of 20 dB on return loss at the 5 crossover frequencies has also been imposed. The problem involves 8 variables, 65 minimax functions and the solution time is about 5.5 minutes.

Summary

A powerful and efficient optimization procedure for contiguous-band multiplexers has been presented. It employs a fast and robust gradient-based minimax algorithm. The multiplexer responses and their first-order sensitivities are calculated efficiently and exactly. The Fortran package developed allows flexibility in formulating multiplexer optimization problems of interest as well as flexibility in selecting optimization variables and multiplexer models. It is designed to handle multiplexer structures up to 16 channels with filters of order 8. Optimization on a 14-channel design has been successfully performed. The package facilitates tests on various candidate models for junctions. An important feature is the possibility of including linear equality and inequality constraints on optimization variables.

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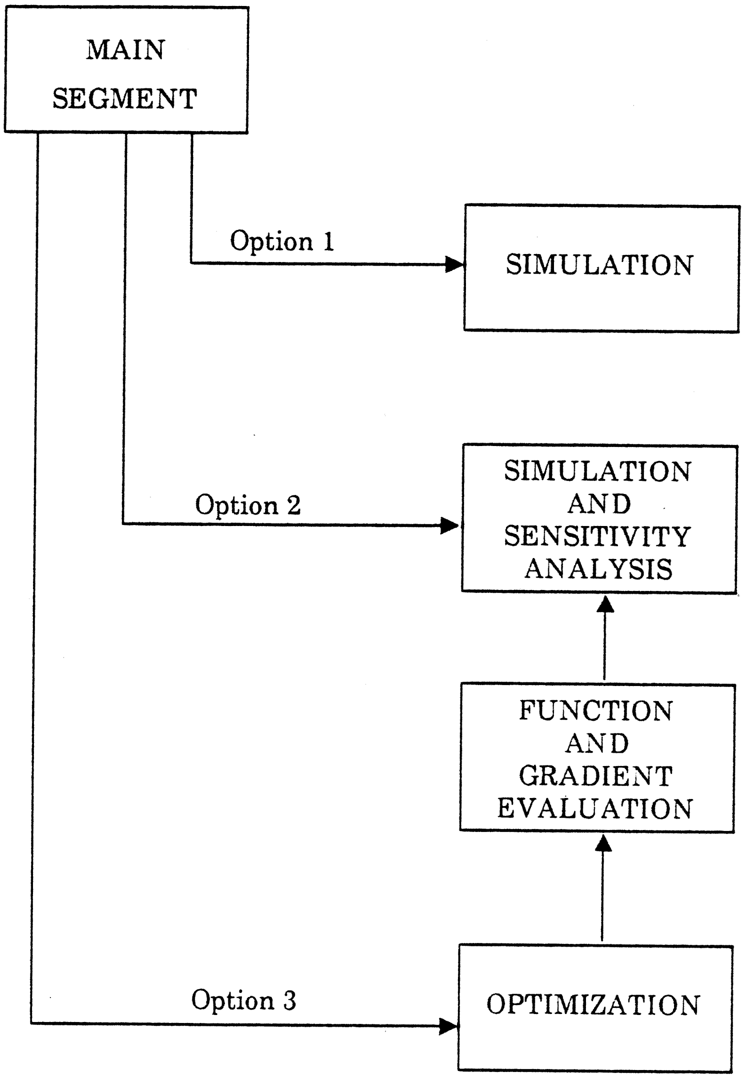

Fig. 1 Functional blocks of the computer package for multiplexer simulation, sensitivity analysis and optimization.

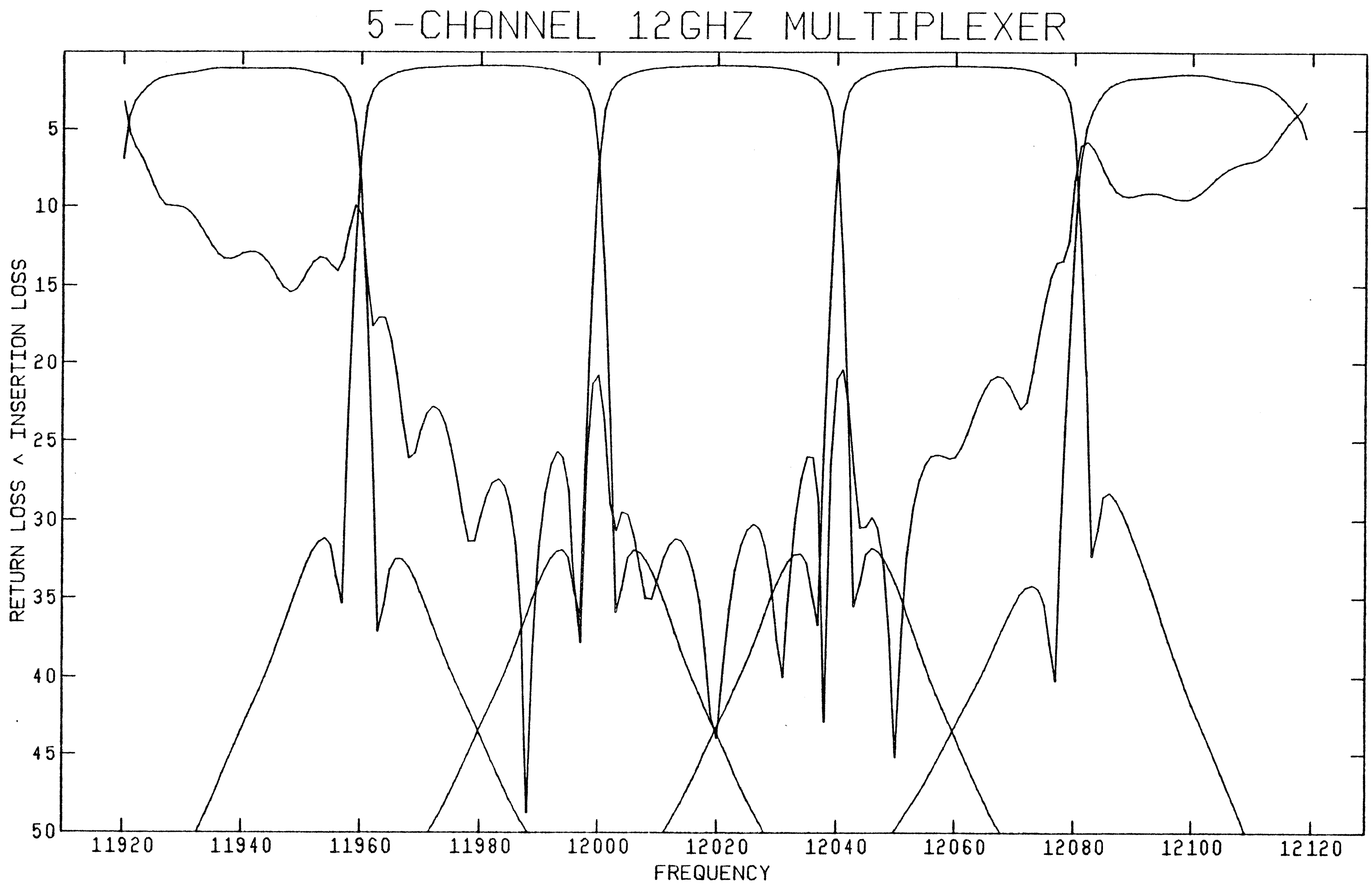

Fig. 2 Responses in dB of a 5-channel multiplexer (including two dummy channels) with optimized spacings and input-output transformer ratios. The filters are lossy and dispersive with unloaded Q = 12000; nonideal junctions are assumed.

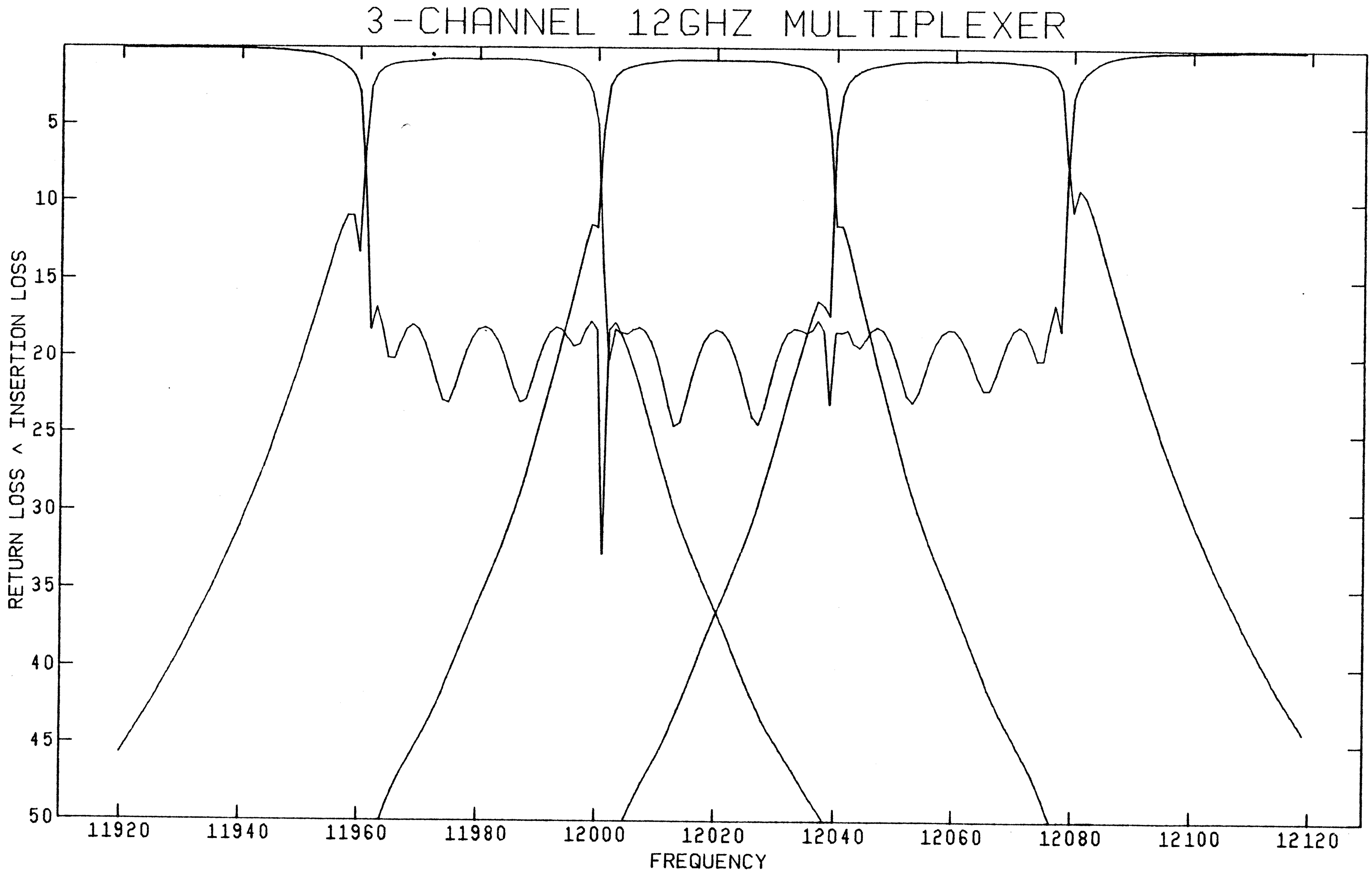

Fig. 3 Responses in dB of a 3-channel multiplexer with optimized spacings and coupling parameters (including cavity resonant frequencies). Other data as in Fig. 1.

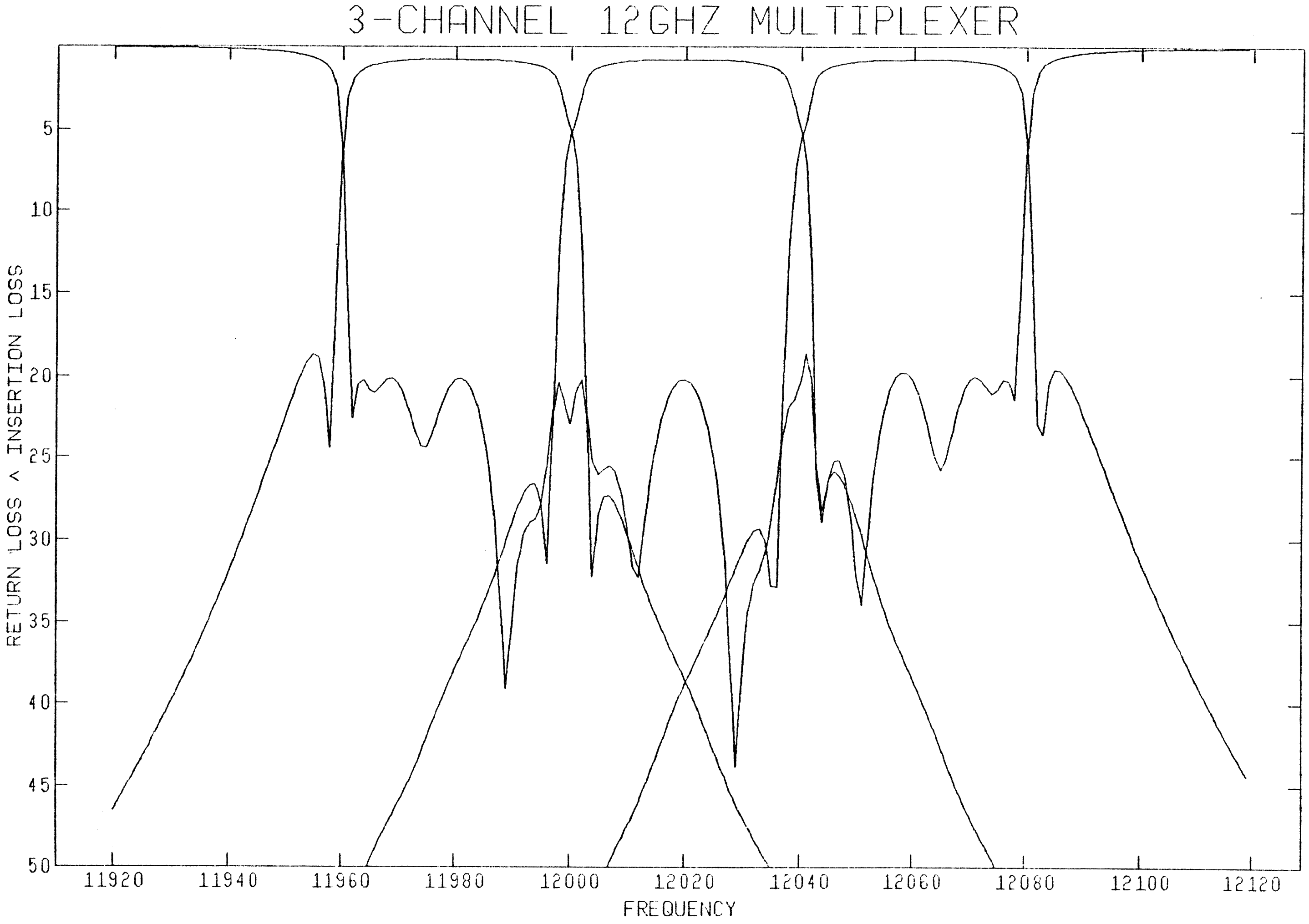

Fig. 4 Responses in dB of a 3-channel multiplexer with optimized spacings, input-output transformer ratios and coupling parameters. Other data as in Fig. 1.