OSA

CONTIGUOUS BAND MULTIPLEXER SIMULATION AND OPTIMIZATION

OSA-84-MX-12-M

July 16, 1984

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Section

INTRODUCTION

This report gives a user-oriented description of the MXSOS2 package consisting of twenty-two Fortran subroutines and a main segment. The package is designed for microwave multiplexer simulation, sensitivity analysis and optimization. The package and documentation have been prepared for the CDC 170/730 system with the NOS 2.1 -580/577 operating system and the Fortran Extended (FTN) version 4.8 compiler.

The design of a contiguous-band multiplexer structure (Fig. 1) is formulated as an optimization problem using a recently developed minimax algorithm of Hald and Madsen [1]. All design parameters of interest, e.g., filter spacings, input-output transformer ratios 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 weighting factors.

The minimax optimization package we use [2] requires functions and their first-order derivatives to be supplied. They are calculated using a theory developed for multiplexer structures, which employs some features of the method of forward and reverse analyses for cascaded structures developed by Bandler, Rizk and Abdel-Malek [3].

Fig. 2 shows the functional blocks of the package, which illustrates the three modes of operation of the package, namely, only multiplexer simulation, multiplexer sensitivity analysis (implies simulation) and multiplexer optimization (implies both simulation and sensitivity analysis).

If the multiplexer optimization option is selected three modes of optimization are allowed for, namely, only return loss optimization, only insertion loss optimization, simultaneous return loss and insertion loss optimization, all at user-defined sets of frequency points. A suitable and sophisticated coding scheme has been developed (details of which are explained in the section MULTIPLEXER OPTIMIZATION: FORMAL DESCRIPTION), 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.

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 selected combinations of parameters to be optimization variables.

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

The aim of this report is to familiarize the user with the package using a mixture of formal description and illustrative examples. We consider, for example, a three-channel, 12 GHz multiplexer without dummy channels to illustrate many features of the package.

References

[1] J. Hald and K. Madsen, "Combined LP and quasi-Newton methods for minimax optimization", Mathematical Programming, vol. 20, 1981, pp. 49-62.

[2] J.W. Bandler and W.M. Zuberek, "MMLC - a Fortran package for linearly constrained minimax optimization", Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, Report SOS-82-5, 1982.

[3] J.W. Bandler, M.R.M. Rizk and H.L. Abdel-Malek, "New results in network simulation, sensitivity and tolerance analysis for cascaded structures", IEEE Trans. Microwave Theory Tech., vol. MTT-26, 1978, pp. 963-972.

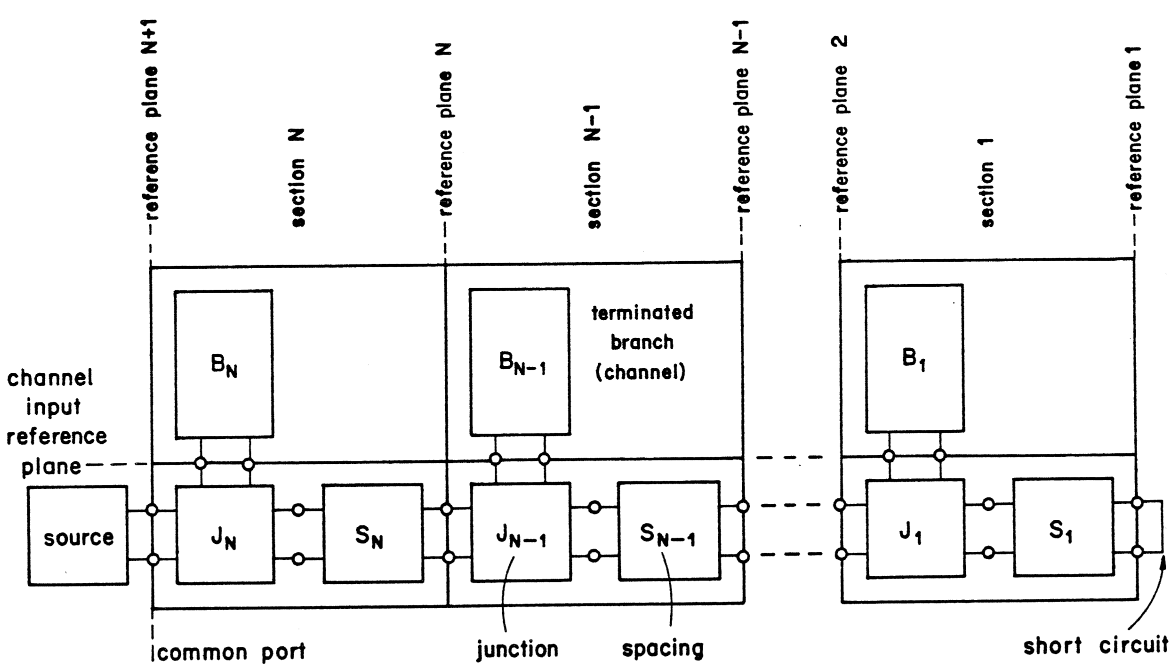

Fig. 1 The multiplexer configuration under consideration. $J_1, J_2, \ldots, J_N$ are arbitrarily defined 3-port junctions, $B_1, B_2 \ldots, B_N$ are terminated branches or channels which may each be represented in reduced cascade form and $S_1, S_2, \ldots, S_N$ are usually waveguide spacing elements.

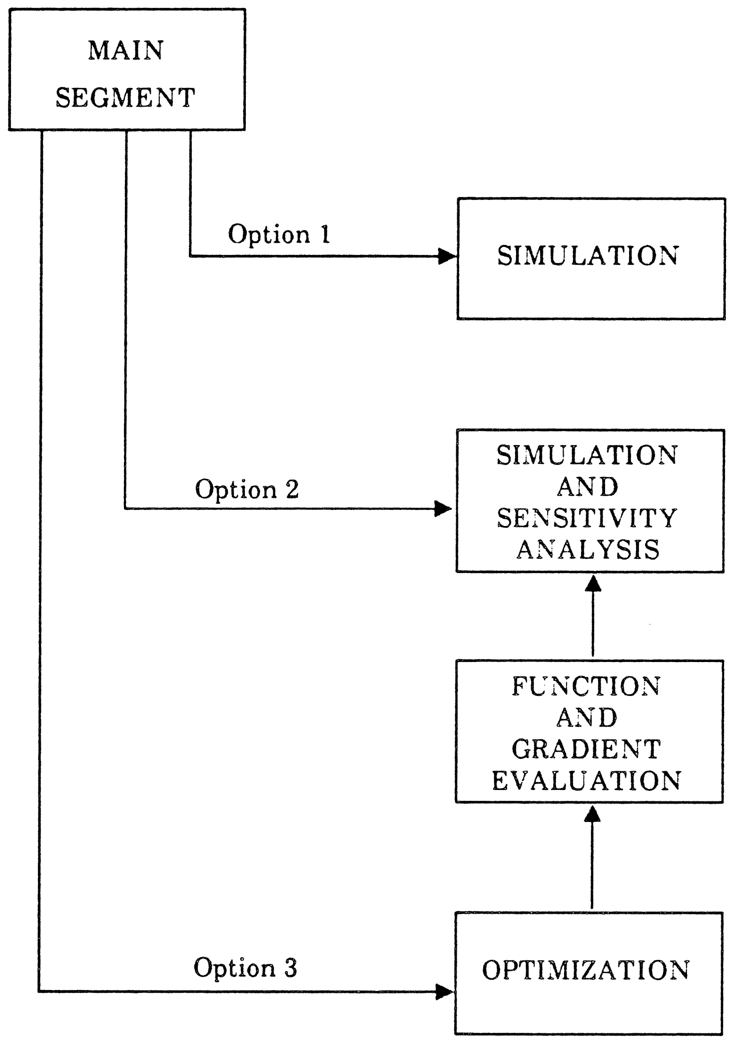

Fig. 2 Functional blocks of the computer package for multiplexer simulation, sensitivity analysis and optimization.

STRUCTURE OF THE PACKAGE

Introduction

The whole package has been modularized into 22 Fortran subroutines and one main segment. The overall structure of the package is shown in Fig. 1, where the calling and called subroutines are identified. The name of the main segment is MXSOS2 and is referred to by this name throughout the report.

Basic Entries

There are three basic entries to the package through the higher-level subroutines SIMUL, SIMGRD2 and MMLC1A, depending on the mode of operation of the package selected by the user in the main segment. If multiplexer simulation is required, the subroutine SIMUL is called. If multiplexer sensitivity analysis is required the subroutine SIMGRD2 is called. If multiplexer optimization is required the subroutine MMLC1A is called.

Lower Level Subroutines

The lower level subroutines form the heart of the simulation, which is conducted on an individual frequency point basis, and the required sensitivity analysis. The package is designed for an 8 × 8 coupling matrix, 16 channels and an arbitrary number of frequencies.

MMLC1A calls subroutine FDF2 in order to evaluate necessary error functions and partial derivatives. This is achieved at each frequency by a call to SIMGRD2, which in turn has at its disposal subroutines BETAVAL, FILTER, FILABCD, WGUIDE, SEQUENC, RESPONS, DABCDF2, DABCDG2, DRLOSS2, DVOLTA2 and INSERT, which are fully described in ensuing sections of this report. INSOUT and PHASE are called only by SIMUL.

Basic operations essential for simulation and sensitivity analysis are conducted by CSOLLU and MATMUL, the latter for matrix multiplications and the former for solving systems of complex linear equations using LU decomposition.

Other subroutines are DISPER, DISPAT, CONST1 and TOTAL2, also described fully later.

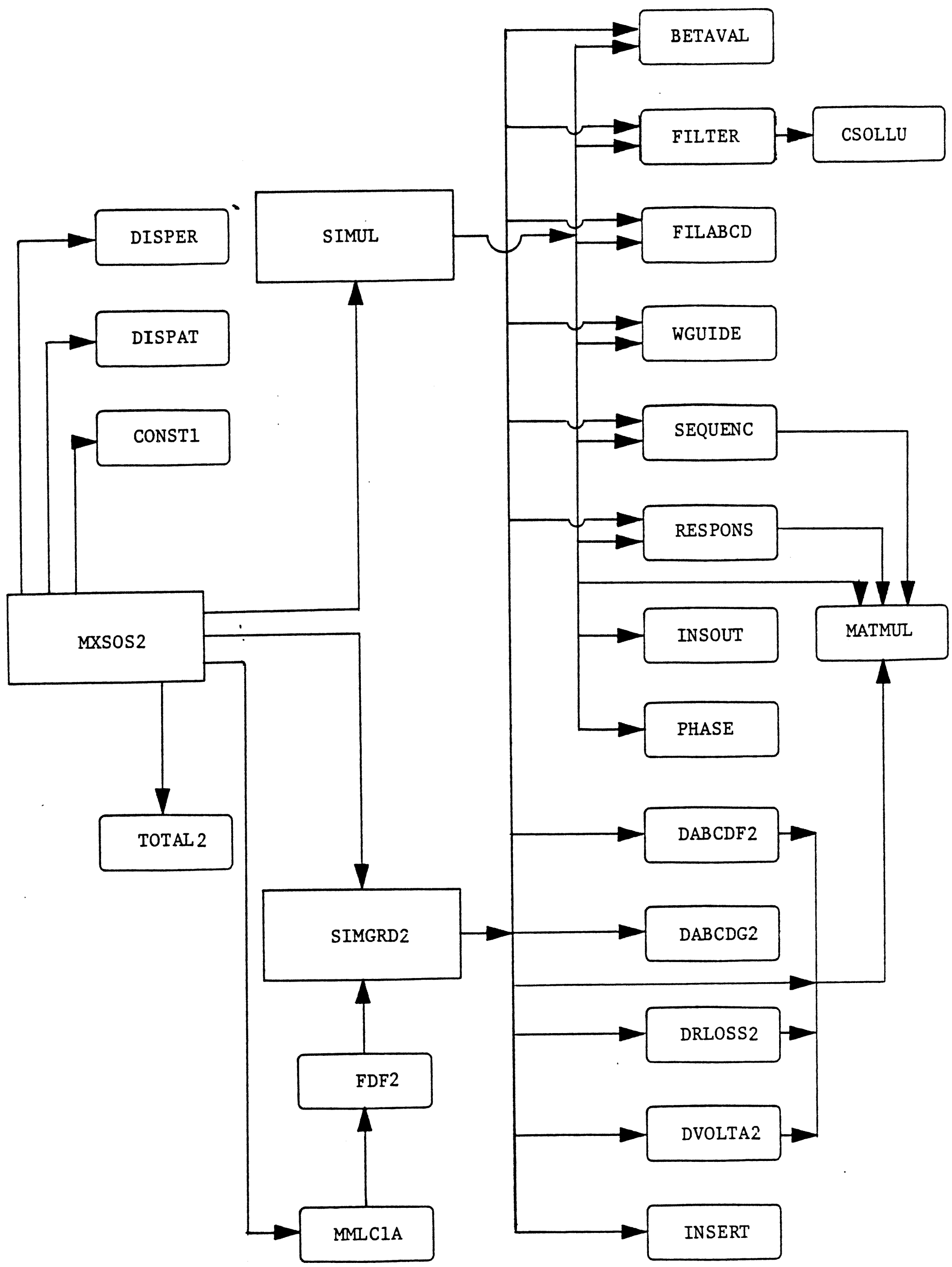

Fig. 1 The structure of the MXSOS2 package identifying the calling and called subprograms.

THE MAIN SEGMENT MXSOS2

General Description

MXSOS2 is a user defined main segment of the package for multiplexer simulation, sensitivity analysis and optimization. The program sets up arrays, initializes the data and executes some simple steps to organize the problem as required by the package. It consists of three parts. The first part initializes the data required for simulation; the second part initializes addtional data required for sensitivity analysis; and the third part initializes the data required for the multiplexer optimization problem of interest, including specifications and weighting factors as well as the data required by the minimax optimization package MMLC [1]. Only common port return loss and channel insertion loss are handled for optimization. During simulation the group delay is estimated by differencing the phase at a pair of frequencies.

The user must provide appropriate dimensions for all arrays corresponding to the dimensions declared in all subroutines except for the MMLC package.

Modes of Operation of the Package

The MXSOS2 package can operate in three modes, namely, simulation, sensitivity analysis and optimization. To select the required function of the package the integer variable LMODE should be set to

1 if multiplexer simulation is required,

2 if multiplexer sensitivity analysis is required,

3 if multiplexer optimization is required.

List of Variables for all Modes of Operation

Part of the main segment is used to define the necessary data for any multiplexer problem. It must always be defined, regardless of the mode of operation of the package selected.

The following variables and arrays have to be defined:

NCH	is an integer variable, which must be set to the number of filter channels including dummy channels (if any).
MO	is an integer variable, which must be set to the order of the filters (the same for all filters, odd or even).
WO	is a real array of dimension at least NCH. It must contain the center frequencies in MHz for all channels ordered consecutively.
QO	is a real array of dimension at least NCH. It must contain the unloaded Q factor for the filters.
DIA	is a real array of dimension at least NCH. It must contain the filter diameters in inches.
BW	is a real array of dimension at least NCH. It must contain the channel bandwidths in MHz.
SPN1	is a real array of dimension at least NCH. It must contain the input transformer ratios (squared), one per channel.
SPN2	is a real array of dimension at least NCH. It must contain the output transformer ratios (squared), one per channel.
GL	is a real array of dimension at least NCH. It must contain the values of channel terminating conductances, one per channel.
CM	is a real array of dimensions at least NCH by MO by MO. It must contain the filter coupling parameters (channel, row, column), including nonzero diagonal elements to model asynchronous designs. Because of symmetry, only the upper part of the CM matrix has to be defined.

CEL is an integer array of dimensions at least NCH by MO by MO. It must contain the type of the coupling, 1 for a screw, –1 for an iris, corresponding to CM as above.

WGL is a real array of dimension at least NCH. It must contain the waveguide spacings for each channel, measured in inches along the manifold from the adjacent channel (distance from the short circuit for the first channel).

VS is a real variable, which must be set to the source voltage at the common port.

RS is a real variable, which must be set to the source resistance at the common port.

PI2 is a constant equal to twice π.

WIDTH is a real variable, which must be set to the manifold width in inches.

IFLAGJS is an integer variable, which must be set to 0 for ideal junctions, or to 1 for nonideal junctions.

IFLAGDP is an integer variable, which must be set to 0 if the filters are considered lossless or to 1 if the filters are considered lossy.

IDISPER is an integer variable, which must be set to 0 if the filters are nondispersive or to 1 if the filters are dispersive.

References

[1] J.W. Bandler and W.M. Zuberek, "MMLC - a Fortran package for linearly constrained minimax optimization", Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, Report SOS-82-5, 1982.

MULTIPLEXER SIMULATION : FORMAL DESCRIPTION

General Description

A part of the main segment is used to generate frequencies at which simulation is to be performed. A frequency step of 1 MHz is assumed. None of the generated frequencies must be set exactly equal to any of the center frequencies. The subroutine SIMUL is called at each generated frequency. If a different frequency step is required, the frequency points for simulation have to be generated in an alternative way.

To perform the simulation, the subroutine SIMUL is called at each generated frequency. It returns the common port return loss function value, individual channel insertion loss function values and group delay.

Group delay is estimated from the phase difference at two frequencies, namely, the selected frequency and the selected frequency minus 0.5 MHz. Thus, a separate column of frequencies and group delays is generated and printed out. The evaluation of group delay is a true quadratic approximation at the selected frequency minus 0.25 MHz.

List of Variables for Multiplexer Simulation

The following variables have to be defined before the subroutine SIMUL is called:

FREQST — is a real variable, which must be set to the starting frequency in MHz minus 1 MHz for simulation.

NFRSIM — is an integer variable, which must be set to the number of frequency points at which simulation is performed.

Simulation Entry (Subroutine SIMUL)

The subroutine call is:

CALL SIMUL (FREQ, NCHAN, MORDER, ICOUNT, IFLAGJS, IFLAGDP, IDISPER, FRL, FIL, ANGLE).

The arguments are as follows:

FREQ is a real argument, which must be set to the actual frequency at which SIMUL is called.

NCHAN is an integer argument, which must be set to the number of filter channels including dummy channels (if any).

MORDER is an integer argument, which must be set to the order of the filters (the same for all filters).

ICOUNT is an integer argument, which is a counter for frequencies at which SIMUL is called.

IFLAGJS is an integer argument indicating ideal or nonideal junctions.

IFLAGDP is an integer argument indicating whether the filters are lossless or lossy.

IDISPER is an integer argument indicating whether the filters are dispersive or nondispersive.

FRL is a a real argument, which is set by the package to the value of the common port return loss in dB at the frequency FREQ.

FIL is a real array of length at least NCH. It is set by the package to the value of the insertion loss in dB for each channel at the frequency FREQ.

ANGLE is a real argument, which is set by the package to the phase at the frequency FREQ. It is used for estimating group delay.

MULTIPLEXER SIMULATION : EXAMPLE

Introduction

As an example of how to use the package in the simulation mode we present a three-channel, 12 GHz muliplexer simulation at 120 frequency points. The following algorithm defines all the steps required to run the program in the simulation mode of operation.

Algorithm for Three-Channel, 12 GHz Multiplexer Simulation

Step 1 Select the simulation mode of operation.

LMODE = 1 .

Step 2 Define the number of channels.

NCH = 3 .

Step 3 Define the order of the filters.

MO = 6 .

Step 4 Define the center frequencies in MHz for all channels, namely, ω_{01}, ω_{02}, ω_{03}.

WO(1) = 12060.0 ,

WO(2) = 12020.0 ,

WO(3) = 11980.0 .

Step 5 Define unloaded Q factors of the filters. In this example the unloaded Q factors are the same for all filters.

QO(I) = 12000.0, I = 1, 2, 3.

Step 6 Define the circular waveguide diameter for the filters in inches. In this example the diameter is the same for all filters.

DIA(I) = 1.07, I = 1, 2, 3.

Step 7 Define the bandwidths $\Delta\omega$ of the channels in MHz. In this example the bandwidths are assumed to be the same for all channels.

$$BW(I) = 39.5\,, \qquad I = 1, 2, 3.$$

Step 8 Define the input (output) transformer ratios n_1 (n_2) squared. In this example n_1 and n_2 are the same for all channels.

$$\begin{array}{l} SPN1(I) = 0.69967, \\ SPN2(I) = 1.09450, \end{array} \qquad I = 1, 2, 3.$$

Step 9 Define the output conductances GL in ohms. Here, they are the same for all channels.

$$GL(I) = 1.0, \qquad I = 1, 2, 3.$$

Step 10 Define the symmetrical coupling matrix. Only the upper part of the coupling matrix has to be defined. In this example the non-zero coupling elements (same for all channels) are M_{12}, M_{23}, M_{34}, M_{36}, M_{45}, M_{56}.

$$CM\,(I, 1, 2) = 0.59395,$$

$$CM\,(I, 2, 3) = 0.53514,$$

$$CM\,(I, 3, 4) = 0.42471,$$

$$CM\,(I, 3, 6) = -0.39967,$$

$$CM\,(I, 4, 5) = 0.83371,$$

$$CM\,(I, 5, 6) = 0.76313,$$

where I = 1, 2, 3.

Step 11 Define the type of non-zero coupling elements in the filter (the same for all channels in this example). Integer 1 denotes a screw coupling and integer -1 denotes an iris coupling.

$$CEL\,(I, 1, 2) = 1,$$

$$CEL\,(I, 2, 3) = -1,$$

$$CEL\,(I, 3, 4) = 1,$$

$$CEL\,(I, 3, 6) = -1,$$

$$CEL\,(I, 4, 5) = -1,$$

$$CEL\,(I, 5, 6) = 1,$$

where I = 1, 2, 3.

Step 12 Define the section lengths (spacings along the waveguide manifold) in inches, namely, ℓ_1, ℓ_2 and ℓ_3.

WGL(1) = 0.641,

WGL(2) = 0.631,

WGL(3) = 0.633.

Step 13 Define the source voltage V_S in volts, the source resistance R_S in ohms and the manifold width w in inches.

VS = 1.0,

RS = 1.0,

WIDTH = 0.75.

Step 14 Define the flag for junction susceptance. In this example we set the flag to 1, which corresponds to nonideal junctions.

IFLAGJS = 1.

If the flag for junction susceptance is 1 the subroutine CONST1 is called. For details see section CONST1.

Step 15 Define the flag for filter dissipation. In this example the filters are assumed to be lossy.

IFLAGDP = 1.

If the flag for dissipation is 1 the subroutine DISPAT is called. For details see section DISPAT.

Step 16 Define the flag for dispersive effects in the coupled-cavity filters. In this example the filters are assumed to be dispersive.

IDISPER = 1.

If the flag for dispersion is 1 the subroutine DISPER is called. For details see section DISPER.

Step 17 Define the starting frequency in MHz minus 1 MHz and the number of frequency points at which simulation is to be performed.

FREQST = 11959.0,

NFRSIM = 120.

The listing of the main program implementing the steps given above and the results of simulation are shown on the following pages, in Figs. 1 and 2.

```
      PROGRAM MXSOS2(OUTPUT,TAPE6=OUTPUT)
C
C     THIS PROGRAM IS A USER DEFINED MAIN SEGMENT OF THE MXSOS2 PACKAGE
C     FOR MULTIPLEXER SIMULATION, SENSITIVITY ANALYSIS AND OPTIMIZATION.
C     THE PROGRAM SETS UP ARRAYS, INITIALIZES THE DATA AND EXECUTES SOME
C     SIMPLE STEPS TO ORGANIZE THE PROBLEM AS REQUIRED BY THE PACKAGE.
C     IT CONSISTS OF THREE PARTS. THE FIRST PART INITIALIZES THE DATA
C     REQUIRED FOR SIMULATION, THE SECOND PART INITIALIZES ADDITIONAL
C     DATA REQUIRED FOR SENSITIVITY ANALYSIS AND THE THIRD PART INITIA-
C     LIZES THE DATA REQUIRED FOR THE MULTIPLEXER OPTIMIZATION PROBLEM
C     OF INTEREST INCLUDING SPECIFICATIONS AND WEIGHTING FACTORS AS WELL
C     AS THE DATA REQUIRED BY THE MINIMAX OPTIMIZATION PACKAGE MMLC. AT
C     THIS TIME ONLY COMMON PORT RETURN LOSS AND CHANNEL INSERTION LOSS
C     IN DB ARE HANDLED FOR OPTIMIZATION. IN THE CASE OF SIMULATION
C     GROUP DELAY IS ESTIMATED BY DIFFERENCING THE PHASE AT A PAIR
C     OF FREQUENCIES.
C
C     THE USER MUST PROVIDE APPROPRIATE DIMENSIONS FOR THE FOLLOWING
C     VARIABLES AFTER STUDYING THE COMMENTS PLACED THROUGHOUT THE MAIN
C     SEGMENT MXSOS2. CORRESPONDING DIMENSIONS MUST BE DECLARED IN ALL
C     SUBROUTINES EXCEPT FOR THE MMLC PACKAGE.
C
      REAL X(45),W(20000),B(1),C(1,1),T(3),DISP(16),QO(16)
      REAL OMEGA(47),SURL(47),SLRL(47),WURL(47),WLRL(47),
     1     SU(20,16),SL(20,16),WU(20,16),WL(20,16)
      INTEGER RLSCODE(47),SPCODE(20,16),CHBCODE(16,2)
      REAL WO(16),BW(16),CM(16,8,8),PN1(16),PN2(16),SPN1(16),SPN2(16),
     1          GL(16),WGL(16),DIA(16)
      INTEGER CEL(16,8,8)
      REAL FCNST(16),LAMRES(16),LAMDEL(16)
      REAL DRL(100),FIL(16),DIL(16,100)
      REAL ANGLE1(16),ANGLE2(16),GRDEL(16)
      INTEGER IR(16),IRT(16),IPN1(16),IPN2(16),IWG(16)
      INTEGER LC(16,36),KC(16,36)
      EXTERNAL FDF2
      COMMON /BLK1/WO,BW,PN1,PN2,GL,VS,RS,P12,WIDTH,NP1
      COMMON /BLK2/CM,WGL
      COMMON /BLK3/OMEGA,SURL,SLRL,WURL,WLRL,SU,SL,WU,WL,
     1             RLSCODE,SPCODE,NCOUNT,MODE,NCH,MO,NFREQ,NFRL,
     2       CHBCODE,IFLAGJS,IFLAGDP,IDISPER
      COMMON /BLK4/CBR,FCUT
      COMMON /BLK5/DISP
      COMMON/BLK6/FCNST,LAMRES,LAMDEL
      COMMON/BLK7/CEL
      COMMON/BLK8/IR,IRT,IPN1,IPN2,IWG,LC,KC
      DATA T/10HMULTIPLEXE,10HR PROBLEM ,10HMXTST6C   /
C
C     THE MXSOS2 PACKAGE CAN OPERATE IN THREE MODES: SIMULATION, SENSITI
C     VITY ANALYSIS AND OPTIMIZATION. TO SELECT THE REQUIRED FUNCTION OF
C     THE PACKAGE SET LMODE TO
C     1 - IF MULTIPLEXER SIMULATION IS REQUIRED,
C     2 - IF MULTIPLEXER SENSITIVITY ANALYSIS IS REQUIRED,
C     3 - IF MULTIPLEXER OPTIMIZATION IS REQUIRED.
C
C     SELECT MODE OF OPERATION OF THE PACKAGE
C
      LMODE=1
C
C     THIS PART OF THE MAIN SEGMENT IS USED TO DEFINE THE DATA FOR
C     MULTIPLEXER SIMULATION. IT MUST ALWAYS BE DEFINED, REGARDLESS OF
C     THE MODE OF OPERATION OF THE PACKAGE SELECTED.
C
C     NCH     - NUMBER OF FILTER CHANNELS INCLUDING DUMMY CHANNELS
C     MO      - ORDER OF FILTERS(THE SAME FOR ALL FILTERS, ODD OR EVEN)
C     WO      - VECTOR OF CENTER FREQUENCIES IN MHZ, ONE PER CHANNEL
```

Fig. 1 Listing of MXSOS2 arranged for simulation only.

```
C     QO      - VECTOR OF UNLOADED Q FOR THE FILTERS, ONE PER CHANNEL
C     DIA     - VECTOR OF FILTER DIAMETERS IN INCHES, ONE PER CHANNEL
C     BW      - VECTOR OF CHANNEL BANDWIDTHS IN MHZ, ONE PER CHANNEL
C     SPN1    - VECTOR OF INPUT TRANSFORMER RATIOS(SQUARED), ONE PER
C               CHANNEL
C     SPN2    - VECTOR OF OUTPUT TRANSFORMER RATIOS(SQUARED), ONE PER
C               CHANNEL
C     GL      - VECTOR OF CHANNEL TERMINATING CONDUCTANCES, ONE PER
C               CHANNEL
C     CM      - SYMMETRICAL MATRIX OF COUPLING PARAMETERS(CHANNEL,ROW,
C               COLUMN), INCLUDING NONZERO DIAGONAL ELEMENTS TO MODEL
C               ASYNCHRONOUS DESIGNS
C     CEL     - SYMMETRICAL MATRIX FOR TYPE OF COUPLING, +1 FOR SCREW,
C               -1 FOR IRIS, CORRESPONDING TO CM AS ABOVE
C     WGL     - VECTOR OF WAVEGUIDE SPACINGS FOR EACH CHANNEL, MEASURED
C               IN INCHES ALONG THE MANIFOLD FROM THE ADJACENT CHANNEL
C               (DISTANCE FROM THE SHORT CIRCUIT FOR THE FIRST CHANNEL)
C     VS      - SOURCE VOLTAGE AT THE COMMON PORT
C     RS      - SOURCE RESISTANCE AT THE COMMON PORT
C     PI2     - CONSTANT EQUAL TO TWICE PI
C     WIDTH   - MANIFOLD WIDTH IN INCHES
C
C     DEFINE THE NUMBER OF CHANNELS AND THE ORDER OF THE FILTERS
C
      NCH=3
      MO=6
      NP1=NCH+1
C
C     DEFINE CENTER FREQUENCIES IN MHZ
C
      WO(1)=12060.0
      WO(2)=12020.0
      WO(3)=11980.0
C
C     DEFINE UNLOADED Q FACTORS OF THE FILTERS
C
      DO 5 I=1,NCH
      QO(I)=12000.0
    5 CONTINUE
C
C     DEFINE THE DIAMETER OF THE FILTERS IN INCHES
C
      DO 70 I=1,NCH
      DIA(I)=1.07
   70 CONTINUE
C
C     DEFINE BANDWIDTHS, INPUT/OUTPUT TRANSFORMER RATIOS AND OUTPUT
C     CONDUCTANCES
C
      DO 1 I=1,NCH
      BW(I)=39.5
      GL(I)=1.0
      SPN1(I)=0.69967
      SPN2(I)=1.09450
      PN1(I)=SQRT(SPN1(I))
      PN2(I)=SQRT(SPN2(I))
    1 CONTINUE
C
C     DEFINE THE SYMMETRICAL COUPLING MATRIX. ONLY THE UPPER PART OF THE
C     CM MATRIX HAS TO BE DEFINED.
C
      DO 30 I=1,NCH
      DO 30 J=1,MO
      DO 30 KK=1,MO
      CM(I,J,KK)=0.0
```

Fig. 1 (continued)   Listing of MXSOS2 arranged for simulation only.

```
   30 CONTINUE
      DO 2 I=1,NCH
      CM(I,1,2)=0.59395
      CM(I,2,3)=0.53514
      CM(I,3,4)=0.42471
      CM(I,3,6)=-0.39967
      CM(I,4,5)=0.83371
      CM(I,5,6)=0.76313
    2 CONTINUE
C
C     DEFINE THE TYPE OF COUPLING IN THE FILTER
C              +1 >> SCREW COUPLING     -1 >> IRIS COUPLING
C
      DO 71 I=1,NCH
      DO 71 J=1,MO
      DO 71 KK=1,MO
      CEL(I,J,KK)=0
   71 CONTINUE
C
      DO 72 I=1,NCH
      CEL(I,1,2)=1
      CEL(I,2,3)=-1
      CEL(I,3,4)=1
      CEL(I,3,6)=-1
      CEL(I,4,5)=-1
      CEL(I,5,6)=1
C
      DO 72 J=1,MO
      DO 72 KK=1,J
      CEL(I,J,KK)=CEL(I,KK,J)
   72 CONTINUE
C
C     DEFINE THE SECTION LENGTHS (SPACINGS ALONG THE WAVEGUIDE MANIFOLD)
C
      WGL(1)=0.641
      WGL(2)=0.631
      WGL(3)=0.633
C
C     DEFINE SOME CONSTANTS, SOURCE VOLTAGE, SOURCE RESISTANCE, TWICE PI
C     MANIFOLD WIDTH
C
      VS=1.0
      RS=1.0
      PI2=8.0*ATAN(1.0)
      WIDTH=0.75
C
C     THE MXSOS2 PACKAGE CAN EXPLOIT THREE PRACTICAL MODELS OF THE
C     MULTIPLEXER AS DETERMINED BY THE PARAMETERS IFLAGJS, IFLAGDP
C     AND IDISPER.
C
C     IFLAGJS
C     0 - IF JUNCTIONS ARE IDEAL
C     1 - IF JUNCTIONS ARE NONIDEAL
C
C     IFLAGDP
C     0 - IF FILTERS ARE LOSSLESS
C     1 - IF FILTERS ARE LOSSY
C
C     IDISPER
C     0 - IF FILTERS ARE DISPERSIVE
C     1 - IF FILTERS ARE NONDISPERSIVE
C
C     FLAG FOR JUNCTION SUSCEPTANCE (SET TO 0 OR 1)
C
      IFLAGJS=1
```

Fig. 1 (continued) Listing of MXSOS2 arranged for simulation only.

```
      IF(IFLAGJS.NE.1)GO TO 42
C
      CALL CONST1(WIDTH)
C
   42 CONTINUE
C
C     FLAG FOR FILTER DISSIPATION (SET TO 0 OR 1)
C
      IFLAGDP=1
      IF(IFLAGDP.NE.1)GO TO 43
C
      CALL DISPAT(NCH,WO,BW,QO)
C
   43 CONTINUE
C
C     FLAG FOR DISPERSIVE EFFECTS IN THE COUPLED CAVITY FILTERS
C     (SET TO 0 OR 1)
C
      IDISPER=1
      IF(IDISPER.NE.1)GO TO 44
C
      CALL DISPER(NCH,WO,BW,DIA)
C
   44 CONTINUE
C
C     CHECK WHETHER THE SIMULATION MODE IS REQUIRED
C
      IF(LMODE.NE.1)GO TO 16
C
C     SIMULATION, CORRESPONDING TO LMODE=1
C
C     THIS PART OF THE MAIN SEGMENT IS USED TO GENERATE FREQUENCIES AT
C     WHICH SIMULATION IS TO BE PERFORMED. A FREQUENCY STEP OF 1 MHZ IS
C     ASSUMED. NONE OF THE GENERATED FREQUENCIES MUST BE SET EQUAL TO
C     ANY OF THE CENTER FREQUENCIES. SUBROUTINE "SIMUL" IS CALLED AT
C     EACH GENERATED FREQUENCY. IF A DIFFERENT FREQUENCY STEP IS REQUI-
C     RED THE FREQUENCY POINTS FOR SIMULATION HAVE TO BE GENERATED IN A
C     DIFFERENT WAY.
C
C     FREQST - START FREQUENCY FOR SIMULATION
C     FREQ   - ACTUAL FREQUENCY AT WHICH "SIMUL" IS CALLED
C     NFRSIM - NUMBER OF FREQUENCY POINTS FOR SIMULATION
C
      PRINT(6,199)
  199 FORMAT(1H1)
      PRINT(6,205)
  205 FORMAT(6X,"FREQUENCY",5X,"RETURN LOSS",5X,"INSERTION LOSS",
     1       8X,"FREQUENCY FOR",7X,"GROUP DELAY")
      PRINT(6,206)
  206 FORMAT(8X,"MHZ",9X,"COMMON PORT",9X,"DB",17X,"GROUP DELAY",
     1       9X,"NANO SECS")
C
C
C     THE FOLLOWING TWO PARAMETERS MUST BE DEFINED
C
      FREQST=11959.0
      NFRSIM=120
C
      NCHAN=NCH
      MORDER=MO
      IREL=NCH+1
      DO 200 ICOUNT=1,NFRSIM
      FREQ=FREQST+FLOAT(ICOUNT)
      ITEST=INT(FREQ)
C
```

Fig. 1 (continued)   Listing of MXSOS2 arranged for simulation only.

```
C      THE FOLLOWING STATEMENT PRINTS DASHED LINE EVERY 20 MHZ
C
       IF(MOD(ITEST,20).EQ.0)PRINT(6,208)
  208  FORMAT(90("-"))
       DO 210 I=1,NCH
       IF(ABS(FREQ-WO(I)).LT.1.E-10)FREQ=FREQ+0.001
  210  CONTINUE
C
C      GROUP DELAY IS ESTIMATED FROM THE PHASE DIFFERENCE AT TWO
C      FREQUENCIES, NAMELY, THE SELECTED FREQUENCY AND THE SELECTED
C      FREQUENCY MINUS 0.5 MHZ. CONSEQUENTLY, THE EVALUATION IS A
C      TRUE QUADRATIC APPROXIMATION AT THE SELECTED FREQUENCY MINUS
C      0.25 MHZ. THUS, A SEPARATE COLUMN OF FREQUENCIES AND GROUP
C      DELAYS IS GENERATED AND PRINTED OUT.
C
C      SUBTRACT 0.5 MHZ FROM FREQ
C
       FREQ=FREQ-0.5
C
       CALL SIMUL(FREQ,NCHAN,MORDER,ICOUNT,IFLAGJS,IFLAGDP,IDISPER,
      1           FRL,FIL,ANGLE1)
C
C      RESET FREQ BY ADDING 0.5 MHZ
C
       FREQ=FREQ+0.5
C
       CALL SIMUL(FREQ,NCHAN,MORDER,ICOUNT,IFLAGJS,IFLAGDP,IDISPER,
      1           FRL,FIL,ANGLE2)
C
       DO 300 I=1,NCH
       DELANG=ANGLE2(I)-ANGLE1(I)
       PI=PI2/2.0
       IF(DELANG.GT.PI)DELANG=DELANG-PI2
       GRDEL(I)=-2000.0*DELANG/PI2
  300  CONTINUE
C
C      THE FOLLOWING STATEMENT CAUSES THE PRINTING OF INSERTION LOSS
C      FUNCTION VALUES ONLY FOR THE BAND OF INTEREST.
C
       IF(MOD(ITEST,40).EQ.0)IREL=IREL-1
C
C      GROUP DELAY IS ESTIMATED AT FREQ MINUS 0.25 MHZ
C
       FRGROUP=FREQ-0.25
       PRINT(6,207)FREQ,FRL,FIL(IREL),FRGROUP,GRDEL(IREL)
  207  FORMAT(6X,F7.1,9X,F5.2,12X,F5.2,17X,F8.2,10X,F8.2)
  200  CONTINUE
   16   CONTINUE
       STOP
       END
```

Fig. 1 (continued)   Listing of MXSOS2 arranged for simulation only.

FREQUENCY MHZ	RETURN LOSS COMMON PORT	INSERTION LOSS DB	FREQUENCY FOR GROUP DELAY	GROUP DELAY NANO SECS
11960.0	3.10	6.99	11959.75	102.10
11961.0	5.24	4.13	11960.75	101.31
11962.0	6.23	3.13	11961.75	77.10
11963.0	6.96	2.60	11962.75	61.44
11964.0	7.89	2.20	11963.75	53.63
11965.0	8.93	1.88	11964.75	49.01
11966.0	9.77	1.66	11965.75	45.41
11967.0	10.26	1.53	11966.75	42.17
11968.0	10.46	1.45	11967.75	39.31
11969.0	10.57	1.39	11968.75	36.95
11970.0	10.76	1.34	11969.75	35.15
11971.0	11.12	1.28	11970.75	33.86
11972.0	11.68	1.21	11971.75	32.99
11973.0	12.44	1.14	11972.75	32.42
11974.0	13.38	1.07	11973.75	32.03
11975.0	14.40	1.02	11974.75	31.73
11976.0	15.35	.97	11975.75	31.47
11977.0	16.03	.95	11976.75	31.20
11978.0	16.33	.93	11977.75	30.94
11979.0	16.31	.93	11978.75	30.69
11980.0	16.13	.94	11979.75	30.51
11981.0	16.00	.94	11980.75	30.43
11982.0	16.02	.95	11981.75	30.49
11983.0	16.30	.95	11982.75	30.69
11984.0	16.87	.95	11983.75	31.05
11985.0	17.80	.94	11984.75	31.57
11986.0	19.14	.94	11985.75	32.24
11987.0	20.94	.94	11986.75	33.04
11988.0	23.15	.95	11987.75	33.97
11989.0	25.34	.97	11988.75	35.04
11990.0	26.27	1.01	11989.75	36.28
11991.0	25.53	1.05	11990.75	37.75
11992.0	24.41	1.11	11991.75	39.56
11993.0	23.80	1.19	11992.75	41.86
11994.0	23.95	1.28	11993.75	44.88
11995.0	24.98	1.40	11994.75	48.92
11996.0	26.91	1.56	11995.75	54.52
11997.0	29.91	1.81	11996.75	62.74
11998.0	34.35	2.25	11997.75	75.78
11999.0	26.62	3.25	11998.75	97.49

Fig. 2 Results of the three-channel simulation problem.

12000.0	19.41	8.30	11999.75	99.97
12001.0	16.95	4.12	12000.75	121.27
12002.0	16.88	2.66	12001.75	94.29
12003.0	18.41	2.04	12002.75	74.44
12004.0	20.77	1.70	12003.75	62.68
12005.0	22.64	1.48	12004.75	54.99
12006.0	22.67	1.34	12005.75	49.51
12007.0	21.71	1.25	12006.75	45.39
12008.0	20.99	1.18	12007.75	42.26
12009.0	20.87	1.12	12008.75	39.85
12010.0	21.40	1.06	12009.75	37.99
12011.0	22.61	1.02	12010.75	36.54
12012.0	24.63	.97	12011.75	35.38
12013.0	27.80	.94	12012.75	34.44
12014.0	32.89	.91	12013.75	33.66
12015.0	39.10	.90	12014.75	33.01
12016.0	34.27	.88	12015.75	32.46
12017.0	30.06	.87	12016.75	32.02
12018.0	27.89	.87	12017.75	31.69
12019.0	26.98	.87	12018.75	31.47
12020.0	27.07	.86	12019.75	31.37
12021.0	28.19	.86	12020.75	31.38
12022.0	30.72	.86	12021.75	31.50
12023.0	36.23	.87	12022.75	31.72
12024.0	53.29	.88	12023.75	32.04
12025.0	34.24	.89	12024.75	32.44
12026.0	28.52	.91	12025.75	32.93
12027.0	25.35	.94	12026.75	33.54
12028.0	23.46	.97	12027.75	34.30
12029.0	22.45	1.00	12028.75	35.25
12030.0	22.21	1.04	12029.75	36.47
12031.0	22.73	1.08	12030.75	38.04
12032.0	23.96	1.13	12031.75	40.03
12033.0	25.19	1.19	12032.75	42.53
12034.0	24.32	1.29	12033.75	45.65
12035.0	21.58	1.43	12034.75	49.62
12036.0	19.21	1.62	12035.75	54.95
12037.0	18.11	1.89	12036.75	62.92
12038.0	18.66	2.33	12037.75	76.25
12039.0	18.55	3.34	12038.75	98.98

Fig. 2 (continued) Results of the three-channel simulation problem.

12040.0	14.39	8.29	12039.75	100.78
12041.0	12.67	4.22	12040.75	119.40
12042.0	13.21	2.76	12041.75	92.79
12043.0	15.07	2.10	12042.75	74.10
12044.0	16.90	1.74	12043.75	62.76
12045.0	17.40	1.53	12044.75	54.94
12046.0	16.93	1.40	12045.75	49.20
12047.0	16.54	1.31	12046.75	44.97
12048.0	16.64	1.23	12047.75	41.87
12049.0	17.26	1.16	12048.75	39.61
12050.0	18.32	1.09	12049.75	37.91
12051.0	19.56	1.03	12050.75	36.57
12052.0	20.38	.99	12051.75	35.43
12053.0	20.14	.97	12052.75	34.42
12054.0	19.03	.96	12053.75	33.50
12055.0	17.73	.96	12054.75	32.66
12056.0	16.65	.96	12055.75	31.94
12057.0	15.89	.97	12056.75	31.37
12058.0	15.47	.97	12057.75	30.97
12059.0	15.35	.97	12058.75	30.75
12060.0	15.47	.96	12059.75	30.71
12061.0	15.74	.96	12060.75	30.82
12062.0	15.99	.95	12061.75	31.04
12063.0	15.99	.96	12062.75	31.33
12064.0	15.55	.98	12063.75	31.63
12065.0	14.72	1.01	12064.75	31.92
12066.0	13.69	1.07	12065.75	32.19
12067.0	12.69	1.13	12066.75	32.50
12068.0	11.84	1.20	12067.75	32.91
12069.0	11.21	1.28	12068.75	33.55
12070.0	10.80	1.34	12069.75	34.55
12071.0	10.59	1.40	12070.75	36.02
12072.0	10.49	1.45	12071.75	38.07
12073.0	10.34	1.53	12072.75	40.70
12074.0	9.90	1.66	12073.75	43.80
12075.0	9.06	1.87	12074.75	47.25
12076.0	8.00	2.18	12075.75	51.19
12077.0	7.02	2.60	12076.75	56.81
12078.0	6.26	3.12	12077.75	67.45
12079.0	5.30	4.10	12078.75	88.14

Fig. 2 (continued) Results of the three-channel simulation problem.

MULTIPLEXER SENSITIVITY ANALYSIS : FORMAL DESCRIPTION

General Description

The second part of the main segment is used to define codes for multiplexer parameters w.r.t. which we want to find the sensitivities. The user must define the number of coupling variables per channel, codes to identify variables for input-output transformer ratios, waveguide spacings and variables contained in the coupling matrices.

Subroutine SIMGRD2 is called at each frequency defined in the vector OMEGA (I). The parameter IR(I) = 0 signifies that no elements of the filter coupling matrices are optimization variables.

List of Variables for Multiplexer Sensitivity Analysis

The following variables have to be defined before the subroutine SIMGRD2 is called.

IR — is an integer array of dimension at least NCH. It must contain the number of coupling parameters being variables for each channel.

LC — is an integer array of dimensions at least NCH by MO(MO − 1)/2 + MO. It must contain the row indices of coupling parameters being variables for each channel in the form LC (channel, row index).

KC — is an integer array of dimensions at least NCH by MO(MO − 1)/2 + MO. It must contain the column indices of coupling parameters being variables for each channel in the form KC (channel, column index).

IPN1 — is an integer array of dimension at least NCH, indicating whether the input transformer ratio is an optimization variable (IPN1(I) = 1) or not (IPN1(I) = 0).

IPN2 — is an integer array of dimension at least NCH, indicating whether the output transformer ratio is an optimization variable (IPN2(I) = 1) or not (IPN2(I) = 0).

IWG is an integer array of dimension at least NCH indicating whether the waveguide section length is an optimization variable (IWG(I) = 1) or not (IWG(I) = 0).

OMEGA is a real array of dimension at least NFREQ (the number of frequency points at which the sensitivity analysis is to be performed). It must contain arbitrary frequencies (except center frequencies) at which the sensitivity analysis is to be performed.

FRSNS is a real variable, which must be set to the actual frequency at which the subroutine SIMGRD2 is called.

Sensitivity Analysis Entry (Subroutine SIMGRD2)

The subroutine call is:

CALL SIMGRD2 (FRSNS, FRL, DRL, FIL, DIL, NCHAN, MORDER, ICOUNT, IFLAGJS, IFLAGDP, IDISPER).

The arguments are as follows:

FRSNS is a real argument, which must be set to the actual frequency at which the subroutine SIMGRD2 is called.

FRL is a real argument, which on exit from SIMGRD2, is set by the package to the value of the common port return loss in dB at the frequency FRSNS.

DRL is a real array of dimension at least NV (the total number of variables w.r.t. which sensitivities are required). On exit from SIMGRD2, it is set by the package to the sensitivities of the common port return loss w.r.t. all variables.

FIL is a real array of length at least NCH. On exit from SIMGRD2, it is set by the package to the values of the insertion loss in dB for each channel at the frequency FRSNS.

DIL is a real array of dimensions at least NCH by NV (channel, variable). On exit from SIMGRD2, it is set by the package to the sensitivities of the insertion loss function for each channel w.r.t. all variables.

Arguments NCHAN, MORDER, ICOUNT, IFLAGJS, IFLAGDP, IDISPER have the same meaning as in the simulation entry described in the SIMULATION section.

MULTIPLEXER SENSITIVITY ANALYSIS : EXAMPLE

Introduction

To illustrate the use of the package in the sensitivity analysis mode of operation we present how to obtain the sensitivities of the three-channel multiplexer responses w.r.t. some multiplexer parameters. The following algorithm defines all the steps required to run the program in the sensitivity analysis mode of operation.

Algorithm for Three-Channel, 12 GHz Multiplexer Sensitivity Analysis

Step 1 Select the sensitivity analysis mode of operation.

LMODE = 2

Step 2 Execute Steps 2-16 of the algorithm presented in the SIMULATION EXAMPLE section.

Step 3 Define the number of coupling variables per channel. In this example we select 12 couplings (the same for all filters) per channel as variables including cavity resonant frequencies.

IR(I) = 12, I = 1, 2, 3.

Step 4 Define codes to identify variables for waveguide spacings. In this example we want to declare all waveguide spacings as variables

IWG(I) = 1, I = 1, 2, 3.

Step 5 Define codes to identify variables for input and output transformer ratios. In this example all input and output transformer ratios are declared as variables.

IPN1(I) = 1,

IPN2(I) = 1.

where I = 1, 2, 3.

Step 6 Evaluate the total number of variables accumulated after each section. To execute this step subroutine TOTAL2 is called. On exit from TOTAL2 one of the arguments, namely, IRT(I) contains the total number of variables accumulated after each section. For details see section TOTAL2.

Step 7 Define codes to identify variables contained in the coupling matrices. For the three-channel multiplexer considered the same variables are selected for all channels, namely,

M_{11}:	row index	LC (I, 1) = 1,	column index	KC (I, 1) = 1
M_{12}:	row index	LC (I, 2) = 1,	column index	KC (I, 2) = 2
M_{22}:	row index	LC (I, 3) = 2,	column index	KC (I, 3) = 2
M_{23}:	row index	LC (I, 4) = 2	column index	KC (I, 4) = 3
M_{33}:	row index	LC (I, 5) = 3,	column index	KC (I, 5) = 3
M_{34}:	row index	LC (I, 6) = 3,	column index	KC (I, 6) = 4
M_{36}:	row index	LC (I, 7) = 3,	column index	KC (I, 7) = 6
M_{44}:	row index	LC (I, 8) = 4,	column index	KC (I, 8) = 4
M_{45}:	row index	LC (I, 9) = 4,	column index	KC (I, 9) = 5
M_{55}:	row index	LC (I, 10) = 5,	column index	KC (I, 10) = 5
M_{56}:	row index	LC (I, 11) = 5,	column index	KC (I, 11) = 6
M_{66}:	row index	LC (I, 12) = 6,	column index	KC (I, 12) = 6.

Step 8 Define the number of frequency points for sensitivity analysis.

NFREQ = 3.

Step 9 Define the frequency points at which the sensitivity analysis is to be performed.

OMEGA(1) = 12062.0

OMEGA(2) = 12022.0

OMEGA(3) = 11982.0

The listing of the main program implementing the steps given above and the results of the sensitivity analysis are shown on the following pages, in Figs. 1 and 2.

```
      PROGRAM MXSOS2(OUTPUT,TAPE6=OUTPUT)
C
C     THIS PROGRAM IS A USER DEFINED MAIN SEGMENT OF THE MXSOS2 PACKAGE
C     FOR MULTIPLEXER SIMULATION, SENSITIVITY ANALYSIS AND OPTIMIZATION.
C     THE PROGRAM SETS UP ARRAYS, INITIALIZES THE DATA AND EXECUTES SOME
C     SIMPLE STEPS TO ORGANIZE THE PROBLEM AS REQUIRED BY THE PACKAGE.
C     IT CONSISTS OF THREE PARTS. THE FIRST PART INITIALIZES THE DATA
C     REQUIRED FOR SIMULATION, THE SECOND PART INITIALIZES ADDITIONAL
C     DATA REQUIRED FOR SENSITIVITY ANALYSIS AND THE THIRD PART INITIA-
C     LIZES THE DATA REQUIRED FOR THE MULTIPLEXER OPTIMIZATION PROBLEM
C     OF INTEREST INCLUDING SPECIFICATIONS AND WEIGHTING FACTORS AS WELL
C     AS THE DATA REQUIRED BY THE MINIMAX OPTIMIZATION PACKAGE MMLC. AT
C     THIS TIME ONLY COMMON PORT RETURN LOSS AND CHANNEL INSERTION LOSS
C     IN DB ARE HANDLED FOR OPTIMIZATION. IN THE CASE OF SIMULATION
C     GROUP DELAY IS ESTIMATED BY DIFFERENCING THE PHASE AT A PAIR
C     OF FREQUENCIES.
C
C     THE USER MUST PROVIDE APPROPRIATE DIMENSIONS FOR THE FOLLOWING
C     VARIABLES AFTER STUDYING THE COMMENTS PLACED THROUGHOUT THE MAIN
C     SEGMENT MXSOS2. CORRESPONDING DIMENSIONS MUST BE DECLARED IN ALL
C     SUBROUTINES EXCEPT FOR THE MMLC PACKAGE.
C
      REAL X(45),W(20000),B(1),C(1,1),T(3),DISP(16),QO(16)
      REAL OMEGA(47),SURL(47),SLRL(47),WURL(47),WLRL(47),
     1     SU(20,16),SL(20,16),WU(20,16),WL(20,16)
      INTEGER RLSCODE(47),SPCODE(20,16),CHBCODE(16,2)
      REAL WO(16),BW(16),CM(16,8,8),PN1(16),PN2(16),SPN1(16),SPN2(16),
     1          GL(16),WGL(16),DIA(16)
      INTEGER CEL(16,8,8)
      REAL FCNST(16),LAMRES(16),LAMDEL(16)
      REAL DRL(100),FIL(16),DIL(16,100)
      REAL ANGLE1(16),ANGLE2(16),GRDEL(16)
      INTEGER IR(16),IRT(16),IPN1(16),IPN2(16),IWG(16)
      INTEGER LC(16,36),KC(16,36)
      EXTERNAL FDF2
      COMMON /BLK1/WO,BW,PN1,PN2,GL,VS,RS,PI2,WIDTH,NP1
      COMMON /BLK2/CM,WGL
      COMMON /BLK3/OMEGA,SURL,SLRL,WURL,WLRL,SU,SL,WU,WL,
     1            RLSCODE,SPCODE,NCOUNT,MODE,NCH,MO,NFREQ,NFRL,
     2        CHBCODE,IFLAGJS,IFLAGDP,IDISPER
      COMMON /BLK4/CBR,FCUT
      COMMON /BLK5/DISP
      COMMON/BLK6/FCNST,LAMRES,LAMDEL
      COMMON/BLK7/CEL
      COMMON/BLK8/IR,IRT,IPN1,IPN2,IWG,LC,KC
      DATA T/10HMULTIPLEXE,10HR PROBLEM ,10HMXTST6C   /
C
C     THE MXSOS2 PACKAGE CAN OPERATE IN THREE MODES: SIMULATION, SENSITI
C     VITY ANALYSIS AND OPTIMIZATION. TO SELECT THE REQUIRED FUNCTION OF
C     THE PACKAGE SET LMODE TO
C     1 - IF MULTIPLEXER SIMULATION IS REQUIRED,
C     2 - IF MULTIPLEXER SENSITIVITY ANALYSIS IS REQUIRED,
C     3 - IF MULTIPLEXER OPTIMIZATION IS REQUIRED.
C
C     SELECT MODE OF OPERATION OF THE PACKAGE
C
      LMODE=2
C
C     THIS PART OF THE MAIN SEGMENT IS USED TO DEFINE THE DATA FOR
C     MULTIPLEXER SIMULATION. IT MUST ALWAYS BE DEFINED, REGARDLESS OF
C     THE MODE OF OPERATION OF THE PACKAGE SELECTED.
C
C     NCH     - NUMBER OF FILTER CHANNELS INCLUDING DUMMY CHANNELS
C     MO      - ORDER OF FILTERS(THE SAME FOR ALL FILTERS, ODD OR EVEN)
C     WO      - VECTOR OF CENTER FREQUENCIES IN MHZ, ONE PER CHANNEL
```

Fig. 1 Listing of MXSOS2 arranged for sensitivity analysis.

```
C      QO      - VECTOR OF UNLOADED Q FOR THE FILTERS, ONE PER CHANNEL
C      DIA     - VECTOR OF FILTER DIAMETERS IN INCHES, ONE PER CHANNEL
C      BW      - VECTOR OF CHANNEL BANDWIDTHS IN MHZ, ONE PER CHANNEL
C      SPN1    - VECTOR OF INPUT TRANSFORMER RATIOS(SQUARED), ONE PER
C                CHANNEL
C      SPN2    - VECTOR OF OUTPUT TRANSFORMER RATIOS(SQUARED), ONE PER
C                CHANNEL
C      GL      - VECTOR OF CHANNEL TERMINATING CONDUCTANCES, ONE PER
C                CHANNEL
C      CM      - SYMMETRICAL MATRIX OF COUPLING PARAMETERS(CHANNEL,ROW,
C                COLUMN), INCLUDING NONZERO DIAGONAL ELEMENTS TO MODEL
C                ASYNCHRONOUS DESIGNS
C      CEL     - SYMMETRICAL MATRIX FOR TYPE OF COUPLING, +1 FOR SCREW,
C                -1 FOR IRIS, CORRESPONDING TO CM AS ABOVE
C      WGL     - VECTOR OF WAVEGUIDE SPACINGS FOR EACH CHANNEL, MEASURED
C                IN INCHES ALONG THE MANIFOLD FROM THE ADJACENT CHANNEL
C                (DISTANCE FROM THE SHORT CIRCUIT FOR THE FIRST CHANNEL)
C      VS      - SOURCE VOLTAGE AT THE COMMON PORT
C      RS      - SOURCE RESISTANCE AT THE COMMON PORT
C      PI2     - CONSTANT EQUAL TO TWICE PI
C      WIDTH   - MANIFOLD WIDTH IN INCHES
C
C      DEFINE THE NUMBER OF CHANNELS AND THE ORDER OF THE FILTERS
C
       NCH=3
       MO=6
       NP1=NCH+1
C
C      DEFINE CENTER FREQUENCIES IN MHZ
C
       WO(1)=12060.0
       WO(2)=12020.0
       WO(3)=11980.0
C
C      DEFINE UNLOADED Q FACTORS OF THE FILTERS
C
       DO 5 I=1,NCH
       QO(I)=12000.0
     5 CONTINUE
C
C      DEFINE THE DIAMETER OF THE FILTERS IN INCHES
C
       DO 70 I=1,NCH
       DIA(I)=1.07
    70 CONTINUE
C
C      DEFINE BANDWIDTHS, INPUT/OUTPUT TRANSFORMER RATIOS AND OUTPUT
C      CONDUCTANCES
C
       DO 1 I=1,NCH
       BW(I)=39.5
       GL(I)=1.0
       SPN1(I)=0.69967
       SPN2(I)=1.09450
       PN1(I)=SQRT(SPN1(I))
       PN2(I)=SQRT(SPN2(I))
     1 CONTINUE
C
C      DEFINE THE SYMMETRICAL COUPLING MATRIX. ONLY THE UPPER PART OF THE
C      CM MATRIX HAS TO BE DEFINED.
C
       DO 30 I=1,NCH
       DO 30 J=1,MO
       DO 30 KK=1,MO
       CM(I,J,KK)=0.0
```

Fig. 1 (continued)   Listing of MXSOS2 arranged for sensitivity analysis.

```
   30 CONTINUE
      DO 2  I=1,NCH
      CM(I,1,2)=0.59395
      CM(I,2,3)=0.53514
      CM(I,3,4)=0.42471
      CM(I,3,6)=-0.39967
      CM(I,4,5)=0.83371
      CM(I,5,6)=0.76313
    2 CONTINUE
C
C     DEFINE THE TYPE OF COUPLING IN THE FILTER
C               +1 >> SCREW COUPLING     -1 >> IRIS COUPLING
C
      DO 71  I=1,NCH
      DO 71  J=1,MO
      DO 71  KK=1,MO
      CEL(I,J,KK)=0
   71 CONTINUE
C
      DO 72  I=1,NCH
      CEL(I,1,2)=1
      CEL(I,2,3)=-1
      CEL(I,3,4)=1
      CEL(I,3,6)=-1
      CEL(I,4,5)=-1
      CEL(I,5,6)=1
C
      DO 72  J=1,MO
      DO 72  KK=1,J
      CEL(I,J,KK)=CEL(I,KK,J)
   72 CONTINUE
C
C     DEFINE THE SECTION LENGTHS (SPACINGS ALONG THE WAVEGUIDE MANIFOLD)
C
      WGL(1)=0.641
      WGL(2)=0.631
      WGL(3)=0.633
C
C     DEFINE SOME CONSTANTS, SOURCE VOLTAGE, SOURCE RESISTANCE, TWICE PI
C     MANIFOLD WIDTH
C
      VS=1.0
      RS=1.0
      PI2=8.0*ATAN(1.0)
      WIDTH=0.75
C
C     THE MXSOS2 PACKAGE CAN EXPLOIT THREE PRACTICAL MODELS OF THE
C     MULTIPLEXER AS DETERMINED BY THE PARAMETERS IFLAGJS, IFLAGDP
C     AND IDISPER.
C
C     IFLAGJS
C     0 - IF JUNCTIONS ARE IDEAL
C     1 - IF JUNCTIONS ARE NONIDEAL
C
C     IFLAGDP
C     0 - IF FILTERS ARE LOSSLESS
C     1 - IF FILTERS ARE LOSSY
C
C     IDISPER
C     0 - IF FILTERS ARE DISPERSIVE
C     1 - IF FILTERS ARE NONDISPERSIVE
C
C     FLAG FOR JUNCTION SUSCEPTANCE (SET TO 0 OR 1)
C
      IFLAGJS=1
```

Fig. 1 (continued) Listing of MXSOS2 arranged for sensitivity analysis.

```
      IF(IFLAGJS.NE.1)GO TO 42
C
      CALL CONST1(WIDTH)
C
   42 CONTINUE
C
C     FLAG FOR FILTER DISSIPATION (SET TO 0 OR 1)
C
      IFLAGDP=1
      IF(IFLAGDP.NE.1)GO TO 43
C
      CALL DISPAT(NCH,WO,BW,QO)
C
   43 CONTINUE
C
C     FLAG FOR DISPERSIVE EFFECTS IN THE COUPLED CAVITY FILTERS
C     (SET TO 0 OR 1)
C
      IDISPER=1
      IF(IDISPER.NE.1)GO TO 44
C
      CALL DISPER(NCH,WO,BW,DIA)
C
   44 CONTINUE
C
C     CHECK WHETHER THE SIMULATION MODE IS REQUIRED
C
      IF(LMODE.NE.1)GO TO 16
C
C
C     SENSITIVITY ANALYSIS, CORRESPONDING TO LMODE=2
C
C     THIS PART OF THE MAIN PROGRAM IS USED TO DEFINE CODES FOR MULTI-
C     PLEXER PARAMETERS W.R.T. WHICH WE WANT TO FIND THE SENSITIVITIES.
C     THE PARAMETER IR(I)=0 SIGNIFIES THAT NO ELEMENTS OF THE FILTER
C     COUPLING MATRICES ARE OPTIMIZATION VARIABLES. SUBROUTINE
C     "SIMGRD2" IS CALLED AT EACH FREQUENCY DEFINED IN THE VECTOR
C     OMEGA(I).
C
C     IR      - VECTOR CONTAINING THE NUMBER OF COUPLING PARAMETERS BE-
C               ING VARIABLES FOR EACH CHANNEL
C     LC      - MATRIX CONTAINING THE ROW INDICES OF COUPLING PARAMETERS
C               BEING VARIABLES FOR EACH CHANNEL
C     KC      - MATRIX CONTAINING THE COLUMN INDICES OF COUPLING PARAME-
C               TERS BEING VARIABLES FOR EACH CHANNEL
C     IPN1    - INTEGER ARRAY OF DIMENSION AT LEAST NCH INDICATING
C               WHETHER THE INPUT TRANSFORMER RATIO IS AN OPTIMIZATION
C               VARIABLE (IPN1(I)=1) OR NOT (IPN1(I)=0).
C     IPN2    - INTEGER ARRAY OF DIMENSION AT LEAST NCH INDICATING
C               WHETHER THE OUTPUT TRANSFORMER RATIO IS AN OPTIMIZA-
C               TION VARIABLE (IPN2(I)=1) OR NOT (IPN2(I)=0).
C     IWG     - INTEGER ARRAY OF DIMENSION AT LEAST NCH INDICATING
C               WHETHER THE WAVEGUIDE SECTION LENGTH IS AN OPTIMIZA-
C               TION VARIABLE (IWG(I)=1) OR NOT (IWG(I)=0).
C     OMEGA   - VECTOR OF ARBITRARY FREQUENCIES (EXCEPT CENTER FREQUEN-
C               CIES) AT WHICH THE SENSITIVITY ANALYSIS IS TO BE PERFOR-
C               MED.
C     FRSNS   - ACTUAL FREQUENCY AT WHICH THE SUBROUTINE "SIMGRD" IS
C               CALLED
C     NV      - TOTAL NUMBER OF VARIABLES W.R.T. WHICH THE SENSITIVITIES
C               ARE REQUIRED
C     FRL     - VALUE OF THE COMMON PORT RETURN LOSS IN DB AT THE FREQU-
C               ENCY FRSNS
C     DRL     - SENSITIVITIES OF THE COMMON PORT RETURN LOSS W.R.T. ALL
C               VARIABLES
```

Fig. 1 (continued)   Listing of MXSOS2 arranged for sensitivity analysis.

```
C      FIL      - VECTOR OF THE INSERTION LOSS FUNCTION IN DB FOR EACH
C                 CHANNEL AT THE FREQUENCY FRSNS
C      DIL      - MATRIX OF SENSITIVITIES OF THE INSERTION LOSS FUNCTION
C                 FOR EACH CHANNEL W.R.T. ALL VARIABLES
C
C      DEFINE THE NUMBER OF COUPLING VARIABLES PER CHANNEL
C
   16  CONTINUE
       IR(1)=12
       IR(2)=12
       IR(3)=12
C
C      DEFINE CODES TO IDENTIFY VARIABLES FOR INPUT-OUTPUT TRANSFORMER
C      RATIOS AND WAVEGUIDE SPACINGS
C
       DO 55 I=1,NCH
       IWG(I)=1
       IPN1(I)=1
       IPN2(I)=1
   55  CONTINUE
C
C      EVALUATE THE TOTAL NUMBER OF VARIABLES ACCUMULATED AFTER
C      EACH SECTION
C
       CALL TOTAL2(NCH,IR,IRT,IPN1,IPN2,IWG)
C
C      DEFINE CODES FOR THE VARIABLES CONTAINED IN THE COUPLING MATRICES
C
       DO 127 I=1,3
       LC(I,1)=1
       LC(I,2)=1
       LC(I,3)=2
       LC(I,4)=2
       LC(I,5)=3
       LC(I,6)=3
       LC(I,7)=3
       LC(I,8)=4
       LC(I,9)=4
       LC(I,10)=5
       LC(I,11)=5
       LC(I,12)=6
       KC(I,1)=1
       KC(I,2)=2
       KC(I,3)=2
       KC(I,4)=3
       KC(I,5)=3
       KC(I,6)=4
       KC(I,7)=6
       KC(I,8)=4
       KC(I,9)=5
       KC(I,10)=5
       KC(I,11)=6
       KC(I,12)=6
  127  CONTINUE
C
C      CHECK WHETHER THE SIMULATION AND SENSITIVITY ANALYSIS MODE
C      IS REQUIRED
C
       IF(LMODE.NE.2) CO TO 17
C
C      GENERATE FREQUENCY POINTS IN MHZ
C
       NFREQ=3
       OMEGA(1)=12062.0
       OMEGA(2)=12022.0
```

Fig. 1 (continued)   Listing of MXSOS2 arranged for sensitivity analysis.

```
      OMEGA(3)=11982.0
      NCHAN=NCH
      MORDER=MO
      DO 18 ICOUNT=1,NFREQ
      FRSNS=OMEGA(ICOUNT)
C
      CALL SIMGRD2(FRSNS,FRL,DRL,FIL,DIL,NCHAN,MORDER,ICOUNT,IFLAGJS,
     1             IFLAGDP,IDISPER)
C
      WRITE(6,800) FRSNS
  800  FORMAT(//7X,"FREQUENCY = ",F10.3/)
      WRITE(6,810)
  810  FORMAT(7X,"RETURN LOSS",3(5X," INSERTION "),/
     1    23X," LOSS CHN1 ",5X," LOSS CHN2 ",5X," LOSS CHN3 ",//)
      DO 830 I=1,45
      WRITE(6,820) I,DRL(I),(DIL(J,I),J=1,3)
  820  FORMAT(1X,I3,2X,4(E13.7,3X)/)
  830  CONTINUE
   18 CONTINUE
   17 CONTINUE
      STOP
      END
```

Fig. 1 (continued)   Listing of MXSOS2 arranged for sensitivity analysis.

FREQUENCY = 12062.000

	RETURN LOSS	INSERTION LOSS CHN1	INSERTION LOSS CHN2	INSERTION LOSS CHN3
1	-.3519404E+02	.8961685E+00	.2753685E+01	.4634337E+01
2	-.2595370E+02	.2085088E+00	-.1326312E+02	-.1174383E+02
3	.4771767E+02	-.1147921E+01	-.1463513E+01	-.4033040E+01
4	.9675811E+01	-.5768095E+00	.1455436E+02	.1390475E+02
5	-.4269060E+02	.1047668E+01	.4166345E+00	.2723190E+01
6	.1767393E+01	-.1739167E+00	-.8878407E+01	-.8897179E+01
7	-.7377125E+01	.5807486E+00	.9392055E+01	.9709946E+01
8	.1765466E+02	-.4018802E+00	.2534749E+00	-.7040857E+00
9	-.5142400E+01	-.1782476E-01	.4286271E+01	.4527437E+01
10	-.9866458E+01	.2483579E+00	-.4228866E+00	.1146891E+00
11	.8091632E+01	-.1780651E+00	-.4462083E+01	-.4861322E+01
12	.1921909E+02	-.4536889E+00	.8852856E+00	-.1624025E+00
13	.2808763E+02	-.7836352E+00	.9082565E+01	.7483993E+01
14	-.1221682E+02	.2423505E+00	.6517218E+01	.7121895E+01
15	.1119741E+03	-.2845380E+01	-.9732153E+01	-.1570727E+02
16	.4735677E+01	-.1446217E+00	.4323698E+01	-.3996365E+00
17	-.2820654E+01	.9310488E-01	-.1719847E+02	.2449359E+00
18	.4228542E+00	-.1500772E-01	.4782688E+01	-.3776016E-01
19	-.2290972E+00	.9181533E-02	-.1883435E+02	.2149942E-01
20	.3079065E-01	-.1376970E-02	.4741956E+01	-.3031256E-02
21	-.1332824E-01	.4856780E-03	.2357284E+01	.1202718E-02
22	.6875508E-02	-.1176946E-02	.2763118E+02	-.1538818E-02
23	.1448850E-02	-.4103929E-04	-.7275892E+00	-.1190872E-03
24	-.5954572E-03	-.5278727E-04	.2500924E+01	-.2010762E-04
25	.2953330E-04	.1178987E-04	-.4250901E+00	.1008963E-04
26	.4912742E-03	-.8191612E-05	-.3925802E+00	-.3470555E-04
27	.1613312E-03	-.1219991E-03	.3519750E+01	-.1296731E-03
28	-.2206056E+02	.6211138E+00	-.9762958E+01	.1809523E+01
29	.1577621E-02	.4982725E-04	-.3538580E+01	-.3597565E-04
30	-.5705633E+01	.1440959E+00	.6426574E+00	.9458484E+00
31	.1012517E+01	-.2830083E-01	-.2830083E-01	.2121870E+01
32	-.2930252E+00	.8499031E-02	.8499031E-02	-.1523696E+02
33	.2149101E-01	-.6459243E-03	-.6459243E-03	.2187578E+01
34	-.5771667E-02	.1817344E-03	.1817344E-03	-.1681766E+02
35	.3822295E-03	-.1258114E-04	-.1258114E-04	.2185606E+01
36	-.7829787E-04	.2537537E-05	.2537537E-05	.4236703E+00
37	.7209554E-04	-.5549194E-05	-.5549194E-05	.2305336E+02
38	.4064799E-05	-.1296748E-06	-.1296748E-06	-.6727889E-01
39	-.3009996E-06	-.5096539E-07	-.5096539E-07	.4500352E+00
40	-.3010533E-08	.2735101E-08	.2735101E-08	-.1960763E-01
41	.3624496E-06	.2607968E-07	.2607968E-07	-.2809897E+00
42	.3104291E-05	-.3856550E-06	-.3856550E-06	.2038193E+01
43	-.9767977E+01	.2627051E+00	.2627051E+00	-.1012137E+02
44	.2733249E-05	.8820953E-06	.8820953E-06	-.7090034E+01
45	-.8690840E+01	.2346737E+00	.2346737E+00	-.9945607E+01

Fig. 2 Results of the three-channel sensitivity analysis problem.

FREQUENCY = 12022.000

	RETURN LOSS	INSERTION LOSS CHN1	INSERTION LOSS CHN2	INSERTION LOSS CHN3
1	-.8938535E+01	-.4638673E+01	.3647777E-01	-.2600154E+00
2	-.5706447E+01	-.1774849E+02	.3459453E-01	-.1662947E+00
3	-.9016115E+00	-.5433870E+01	.7476605E-02	-.2632742E-01
4	-.4780550E+00	-.1948497E+02	.6313271E-02	-.1402139E-01
5	-.6259816E-01	-.5386128E+01	.1227717E-02	-.1846593E-02
6	-.3994179E-01	.3271034E+01	.3365164E-03	-.1166456E-02
7	-.3988235E-01	.2939090E+02	-.1932505E-02	-.1104853E-02
8	-.5976587E-02	.1123113E+01	.8391596E-05	-.1734323E-03
9	-.8372691E-02	.3529402E+01	-.1646502E-03	-.2383084E-03
10	-.1462041E-02	.7468514E+00	-.3868933E-04	-.4135120E-04
11	.1755534E-02	-.1171976E+00	-.1665343E-04	.5131761E-04
12	.6866322E-02	-.3702453E+01	.2224542E-03	.1931260E-03
13	-.3891205E+02	-.8842719E+01	.9181233E-01	-.1130155E+01
14	.8597621E-02	-.2471830E+01	.9186842E-04	.2467480E-03
15	-.2054311E+03	.7450036E+01	.1652422E+00	-.5958076E+01
16	.6167365E+02	-.3354280E+00	-.6086830E-01	.1796251E+01
17	-.4763673E+03	-.1342368E+02	.1895081E-01	-.1345161E+02
18	-.6152977E+01	.2411308E+01	.7306638E-01	-.2419590E+00
19	.5055721E+03	.1328559E+02	-.8279873E+00	.1430165E+02
20	-.2495477E+02	-.2926610E+01	-.1472336E-01	-.6459931E+00
21	-.3014046E+03	-.7515053E+01	.1688113E+00	-.8536850E+01
22	.3138117E+03	.7526460E+01	.8204542E-01	.8896126E+01
23	.2485572E+02	.1577416E+01	.2303519E-01	.6787286E+00
24	.1415924E+03	.3298357E+01	-.2879527E+00	.4016524E+01
25	-.2349311E+02	-.1124075E+01	.2028166E-01	-.6512019E+00
26	-.1448973E+03	-.3223067E+01	.1708311E+00	-.4114290E+01
27	.4786680E+02	.2242742E+01	-.1158789E-01	.1328067E+01
28	.3356340E+03	.9984863E+01	-.3992084E+00	.9463690E+01
29	.2112683E+03	.4676843E+01	-.2769331E+00	.5999460E+01
30	-.2353287E+03	-.8600616E+01	.2904115E+00	-.6827856E+01
31	-.5878510E+00	-.2402860E-01	-.2402860E-01	.4444338E+01
32	.6102327E+00	.2167673E-01	.2167673E-01	-.1726990E+02
33	-.1306936E+00	-.4359952E-02	-.4359952E-02	.4793404E+01
34	.1100973E+00	.3474686E-02	.3474686E-02	-.1884019E+02
35	-.2014408E-01	-.6184035E-03	-.6184035E-03	.4742796E+01
36	.4581208E-02	.1505014E-03	.1505014E-03	.2356995E+01
37	-.3706725E-01	-.1060310E-02	-.1060310E-02	.2763148E+02
38	-.5717165E-04	-.3877884E-05	-.3877884E-05	-.7275628E+00
39	-.2585893E-02	-.7229326E-04	-.7229326E-04	.2500894E+01
40	.4718398E-03	.1331450E-04	.1331450E-04	-.4250381E+00
41	.1951475E-03	.4759705E-05	.4759705E-05	-.3927882E+00
42	-.4405361E-02	-.1249929E-03	-.1249929E-03	.3519953E+01
43	.7751258E+00	.5634120E-01	.5634120E-01	-.1032773E+02
44	.3477530E-02	.9600908E-04	.9600908E-04	-.3538636E+01
45	.3822605E+03	-.3852653E+00	-.3852653E+00	.1077355E+02

Fig. 2 (continued) Results of the three-channel sensitivity analysis problem.

FREQUENCY = 11982.000

	RETURN LOSS	INSERTION LOSS CHN1	INSERTION LOSS CHN2	INSERTION LOSS CHN3
1	-.1021814E+01	-.2060321E+01	.9765237E-01	.2785507E-01
2	-.3150864E+00	-.1525917E+02	.3046251E-01	.8932318E-02
3	-.2397585E-01	-.2274935E+01	.2344674E-02	.7058057E-03
4	-.6505257E-02	-.1684870E+02	.6461660E-03	.2012852E-03
5	-.4469836E-03	-.2274755E+01	.4508676E-04	.1450375E-04
6	-.9777687E-04	.4739968E+00	.9803486E-05	.3114773E-05
7	.7892172E-04	.2317703E+02	-.1193061E-04	-.6445611E-05
8	-.5278142E-05	.7800556E-01	.5260152E-06	.1650168E-06
9	-.5296567E-06	.5021415E+00	-.3103552E-07	-.6546439E-07
10	-.1233507E-08	.2337036E-01	-.3780091E-08	-.3780782E-08
11	.5673644E-06	-.3068098E+00	-.5604874E-08	.3210796E-07
12	-.3205749E-05	-.2111599E+01	.6886469E-06	.4614755E-06
13	-.9488021E+01	-.8749858E+01	.8961758E+00	.2483019E+00
14	.5262981E-05	-.6992219E+01	.6618839E-06	.9964111E-06
15	-.1068917E+03	.1828916E+02	.9977267E+01	.2680897E+01
16	-.5291011E+01	.5236022E+00	-.4502216E+01	.1618029E+00
17	-.3571121E+01	.3636518E+00	-.1765637E+02	.1192388E+00
18	-.5985942E+00	.6267992E-01	-.5418371E+01	.2167425E-01
19	-.3575269E+00	.3933874E-01	-.1947562E+02	.1480621E-01
20	-.5366981E-01	.6193465E-02	-.5384701E+01	.2504609E-02
21	-.2660820E-01	.2789774E-02	.3271788E+01	.9669481E-03
22	.1220231E-01	-.3112435E-02	.2939069E+02	-.2237204E-02
23	-.3264219E-02	.3083055E-03	.1123178E+01	.8541389E-04
24	-.1557823E-02	-.2673494E-04	.3529341E+01	-.1293807E-03
25	-.1021483E-03	-.3050680E-04	.7467257E+00	-.3662097E-04
26	.1201373E-02	-.1274419E-03	-.1176303E+00	-.4510863E-04
27	-.2164931E-03	.2491932E-03	-.3702693E+01	.2295064E-03
28	-.2188860E+02	.2105394E+01	-.8278678E+01	.6099536E+00
29	.2919480E-02	-.1733443E-03	-.2472128E+01	.2381207E-04
30	-.1087422E+03	.1153238E+02	.1015720E+02	.2734358E+01
31	.3881417E+02	-.1266533E+01	-.1266533E+01	-.9924119E+00
32	-.1984458E+02	-.1338578E+02	-.1338578E+02	.6057205E-01
33	-.4544877E+02	.3567410E+01	.3567410E+01	.1228414E+01
34	.3787113E+02	.1281777E+02	.1281777E+02	-.1299115E+01
35	.3784055E+02	-.3919085E+01	-.3919085E+01	-.1006219E+01
36	-.2966867E+02	-.7055742E+01	-.7055742E+01	.6320069E+00
37	.3610376E+02	.6915447E+01	.6915447E+01	-.5343410E+00
38	-.1430177E+02	.1968049E+01	.1968049E+01	.4127896E+00
39	.1799776E+02	.2979163E+01	.2979163E+01	-.6086355E+00
40	.7102750E+01	-.1329338E+01	-.1329338E+01	-.1842857E+00
41	-.2108300E+02	-.2828455E+01	-.2828455E+01	.5675335E+00
42	-.1363996E+02	.2639771E+01	.2639771E+01	.3838579E+00
43	.4768819E+01	.1019229E+02	.1019229E+02	-.1917864E+00
44	.3113555E+02	.4091332E+01	.4091332E+01	-.8653616E+00
45	-.1323121E+03	-.7037096E+01	-.7037096E+01	.3459646E+01

Fig. 2 (continued) Results of the three-channel sensitivity analysis problem.

MULTIPLEXER OPTIMIZATION : FORMAL DESCRIPTION

General Description

The third part of the main segment is used to define all variables and arrays for multiplexer optimization. To select the multiplexer parameters which are the optimization variables the matrices LC and KC have to be used, as described in the sensitivity analysis part SENSITIVITY.

Three modes of optimization are allowed. To select the desired mode of optimization, the user must set the parameter MODE to

0 if only common port return loss optimization is required,

1 if only insertion loss optimization is required,

2 if both return loss and insertion loss optimization are required.

In each case, a different header for the printout of optimization results can be obtained by calling the subroutine MMXHDR (part of the MMLC package [1]) for which the argument T can be defined using the DATA statement. Values of the optimization variables at the starting point must be supplied by defining the X vector using either the DATA statement or explicitly.

Formulation of the Problem

The design of a contiguous-band multiplexer structure is formulated as a minimax optimization problem [2, 3]. The objective function to be minimized is given by

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

where $\mathbf{x}$ 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 [2, 3]

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

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

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

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

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.

A typical example of specifications the package can handle directly on return loss and insertion loss for a five-channel multiplexer is shown in Fig. 1. Table 1 gives an example of functions, specifications, weighting factors and frequency bands of interest for optimization.

Basic Variables for Multiplexer Optimization

The following variables must be defined regardless of the mode of optimization selected.

NFREQ is an integer variable, which must be set to the number of frequency points at which the minimax functions are to be created.

OMEGA is a real array of dimension at least NFREQ. It contains arbitrary frequency points (except center frequencies) in MHz at which the minimax functions are to be created.

NFRL is an integer array, which must be set to the number of minimax functions created due to return loss specifications.

Arrays and Codes for Common Port Return Loss Optimization

RLSCODE is an integer array of length at least NFREQ. Each element must be set to the following specification code value at each frequency.

- 0 no specification required,
- -1 only lower specification required,
- 1 only upper specification required,
- 2 both upper and lower specifications required.

SURL is a real array of length at least NFREQ. It must contain the upper specifications applicable at each frequency.

SLRL is a real array of length at least NFREQ. It must contain the lower specifications applicable at each frequency.

WURL is a real array of length at least NFREQ. It must contain the weighting factors corresponding to upper specifications.

WLRL is a real array of length at least NFREQ. It must contain the weighting factors corresponding to lower specifications.

Arrays and Codes for Insertion Loss Optimization

CHBCODE is an integer array of dimensions at least NCH by 2. Each row must contain the range of frequencies over which specifications for the corresponding channel are given. The first element of a row indicates the lower frequency edge of interest, the second the upper frequency edge.

SPCODE is an integer array dimensions at least NSPMAX by NCH. NSPMAX is the maximum number of frequency points considered for any of the channels. Each column must contain the specification code at each frequency for the corresponding channel. Each element of a column must be set to one of the following values:

- 0 no specification required,

−1	only lower specifications required,
1	only upper specifications required,
2	both upper and lower specifications required.

SU is a real array of dimensions at least NSPMAX by NCH. It must contain the upper specifications for each channel ordered consecutively w.r.t. frequency index implied by the CHBCODE matrix in the form (frequency index, channel).

SL is a real array of dimensions of least NSPMAX by NCH. It must contain the lower specifications for each channel ordered consecutively w.r.t. frequency index implied by the CHBCODE matrix in the form (frequency index, channel).

WU is a real array of dimensions at least NSPMAX by NCH. It must contain the weighting factors for upper specifications. It is arranged to correspond to SU.

WL is a real array of dimensions at least NSPMAX by NCH. It must contain the weighting factors for lower specifications. It is arranged to correspond to SL.

The Starting Point for Optimization

The starting point for optimization must be initialized by setting consecutively numbered X values. It is imperative that the optimization variables for each channel are defined consecutively as follows: variable filter couplings come first, followed by variable input, then output, transformer ratios, the section length being the last variable in the set of optimization variables for a particular channel.

Optimization Entry (Subroutine MMLC1A)

The subroutine call is

CALL MMLC1A (FDF2, NV, MF, L, LEQ, B, C, IIC, X, DX, EPS, MAXF, KEQS, W, IW, ICH, IPR, IFALL).

The arguments are as follows

FDF2 is a name of a subroutine calculating minimax functions and their derivatives at the point defined by the X vector. The name FDF2 is arbitrary and must appear in the EXTERNAL statement in the segment calling MMLC1A.

NV is an integer argument, which must be set to the number of optimization variables. Its value must be positive and is not changed by the package.

MF is an integer argument, which must be set to the number of residual functions defining the minimax objective function. Its value must be positive and is not changed by the package.

L is an integer argument, which must be set to the total number of equality and inequality constraints. Its value must be positive or zero and it is not changed by the package.

LEQ is an integer argument, which must be set to the number of equality constraints. Its value must be positive or zero and not greater than NV, and not greater than L. Its value is not changed by the package.

B is a real array of length IIC > L. The elements of B must be set to the constant terms in the linear constraints. The contents of B are not changed by the package.

C is a real matrix of dimensions (IIC, NV). The first L rows of C must be set to the coefficients of **x** in the linear constraints.

IIC is an integer argument, which must be set to the length of the array B and to the number of rows of the matrix C. Its value must not be less than L, and it is not changed by the package.

X is a real array of length at least NV which, on entry, must be set to the initial approximation of the solution. On exit, X contains the best solution found by the package.

DX is a real variable, which controls the step length of the iterative algorithm. On entry, it must be set to an initial value approximately equal to $0.1*\|\mathbf{x}^0\|$. The value of DX must be positive. On exit, DX contains the last value of the stepsize. For extensive details, refer to [1].

EPS is a real variable which, on entry, must be set to the required accuracy of the solution. On exit, EPS contains the length of the last step taken in the iteration.

MAXF is an integer variable which must be set to an upper bound on the number of calls to FDF2. On exit, MAXF contains the number of calls to FDF2 that have been performed by the package.

KEQS is an integer variable, which must be set to the number of successive iterations with identical sets of active residual functions and active constraints that is required before a switch to Stage 2 is made [1]. On exit, KEQS contains the number of switches to Stage 2 that have taken place.

W is a real array which is used for working space. Its length is given by IW. On exit, the first MF elements of W contain the residual function values at the solution.

IW is an integer argument, which must be set to the length of W. The value must be at least

IWR = 2*MF*NV + 5*NV*NV + 4*MF + 8*NV + 4*IIC + 3

ICH is an integer argument, which must be set to the unit number that is to be used for the printed output generated by the package. If ICH is less than or equal to zero, no printed output will be generated by the package.

IPR is an integer argument which controls the printed output generated by the package. For extensive details see [1].

IFALL is an integer variable which on exit contains information about the solution:

IFALL = −2 feasible region is empty,

IFALL = −1	incorrect input data,
IFALL = 0	regular solution, required accuracy obtained,
IFALL = 1	singular solution, required accuracy obtained,
IFALL = 2	machine accuracy reached,
IFALL = 3	maximum number of function evaluations reached,
IFALL = 4	iteration terminated by the user

References

[1] J.W. Bandler and W.M. Zuberek, "MMLC - a Fortran package for linearly constrained minimax optimization", Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, Report SOS-82-5, 1982.

[2] J.W. Bandler and M.R.M. Rizk, "Optimization of electrical circuits", Mathematical Programming Study II, 1979, pp. 1-64.

[3] J.W. Bandler, S.H. Chen, S. Daijavad and W. Kellermann, "Optimal design of multi-cavity filters and contiguous-band multiplexers", Proc. 14th European Microwave Conference, (Liège, Belgium, Sept. 1984).

TABLE 1

EXAMPLE OF FUNCTIONS, SPECIFICATIONS, WEIGHTING FACTORS AND FREQUENCY BANDS

Function	Specification		Weighting Factors		Frequency Band of Interest	
a) insertion loss b) return loss	lower	upper	lower spec.	upper spec.	lower spec.	upper spec.
a) $F^1{}_k(\mathbf{x},\omega_i)$	$S^1{}_{Lk}(\omega_i)$	$S^1{}_{Uk}(\omega_i)$	$w^1{}_{Lk}(\omega_i)$	$w^1{}_{Uk}(\omega_i)$	$[\omega_{Lk}, \omega^L{}_{Uk}]$ and $[\omega^L{}_{Lk}, \omega_{Uk}]$	$[\omega^U{}_{Lk}, \omega^U{}_{Uk}]$
b) $F^2(\mathbf{x}, \omega_i)$	$S^2{}_L(\omega_i)$	$S^2{}_U(\omega_i)$	$w^2{}_L(\omega_i)$	$w^2{}_U(\omega_i)$	$[\omega^L{}_L, \omega^L{}_U]$	$[\omega_L, \omega^U{}_U]$ and $[\omega^U{}_L, \omega_U]$

k	is the channel number
ω_i	is the ith frequency point
$[\omega_{Lk}, \omega_{Uk}]$	is the band of interest for the kth channel insertion loss calculations
$[\omega_L, \omega_U]$	is the band of interest for return loss calculations.

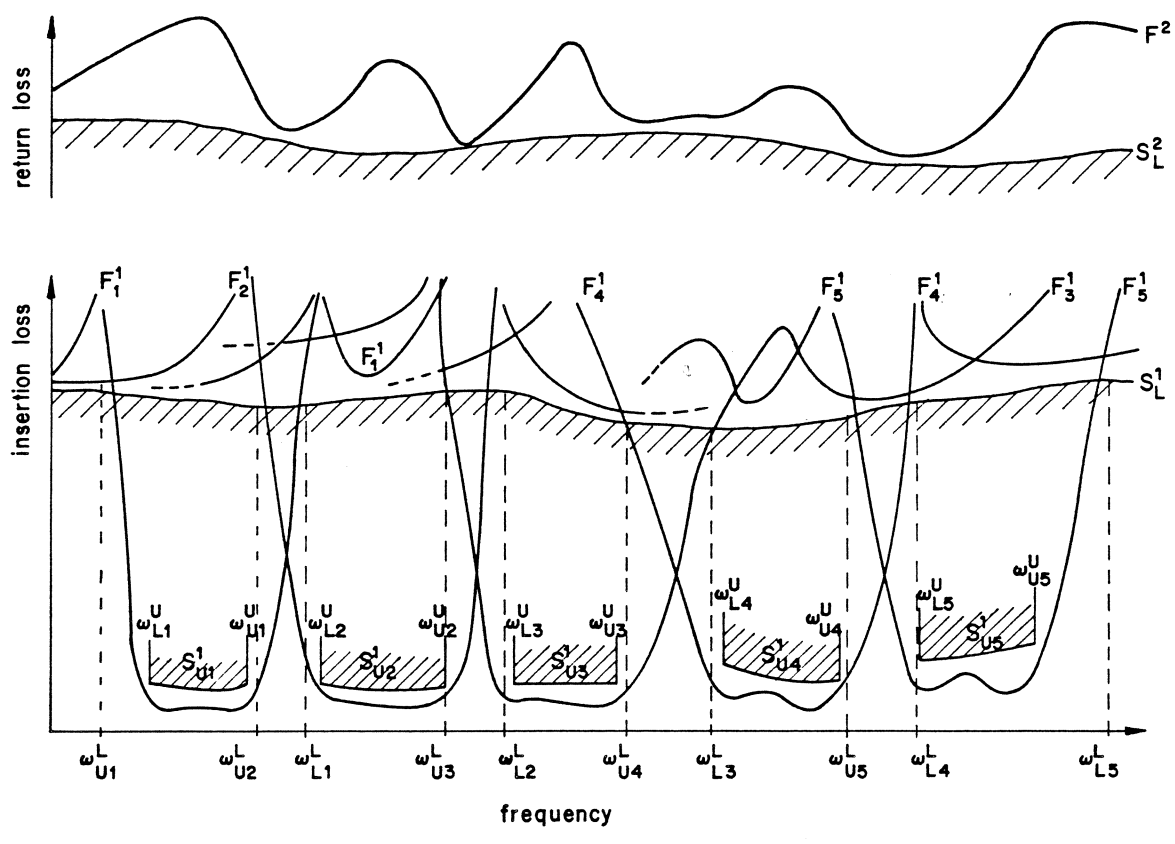

Fig. 1 Five channel example, illustrating our flexibility in choice of responses to be optimized and frequency bands of interest. See the text and Table 1 for some definitions.

MULTIPLEXER OPTIMIZATION: EXAMPLE

Introduction

Suppose we want to design a three-channel, 12 GHz multiplexer without dummy channels such that certain specifications on the common port return loss and individual channel insertion loss functions are satisfied. We start the design process with three identical filters of order six, data for which has been given in the simulation section example.

A lower specification of 20 dB on return loss over the whole band of interest should be satisfied and the following upper specifications on channel insertion loss should also be satisfied for all three channels:

$\omega_0 \pm 10$ MHz	1.12 dB,
$\omega_0 \pm 12$ MHz	1.24 dB,
$\omega_0 \pm 14$ MHz	1.41 dB,
$\omega_0 \pm 16$ MHz	1.77 dB,
$\omega_0 \pm 18$ MHz	2.79 dB.

Fig. 1 shows the shape of specifications for individual channel insertion loss functions and for the common port return loss.

Algorithm for Three Channel, 12 GHz Multiplexer Optimization

Step 1 Select the optimization mode of operation

$$\text{LMODE} = 3.$$

Step 2 Execute Steps 2 - 16 of the algorithm presented in the SIMULATION EXAMPLE section.

Step 3 Select the optimization variables and define the corresponding codes to identify them. In this example the multiplexer parameters selected in the

SENSITIVITY EXAMPLE section are declared as optimization variables. This corresponds to executing Steps 3 - 7 from the SENSITIVITY EXAMPLE section.

Step 4 Select the desired mode of optimization. Since the specifications are defined for the common port return loss and for the individual channel insertion loss functions we select mode of optimization 2.

MODE = 2.

Comment The selected mode of optimization corresponds to the situation in which the minimax functions will be created due to specifications on return loss and insertion loss functions.

Step 5 Define the starting point for optimization. As indicated earlier in the OPTIMIZATION section, the optimization variables for each channel are defined consecutively as follows: variable filter couplings come first, followed by variable input then output, transformer ratios, the section length being the last variable in the set of optimization variables for a particular channel.

For the optimization problem defined in this section the first fifteen variables (all in channel number 1) are

X(1) = CM (1,1,1)

X(2) = CM (1,1,2)

X(3) = CM (1,2,2)

X(4) = CM (1,2,3)

X95) = CM (1,3,3)

X(6) = CM (1,3,4)

X(7) = CM(1,3,6)

X(8) = CM (1,4,4)

X(9) = CM (1,4,5)

X(10) = CM (1,5,5)

X(11) = CM (1,5,6)

X(12) = CM (1,6,6)

X(13) = PN1 (1)

X(14) = PN2 (1)

X(15) = WGL (1).

Similarly, the remaining 30 variables (from X(16) to X(45)) should be defined using parameter values in channels 2 and 3.

Step 6 Select frequency points for optimization. The choice of frequency points at which the minimax functions are to be created is partly dictated by the design specifications. For the problem defined above we select 15 frequency points per channel which are defined as

ω_0 + 0.001 MHz ,

$\omega_0 \pm$ 4 MHz ,

$\omega_0 \pm$ 8 MHz ,

$\omega_0 \pm$ 10 MHz ,

$\omega_0 \pm$ 12 MHz ,

$\omega_0 \pm$ 14 MHz ,

$\omega_0 \pm$ 16 MHz ,

$\omega_0 \pm$ 18 MHz .

Those frequency points will be used to create error functions due to insertion loss specifications. At the same frequency points error functions corresponding to return loss specifications will be created. Two additional frequency points for return loss only are selected. These are the two crossover frequencies, namely, 12000.0 MHz and 12040.0 MHz. All frequency points selected in this step are contained in the OMEGA(I) vector.

Step 7 Define the total number of frequency points at which the minimax functions are to be created.

NFREQ = 47 .

Step 8 Define the number of minimax functions resulting from the specifications on the common port return loss.

$$NFRL = 47 .$$

Step 9 Define the codes and arrays for return loss optimization. To create error functions due to return loss specifications (see the subsection on the formulation of the problem) we have to define the RLSCODE vector indicating the type of specification at each frequency point. In this problem we have only a lower specification of 20 dB on return loss, so the RLSCODE(I) is defined as

$$RLSCODE(I) = [-1 \ -1 \ldots -1]^T, \ I = 1, \ldots, NFREQ.$$

The SLRL vector contains the actual numerical values of lower specification at each frequency point and is defined as

$$SLRL(I) = [20.0 \ 20.0 \ldots 20.0]^T, \ I = 1, \ldots, NFREQ.$$

The WLRL vector containing the weighting factors for lower specification at each fre ency point and is defined as

$$WLRL(I) = [1.0 \ 1.0 \ldots 1.0]^T, \ I = 1, \ldots, NFREQ.$$

Comment The SURL and WURL vectors corresponding to upper specifications need not be defined since no element of the RLSCODE vector is equal to 1 or 2 (indicating only upper or both upper and lower specification).

Step 10 Define the codes and arrays for insertion loss optimization. For each of the multiplexer channels we define a band of frequencies over which specifications for that channel are given using the frequency point indices implied by the vector OMEGA. In this example the channel band code matrix is defined as

$$CHBCODE(I,J) = \begin{bmatrix} 31 & 45 \\ 16 & 30 \\ 1 & 15 \end{bmatrix} .$$

The maximum number of frequency points for any of the three channels NSPMAX is 15. This number determines the number of rows in the insertion loss specification code matrix SPCODE. The number of columns is equal to the number of channels, NCH = 3. In this example only upper specifications for insertion loss functions are given and the SPCODE matrix is

$$SPCODE(I,J) = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 1 & 1 & 1 \end{bmatrix}, \quad \begin{array}{l} I = 1, \ldots, NSPMAX, \\ J = 1, \ldots, NCH. \end{array}$$

According to the SPCODE matrix the actual numerical values of the specifications are given by the SU matrix:

$$\begin{aligned} SU(1,K) &= 2.79, \\ SU(2,K) &= 1.77, \\ SU(3,K) &= 1.41, \\ SU(4,K) &= 1.24, \\ SU(J,K) &= 1.12, \qquad J = 5, 6, \ldots, 11, \quad K = 1, 2, 3, \\ SU(12,K) &= 1.24, \\ SU(13,K) &= 1.41, \\ SU(14,K) &= 1.77, \\ SU(15,K) &= 2.79. \end{aligned}$$

All weighting factors corresponding to those specifications are assumed to be 1.0, i.e.,

$$WU(J,K) = 1.0 \qquad J = 1, 2, \ldots, 15, \qquad K = 1, 2, 3.$$

Comment The SL and WL matrices corresponding to lower specifications need not be defined since no element of the SPCODE matrix is equal to 1 or 2 (only lower or both lower and upper specification).

Step 11 Define arguments for the MMLC1A call statement. The number of optimization variables is

$$NV = 45 .$$

The number of error functions defining the minimax objective function is

$$MF = 92.$$

The total number of equality and inequality constraints is

$$L = 0.$$

The number of equality constraints is

$$LEQ = 0.$$

The number of constant terms in the linear constraints is

$$IIC = 0.$$

The initial step length of the iterative algorithm is

$$DX = 0.05.$$

The required accuracy of the solution is

$$EPS = 10^{-6}.$$

The upper bound on the number of calls of FDF2 is

$$MAXF = 65.$$

The number of successive iterations with identical sets of active functions before a switch to Stage 2 is made

$$KEQS = 3.$$

The overestimate of the length of W (the workspace) is

$$IW = 20000.$$

The unit number for the printed output generated by the package is

$$ICH = 6.$$

The argument which controls the printed output generated by the package is

$$IPR = 10.$$

If IPR is set to 10 variables and function values will be printed out only at the starting point and at the solution.

The listing of the main program implementing the foregoing steps, the corresponding subroutine FDF2 and the results of optimization are shown in Figs. 2-4

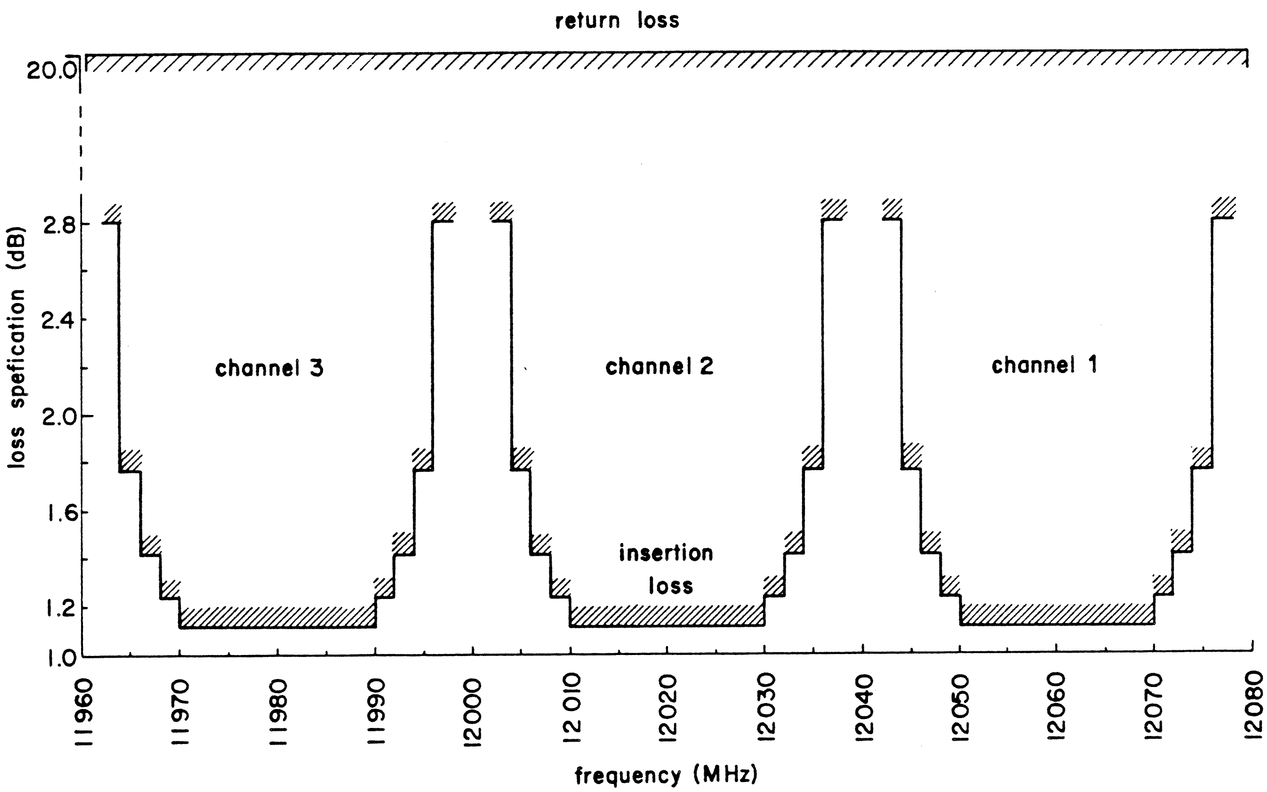

Fig. 1	Illustration of the specifications for the three channel example under consideration.

```
      PROGRAM MXSOS2(OUTPUT,TAPE6=OUTPUT)
C
C     THIS PROGRAM IS A USER DEFINED MAIN SEGMENT OF THE MXSOS2 PACKAGE
C     FOR MULTIPLEXER SIMULATION, SENSITIVITY ANALYSIS AND OPTIMIZATION.
C     THE PROGRAM SETS UP ARRAYS, INITIALIZES THE DATA AND EXECUTES SOME
C     SIMPLE STEPS TO ORGANIZE THE PROBLEM AS REQUIRED BY THE PACKAGE.
C     IT CONSISTS OF THREE PARTS. THE FIRST PART INITIALIZES THE DATA
C     REQUIRED FOR SIMULATION. THE SECOND PART INITIALIZES ADDITIONAL
C     DATA REQUIRED FOR SENSITIVITY ANALYSIS AND THE THIRD PART INITIA-
C     LIZES THE DATA REQUIRED FOR THE MULTIPLEXER OPTIMIZATION PROBLEM
C     OF INTEREST INCLUDING SPECIFICATIONS AND WEIGHTING FACTORS AS WELL
C     AS THE DATA REQUIRED BY THE MINIMAX OPTIMIZATION PACKAGE MMLC. AT
C     THIS TIME ONLY COMMON PORT RETURN LOSS AND CHANNEL INSERTION LOSS
C     IN DB ARE HANDLED FOR OPTIMIZATION. IN THE CASE OF SIMULATION
C     GROUP DELAY IS ESTIMATED BY DIFFERENCING THE PHASE AT A PAIR
C     OF FREQUENCIES.
C
C     THE USER MUST PROVIDE APPROPRIATE DIMENSIONS FOR THE FOLLOWING
C     VARIABLES AFTER STUDYING THE COMMENTS PLACED THROUGHOUT THE MAIN
C     SEGMENT MXSOS2. CORRESPONDING DIMENSIONS MUST BE DECLARED IN ALL
C     SUBROUTINES EXCEPT FOR THE MMLC PACKAGE.
C
      REAL X(45),W(20000),B(1),C(1,1),T(3),DISP(16),QO(16)
      REAL OMEGA(47),SURL(47),SLRL(47),WURL(47),WLRL(47),
     1    SU(20,16),SL(20,16),WU(20,16),WL(20,16)
      INTEGER RLSCODE(47),SPCODE(20,16),CHBCODE(16,2)
      REAL WO(16),BW(16),CM(16,8,8),PN1(16),PN2(16),SPN1(16),SPN2(16),
     1        GL(16),WGL(16),DIA(16)
      INTEGER CEL(16,8,8)
      REAL FCNST(16),LAMRES(16),LAMDEL(16)
      REAL DRL(100),FIL(16),DIL(16,100)
      REAL ANGLE1(16),ANGLE2(16),GRDEL(16)
      INTEGER IR(16),IRT(16),IPN1(16),IPN2(16),IWG(16)
      INTEGER LC(16,36),KC(16,36)
      EXTERNAL FDF2
      COMMON /BLK1/WO,BW,PN1,PN2,GL,VS,RS,P12,WIDTH,NP1
      COMMON /BLK2/CM,WGL
      COMMON /BLK3/OMEGA,SURL,SLRL,WURL,WLRL,SU,SL,WU,WL,
     1          RLSCODE,SPCODE,NCOUNT,MODE,NCH,MO,NFREQ,NFRL,
     2      CHBCODE,IFLAGJS,IFLAGDP,IDISPER
      COMMON /BLK4/CBR,FCUT
      COMMON /BLK5/DISP
      COMMON/BLK6/FCNST,LAMRES,LAMDEL
      COMMON/BLK7/CEL
      COMMON/BLK8/IR,IRT,IPN1,IPN2,IWG,LC,KC
      DATA T/10HMULTIPLEXE,10HR PROBLEM ,10HMXTST6C   /
C
C     THE MXSOS2 PACKAGE CAN OPERATE IN THREE MODES: SIMULATION, SENSITI
C     VITY ANALYSIS AND OPTIMIZATION. TO SELECT THE REQUIRED FUNCTION OF
C     THE PACKAGE SET LMODE TO
C     1 - IF MULTIPLEXER SIMULATION IS REQUIRED,
C     2 - IF MULTIPLEXER SENSITIVITY ANALYSIS IS REQUIRED,
C     3 - IF MULTIPLEXER OPTIMIZATION IS REQUIRED.
C
C     SELECT MODE OF OPERATION OF THE PACKAGE
C
      LMODE=3
C
C     THIS PART OF THE MAIN SEGMENT IS USED TO DEFINE THE DATA FOR
C     MULTIPLEXER SIMULATION. IT MUST ALWAYS BE DEFINED, REGARDLESS OF
C     THE MODE OF OPERATION OF THE PACKAGE SELECTED.
C
C     NCH     - NUMBER OF FILTER CHANNELS INCLUDING DUMMY CHANNELS
C     MO      - ORDER OF FILTERS(THE SAME FOR ALL FILTERS, ODD OR EVEN)
C     WO      - VECTOR OF CENTER FREQUENCIES IN MHZ, ONE PER CHANNEL
```

Fig. 2 Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
C     QO     - VECTOR OF UNLOADED Q FOR THE FILTERS, ONE PER CHANNEL
C     DIA    - VECTOR OF FILTER DIAMETERS IN INCHES, ONE PER CHANNEL
C     BW     - VECTOR OF CHANNEL BANDWIDTHS IN MHZ, ONE PER CHANNEL
C     SPN1   - VECTOR OF INPUT TRANSFORMER RATIOS(SQUARED), ONE PER
C              CHANNEL
C     SPN2   - VECTOR OF OUTPUT TRANSFORMER RATIOS(SQUARED), ONE PER
C              CHANNEL
C     GL     - VECTOR OF CHANNEL TERMINATING CONDUCTANCES, ONE PER
C              CHANNEL
C     CM     - SYMMETRICAL MATRIX OF COUPLING PARAMETERS(CHANNEL,ROW,
C              COLUMN), INCLUDING NONZERO DIAGONAL ELEMENTS TO MODEL
C              ASYNCHRONOUS DESIGNS
C     CEL    - SYMMETRICAL MATRIX FOR TYPE OF COUPLING, +1 FOR SCREW,
C              -1 FOR IRIS, CORRESPONDING TO CM AS ABOVE
C     WGL    - VECTOR OF WAVEGUIDE SPACINGS FOR EACH CHANNEL, MEASURED
C              IN INCHES ALONG THE MANIFOLD FROM THE ADJACENT CHANNEL
C              (DISTANCE FROM THE SHORT CIRCUIT FOR THE FIRST CHANNEL)
C     VS     - SOURCE VOLTAGE AT THE COMMON PORT
C     RS     - SOURCE RESISTANCE AT THE COMMON PORT
C     PI2    - CONSTANT EQUAL TO TWICE PI
C     WIDTH  - MANIFOLD WIDTH IN INCHES
C
C     DEFINE THE NUMBER OF CHANNELS AND THE ORDER OF THE FILTERS
C
      NCH=3
      MO=6
      NP1=NCH+1
C
C     DEFINE CENTER FREQUENCIES IN MHZ
C
      WO(1)=12060.0
      WO(2)=12020.0
      WO(3)=11980.0
C
C     DEFINE UNLOADED Q FACTORS OF THE FILTERS
C
      DO 5 I=1,NCH
      QO(I)=12000.0
    5 CONTINUE
C
C     DEFINE THE DIAMETER OF THE FILTERS IN INCHES
C
      DO 70 I=1,NCH
      DIA(I)=1.07
   70 CONTINUE
C
C     DEFINE BANDWIDTHS, INPUT/OUTPUT TRANSFORMER RATIOS AND OUTPUT
C     CONDUCTANCES
C
      DO 1 I=1,NCH
      BW(I)=39.5
      GL(I)=1.0
      SPN1(I)=0.69967
      SPN2(I)=1.09450
      PN1(I)=SQRT(SPN1(I))
      PN2(I)=SQRT(SPN2(I))
    1 CONTINUE
C
C     DEFINE THE SYMMETRICAL COUPLING MATRIX. ONLY THE UPPER PART OF THE
C     CM MATRIX HAS TO BE DEFINED.
C
      DO 30 I=1,NCH
      DO 30 J=1,MO
      DO 30 KK=1,MO
      CM(I,J,KK)=0.0
```

Fig. 2 (continued)   Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
   30 CONTINUE
      DO 2 I=1,NCH
      CM(I,1,2)=0.59395
      CM(I,2,3)=0.53514
      CM(I,3,4)=0.42471
      CM(I,3,6)=-0.39967
      CM(I,4,5)=0.83371
      CM(I,5,6)=0.76313
    2 CONTINUE
C
C     DEFINE THE TYPE OF COUPLING IN THE FILTER
C             +1 >> SCREW COUPLING     -1 >> IRIS COUPLING
C
      DO 71 I=1,NCH
      DO 71 J=1,MO
      DO 71 KK=1,MO
      CEL(I,J,KK)=0
   71 CONTINUE
C
      DO 72 I=1,NCH
      CEL(I,1,2)=1
      CEL(I,2,3)=-1
      CEL(I,3,4)=1
      CEL(I,3,6)=-1
      CEL(I,4,5)=-1
      CEL(I,5,6)=1
C
      DO 72 J=1,MO
      DO 72 KK=1,J
      CEL(I,J,KK)=CEL(I,KK,J)
   72 CONTINUE
C
C     DEFINE THE SECTION LENGTHS (SPACINGS ALONG THE WAVEGUIDE MANIFOLD)
C
      WGL(1)=0.641
      WGL(2)=0.631
      WGL(3)=0.633
C
C     DEFINE SOME CONSTANTS, SOURCE VOLTAGE, SOURCE RESISTANCE, TWICE PI
C     MANIFOLD WIDTH
C
      VS=1.0
      RS=1.0
      PI2=8.0*ATAN(1.0)
      WIDTH=0.75
C
C     THE MXSOS2 PACKAGE CAN EXPLOIT THREE PRACTICAL MODELS OF THE
C     MULTIPLEXER AS DETERMINED BY THE PARAMETERS IFLAGJS, IFLAGDP
C     AND IDISPER.
C
C     IFLAGJS
C     0 - IF JUNCTIONS ARE IDEAL
C     1 - IF JUNCTIONS ARE NONIDEAL
C
C     IFLAGDP
C     0 - IF FILTERS ARE LOSSLESS
C     1 - IF FILTERS ARE LOSSY
C
C     IDISPER
C     0 - IF FILTERS ARE DISPERSIVE
C     1 - IF FILTERS ARE NONDISPERSIVE
C
C     FLAG FOR JUNCTION SUSCEPTANCE (SET TO 0 OR 1)
C
      IFLAGJS=1
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
      IF(IFLAGJS.NE.1)GO TO 42
C
      CALL CONST1(WIDTH)
C
   42 CONTINUE
C
C     FLAG FOR FILTER DISSIPATION (SET TO 0 OR 1)
C
      IFLAGDP=1
      IF(IFLAGDP.NE.1)GO TO 43
C
      CALL DISPAT(NCH,WO,BW,QO)
C
   43 CONTINUE
C
C     FLAG FOR DISPERSIVE EFFECTS IN THE COUPLED CAVITY FILTERS
C     (SET TO 0 OR 1)
C
      IDISPER=1
      IF(IDISPER.NE.1)GO TO 44
C
      CALL DISPER(NCH,WO,BW,DIA)
C
   44 CONTINUE
C
C     CHECK WHETHER THE SIMULATION MODE IS REQUIRED
C
      IF(LMODE.NE.1)GO TO 16
C
C     SENSITIVITY ANALYSIS, CORRESPONDING TO LMODE=2
C
C     THIS PART OF THE MAIN PROGRAM IS USED TO DEFINE CODES FOR MULTI-
C     PLEXER PARAMETERS W.R.T. WHICH WE WANT TO FIND THE SENSITIVITIES.
C     THE PARAMETER IR(I)=0 SIGNIFIES THAT NO ELEMENTS OF THE FILTER
C     COUPLING MATRICES ARE OPTIMIZATION VARIABLES. SUBROUTINE
C     "SIMGRD2" IS CALLED AT EACH FREQUENCY DEFINED IN THE VECTOR
C     OMEGA(I).
C
C     IR      - VECTOR CONTAINING THE NUMBER OF COUPLING PARAMETERS BE-
C               ING VARIABLES FOR EACH CHANNEL
C     LC      - MATRIX CONTAINING THE ROW INDICES OF COUPLING PARAMETERS
C               BEING VARIABLES FOR EACH CHANNEL
C     KC      - MATRIX CONTAINING THE COLUMN INDICES OF COUPLING PARAME-
C               TERS BEING VARIABLES FOR EACH CHANNEL
C     IPN1    - INTEGER ARRAY OF DIMENSION AT LEAST NCH INDICATING
C               WHETHER THE INPUT TRANSFORMER RATIO IS AN OPTIMIZATION
C               VARIABLE (IPN1(I)=1) OR NOT (IPN1(I)=0).
C     IPN2    - INTEGER ARRAY OF DIMENSION AT LEAST NCH INDICATING
C               WHETHER THE OUTPUT TRANSFORMER RATIO IS AN OPTIMIZA-
C               TION VARIABLE (IPN2(I)=1) OR NOT (IPN2(I)=0).
C     IWG     - INTEGER ARRAY OF DIMENSION AT LEAST NCH INDICATING
C               WHETHER THE WAVEGUIDE SECTION LENGTH IS AN OPTIMIZA-
C               TION VARIABLE (IWG(I)=1) OR NOT (IWG(I)=0).
C     OMEGA   - VECTOR OF ARBITRARY FREQUENCIES (EXCEPT CENTER FREQUEN-
C               CIES) AT WHICH THE SENSITIVITY ANALYSIS IS TO BE PERFOR-
C               MED.
C     FRSNS   - ACTUAL FREQUENCY AT WHICH THE SUBROUTINE "SIMGRD" IS
C               CALLED
C     NV      - TOTAL NUMBER OF VARIABLES W.R.T. WHICH THE SENSITIVITIES
C               ARE REQUIRED
C     FRL     - VALUE OF THE COMMON PORT RETURN LOSS IN DB AT THE FREQU-
C               ENCY FRSNS
C     DRL     - SENSITIVITIES OF THE COMMON PORT RETURN LOSS W.R.T. ALL
C               VARIABLES
C     FIL     - VECTOR OF THE INSERTION LOSS FUNCTION IN DB FOR EACH
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
C              CHANNEL AT THE FREQUENCY FRSNS
C     DIL    - MATRIX OF SENSITIVITIES OF THE INSERTION LOSS FUNCTION
C              FOR EACH CHANNEL W.R.T. ALL VARIABLES
C
C     DEFINE THE NUMBER OF COUPLING VARIABLES PER CHANNEL
C
   16 CONTINUE
      IR(1)=12
      IR(2)=12
      IR(3)=12
C
C     DEFINE CODES TO IDENTIFY VARIABLES FOR INPUT-OUTPUT TRANSFORMER
C     RATIOS AND WAVEGUIDE SPACINGS
C
      DO 55 I=1,NCH
      IWG(I)=1
      IPN1(I)=1
      IPN2(I)=1
   55 CONTINUE
C
C     EVALUATE THE TOTAL NUMBER OF VARIABLES ACCUMULATED AFTER
C     EACH SECTION
C
      CALL TOTAL2(NCH,IR,IRT,IPN1,IPN2,IWG)
C
C     DEFINE CODES FOR THE VARIABLES CONTAINED IN THE COUPLING MATRICES
C
      DO 127 I=1,3
      LC(I,1)=1
      LC(I,2)=1
      LC(I,3)=2
      LC(I,4)=2
      LC(I,5)=3
      LC(I,6)=3
      LC(I,7)=3
      LC(I,8)=4
      LC(I,9)=4
      LC(I,10)=5
      LC(I,11)=5
      LC(I,12)=6
      KC(I,1)=1
      KC(I,2)=2
      KC(I,3)=2
      KC(I,4)=3
      KC(I,5)=3
      KC(I,6)=4
      KC(I,7)=6
      KC(I,8)=4
      KC(I,9)=5
      KC(I,10)=5
      KC(I,11)=6
      KC(I,12)=6
  127 CONTINUE
C
C     CHECK WHETHER THE SIMULATION AND SENSITIVITY ANALYSIS MODE
C     IS REQUIRED
C
      IF(LMODE.NE.2) GO TO 17
C
C     OPTIMIZATION, CORRESPONDING TO LMODE=3
C
C     THIS PART OF THE MAIN SEGMENT IS USED TO DEFINE ALL VARIABLES AND
C     ARRAYS FOR MULTIPLEXER OPTIMIZATION. TO SELECT THE MULTIPLEXER PA-
C     RAMETERS WHICH ARE THE OPTIMIZATION VARIABLES THE MATRICES LC AND
C     KC HAVE TO BE USED AS DESCRIBED IN THE SENSITIVITY ANALYSIS PART.
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
C     THREE MODES OF OPTIMIZATION ARE ALLOWED. TO SELECT THE DESIRED
C     MODE OF OPTIMIZATION SET PARAMETER MODE TO
C     0 - IF ONLY COMMON PORT RETURN LOSS OPTIMIZATION IS REQUIRED
C     1 - IF ONLY INSERTION LOSS OPTIMIZATION IS REQUIRED
C     2 - IF BOTH RETURN LOSS AND INSERTION LOSS OPTIMIZATION ARE
C         REQUIRED.
C     IN EACH CASE A DIFFERENT HEADER FOR THE PRINTOUT OF OPTIMIZATION
C     RESULTS CAN BE OBTAINED BY CALLING THE SUBROUTINE "MMXHDR" FOR
C     WHICH THE ARGUMENT T CAN BE DEFINED USING THE DATA STATEMENT. VA-
C     LUES OF OPTIMIZATION VARIABLES AT THE STARTING POINT MUST BE SUP-
C     PLIED BY DEFINING THE X VECTOR USING EITHER THE DATA STATEMENT OR
C     EXPLICITLY. THE MINIMAX FUNCTIONS ARE CREATED AT THE FREQUENCIES
C     DEFINED IN THE VECTOR OMEGA(I), WHICH IS A REAL ARRAY OF LENGTH
C     AT LEAST NFREQ.
C
C     NFREQ  - NUMBER OF FREQUENCY POINTS AT WHICH THE MINIMAX FUNCTI-
C              ONS ARE TO BE CREATED
C     OMEGA  - VECTOR OF ARBITRARY FREQUENCY POINTS (EXCEPT CENTER FRE-
C              QUENCIES) IN MHZ AT WHICH THE MINIMAX FUNCTIONS ARE TO
C              BE CREATED
C     NFRL   - NUMBER OF MINIMAX FUNCTIONS CREATED DUE TO RETURN LOSS
C              SPECIFICATIONS
C
C     ARRAYS AND CODES FOR COMMON PORT RETURN LOSS OPTIMIZATION
C
C     RLSCODE- INTEGER ARRAY OF LENGTH AT LEAST NFREQ. EACH ELEMENT MUST
C              BE SET TO THE FOLLOWING SPECIFICATION CODE VALUE AT EACH
C              FREQUENCY :
C              0 - NO SPECIFICATION REQUIRED
C             -1 - ONLY LOWER SPECIFICATION REQUIRED
C              1 - ONLY UPPER SPECIFICATION REQUIRED
C              2 - BOTH UPPER AND LOWER SPECIFICATIONS REQUIRED
C     SURL   - REAL ARRAY OF LENGTH AT LEAST NFREQ. IT MUST CONTAIN THE
C              UPPER SPECIFICATIONS APPLICABLE AT EACH FREQUENCY
C     SLRL   - REAL ARRAY OF LENGTH AT LEAST NFREQ. IT MUST CONTAIN THE
C              LOWER SPECIFICATIONS APPLICABLE AT EACH FREQUENCY
C     WURL   - REAL ARRAY OF LENGTH AT LEAST NFREQ. IT MUST CONTAIN THE
C              WEIGHTING FACTORS CORRESPONDING TO UPPER SPECIFICATIONS
C     WLRL   - REAL ARRAY OF LENGTH AT LEAST NFREQ. IT MUST CONTAIN THE
C              WEIGHTING FACTORS CORRESPONDING TO LOWER SPECIFICATIONS
C
C     ARRAYS AND CODES FOR INSERTION LOSS OPTIMIZATION
C
C     CHBCODE- INTEGER ARRAY OF DIMENSIONS AT LEAST NCH BY 2. EACH ROW
C              MUST CONTAIN THE RANGE OF FREQUENCIES OVER WHICH SPECI-
C              FICATIONS FOR THE CORRESPONDING CHANNEL ARE GIVEN. THE
C              FIRST ELEMENT OF A ROW INDICATES THE LOWER FREQUENCY
C              EDGE OF INTEREST, THE SECOND THE UPPER FREQUENCY EDGE.
C     SPCODE - INTEGER ARRAY OF DIMENSIONS AT LEAST NSPMAX BY NCH.
C              NSPMAX IS THE MAXIMUM NUMBER OF FREQUENCY POINTS CONSI-
C              DERED FOR ANY OF THE CHANNELS.
C              EACH COLUMN MUST CONTAIN THE SPECIFICATION CODE AT EACH
C              FREQUENCY FOR THE CORRESPONDING CHANNEL. EACH ELEMENT
C              OF A COLUMN MUST BE SET TO ONE OF THE FOLLOWING VALUES:
C              0 - NO SPECIFICATION REQUIRED
C             -1 - ONLY LOWER SPECIFICATION REQUIRED
C              1 - ONLY UPPER SPECIFICATION REQUIRED
C              2 - BOTH UPPER AND LOWER SPECIFICATIONS REQUIRED
C     SU     - REAL ARRAY OF DIMENSIONS AT LEAST NSPMAX BY NCH. IT
C              MUST CONTAIN THE UPPER SPECIFICATIONS FOR EACH CHANNEL
C              ORDERED CONSECUTIVELY W.R.T. FREQUENCY INDEX IMPLIED
C              BY THE CHBCODE MATRIX IN THE FORM (FREQUENCY INDEX,
C              CHANNEL).
C     SL     - REAL ARRAY OF DIMENSIONS AT LEAST NSPMAX BY NCH. IT
C              MUST CONTAIN THE LOWER SPECIFICATIONS FOR EACH CHANNEL
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
C               ORDERED CONSECUTIVELY W.R.T. FREQUENCY INDEX IMPLIED
C               BY THE CHBCODE MATRIX IN THE FORM (FREQUENCY INDEX,
C               CHANNEL).
C     WU      - REAL ARRAY OF DIMENSIONS AT LEAST NSPMAX BY NCH. IT
C               MUST CONTAIN THE WEIGHTING FACTORS FOR UPPER SPECIFI-
C               CATIONS. IT IS ARRANGED TO CORRESPOND TO SU.
C     WL      - REAL ARRAY OF DIMENSIONS AT LEAST NSPMAX BY NCH. IT
C               MUST CONTAIN THE WEIGHTING FACTORS FOR LOWER SPECIFI-
C               CATIONS. IT IS ARRANGED TO CORRESPOND TO SL.
C
C
   17 CALL MMXHDR(3,T)
C
C     SELECT THE DESIRED MODE OF OPTIMIZATION
C
      MODE=2
C
C     THE STARTING POINT FOR OPTIMIZATION MUST BE INITIALIZED BY
C     SETTING CONSECUTIVELY NUMBERED X VALUES. IT IS IMPERATIVE THAT
C     THE OPTIMIZATION VARIABLES FOR EACH CHANNEL ARE DEFINED CON-
C     SECUTIVELY AS FOLLOWS: VARIABLE FILTER COUPLINGS COME FIRST,
C     FOLLOWED BY VARIABLE INPUT, THEN OUTPUT, TRANSFORMER RATIOS,
C     THE SECTION LENGTH BEING THE LAST VARIABLE IN THE SET OF OPTI-
C     MIZATION VARIABLES FOR A PARTICULAR CHANNEL.
C
      X(1)=CM(1,1,1)
      X(2)=CM(1,1,2)
      X(3)=CM(1,2,2)
      X(4)=CM(1,2,3)
      X(5)=CM(1,3,3)
      X(6)=CM(1,3,4)
      X(7)=CM(1,3,6)
      X(8)=CM(1,4,4)
      X(9)=CM(1,4,5)
      X(10)=CM(1,5,5)
      X(11)=CM(1,5,6)
      X(12)=CM(1,6,6)
      X(13)=PN1(1)
      X(14)=PN2(1)
      X(15)=WGL(1)
      X(30)=WGL(2)
      X(45)=WGL(3)
      DO 128 I=1,14
      II=I+15
      X(II)=X(I)
      III=I+30
      X(III)=X(I)
  128 CONTINUE
C
C     GENERATE FREQUENCY POINTS IN MHZ
C
      NFREQ=47
      OMEGA(1)=11962.0
      OMEGA(2)=11964.0
      OMEGA(3)=11966.0
      OMEGA(4)=11968.0
      OMEGA(5)=11970.0
      OMEGA(6)=11972.0
      OMEGA(7)=11976.0
      OMEGA(8)=11980.0001
      OMEGA(9)=11984.0
      OMEGA(10)=11988.0
      OMEGA(11)=11990.0
      OMEGA(12)=11992.0
      OMEGA(13)=11994.0
```

Fig. 2 (continued)　　Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
      OMEGA(14)=11996.0
      OMEGA(15)=11998.0
      DO 10 I=16,45
      OMEGA(I)=OMEGA(I-15)+40.0
   10 CONTINUE
      OMEGA(46)=12000.0
      OMEGA(47)=12040.0
C
C     DEFINE THE NUMBER OF MINIMAX FUNCTIONS RESULTING FROM THE
C     SPECIFICATIONS ON RETURN LOSS
C
      NFRL=47
C
C     DEFINE CODES AND ARRAYS REQUIRED FOR RETURN LOSS OPTIMIZATION
C
      DO 150 I=1,47
      RLSCODE(I)=-1
      SLRL(I)=20.0
      WLRL(I)=1.0
  150 CONTINUE
C
C     DEFINE CHANNEL BAND CODE (CHANNEL, FREQUENCY EDGE INDEX), WHERE
C     THE FIRST CHANNEL IS CLOSEST TO THE SHORT CIRCUIT AND CORRESPONDS
C     TO THE HIGHEST CENTER FREQUENCY, AND THE FREQUENCY EDGES ARE 1
C     FOR LOWER EDGE AND 2 FOR UPPER EDGE. THE VALUE OF CHBCODE CORRES-
C     PONDS TO THE FREQUENCY POINT INDEX USED AS ARGUMENT OF OMEGA(I).
C     IF THERE IS NO SPECIFICATION FOR A PARTICULAR CHANNEL, THE VALUE
C     OF CHBCODE MUST BE SET TO 0.
C
      CHBCODE(1,1)=31
      CHBCODE(1,2)=45
      CHBCODE(2,1)=16
      CHBCODE(2,2)=30
      CHBCODE(3,1)=1
      CHBCODE(3,2)=15
C
C     DEFINE THE SPECIFICATION CODE FOR INSERTION LOSS OPTIMIZATION
C     (FREQUENCY INDEX, CHANNEL)
C
      DO 20 I=1,15
      DO 20 J=1,3
      SPCODE(I,J)=1
   20 CONTINUE
C
C     DEFINE VALUES FOR THE SPECIFICATIONS (FREQUENCY INDEX, CHANNEL)
C
      DO 25 I=1,3
      SU(1,I)=2.79
      SU(2,I)=1.77
      SU(3,I)=1.41
      SU(4,I)=1.24
      DO 33 J=5,11
      SU(J,I)=1.12
   33 CONTINUE
      SU(12,I)=1.24
      SU(13,I)=1.41
      SU(14,I)=1.77
      SU(15,I)=2.79
   25 CONTINUE
C
C     DEFINE WEIGHTING FACTORS CORRESPONDING TO THE SPECIFICATIONS
C
      DO 35 I=1,15
      DO 35 J=1,3
      WU(I,J)=1.0
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
   35 CONTINUE
C
C     ARGUMENTS OF THE MINIMAX OPTIMIZATION(MMLC) CALL STATEMENT
C
C     FDF2     - NAME OF A SUBROUTINE CALCULATING MINIMAX FUNCTIONS AND
C                THEIR DERIVATIVES AT THE POINT DEFINED BY THE X VECTOR.
C                THE NAME FDF2 IS ARBITRARY AND MUST APPEAR IN THE EXTER-
C                NAL STATEMENT IN THE SEGMENT CALLING MMLC1A.
C     NV       - INTEGER ARGUMENT WHICH MUST BE SET TO THE NUMBER OF OP-
C                TIMIZATION VARIABLES. ITS VALUE MUST BE POSITIVE AND IS
C                NOT CHANGED BY THE PACKAGE.
C     MF       - INTEGER ARGUMENT WHICH MUST BE SET TO THE NUMBER OF RE-
C                SIDUAL FUNCTIONS DEFINING THE MINIMAX OBJECTIVE FUNCTION.
C                ITS VALUE MUST BE POSITIVE AND IS NOT CHANGED BY THE PA-
C                CKAGE.
C     L        - INTEGER ARGUMENT WHICH MUST BE SET TO THE TOTAL NUMBER
C                OF EQUALITY AND INEQUALITY CONSTRAINTS. ITS VALUE MUST
C                BE POSITIVE OR ZERO AND IT IS NOT CHANGED BY THE PACKA-
C                GE.
C     LEQ      - INTEGER ARGUMENT WHICH MUST BE SET TO THE NUMBER OF EQ-
C                UALITY CONSTRAINTS. ITS VALUE MUST BE POSITIVE OR ZERO
C                AND NOT GREATER THAN NV, AND NOT GREATER THAN L. ITS
C                VALUE IS NOT CHANGED BY THE PACKAGE.
C     B        - REAL ARRAY OF LENGTH IIC > L. THE ELEMENTS OF B MUST BE
C                SET TO THE CONSTANT TERMS IN THE LINEAR CONSTRAINTS.
C                THE CONTENTS OF B ARE NOT CHANGED BY THE PACKAGE.
C     C        - REAL MATRIX OF DIMENSIONS (IIC,NV). THE FIRST L ROWS OF
C                C MUST BE SET TO THE COEFFICIENTS OF X IN THE LINEAR
C                CONSTRAINTS.
C     IIC      - INTEGER ARGUMENT WHICH MUST BE SET TO THE LENGTH OF THE
C                ARRAY B AND TO NUMBER OF ROWS OF THE MATRIX C. ITS VA-
C                LUE MUST NOT BE LESS THAN L, AND IT IS NOT CHANGED BY
C                THE PACKAGE.
C     X        - REAL ARRAY OF LENGTH AT LEAST NV WHICH, ON ENTRY, MUST
C                BE SET TO THE INITIAL APPROXIMATION OF THE SOLUTION.
C                ON EXIT X CONTAINS THE BEST SOLUTION FOUND BY THE PACK-
C                AGE.
C     DX       - REAL VARIABLE WHICH CONTROLS THE STEP LENGTH OF THE ITER-
C                ATIVE ALGORITHM. ON ENTRY IT MUST BE SET TO AN INITIAL
C                VALUE APPROXIMATELY EQUAL TO 0.1* X. THE VALUE OF DX
C                MUST BE POSITIVE. ON EXIT DX CONTAINS THE LAST VALUE OF
C                THE STEPSIZE. FOR EXTENSIVE DETAILS PLEASE REFER TO
C                REPORT SOS-82-5-U2, AUGUST 1983.
C     EPS      - REAL VARIABLE WHICH ON ENTRY MUST BE SET TO THE REQUIRED
C                ACCURACY OF THE SOLUTION. ON EXIT EPS CONTAINS THE LENGTH
C                OF THE LAST STEP TAKEN IN THE ITERATION.
C     MAXF     - INTEGER VARIABLE WHICH MUST BE SET TO AN UPPER BOUND ON
C                THE NUMBER OF CALLS OF FDF2. ON EXIT MAXF CONTAINS THE
C                NUMBER OF CALLS OF FDF THAT HAVE BEEN PERFORMED BY THE
C                PACKAGE.
C     KEQS     - INTEGER VARIABLE WHICH MUST BE SET TO THE NUMBER OF SUC=
C                CESSIVE ITERATIONS WITH IDENTICAL SETS OF ACTIVE RESIDUAL
C                FUNCTIONS AND ACTIVE CONSTRAINTS THAT IS REQUIRED BEFORE
C                A SWITCH TO STAGE 2 IS MADE. ON EXIT KEQS CONTAINS THE
C                NUMBER OF SWITCHES TO STAGE 2 THAT HAVE TAKEN PLACE.
C     W        - REAL ARRAY WHICH IS USED FOR WORKING SPACE. ITS LENGTH
C                IS GIVEN BY IW. ON EXIT THE FIRST MF ELEMENTS OF W CON-
C                TAIN THE RESIDUAL FUNCTION VALUES AT THE SOLUTION.
C     IW       - INTEGER ARGUMENT WHICH MUST BE SET TO THE LENGTH OF W.
C                ITS VALUE MUST BE AT LEAST
C
C                     IWR=2*MF*NV+5*NV*NV+4*MF+8*NV+4*IIC+3
C
C     ICH      - INTEGER ARGUMENT WHICH MUST BE SET TO THE UNIT NUMBER
C                THAT IS TO BE USED FOR THE PRINTED OUTPUT GENERATED BY
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
C               THE PACKAGE. IF ICH IS LESS THAN OR EQUAL TO ZERO, NO
C               PRINTED OUTPUT WILL BE GENERATED BY THE PACKAGE.
C     IPR     - INTEGER ARGUMENT WHICH CONTROLS THE PRINTED OUTPUT GE-
C               NERATED BY THE PACKAGE. FOR EXTENSIVE DETAILS PLEASE
C               REFER TO REPORT SOS-82-5-U2, AUGUST 1983.
C     IFALL   - INTEGER VARIABLE WHICH ON EXIT CONTAINS INFORMATION
C               ABOUT THE SOLUTION:
C               IFALL=-2 FEASIBLE REGION IS EMPTY,
C               IFALL=-1 INCORRECT INPUT DATA,
C               IFALL= 0 REGULAR SOLUTION; REQUIRED ACCURACY OBTAINED,
C               IFALL= 1 SINGULAR SOLUTION; REQUIRED ACCURACY OBTAINED,
C               IFALL= 2 MACHINE ACCURACY REACHED,
C               IFALL= 3 MAXIMUM NUMBER OF FUNCTION EVALUATIONS REACHED,
C               IFALL= 4 ITERATION TERMINATED BY THE USER.
C
C     DEFINE PARAMETERS FOR THE MMLC PACKAGE
C
      NV=45
      MF=92
      L=0
      LEQ=0
      IIC=1
      DX=0.05
      EPS=1.E-6
      MAXF=65
      KEQS=3
      IW=20000
      ICH=6
      IPR=10
      NCOUNT=1
C
      CALL MMLC1A(FDF2,NV,MF,L,LEQ,B,C,IIC,X,DX,EPS,MAXF,KEQS,W,IW,ICH,
     1            IPR,IFALL)
C
      STOP
      END
C
```

Fig. 2 (continued)   Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
C
      SUBROUTINE FDF2(NV,MF,X,DF,F)
      REAL X(NV),F(MF),DF(MF,NV)
      REAL OMEGA(47),SURL(47),SLRL(47),WURL(47),WLRL(47),
     1     SU(20,16),SL(20,16),WU(20,16),WL(20,16)
      INTEGER RLSCODE(47),SPCODE(20,16),CHBCODE(16,2)
      REAL CM(16,8,8),WGL(16),DRL(100),FIL(16),DIL(16,100)
      INTEGER IR(16),IRT(16),LC(16,36),KC(16,36)
      INTEGER IPN1(16),IPN2(16),IWG(16)
      REAL WO(16),BW(16),PN1(16),PN2(16),GL(16)
      COMMON /BLK2/CM,WGL
      COMMON /BLK1/WO,BW,PN1,PN2,GL,VS,RS,PI2,WIDTH,NP1
      COMMON /BLK3/OMEGA,SURL,SLRL,WURL,WLRL,SU,SL,WU,WL,
     1             RLSCODE,SPCODE,NCOUNT,MODE,NCH,MO,
     2             NFREQ,NFRL,CHBCODE,IFLAGJS,IFLAGDP,IDISPER
      COMMON/BLK8/IR,IRT,IPN1,IPN2,IWG,LC,KC
C
C     UPDATE OPTIMIZATION VARIABLES
C
      IF(IRT(1).EQ.0)GO TO 20
      IF(IR(1).EQ.0)GO TO 11
      IR1=IR(1)
      DO 10 IV=1,IR1
      CM(1,LC(1,IV),KC(1,IV))=X(IV)
   10 CONTINUE
   11 IF(IPN1(1).EQ.0)GO TO 12
      IV=IR(1)+IPN1(1)
      PN1(1)=X(IV)
   12 IF(IPN2(1).EQ.0)GO TO 13
      IV=IR(1)+IPN1(1)+IPN2(1)
      PN2(1)=X(IV)
   13 IF(IWG(1).EQ.0)GO TO 14
      IV=IR(1)+IPN1(1)+IPN2(1)+IWG(1)
      WGL(1)=X(IV)
   14 CONTINUE
C
   20 CONTINUE
      DO 40 I=2,NCH
      IF(IRT(I).EQ.0)GO TO 40
      IX=IRT(I-1)
      IF(IR(I).EQ.0)GO TO 15
      IRI=IR(I)
      DO 30 IP=1,IRI
      IXX=IX+IP
      CM(I,LC(I,IP),KC(I,IP))=X(IXX)
   30 CONTINUE
   15 IF(IPN1(I).EQ.0)GO TO 16
      IXX=IX+IR(I)+IPN1(I)
      PN1(I)=X(IXX)
   16 IF(IPN2(I).EQ.0)GO TO 17
      IXX=IX+IR(I)+IPN1(I)+IPN2(I)
      PN2(I)=X(IXX)
   17 IF(IWG(I).EQ.0)GO TO 18
      IXX=IX+IR(I)+IPN1(I)+IPN2(I)+IWG(I)
      WGL(I)=X(IXX)
   18 CONTINUE
C
   40 CONTINUE
C
C     DEFINE MINIMAX FUNCTIONS AND THEIR GRADIENTS
C
      NCHAN=NCH
      MORDER=MO
      KFRL=0
      KFUN=NFRL
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
      DO 100 I=1,NFREQ
      FREQ=OMEGA(I)
C
      CALL SIMGRD2(FREQ,FRL,DRL,FIL,DIL,NCHAN,MORDER,I,IFLAGJS,
     1            IFLAGDP,IDISPER)
C
      IF(MODE.EQ.1)GO TO 199
      IF(RLSCODE(I).EQ.0)GO TO 199
      IF(RLSCODE(I).EQ.-1)GO TO 70
      IF(RLSCODE(I).EQ.1)GO TO 75
      KFRL=KFRL+1
      F(KFRL)=WURL(I)*(FRL-SURL(I))
      DO 80 K1=1,NV
      DF(KFRL,K1)=WURL(I)*DRL(K1)
   80 CONTINUE
      KFRL=KFRL+1
      F(KFRL)=-WLRL(I)*(FRL-SLRL(I))
      DO 85 K2=1,NV
      DF(KFRL,K2)=-WLRL(I)*DRL(K2)
   85 CONTINUE
      GO TO 199
   70 KFRL=KFRL+1
      F(KFRL)=-WLRL(I)*(FRL-SLRL(I))
      DO 90 K3=1,NV
      DF(KFRL,K3)=-WLRL(I)*DRL(K3)
   90 CONTINUE
      GO TO 199
   75 KFRL=KFRL+1
      F(KFRL)=WURL(I)*(FRL-SURL(I))
      DO 95 K4=1,NV
      DF(KFRL,K4)=WURL(I)*DRL(K4)
   95 CONTINUE
  199 CONTINUE
      IF(MODE.EQ.0)GO TO 100
      DO 105 J=1,NCH
      NCHECK=0
      IF(I.GE.CHBCODE(J,1).AND.I.LE.CHBCODE(J,2))NCHECK=1
      IF(NCHECK.EQ.0)GO TO 105
      K=I-CHBCODE(J,1)+1
      IF(SPCODE(K,J).EQ.0)GO TO 105
      IF(SPCODE(K,J).EQ.-1)GO TO 110
      IF(SPCODE(K,J).EQ.1)GO TO 115
      KFUN=KFUN+1
      F(KFUN)=WU(K,J)*(FIL(J)-SU(K,J))
      DO 120 I1=1,NV
      DF(KFUN,I1)=WU(K,J)*DIL(J,I1)
  120 CONTINUE
      KFUN=KFUN+1
      F(KFUN)=-WL(K,J)*(FIL(J)-SL(K,J))
      DO 125 I2=1,NV
      DF(KFUN,I2)=-WL(K,J)*DIL(J,I2)
  125 CONTINUE
      GO TO 105
  110 KFUN=KFUN+1
      F(KFUN)=-WL(K,J)*(FIL(J)-SL(K,J))
      DO 130 I3=1,NV
      DF(KFUN,I3)=-WL(K,J)*DIL(J,I3)
  130 CONTINUE
      GO TO 105
  115 KFUN=KFUN+1
      F(KFUN)=WU(K,J)*(FIL(J)-SU(K,J))
      DO 135 I4=1,NV
      DF(KFUN,I4)=WU(K,J)*DIL(J,I4)
  135 CONTINUE
  105 CONTINUE
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

```
100 CONTINUE
    NCOUNT=NCOUNT+1
    RETURN
    END
```

Fig. 2 (continued) Listing of MXSOS2 and the subroutine FDF2 arranged for optimization.

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LINEARLY CONSTRAINED MINIMAX OPTIMIZATION (MMLC PACKAGE) (V:82.04)

MULTIPLEXER PROBLEM MXTST6C

INPUT DATA

NUMBER OF VARIABLES (N) 45

NUMBER OF FUNCTIONS (M) 92

TOTAL NUMBER OF LINEAR CONSTRAINTS (L) 0

NUMBER OF EQUALITY CONSTRAINTS (LEQ) 0

STEP LENGTH (DX) 5.000E-02

ACCURACY (EPS) 1.000E-06

MAX NUMBER OF FUNCTION EVALUATIONS (MAXF) 65

NUMBER OF SUCCESSIVE ITERATIONS (KEQS) 3

WORKING SPACE (IW) 20000

PRINTOUT CONTROL (IPR) 10

STARTING POINT :

	VARIABLES		FUNCTION VALUES
1	0.	1	1.376617388788E+01
2	5.939500000000E-01	2	1.210725700872E+01
3	0.	3	1.022508793930E+01
4	5.351400000000E-01	4	9.539332832200E+00
5	0.	5	9.242400838775E+00
6	4.247100000000E-01	6	8.322091837541E+00
7	-3.996700000000E-01	7	4.652810008359E+00
8	0.	8	3.867665333761E+00
9	8.337100000000E-01	9	3.126529123101E+00
10	0.	10	-3.154641846770E+00
11	7.631300000000E-01	11	-6.266536400448E+00
12	0.	12	-4.410253562100E+00
13	8.364627905651E-01	13	-3.953338929107E+00
14	1.046183540303E+00	14	-6.912146772112E+00
15	6.410000000000E-01	15	-1.435396827914E+01
16	0.	16	3.119334122250E+00
17	5.939500000000E-01	17	-7.712442950287E-01
18	0.	18	-2.665683411725E+00
19	5.351400000000E-01	19	-9.916907250456E-01
20	0.	20	-1.396690512709E+00
21	4.247100000000E-01	21	-4.630832122157E+00
22	-3.996700000000E-01	22	-1.427203203127E+01
23	0.	23	-7.070225476307E+00
24	8.337100000000E-01	24	-3.329177425626E+01
25	0.	25	-3.455972276484E+00
26	7.631300000000E-01	26	-2.209056470880E+00
27	0.	27	-3.964880382496E+00
28	8.364627905651E-01	28	-4.320417138471E+00
29	1.046183540303E+00	29	7.904485223746E-01
30	6.310000000000E-01	30	1.344999825989E+00

Fig. 3 Printout of results for the three-channel optimization problem.

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LINEARLY CONSTRAINED MINIMAX OPTIMIZATION (MMLC PACKAGE) (V:82.04)

MULTIPLEXER PROBLEM MXTST6C

31	0.	31	6.789481124746E+00
32	5.939500000000E-01	32	3.095280387081E+00
33	0.	33	3.070596484094E+00
34	5.351400000000E-01	34	3.361977223309E+00
35	0.	35	1.677997351072E+00
36	4.247100000000E-01	36	-3.810497037170E-01
37	-3.996700000000E-01	37	3.350534703400E+00
38	0.	38	4.529973627815E+00
39	8.337100000000E-01	39	4.448045941187E+00
40	0.	40	8.155693274774E+00
41	7.631300000000E-01	41	9.198413795891E+00
42	0.	42	9.507740957318E+00
43	8.364627905651E-01	43	1.010188526819E+01
44	1.046183540303E+00	44	1.199833518187E+01
45	6.330000000000E-01	45	1.373588782520E+01
		46	5.881726899296E-01
		47	5.606073452421E+00
		48	3.397343518583E-01
		49	4.272216573252E-01
		50	2.547630170446E-01
		51	2.088061948320E-01
		52	2.171340363827E-01
		53	9.014140138119E-02
		54	-1.459429271873E-01
		55	-1.840639900810E-01
		56	-1.722974051960E-01
		57	-1.668893351765E-01
		58	-1.130228510226E-01
		59	-1.273117826421E-01
		60	-1.326792957479E-01
		61	-2.116054575533E-01
		62	-5.411054170164E-01
		63	-1.280821750845E-01
		64	-7.401366925222E-02
		65	-6.622988776045E-02
		66	-6.449319252491E-02
		67	-5.698638585295E-02
		68	-1.450000956344E-01
		69	-2.378459752295E-01
		70	-2.557855803587E-01
		71	-2.432559645821E-01
		72	-1.535450722065E-01
		73	-8.290833706865E-02
		74	-1.117050256841E-01
		75	-1.204251798056E-01
		76	-1.527941620359E-01
		77	-4.575620274459E-01
		78	-2.520671425147E-02
		79	-2.745971306157E-02
		80	-6.062636513491E-03
		81	-1.005897550820E-02
		82	-3.099806085189E-02
		83	-1.275063411426E-01
		84	-1.557719685368E-01
		85	-1.569355189001E-01
		86	-1.439201763664E-01
		87	8.470500807513E-02
		88	2.194009772458E-01

Fig. 3 (continued) Printout of results for the three-channel optimization problem.

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LINEARLY CONSTRAINED MINIMAX OPTIMIZATION (MMLC PACKAGE)   (V:82.04)

MULTIPLEXER PROBLEM MXTST6C

89	2.125154002832E-01
90	2.481392931055E-01
91	4.141733127239E-01
92	3.340379043190E-01

SOLUTION

	VARIABLES		FUNCTION VALUES
1	-6.044027292422E-02	1	-2.600085010356E+00
2	7.325746555378E-01	2	-2.156044754964E-01
3	-6.939183412333E-02	3	-9.891552359371E-01
4	5.598321723712E-01	4	-2.157316419238E-01
5	1.283843451561E-02	5	-3.991827490066E-01
6	4.124508825067E-01	6	-2.181897820656E+00
7	-4.717569056358E-01	7	-3.598592803821E+00
8	4.182049301334E-02	8	-2.154877885846E-01
9	8.863784882748E-01	9	-1.966507434300E+00
10	5.792510733123E-02	10	-1.395234024877E+01
11	7.824970565547E-01	11	-1.518816774199E+01
12	1.346337934973E-02	12	-9.637264457316E+00
13	1.099062965387E+00	13	-8.808487172878E+00
14	1.082354644330E+00	14	-5.262709505118E+00
15	6.736038935441E-01	15	-3.502156885571E-01
16	1.244478609904E-01	16	-2.135127807545E-01
17	6.360872160508E-01	17	-5.223925285351E+00
18	2.427646151828E-03	18	-5.718853056122E+00
19	5.573920279614E-01	19	-5.897830464558E+00
20	-4.178151147506E-03	20	-9.064871534898E+00
21	3.962409124580E-01	21	-1.223432408220E+01
22	-5.640839269006E-01	22	-2.647233965705E+00
23	-8.155794850229E-03	23	-2.153255352886E-01
24	9.544758710356E-01	24	-3.241526245149E+00
25	2.981639393973E-02	25	-1.724416757945E+01
26	7.639824046422E-01	26	-1.813109509977E+01
27	-3.907219043917E-03	27	-1.269197050951E+01
28	9.161514328102E-01	28	-1.080341247641E+01
29	1.111196296523E+00	29	-6.132157719754E+00
30	5.954929663106E-01	30	-1.911168646363E+00
31	1.944047789431E-01	31	-2.152583924184E-01
32	6.707241120483E-01	32	-8.217857458398E+00
33	4.771501445755E-02	33	-5.225706073917E+00
34	5.597795068260E-01	34	-6.282945195725E+00
35	-3.131345747253E-02	35	-1.207969028079E+01
36	3.990357533710E-01	36	-1.015363029176E+01
37	-5.117829489607E-01	37	-7.797221497376E-01
38	-6.068193434428E-02	38	-2.156857538054E-01
39	8.945300524320E-01	39	-5.101679674491E+00
40	-3.206330870620E-02	40	-1.997019524539E+00
41	7.650458312043E-01	41	-2.158308189908E-01
42	-2.231361222110E-02	42	-2.156920079480E-01
43	8.768413389939E-01	43	-1.054938612420E+00
44	1.101422627599E+00	44	-2.162664418719E-01
45	5.914808559808E-01	45	-1.415136100738E+00
		46	-2.934662010578E+00
		47	-4.141597151497E-01

Fig. 3 (continued)   Printout of results for the three-channel optimization problem.

```
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LINEARLY CONSTRAINED MINIMAX OPTIMIZATION (MMLC PACKAGE)                (V:82.04)

MULTIPLEXER PROBLEM MXTST6C

                                             48  -8.347119169367E-01
                                             49  -4.425855756481E-01
                                             50  -3.256185083914E-01
                                             51  -2.725304850270E-01
                                             52  -2.272671082234E-01
                                             53  -2.863173703093E-01
                                             54  -3.409583914303E-01
                                             55  -3.266562886133E-01
                                             56  -3.139281536477E-01
                                             57  -2.730857906156E-01
                                             58  -2.157826056607E-01
                                             59  -2.456825672138E-01
                                             60  -2.769562554074E-01
                                             61  -3.651902579738E-01
                                             62  -2.157696631117E-01
                                             63  -2.157196992603E-01
                                             64  -3.811982727378E-01
                                             65  -2.830739402179E-01
                                             66  -2.470357889608E-01
                                             67  -2.157916545424E-01
                                             68  -2.728217883209E-01
                                             69  -3.101051626394E-01
                                             70  -3.081341083730E-01
                                             71  -3.104423097136E-01
                                             72  -2.703212918590E-01
                                             73  -2.157913531143E-01
                                             74  -2.508910657283E-01
                                             75  -2.857491590056E-01
                                             76  -3.749970668668E-01
                                             77  -3.303927216596E-01
                                             78  -2.156788102678E-01
                                             79  -3.613019739373E-01
                                             80  -2.630637461334E-01
                                             81  -2.383578516485E-01
                                             82  -2.157885426435E-01
                                             83  -2.743326868713E-01
                                             84  -3.116311892216E-01
                                             85  -3.338275754181E-01
                                             86  -3.540731267118E-01
                                             87  -2.940987378800E-01
                                             88  -2.353741911750E-01
                                             89  -2.837203985432E-01
                                             90  -3.408965626962E-01
                                             91  -4.694010789191E-01
                                             92  -9.218129405197E-01

  TYPE OF SOLUTION (IFALL) . . . . . . . . . . . . . . . . . . . . . . . . . .       3

  NUMBER OF FUNCTION EVALUATIONS . . . . . . . . . . . . . . . . . . . . . . .      65

  NUMBER OF SHIFTS TO STAGE-2 . . . . . . . . . . . . . . . . . . . . . . . . .       3

  EXECUTION TIME (IN SECONDS) . . . . . . . . . . . . . . . . . . . . . . . . .455.042
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Fig. 3 (continued) Printout of results for the three-channel optimization problem.

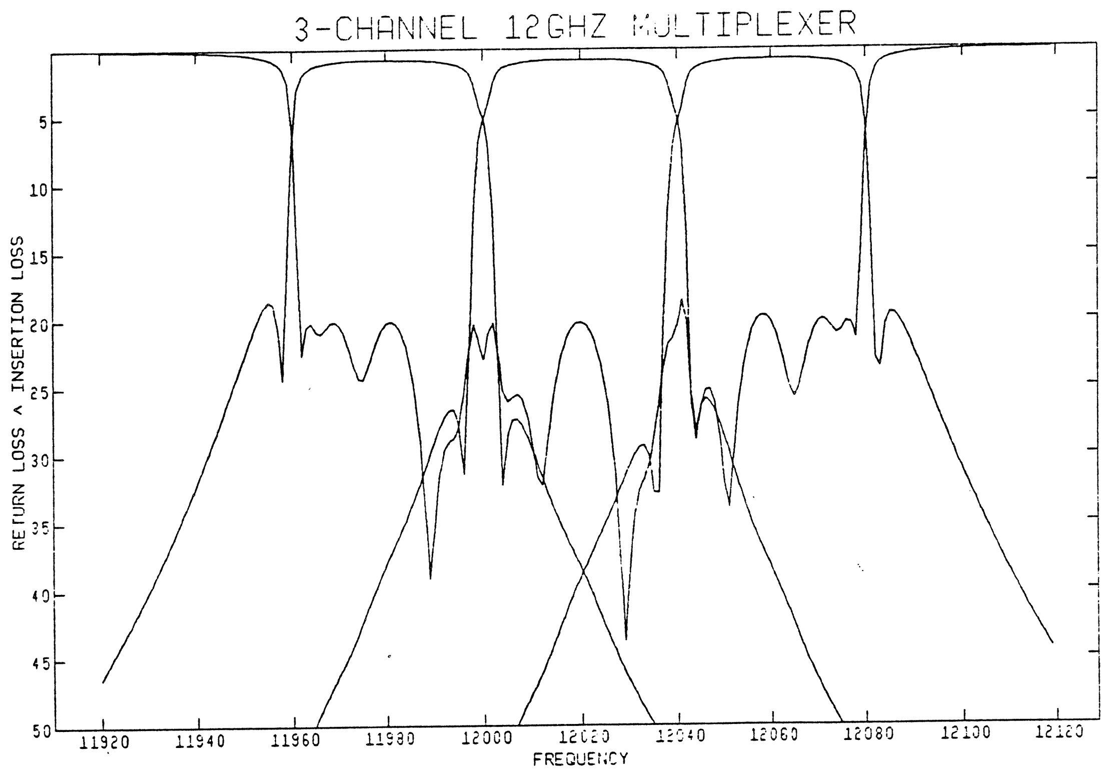

Fig. 4 Responses in dB of the three-channel multiplexer with optimized spacings, input and output transformer ratios and coupling parameters as well as cavity resonant frequencies. See the text for data.

SUBROUTINE FDF2

SUBROUTINE FDF2 (NV, MF, X, DF, F)

Purpose

FDF2 is the name of a subroutine calculating the minimax functions $f_i(\mathbf{x})$ and their derivatives $\partial f_i(\mathbf{x})/\partial x_j$ at the point $\mathbf{x}$ corresponding to X(1), X(2), ..., X(NV), and storing the values in the following way:

$$F(I) = f_I(\mathbf{x}), \qquad I = 1, ..., MF,$$

$$DF(I,J) = \partial f_I(\mathbf{x})/\partial x_J, \quad I = 1, ..., MF, \ J = 1, ..., NV.$$

The name FDF2 must appear in the EXTERNAL statement in the main segment calling MMLC1A. The subroutine updates the multiplexer parameters which are the optimization variables.

List of Arguments

NV — is an integer argument, which must be set to the number of optimization variables. Its value must be positive and is not changed by the package.

MF — is an integer argument, which must be set to the number of residual functions defining the minimax objective function. Its value must be positive and is not changed by the package.

X — is a real array of length at least NV, which must contain the optimization variables values used for calculating the minimax functions and their derivatives.

DF — is a real array of dimensions at least MF by NV. It must contain the derivatives of minimax functions at the point $\mathbf{x}$ corresponding to X(1), X(2), ..., X(NV).

F — is a real array of length at least MF. It must contain the values of minimax functions calculated at the point $\mathbf{x}$ corresponding to X(1), X(2), ..., X(NV).

Common Blocks

COMMON/BLK1/ WO, BW, PN1, PN2, GL, VS, RS, PI2, WIDTH, NP1

COMMON/BLK2/ CM, WGL

COMMON/BLK3/ OMEGA, SURL, SLRL, WURL, WLRL, SU, SL, WU, WL, RLSCODE, SPCODE, NCOUNT, MODE, NCH, MO, NFREQ, NFRL, CHBCODE, IFLAGJS, IFLAGDP, IDISPER

COMMON/BLK8/ IR, IRT, IPN1, IPN2, IWG, LC, KC

All variables and arrays, except NP1 and NCOUNT, have been explained in previous sections.

NCOUNT is an integer variable, which is increased by 1 every time the subroutine FDF2 is called.

NP1 is an integer variable, which is equal to NCH + 1.

Organization of the Subroutine

The approach used to create the minimax functions has been described in the MULTIPLEXER OPTIMIZATION section, subsection Formulation of the Problem. Here, we present flow diagrams to expose the actual organization of FDF2.

Subroutine FDF2 begins, as shown in Fig. 1, by assigning the physical variables associated with the first channel. Thus, the first IRT(1) variables in the X vector coming from MMLC are used to update the corresponding elements of matrix CM(1, ·, ·), PN1(1), PN2(1) and WGL(1), whichever were declared variable in the main segment. IR(1) is the number of variables in CM(1, ·, ·). The IF statements clearly ascertain whether a particular physical parameter is a variable or not.

Figure 2 proceeds exactly as in Fig. 1, except that all remaining channels are treated from 2 to NCH.

Figure 3 shows the assignment of the number of channels and the order of the filters, followed by the initialization of the minimax function counter KFRL due to return loss and the total minimax function counter KFUN. A loop to call SIMGRD2 is initiated on a frequency by frequency point basis, details of the processing of the results of which follow in ensuing figures. The remaining part of Fig. 3 shows the updating of the number of function evaluations (one function evaluation ≡ a complete frequency response simulation and sensitivity analysis) NCOUNT followed by a return to MMLC.

Figure 4 shows the setting of the frequency value FREQ and the call to SIMGRD2. Mode = 1 indicates that return loss is not desired. Otherwise, we go to the questions relating to RLSCODE and ask whether no specification, a lower specification or an upper specification is required. Figure 4 implements the minimax function and gradients for an upper return loss specification, followed immediately by the corresponding statements for the simultaneous lower return loss specification.

Figure 5 implements the minimax function and gradients corresponding to having a lower return loss specification only.

Figure 6 is as Fig. 5 but corresponds to an upper return loss specification.

Figure 7 initiates the channel by channel (at the single frequency under consideration) implementation of insertion loss function and gradients processed appropriately to upper and lower minimax error functions if MODE ≠ 0. An important check is which channels a particular frequency point needs to be considered for. When NCHECK = 1 we ask for possible specifications at the Ith frequency and Jth channel.

Figure 7 continues to process simultaneous upper and lower response specifications on insertion loss for the Kth sample point associated with the Jth channel.

Figure 8 implements the minimax function and gradients corresponding to having a lower insertion loss specification only at the Kth point of the Jth channel (frequency point I).

Figure 9 is as Fig. 8 but corresponds to an upper insertion loss specification only.

In Figs. 5-9 it is clear that KFUN is continually incremented by 1 every time a new insertion loss minimax error function is added to the set, just as in Figs. 3 and 4 the index

KFRL is incremented whenever a new minimax error function due to return loss is added to the set.

The complete listing of the subroutine FDF2 is shown in the section MULTIPLEXER OPTIMIZATION: EXAMPLE.

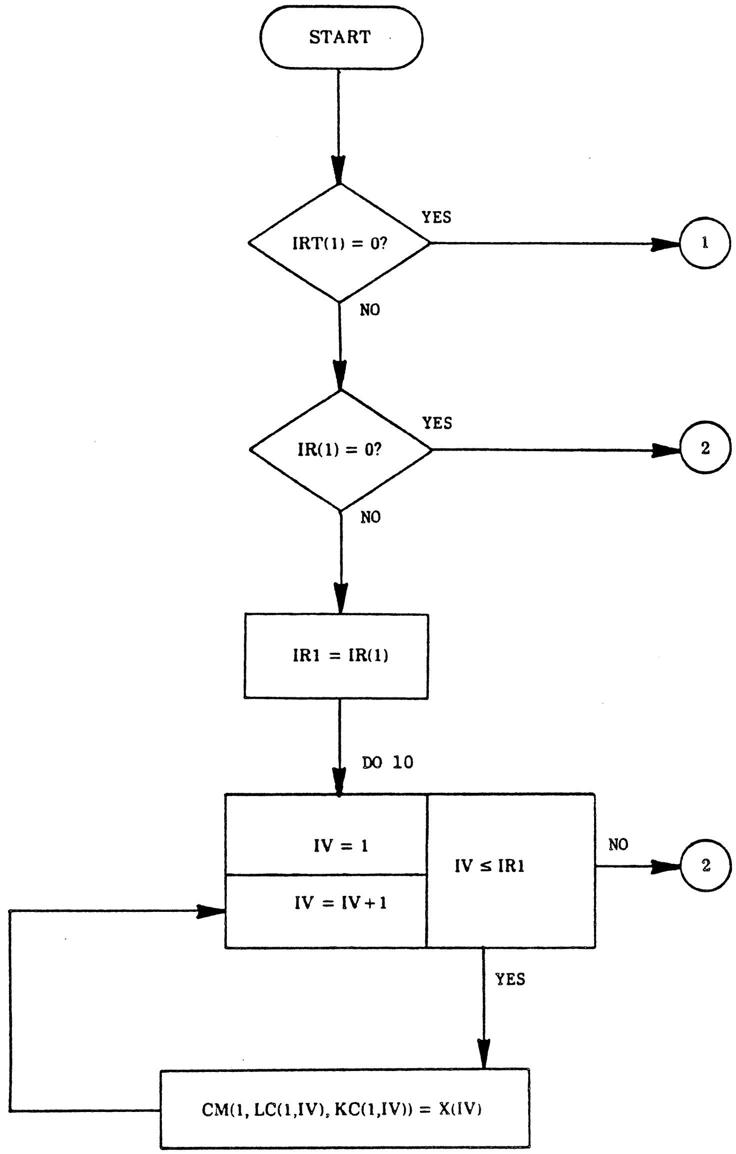

Fig. 1 Assignment of variables for the first channel.

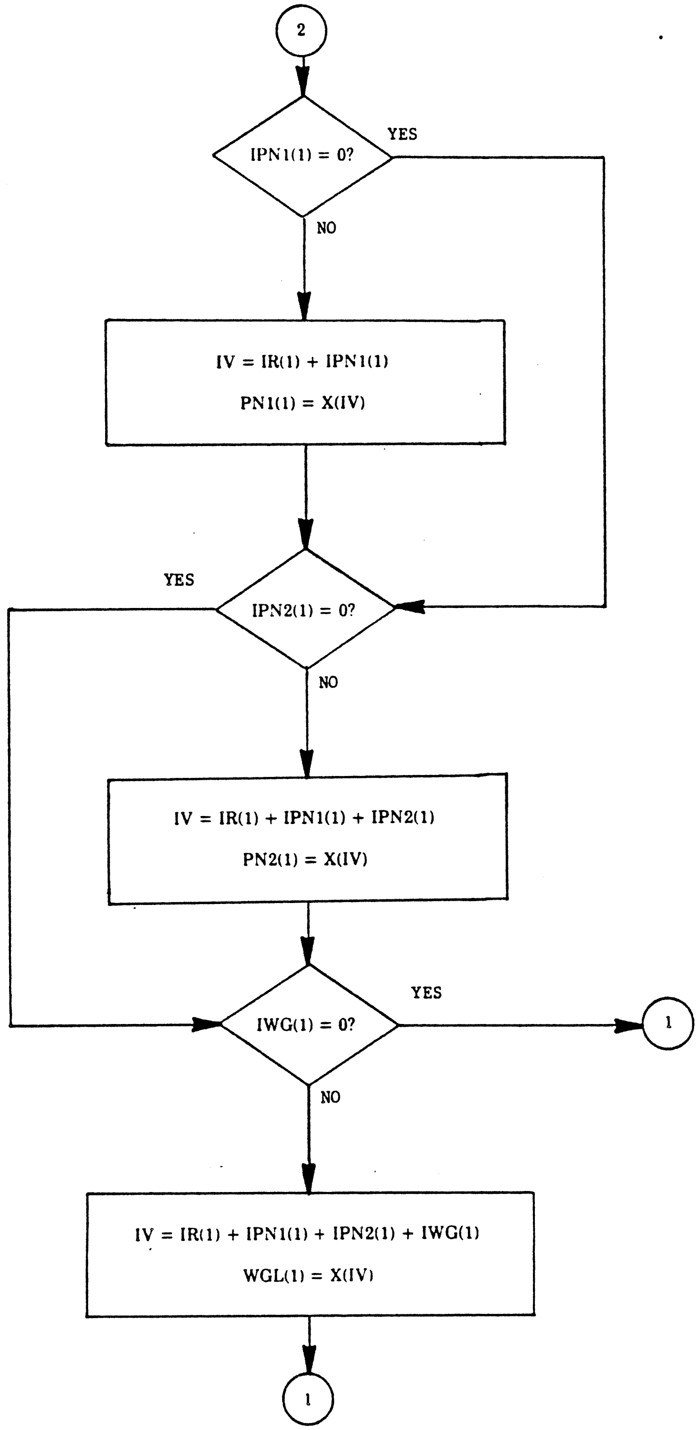

Fig. 1 (continued) Assignment of variables for the first channel.

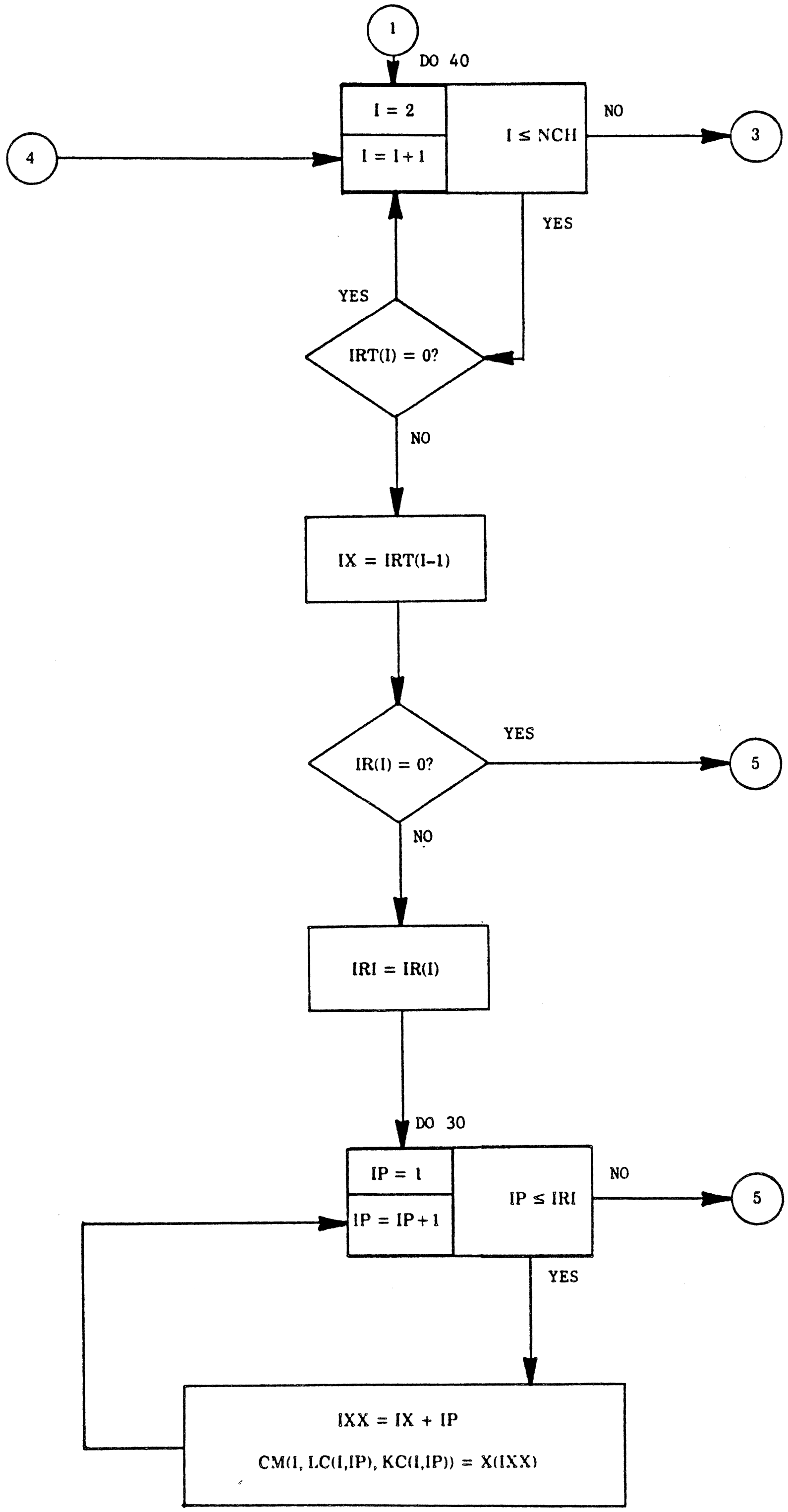

Fig. 2 Assignment of variables for the remaining channels.

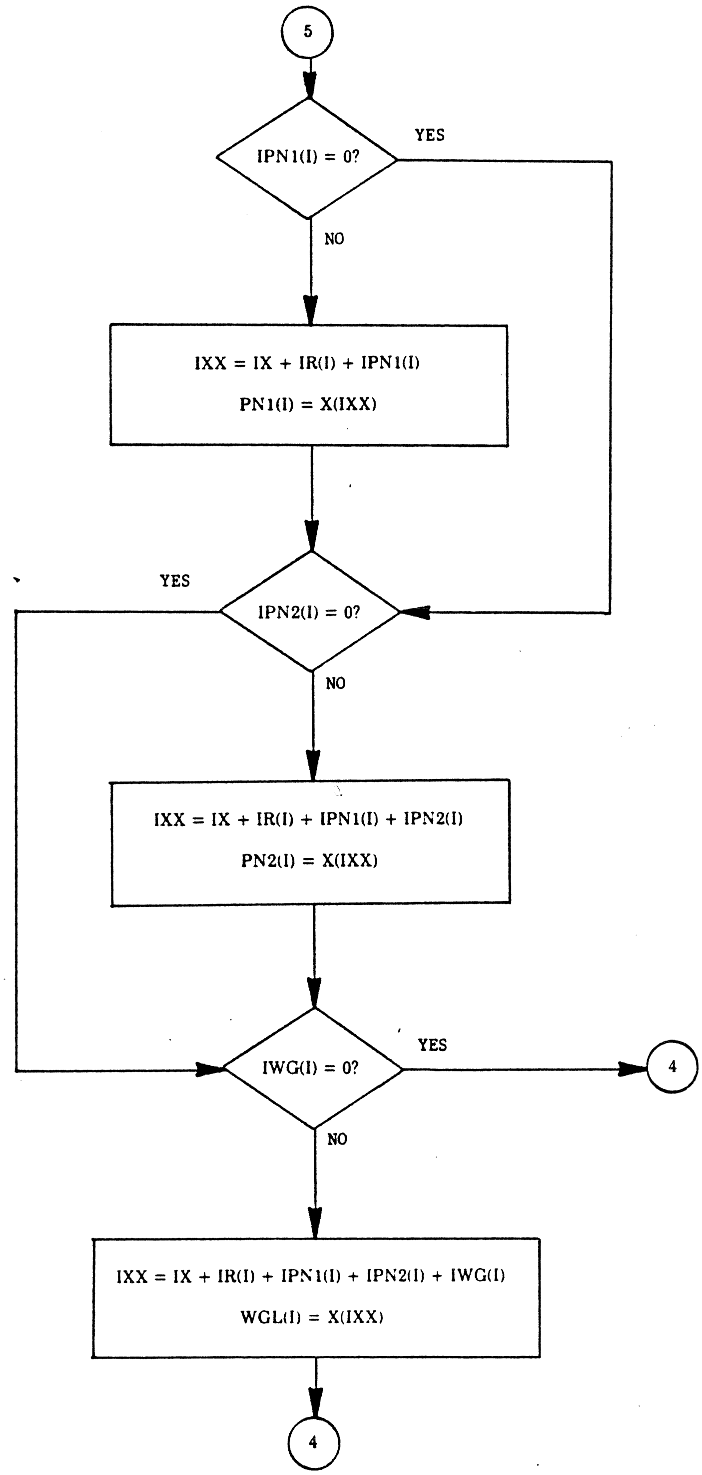

Fig. 2 (continued) Assignment of variables for the remaining channels.

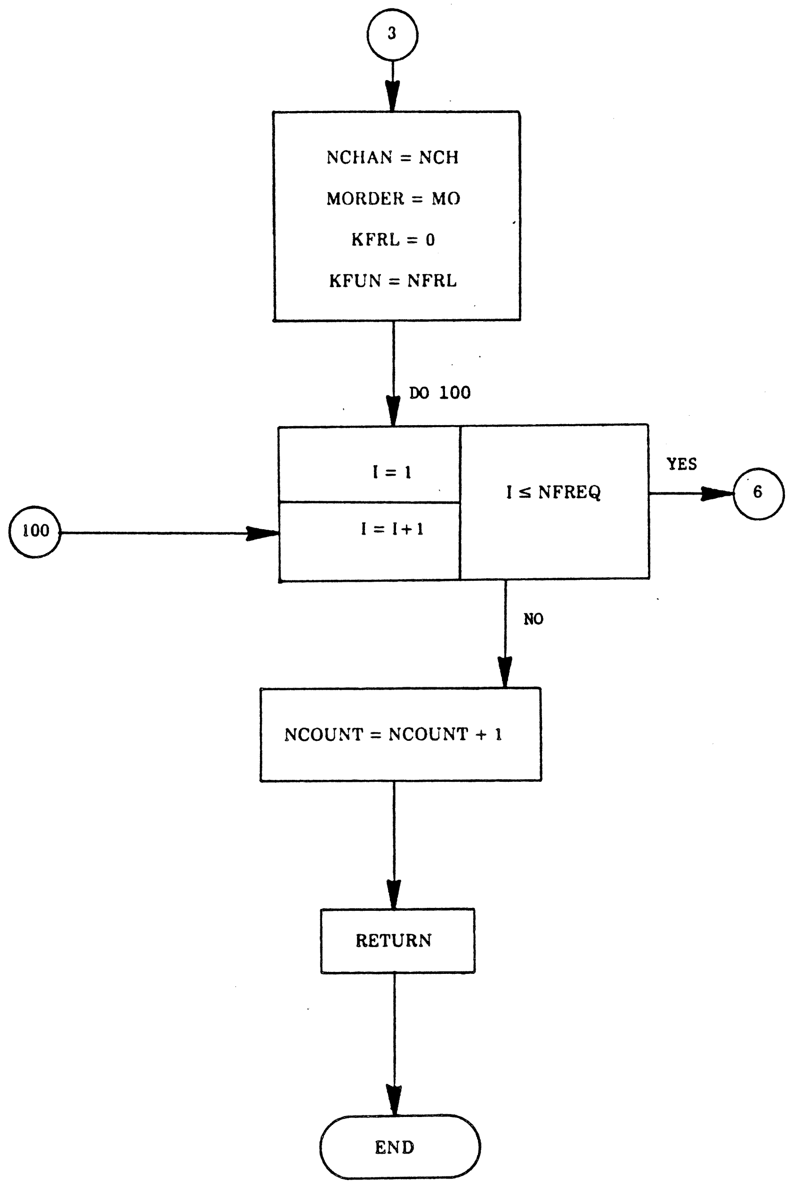

Fig. 3 Initiation of the loop to call SIMGRD2.

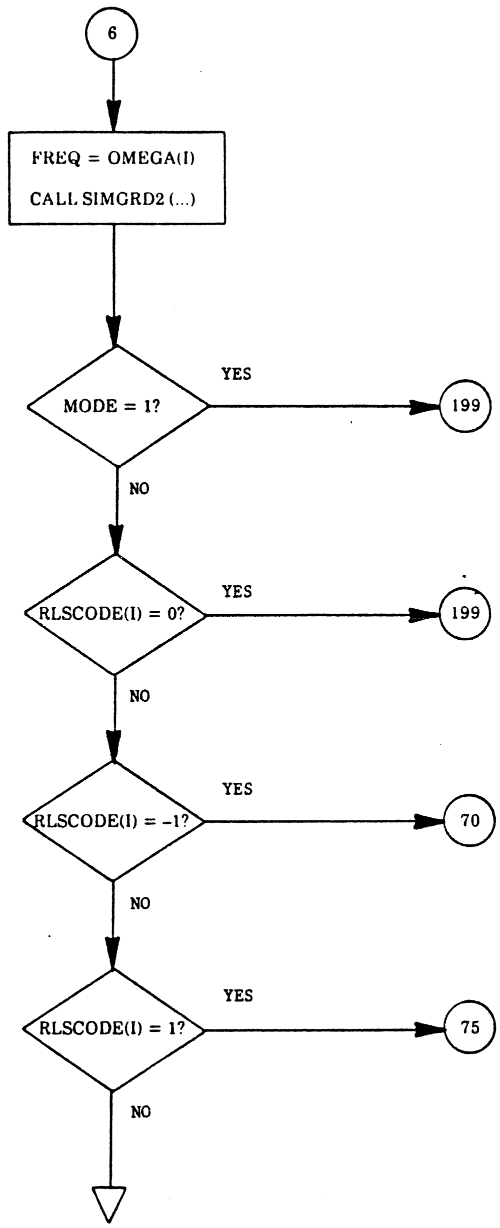

Fig. 4 Call to SIMGRD2 and processing of simultaneous return loss specifications.

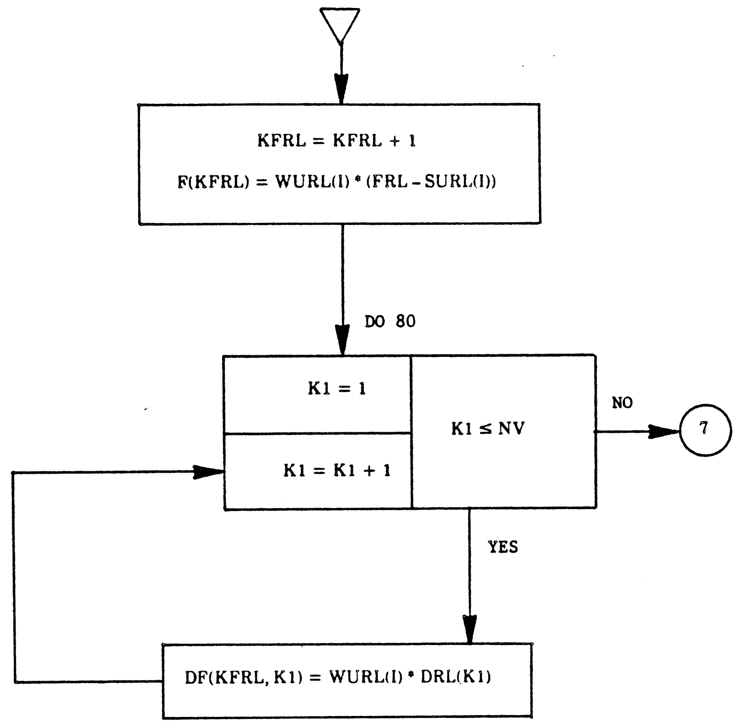

Fig. 4 (continued) Call to SIMGRD2 and processing of simultaneous return loss specifications.

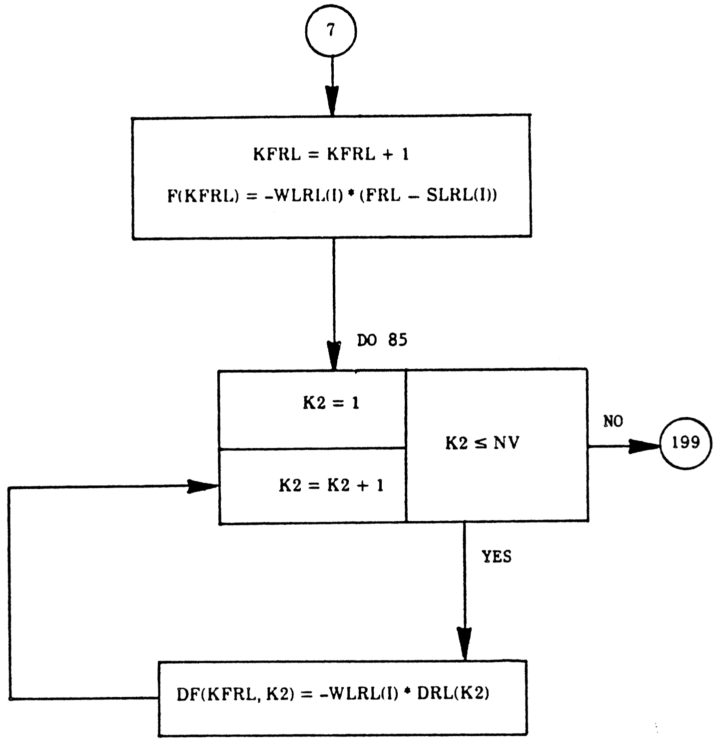

Fig. 4 (continued) Call to SIMGRD2 and processing of simultaneous return loss specifications.

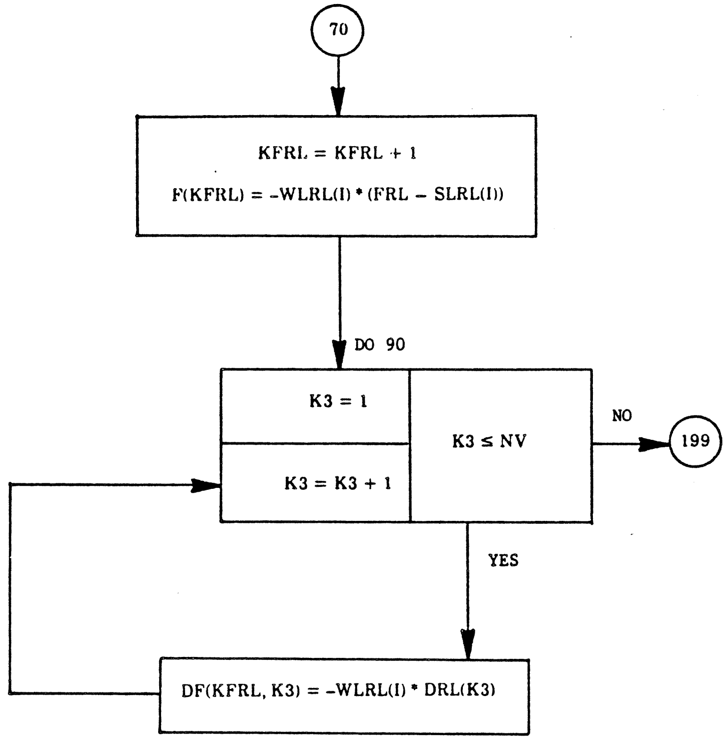

Fig. 5 Assembly of minimax functions due to lower return loss specification only.

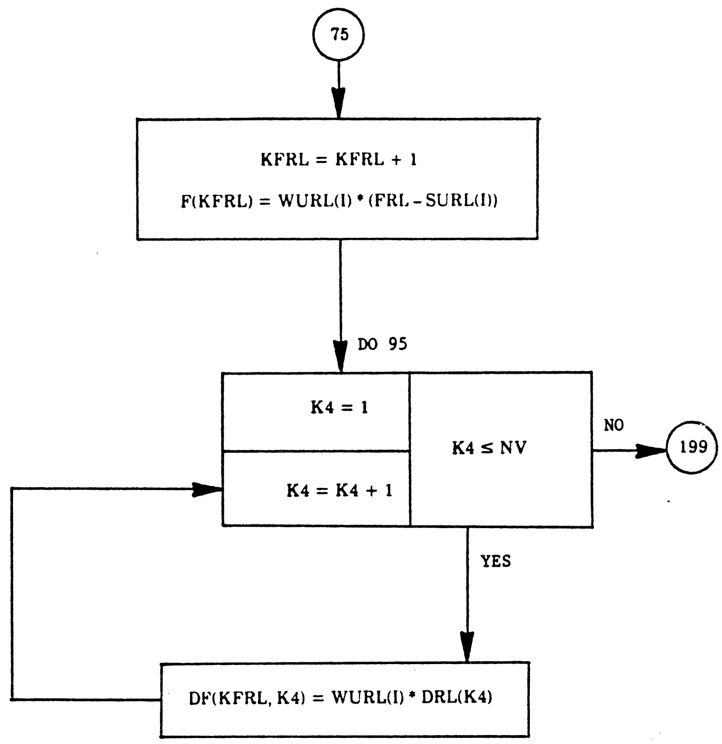

Fig. 6 Assembly of minimax functions due to upper return loss specification only.

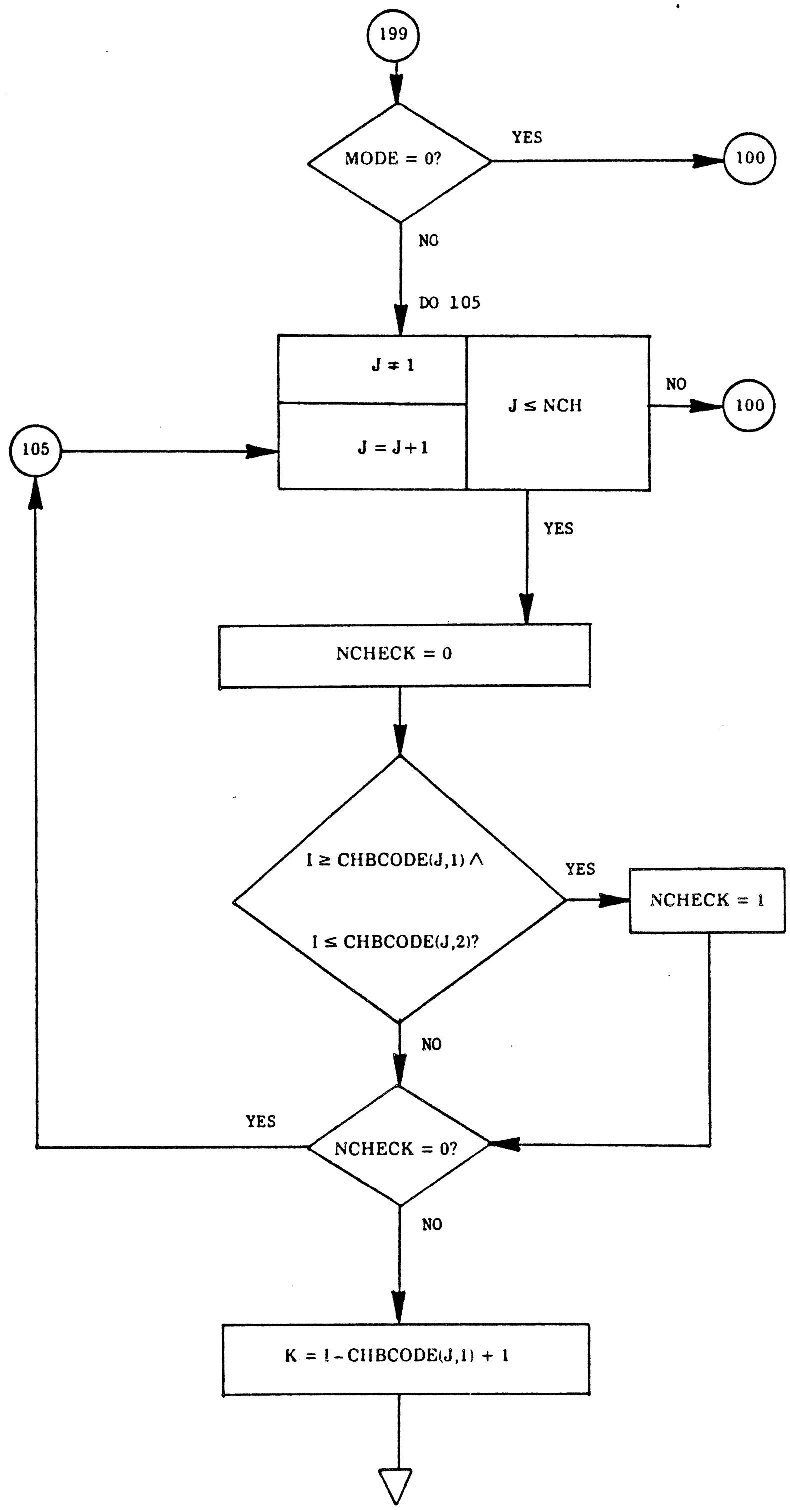

Fig. 7 Processing of channel by channel simultaneous insertion loss specifications.

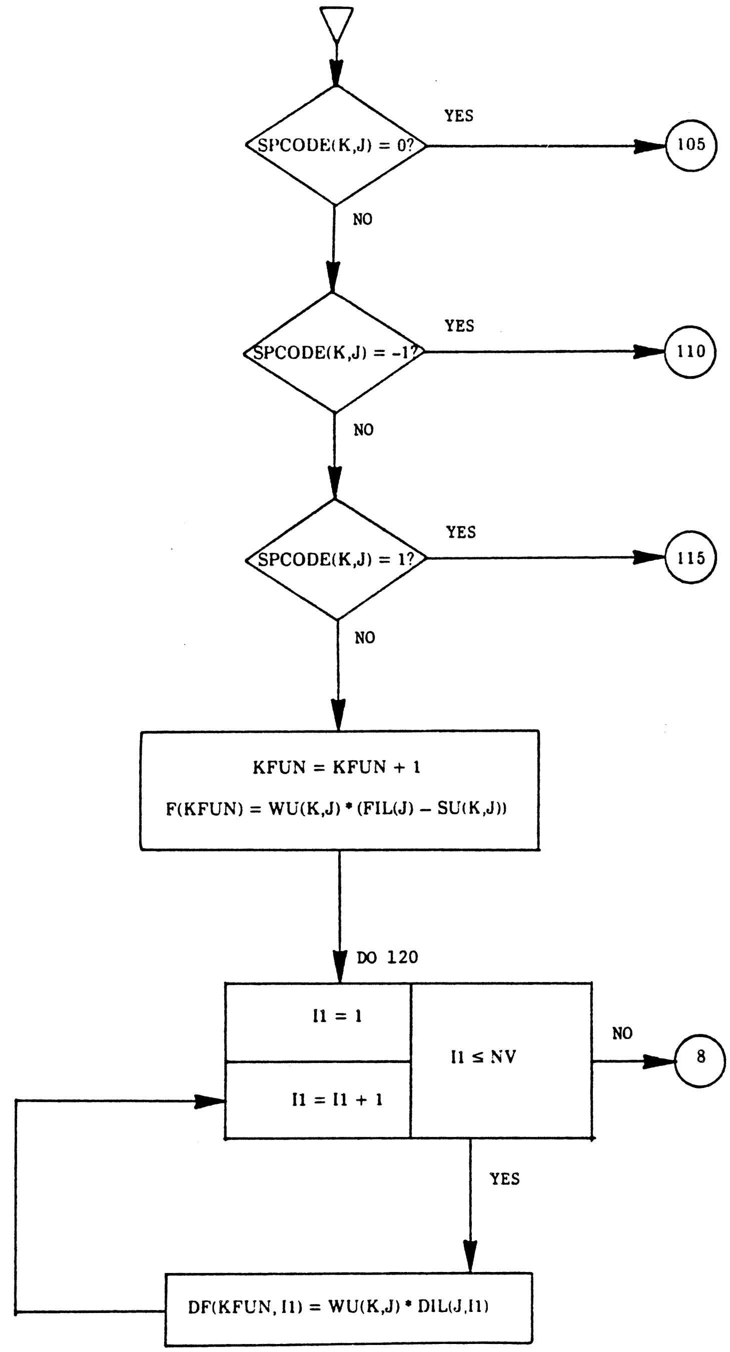

Fig. 7 (continued) Processing of channel by channel simultaneous insertion loss specifications.

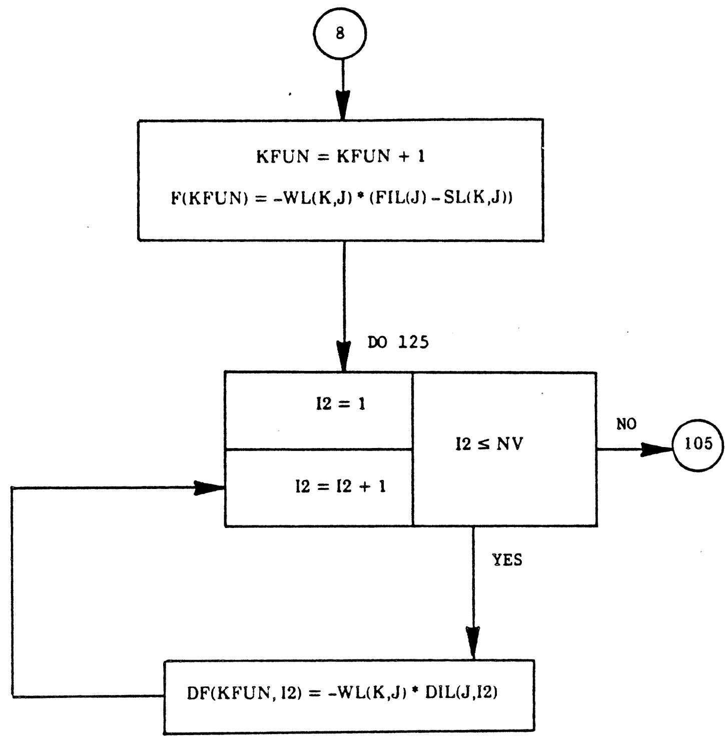

Fig. 7 (continued) Processing of channel by channel simultaneous insertion loss specifications.

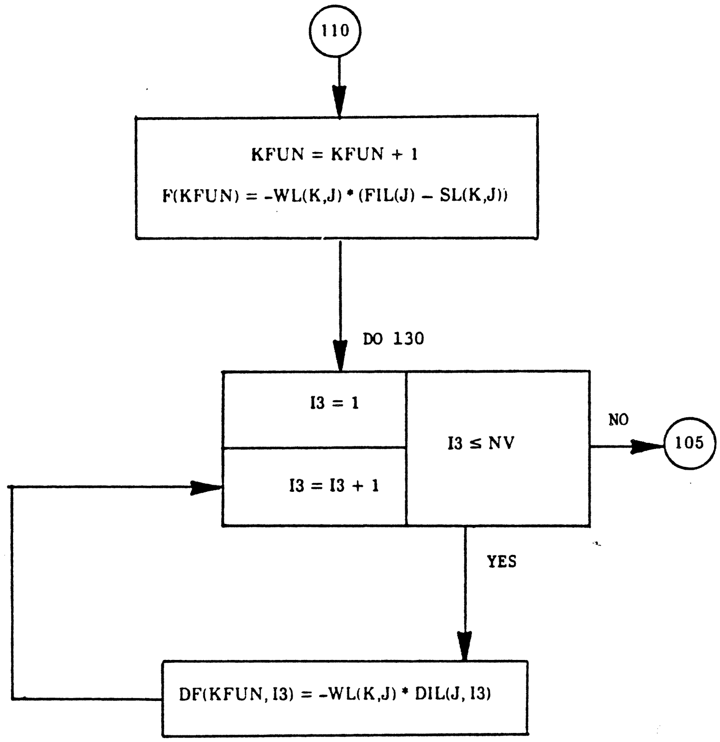

Fig. 8 Assembly of minimax functions due to lower insertion loss specifications only.

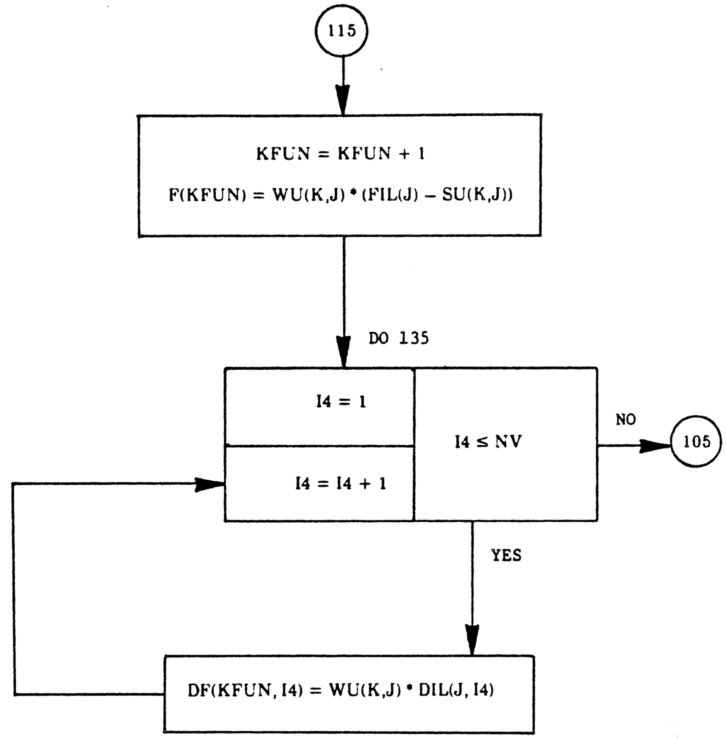

Fig. 9 Assembly of minimax functions due to upper insertion loss specifications only.

SPECIAL FEATURES OF SUBROUTINE ARGUMENTS

Introduction

This section describes some special features related to some subroutine arguments. These features should be studied and referred to frequently from the subsequent sections as if the corresponding comments and explanations are footnotes.

Features Designed as Footnotes

* Arrays designed by * are vectors or matrices corresponding to different channels, with the first dimension identifying the channel.

\+ Arrays denoted by $^+$ correspond to 2×2 matrices. The last dimension, which varies from 1 to 4, identifies the element of the matrix. The (1, 1), (1, 2), (2, 1) and (2, 2) elements are numbered 1, 2, 3 and 4, respectively.

† Variables and arrays denoted by † are intermediate constants needed for response and/or sensitivity formulas. They are used in 3 different ways.

1) Used only in the subroutine in which they are calculated. In this case, they are not among the arguments of the subroutine and are not dimensioned for the channel number.

2) Used both in the subroutine in which they are calculated and subsequent subroutines. These are usually common factors needed for both the response and its sensitivity formula. They are arguments of subroutines and the arrays are dimensioned for the channel number.

3) Used only in the subsequent subroutines. There are only a few such variables or arrays in MXSOS2 and they can be eliminated in an improved program.

Notice that the names of the † variables or arrays, except for Y3SQ, always starts with the character "H", and the INTERMEDIATE VARIABLES section could be referred to for mathematical expressions corresponding to these variables.

SUBROUTINE FILTER

SUBROUTINE FILTER (N, M, Z, P, Q)

Purpose

This subroutine solves two systems of linear equations, namely,

$$\mathbf{Z}\,\mathbf{p} = \mathbf{e}_1 \quad \text{and} \quad \mathbf{Z}\,\mathbf{q} = \mathbf{e}_m \tag{1}$$

for all channels at a given frequency, where

$$\mathbf{e}_1 \triangleq \begin{bmatrix} 1 \\ 0 \\ . \\ . \\ . \\ 0 \end{bmatrix}, \qquad \mathbf{e}_m \triangleq \begin{bmatrix} 0 \\ 0 \\ . \\ . \\ . \\ 1 \end{bmatrix} \tag{2}$$

Theory

Using the narrow-band unterminated model of the multi-cavity filter given by [1]

$$\mathbf{Z}\,\mathbf{I} = \mathbf{V} \tag{3}$$

the s.c. admittance matrix $\mathbf{y}$ is obtained from [1, 2]

$$\mathbf{y} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} = \begin{bmatrix} (\mathbf{Z}^{-1})_{11} & (\mathbf{Z}^{-1})_{1m} \\ (\mathbf{Z}^{-1})_{m1} & (\mathbf{Z}^{-1})_{mm} \end{bmatrix} \tag{4}$$

Our objective is to calculate $\mathbf{y}$ and its sensitivities w.r.t. any variable ϕ. To facilitate this we adopt a computational approach similar to the one introduced to circuit theorists by Branin [3] and which involves only simple matrix manipulations. Starting with y_{11}, we have

$$y_{11} = (\mathbf{Z}^{-1})_{11} = \mathbf{e}_1^T \mathbf{Z}^{-1} \mathbf{e}_1 = \mathbf{e}_1^T \mathbf{p} = p_1 \,, \tag{5}$$

where p_1 is the first component of $\mathbf{p}$ in the solution of

$$\mathbf{Z}\,\mathbf{p} = \mathbf{e}_1 \tag{6}$$

and

$$\frac{\partial y_{11}}{\partial \phi} = \frac{\partial (\mathbf{Z}^{-1})_{11}}{\partial \phi} = \mathbf{e}_1^T \frac{\partial (\mathbf{Z}^{-1})}{\partial \phi} \mathbf{e}_1 = -\,\mathbf{e}_1^T \mathbf{Z}^{-1} \frac{\partial (\mathbf{Z})}{\partial \phi} \mathbf{Z}^{-1} \mathbf{e}_1 = -\,\mathbf{p}^T \frac{\partial \mathbf{Z}}{\partial \phi} \mathbf{p} \,. \tag{7}$$

Similarly, we can find y_{12}, y_{21}, y_{22} and their sensitivities. Taking into account that $\mathbf{Z}$ is symmetric and solving the system

$$\mathbf{Z}\,\mathbf{q} = \mathbf{e}_m, \tag{8}$$

the results can be summarized as [4]:

$$\mathbf{y} = \begin{bmatrix} p_1 & q_1 \\ q_1 & q_m \end{bmatrix} \tag{9}$$

and

$$\frac{\partial \mathbf{y}}{\partial \phi} = \begin{bmatrix} -\mathbf{p}^T \dfrac{\partial \mathbf{Z}}{\partial \phi}\,\mathbf{p} & -\mathbf{q}^T \dfrac{\partial \mathbf{Z}}{\partial \phi}\,\mathbf{p} \\ -\mathbf{q}^T \dfrac{\partial \mathbf{Z}}{\partial \phi}\,\mathbf{p} & -\mathbf{q}^T \dfrac{\partial \mathbf{Z}}{\partial \phi}\,\mathbf{q} \end{bmatrix}. \tag{10}$$

It is clear that the solution vectors $\mathbf{p}$ and $\mathbf{q}$ are needed for solutions of (9) and (10).

List of Arguments

N is the number of multiplexer channels.

M is the order of the matrix (order of the filters).

Z is the impedance matrix at a given frequency. It is a three-dimensional array with the first dimension corresponding to the channel number. Therefore, it contains the elements of impedance matrices for all channels.

P is the solution vector to the system given by (6). It contains the solutions for all channels, hence it is a two-dimensional array with the first dimension identifying the channel number.

Q contains the solutions to (8) for all channels in the same fashion as P above.

Related Software

This subroutine is called from SIMUL and SIMGRD2 and it calls CSOLLU for the solution of linear systems of equations.

Comments

1) The solution is obtained on a channel by channel basis.

2) The solution for the system defined by (6) requires LU factorization with Forward-Backward Substitutions (FBS), however, using the same LU factors, the solution for **q** requires only FBS.

References

[1] A.E. Atia and A.E. Williams, "New types of waveguide bandpass filters for satellite applications", COMSAT Technical Review, vol. 1, 1971, pp. 21-43.

[2] M.H. Chen, "Singly terminated pseudo-elliptic function filter", COMSAT Technical Review, vol. 7, 1977, pp. 527-541.

[3] F.H. Branin, Jr., "Network sensitivity and noise analysis simplified", IEEE Trans. Circuit Theory, vol. CT-20, 1973, pp. 285-288.

[4] J.W. Bandler, S.H. Chen, S. Daijavad and W. Kellermann, "Optimal design of multi-cavity filters and contiguous-band multiplexers", Proc. 14th European Microwave Conf., (Liège, Belgium, Sept. 1984).

```
      SUBROUTINE FILTER(N,M,Z,P,Q)
C
C     PERFORM ANALYSES FOR ALL CHANNELS
C
C     N   NUMBER OF CHANNELS
C     M   ORDER OF MATRIX
C     Z   IMPEDANCE MATRIX
C
      COMPLEX Z(16,8,8),ZT(8,8),P(16,8),Q(16,8),PT(8),QT(8)
C
      DO 10 I=1,N
C
      DO 11 J=1,M
C
      PT(J)=(0.0,0.0)
      QT(J)=(0.0,0.0)
      PT(1)=(1.0,0.0)
      QT(M)=(1.0,0.0)
C
C     SET TWO-DIMENSIONAL Z MATRIX
C
      DO 11 K=1,M
      ZT(J,K)=Z(I,J,K)
   11 CONTINUE
C
C     SET PARAMETER TO PERFORM LU FACTORIZATION AND FORWARD-
C     BACKWARD SUBSTITUTION FOR UNIT VOLTAGE AT INPUT
C
      IPAR=0
C
      CALL CSOLLU(M,ZT,PT,IFALL,IPAR)
C
C     SET PARAMETER TO PERFORM ONLY FORWARD-BACKWARD SUBSTITUTION
C     FOR UNIT VOLTAGE AT OUTPUT
C
      IPAR=1
C
      CALL CSOLLU(M,ZT,QT,IFALL,IPAR)
C
C     SET TWO DIMENSIONAL SOLUTION VECTORS,EACH COLUMN
C     CORRESPONDING TO ONE CHANNEL
C
      DO 12 J=1,M
      P(I,J)=PT(J)
      Q(I,J)=QT(J)
   12 CONTINUE
C
   10 CONTINUE
      RETURN
      END
C
```

Fig. 1   Listing of the subroutine FILTER.

SUBROUTINE FILABCD

SUBROUTINE FILABCD (N, M, P, Q, PN1, PN2, Y1, GL, YC, Y, YP, YIN, Y3, Y3SQ, TF, H7, H8, H13, H14, PN11, PN12, PN22)

Purpose

This subroutine calculates the equivalent ABCD matrices of filter-junction combinations as seen in the waveguide manifold.

Theory

Using the solution vectors **p** and **q** evaluated in FILTER, we form the s.c. admittance matrix **y** of (9). Matrix **y** is then modified to include the input and output transformer ratios n_1 and n_2, respectively. The result is matrix **y**$'$, given by [1]

$$\mathbf{y}' = \begin{bmatrix} n_1^2 y_{11} & n_1 n_2 y_{21} \\ n_1 n_2 y_{21} & n_2^2 y_{22} \end{bmatrix} \tag{1}$$

This modification is illustrated schematically by Fig. 1. Next, we find the input admittance Y_{in} of the filter terminated by a load conductance G_L as

$$Y_{in} = y'_{11} - \frac{(y'_{21})^2}{y'_{22} + G_L} . \tag{2}$$

For appropriate definitions of variables see Fig. 2. Taking the effect of the impedance inverter into account, we assign as per Fig. 3

$$Y_{in} \leftarrow 1/Y_{in} . \tag{3}$$

If the junction is modelled by the complex series and shunt admittances [2-3] Y_c and Y_1, respectively, and we denote (see Fig. 4)

$$Y_3 = Y_{in} + Y_c , \tag{4}$$

we can find the complex ABCD matrix of the filter-junction combination, namely $\mathbf{T}_f$, as

$$\mathbf{T}_f = \begin{bmatrix} 1 + Y_1/Y_3 & 1/Y_3 \\ Y_1(2 + Y_1/Y_3) & 1 + Y_1/Y_3 \end{bmatrix} . \tag{5}$$

T_f is designated by the array TF in Fig. 4.

List of Arguments

N	is the number of multiplexer channels.
M	is the order of the matrix of filter coefficients.
P	is the solution to FILTER (6).*
Q	is the solution to FILTER (8).*
PN1	is the input transformer ratio (n_1), as shown in Fig. 1.*
PN2	is the output transformer ratio (n_2), as shown in Fig. 1.*
Y1	is the shunt junction admittance, as indicated by Fig. 4.*
GL	is the terminating load conductance G_L, as illustrated in Fig. 2.*
YC	is the series admittance of the junction model, as indicated in Fig. 4.*
Y	is the matrix **y** of FILTER (9), as indicated in Fig. 1.*+.
YP	is the matrix **y′** of (1), as indicated in Fig. 1.*+
YIN	is the Y input admittance Y_{in}. See Figs. 2 and 3.*
Y3	is the parallel combination of Y_{in} and Y_c given by (4), as illustrated in Fig. 4.*
Y3SQ	is $(Y_3)^2$.*†
TF	is the ABCD matrix of the filter-junction combination, T_f, defined by (5) and identified in Fig. 4.*+
H7, H8, H13, H14	are intermediate variables defined in the VARIABLES section.† They are easily identified as common variables principally used in (2).
PN11	is $(n_1)^2$.*
PN12	is $n_1 n_2$.*
PN22	is $(n_2)^2$.*

Related Software

This subroutine is called from SIMUL and SIMGRD2.

References

[1] M.H. Chen, "Singly terminated pseudo-elliptic function filter", COMSAT Technical Review, vol. 7, 1977, pp. 527-541.

[2] A.E. Atia, "Computer-aided design of waveguide multiplexers", IEEE Trans. Microwave Theory Tech., vol. MTT-22, 1974, pp. 332-336.

[3] M.H. Chen, F. Assal and C. Mahle, "A contiguous band multiplexer", COMSAT Technical Review, vol. 6, 1976, pp. 285-306.

Footnote

For an explanation of *, + and † see FEATURES.

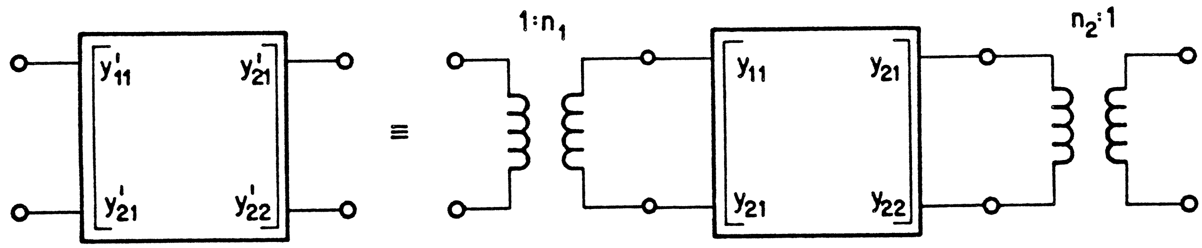

Fig. 1 Modification of the filter equivalent matrix **y** to include input and output ideal transformers.

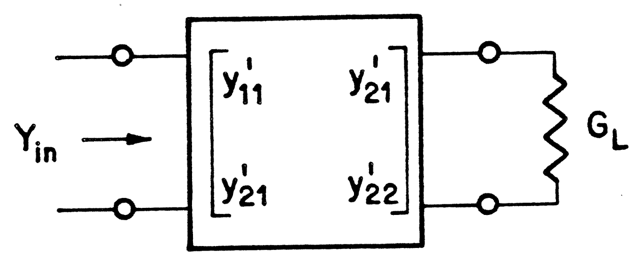

Fig. 2 Input admittance for a filter terminated by conductance G_L after inclusion of n_1 and n_2 as indicated by Fig. 1.

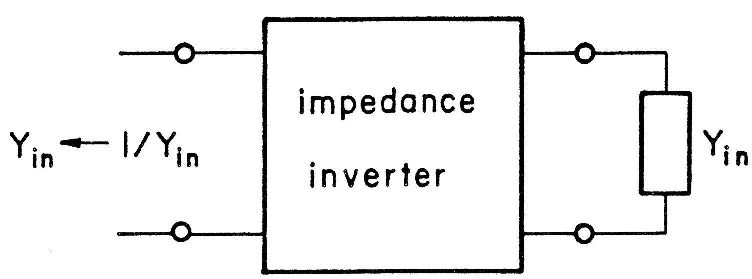

Fig. 3 Effect on Y_{in} of Fig. 2 of an impedance inverter.

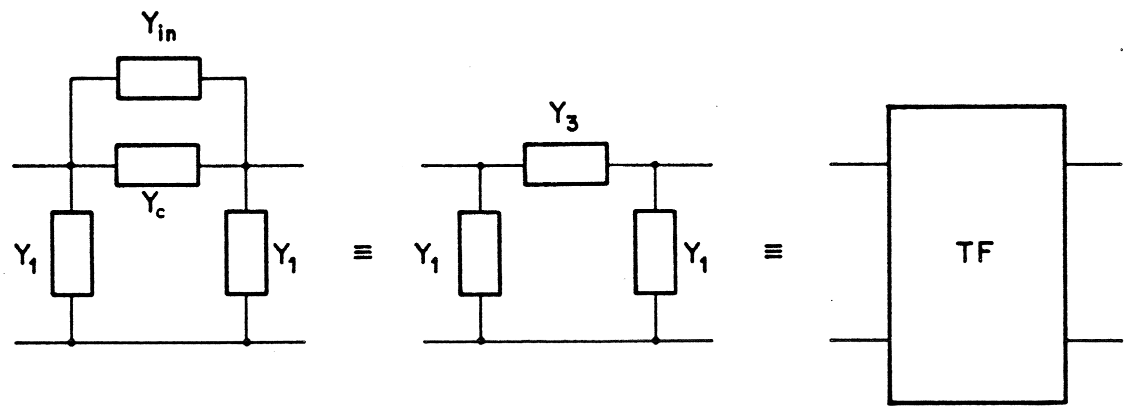

Fig. 4 Filter-junction combination. Y_{in} represents the filter, Y_1 and Y_c the junction admittances. TF represents the ABCD matrix of the combination.

```
C
      SUBROUTINE FILABCD(N,M,P,Q,PN1,PN2,Y1,GL,YC,Y,YP,YIN,Y3,
     +                   Y3SQ,TF,H7,H8,H13,H14,PN11,PN12,PN22)
C
C     CALCULATION OF EQUIVALENT ABCD MATRICES OF FILTER-
C     JUNCTION COMBINATIONS AS SEEN IN THE WAVEGUIDE MANIFOLD
C
      COMPLEX Y(16,4),YP(16,4),YIN(16),Y3(16),Y3SQ(16),TF(16,4)
      COMPLEX P(16,8),Q(16,8),Y1(16),YC(16)
      COMPLEX H7(16),H8(16),H13(16),H14(16)
      REAL PN1(16),PN2(16),GL(16)
      REAL PN11(16),PN12(16),PN22(16)
C
C     CALCULATION OF SHORT-CIRCUIT ADMITTANCE MATRIX "Y" OF
C     EACH FILTER
C
      DO 13 I=1,N
C
      Y(I,1)=P(I,1)
      Y(I,2)=Q(I,1)
      Y(I,3)=Y(I,2)
      Y(I,4)=Q(I,M)
C
C     PREPARATION FOR INCLUSION OF IDEAL TRANSFORMERS
C
      PN11(I)=PN1(I)*PN1(I)
      PN12(I)=PN1(I)*PN2(I)
      PN22(I)=PN2(I)*PN2(I)
C
C     INCLUSION INTO Y MATRIX OF THE INPUT-OUTPUT TRANSFORMERS
C
      YP(I,1)=PN11(I)*Y(I,1)
      YP(I,2)=PN12(I)*Y(I,2)
      YP(I,3)=YP(I,2)
      YP(I,4)=PN22(I)*Y(I,4)
C
C     SAVE COMMON FACTORS FOR USE WITH SENSITIVITY FORMULAS
C
      H7(I)=YP(I,4)+GL(I)
      H8(I)=YP(I,2)*YP(I,2)
      H13(I)=H8(I)/(H7(I)*H7(I))
      H14(I)=Y1(I)*Y1(I)
C
      YIN(I)=YP(I,1)-H8(I)/H7(I)
C
C     USE AN IMPEDANCE INVERTER
C
      YIN(I)=1.0/YIN(I)
C
C     CONNECT THE FILTER TO THE MANIFOLD JUNCTION
C
      Y3(I)=YC(I)+YIN(I)
      Y3SQ(I)=Y3(I)*Y3(I)
C
      TF(I,1)=1.0+Y1(I)/Y3(I)
      TF(I,2)=1.0/Y3(I)
      TF(I,3)=Y1(I)*TF(I,1)+Y1(I)
      TF(I,4)=1.0+Y1(I)/Y3(I)
C
   13 CONTINUE
      RETURN
      END
C
```

Fig. 5 Listing of the subroutine FILABCD.

SUBROUTINE MATMUL

SUBROUTINE MATMUL (V1, V2, V3, V4, V5, V6, V7, V8, V9, V10, V11, V12)

Purpose

This subroutine performs the multiplication of 2×2 complex matrices.

List of Arguments

V1, V2, V3, V4	are elements of the first matrix.
V5, V6, V7, V8	are elements of the second matrix.
V9, V10, V11, V12	are elements of the product matrix.

Related Software

This subroutine is called from SEQUENC, RESPONS, SIMUL, DABCDF2, DRLOSS2, DVOLTA2 and SIMGRD2.

Comments

1) The positions of the elements of the matrices can be shown as

$$\begin{bmatrix} V1 & V2 \\ V3 & V4 \end{bmatrix} \begin{bmatrix} V5 & V6 \\ V7 & V8 \end{bmatrix} = \begin{bmatrix} V9 & V10 \\ V11 & V12 \end{bmatrix} \quad (1)$$

2) The arguments of the subroutine can be elements of one-, two- or three-dimensional arrays.

```
C
      SUBROUTINE MATMUL(V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,V12)
C
C     COMPLEX 2X2 MATRIX MULTIPLICATION
C
      COMPLEX V1,V2,V3,V4,V5,V6,V7,V8,V9,V10,V11,V12
      V9=V1*V5+V2*V7
      V10=V1*V6+V2*V8
      V11=V3*V5+V4*V7
      V12=V3*V6+V4*V8
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine MATMUL.

SUBROUTINE BETAVAL

SUBROUTINE BETAVAL (C1, C2, OMEG, PI2, BETA)

Purpose

This subroutine calculates the rectangular waveguide manifold propagation phase constant β.

Theory

Denoting the velocity of light in free space by c, where c = 11802.85 inch/μsec, we can calculate the free space wavelength λ and the guide wavelength λ_g in inches, from

$$\lambda = \frac{c}{f}, \tag{1}$$

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}} , \tag{2}$$

where f is the frequency in MHz and variable a denotes the manifold width in inches. The phase constant β is then given by

$$\beta = \frac{2\pi}{\lambda_g} , \tag{3}$$

List of Arguments

C1	is the velocity of light c in inch/μsec.
C2	is $4a^2$, where a is the manifold width.
OMEG	is the frequency in MHz.
PI2	is 2π.
BETA	is β given by (3).

Related Software

This subroutine is called from SIMUL and SIMGRD2.

```
C
      SUBROUTINE BETAVAL(C1,C2,OMEG,PI2,BETA)
C
C     WAVEGUIDE MANIFOLD PROPAGATION PHASE CONSTANT IS CALCULATED
C
      REAL LAM,LAMG
      LAM=C1/OMEG
      LAMG=LAM/SQRT(1.0-LAM*LAM/C2)
      BETA=PI2/LAMG
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine BETAVAL.

SUBROUTINE WGUIDE

SUBROUTINE WGUIDE (N, BETA, WGL, TG, DTG)

Purpose

This subroutine calculates the ABCD matrices of the waveguide manifold spacings and their derivatives w.r.t. the spacings (section lengths).

Theory

The ABCD matrix of a waveguide spacing characterized by the phase constant β and characteristic impedance Z_0 is given by

$$\mathbf{T}_g = \begin{bmatrix} \cos\beta\ell & jZ_0\sin\beta\ell \\ \frac{j}{Z_0}\sin\beta\ell & \cos\beta\ell \end{bmatrix} \tag{1}$$

where ℓ denotes the section length. Derivative of $\mathbf{T}_g$ w.r.t. ℓ is given by

$$\frac{\partial}{\partial\ell}(\mathbf{T}_g) = \begin{bmatrix} -\beta\sin\beta\ell & jZ_0\beta\cos\beta\ell \\ \frac{j}{Z_0}\beta\cos\beta\ell & -\beta\sin\beta\ell \end{bmatrix} \tag{2}$$

List of Arguments

N	is the number of channels.
BETA	is the phase constant β given by BETAVAL (3).
WGL	is the section length ℓ.*
TG	is the ABCD matrix of the waveguide spacing given by (1).*+
DTG	is the derivative of TG w.r.t. section length given by (2).*+

Related Software

This subroutine is called from SIMUL and SIMGRD2.

Comment

In an improved program, calculation of $\partial(T_g)/\partial\ell$ should be avoided when only simulation is required.

Footnote

For an explanation of * and + see FEATURES.

```
C
      SUBROUTINE WGUIDE(N,BETA,WGL,TG,DTG)
C
C     CALCULATE ABCD MATRICES OF THE WAVEGUIDE SPACINGS AND
C     THEIR DERIVATIVES W.R.T. SPACINGS(SECTION LENGTHS)
C
      COMPLEX TG(16,4),DTG(16,4)
      REAL WGL(16)
C
      CZ=1.0
      CZ2=CZ*CZ
C
      DO 77 I=1,N
      TETA=BETA*WGL(I)
C
      TG(I,1)=CMPLX(COS(TETA),0.0)
      TG(I,2)=CMPLX(0.0,SIN(TETA)*CZ)
      TG(I,3)=TG(I,2)/CZ2
      TG(I,4)=TG(I,1)
C
      DTG(I,1)=CMPLX(-BETA*SIN(TETA),0.0)
      DTG(I,2)=CMPLX(0.0,COS(TETA)*CZ*BETA)
      DTG(I,3)=DTG(I,2)/CZ2
      DTG(I,4)=DTG(I,1)
   77 CONTINUE
C
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine WGUIDE.

SUBROUTINE SEQUENC

SUBROUTINE SEQUENC (N, NP1, T, A)

Purpose

This subroutine calculates the equivalent ABCD matrices of all possible adjacent cascaded sections.

Theory

After evaluation of $\mathbf{T}_f$ and $\mathbf{T}_g$ for each section (using FILABCD (5) and WGUIDE (1), respectively), we find the ABCD matrix of a section, namely **T**, from (see Fig. 1)

$$\mathbf{T} = \mathbf{T}_f \mathbf{T}_g . \tag{1}$$

Hence, we have $\mathbf{T}_i$, i = 1,2,...,N, where N is the number of channels.

The multiplexer structure is a cascade of N sections, where each section is represented by its T matrix. (See Fig. 2).

For a complete simulation and sensitivity analysis of common port return loss and channel insertion losses, we need all the possible products of adjacent section matrices [1] as shown in Fig. 3. We can denote all possible products by $\mathbf{A}_{i,j}$, where

$$\mathbf{A}_{i,j} = \begin{cases} \mathbf{T}_{j-1} \ \mathbf{T}_{j-2} \ \cdots \ \mathbf{T}_i , & \text{if } j > i , \quad (2a) \\ \mathbf{1}_{2\times 2} \quad , & \text{if } j = 1 , \quad (2b) \\ \text{not defined} , & \text{if } j < i , \quad (2c) \end{cases}$$

for i = 1,2,...,N + 1 and j = 1,2,...,N + 1.

List of Arguments

N is the number of channels.

NP1 is N + 1.

T is the ABCD matrix of a complete section as given in (1).*+

A contains all possible products of adjacent T matrices. It is a three-dimensional array with the first dimension corresponding to the starting section, the second dimension is one more than the ending section and the third dimension identifies the element of the matrix.+

Related Software

This subroutine is called from SIMUL and SIMGRD2.

Comments

1) If we were only interested in the common port return loss and channel insertion loss responses (simulation only), as we see in the theory for SUBROUTINE RESPONS, a full reverse analysis [1] would be sufficient. The return loss formula needs $\mathbf{A}_{1,N+1}$ and the insertion loss for channel i requires $\mathbf{A}_{1,i}$, which is a by-product of calculations for $\mathbf{A}_{1,N+1}$.

2) The derivative of the common port return loss w.r.t. a variable ϕ in section j, requires the evaluation of $\partial\mathbf{A}_{1,N+1}/\partial\phi = \mathbf{A}_{j+1,N+1}\,(\partial\mathbf{T}_j/\partial\phi)\,\mathbf{A}_{1,j}$. A full reverse analysis has already given us $\mathbf{A}_{1,j}$. Evaluation of $\mathbf{A}_{j+1,N+1}$, because of the fact that only j varies, could be accomplished by one full forward analysis. However, in SEQUENC forward analysis is not performed and $\mathbf{A}_{j+1,N+1}$ is obtained as the by-product of a more complicated computational scheme required by channel insertion loss sensitivity analysis.

3) The derivative of the insertion loss for channel i w.r.t. a variable ϕ in section j, where $j < i$, requires the evaluation of $\partial\mathbf{A}_{1,i}/\partial\phi = \mathbf{A}_{j+1,i}\,(\partial\mathbf{T}_j/\partial\phi)\mathbf{A}_{1,j}$. Evaluation of $\mathbf{A}_{j+1,i}$, where both i and j vary, is the reason for the substantial computational effort in SEQUENC, which is considerably more than just a forward and reverse analysis.

References

[1] L.S. Lasdon and A.D. Waren, "Optimal design of filters with bounded, lossy elements", IEEE Trans Circuit Theory, vol. CT-13, 1966, pp. 175-187.

[2] J.W. Bandler, M.R.M. Rizk and H.L. Abdel-Malek, "New results in network simulation, sensitivity and tolerance analysis for cascaded structures", IEEE Trans. Microwave Theory Tech., vol. MTT-26, 1978, pp. 963-972.

Footnote

For an explanation of * and + see FEATURES.

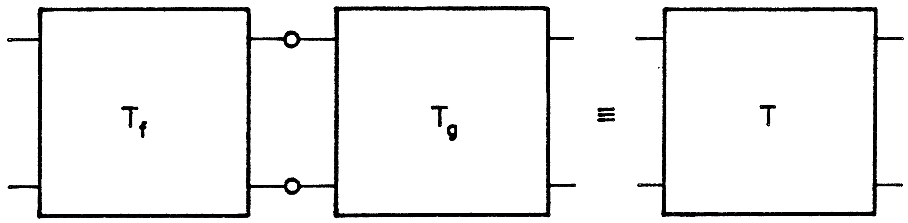

Fig. 1 Cascade combination of a filter-junction and waveguide spacing forming a complete section.

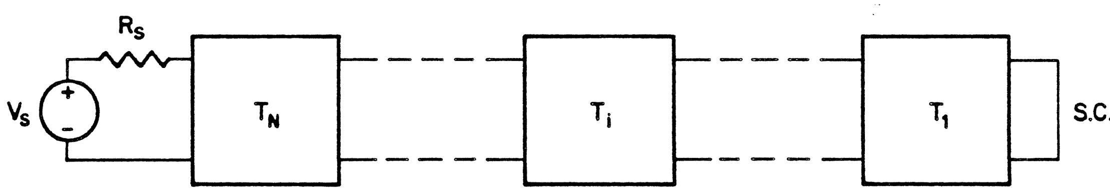

Fig. 2 Multiplexer structure after reduction to a simple cascaded network using the **T** elements defined in Fig. 1.

T_1			
T_2T_1	T_2		
$T_3T_2T_1$	T_3T_2	T_3	
.	.	.	.
.	.	.	.
.	.	.	.
$T_N \dots T_3T_2T_1$	$T_N \dots T_3T_2$	$T_N \dots T_3$	. . . T_NT_{N-1}

Fig. 3 All the possible products of adjacent section matrices as defined by (2).

```
C
      SUBROUTINE SEQUENC(N,NP1,T,A)
C
C     CALCULATE THE EQUIVALENT ABCD MATRICES OF ALL POSSIBLE
C     ADJACENT CASCADED SECTIONS AND STORE THEM IN THE A MATRICES.
C     MATRIX A(I,J,.) INDICATES CALCULATIONS FROM REFERENCE
C     PLANE I TO REFERENCE PLANE J  ,WHERE J>I.
C     T IS THE  ABCD MATRIX OF A SECTION(FILTER-JUNCTION COMBINATION
C     AND WAVEGUIDE SPACING)
C
      COMPLEX T(16,4),A(17,17,4)
C
C     INITIALIZE UNIT MATRICES
C
      DO 16 I=1,NP1
C
      A(I,I,1)=CMPLX(1.0,0.0)
      A(I,I,2)=CMPLX(0.0,0.0)
      A(I,I,3)=A(I,I,2)
      A(I,I,4)=A(I,I,1)
C
   16 CONTINUE
C
      DO 17 I=1,N
      IP1=I+1
C
      DO 18 J=IP1,NP1
      JM1=J-1
C
      CALL MATMUL(T(JM1,1),T(JM1,2),T(JM1,3),T(JM1,4),A(I,JM1,1),
     +            A(I,JM1,2),A(I,JM1,3),A(I,JM1,4),A(I,J,1),
     +            A(I,J,2),A(I,J,3),A(I,J,4))
C
   18 CONTINUE
   17 CONTINUE
      RETURN
      END
C
```

Fig. 4 Listing of the subroutine SEQUENC.

SUBROUTINE RESPONS

SUBROUTINE RESPONS (N, NP1, RS, ZIN, RLOSS, VL, A, H23, H1, RO, RCOEFF, YC, YP, TG, Y1, VS, H2, H3, H4, H5, H6, H7, H9, H10)

Purpose

This subroutine calculates the common port return loss and output voltage for each channel.

Theory

After evaluation of the **A** matrices in SUBROUTINE SEQUENC, Fig. 2 of SEQUENC can be further simplified. The result is shown in Fig. 1. Denoting the input impedance by Z_{in}, the reflection coefficient by ρ and the common port return loss by L_R, we have [1, 2]

$$Z_{in} = \frac{\mathbf{e}_1^T \mathbf{A}_{1,N+1} \mathbf{e}_2}{\mathbf{e}_2^T \mathbf{A}_{1,N+1} \mathbf{e}_2} , \tag{1}$$

$$\rho = \frac{Z_{in} - R_S}{Z_{in} + R_S} , \tag{2}$$

and

$$L_R = -20\log|\rho| , \tag{3}$$

where $\mathbf{e}_1 = [1 \;\; 0]^T$, $\mathbf{e}_2 = [0 \;\; 1]^T$ and R_S is the source resistance.

To calculate the channel output voltages, direct application of the formulas presented by Bandler, Rizk and Abdel-Malek [1], specifically their equation (21), for the ith channel, gives

$$V_L^i = \frac{\mathbf{e}_2^T \begin{bmatrix} 1 & 0 \\ Y_1^i & 1 \end{bmatrix} \mathbf{T}_g^i \mathbf{A}_{1,i} \mathbf{e}_2 V_S}{\left(\mathbf{e}_2^T \begin{bmatrix} 1 & 0 \\ Y_c^i & 1 \end{bmatrix} \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix} \mathbf{T}_{ff}^i \begin{bmatrix} 1 \\ G_L^i \end{bmatrix} \right) \left(\mathbf{e}_1^T \begin{bmatrix} 1 & R_S \\ 0 & 1 \end{bmatrix} \mathbf{A}_{1,N+1} \mathbf{e}_2 \right)} , \tag{4}$$

(see Fig. 2), where V_S is the source voltage and T_{ff} is the ABCD matrix for an unterminated filter including input and output transformers. Using y' from (1) of FILABCD and converting the s.c. admittance matrix to an ABCD matrix, T_{ff} is actually evaluated as [2]

$$T_{ff} = \begin{bmatrix} -y'_{22}/y'_{21} & -1/y'_{21} \\ y'_{21} - \dfrac{y'_{11}\, y'_{22}}{y'_{21}} & -y'_{11}/y'_{21} \end{bmatrix}, \qquad (5)$$

Using (5) and some simplifications, we get

$$e_2^T \begin{bmatrix} 1 & 0 \\ Y_c & 1 \end{bmatrix} \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix} T_{ff} \begin{bmatrix} 1 \\ G_L \end{bmatrix} = j \left[Y_c\, y'_{21} - \frac{\left(y'_{22} + G_L\right)\left(1 + Y_c\, y'_{11}\right)}{y'_{21}} \right], \qquad (6)$$

and $V_L{}^i$ becomes

$$V_L^i = \frac{j[Y_1 \quad 1]\, T_g^i\, A_{1,i}\, e_2\, V_S}{\left(\dfrac{\left(y'_{22} + G_L\right)\left(1 + Y_c\, y'_{11}\right)}{y'_{21}} - Y_c\, y'_{21} \right) [1 \quad R_S] A_{1,N+1}\, e_2}. \qquad (7)$$

Note that we have omitted the superscript i needed for y_{11}', y_{21}', y_{22}', Y_c, G_L and Y_1, for simplicity.

List of Arguments

N	is the number of channels.
NP1	is N + 1.
RS	is the source resistance in ohms.
ZIN	is the complex input impedance at the common port.
RLOSS	is the return loss in dB.
VL	is the channel output voltage.*
A	is as defined in SEQUENC.
H23, H1	are intermediate variables defined in the VARIABLES section.†
RO	is the modulus of the reflection coefficient, $\lvert\rho\rvert$.
RCOEFF	is the complex reflection coefficient ρ.

YC is as defined in FILABCD.

YP is as defined in FILABCD.

TG is as defined in WGUIDE.

Y1 is as defined in FILABCD.

VS is the source voltage.

H2, H3, H4, H5, H6, H7, H9 and H10 are intermediate variables defined in the VARIABLES section.†

Related Software

This subroutine is called from SIMUL and SIMGRD2.

References

[1] J.W. Bandler, M.R.M. Rizk and H.L. Abdel-Malek, "New results in network simulation, sensitivity and tolerance analysis for cascaded structures", IEEE Trans. Microwave Theory Tech., vol. MTT-26, 1978, pp. 963-972.

[2] G.L. Matthaei, L. Young and E.M.T. Jones, Microwave Filters, Impedance Matching Networks and Coupling Structures. New York: McGraw-Hill, 1964, Chap. 2.

Footnote

For an explanation of * and † see FEATURES.

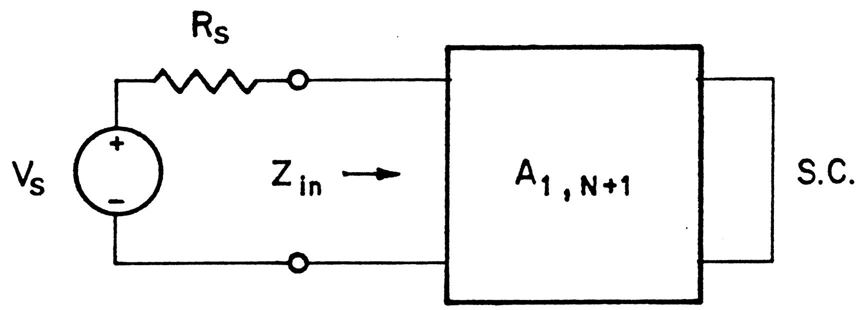

Fig. 1 Simplified multiplexer structure for the calculation of return loss.

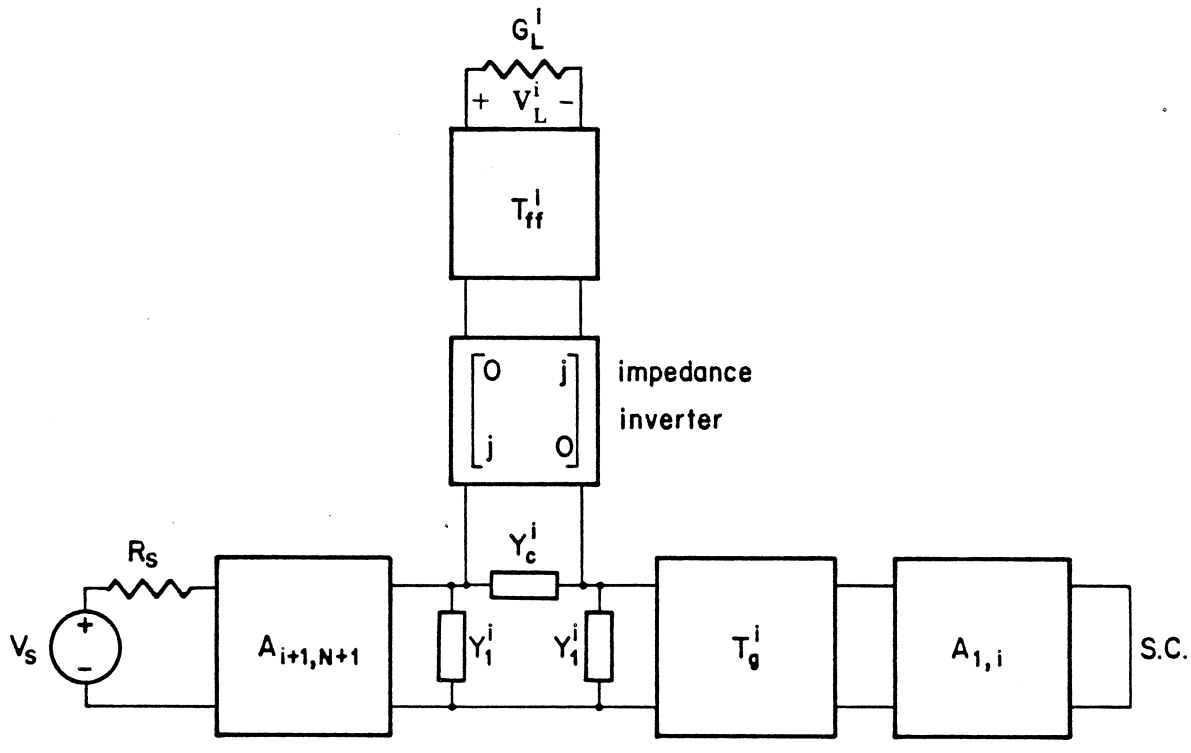

Fig. 2 Simplified multiplexer structure for the calculation of channel output voltage.

```
C
      SUBROUTINE RESPONS(N,NP1,RS,ZIN,RLOSS,VL,A,H23,H1,RO,RCOEFF,
     +                   YC,YP,TG,Y1,VS,H2,H3,H4,H5,H6,H7,H9,H10)
C
C     CALCULATE COMMON PORT RETURN LOSS AND OUTPUT VOLTAGE
C     OF EACH CHANNEL
C
      COMPLEX VL(16),A(17,17,4),HMX(4)
      COMPLEX H2(16),H3(16),H4(16),H5(16),H6(16),H7(16),H9(16),H10(16)
      COMPLEX YC(16),YP(16,4),TG(16,4),Y1(16)
      COMPLEX RCOEFF,ZIN,H22,H23,H1,JPLX
      JPLX=CMPLX(0.0,1.0)
C
C     CALCULATION OF INPUT IMPEDANCE USING ABCD MATRIX FROM
C     REFERENCE PLANE 1 (SHORT CIRCUIT) TO REFERENCE PLANE N+1
C
      ZIN=A(1,NP1,2)/A(1,NP1,4)
      H22=(ZIN+RS)*(ZIN+RS)
      H23=2.0*RS/H22
      RCOEFF=(ZIN-RS)/(ZIN+RS)
      RO=CABS(RCOEFF)
      RLOSS=-20.0*ALOG10(RO)
C
      H1=A(1,NP1,2)+RS*A(1,NP1,4)
C
      DO 19 I=1,N
C
      H9(I)=1.0+YC(I)*YP(I,1)
      H10(I)=H7(I)*H9(I)
      H2(I)=H10(I)/YP(I,2)-YC(I)*YP(I,2)
C
C     CALCULATE ABCD MATRICES FROM THE SHORT CIRCUIT REFERENCE
C     PLANE TO THE REFERENCE PLANE I
C
      CALL MATMUL(TG(I,1),TG(I,2),TG(I,3),TG(I,4),A(1,I,1),A(1,I,2),
     +           A(1,I,3),A(1,I,4),HMX(1),HMX(2),HMX(3),HMX(4))
C
      H3(I)=VS*(HMX(4)+Y1(I)*HMX(2))
      H4(I)=H2(I)*H1
      H5(I)=H4(I)*H4(I)
      H6(I)=H3(I)*H2(I)
C
C     CALCULATE OUTPUT VOLTAGES OF CHANNELS
C
      VL(I)=JPLX*H3(I)/H4(I)
   19 CONTINUE
      RETURN
      END
C
```

Fig. 3 Listing of the subroutine RESPONS.

SUBROUTINE INSOUT

SUBROUTINE INSOUT (N, VL, INLOSS)

Purpose

This subroutine calculates the channel insertion loss using the channel output voltage.

Theory

The channel insertion loss is given by [1]

$$I_L = -20 \log|V_L| - 20 \log(R_S G_L + 1) , \tag{1}$$

where V_L is as defined in (7) of RESPONS. For simplicity, we have again omitted the superscript i for I_L, V_L and G_L. Assuming unity source and load resistances, we have

$$I_L = -20 \log(2|V_L|) . \tag{2}$$

List of Arguments

N	is the number of channels.
VL	is the complex channel output voltage V_L.*
INLOSS	is the channel insertion loss I_L in dB.*

Related Software

This subroutine is called from SIMUL.

References

[1] G.L. Matthaei, L. Young and E.M.T. Jones, Microwave Filters, Impedance Matching Networks and Coupling Structures. New York: McGraw-Hill, 1964, Chap. 2.

Footnote

For an explanation of * see FEATURES.

```
C
      SUBROUTINE INSOUT(N,VL,INLOSS)
C
C     CHANNEL INSERTION LOSS IS CALCULATED
C
      COMPLEX VL(16)
      REAL INLOSS(16)
C
C     THIS SUBROUTINE IS WRITTEN FOR VS=1.0, RS=1.0, GL(I)=1.0
C
      DO 10 I=1,N
      VABS=CABS(VL(I))
      INLOSS(I)=-20.0*ALOG10(2.0*VABS)
   10 CONTINUE
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine INSOUT.

SUBROUTINE PHASE

SUBROUTINE PHASE (N, VL, ANGLE)

Purpose

This subroutine calculates the phase of the complex channel output voltage.

Theory

Given the complex channel output voltage V_L, its phase is calculated as

$$\angle V_L = Im(V_L)/Re(V_L) .$$

List of Arguments

N is the number of channels.

VL is the complex channel output voltage.*

PHASE is the phase of V_L.

Related Software

This subroutine is called from SIMUL.

Footnote

For an explanation of * see FEATURES.

```
C
      SUBROUTINE PHASE(N,VL,ANGLE)
C
C     GIVEN THE COMPLEX CHANNEL OUTPUT VOLTAGE CALCULATE THE
C     CORRESPONDING PHASE
C
      COMPLEX VL(16)
      REAL ANGLE(16)
C
      DO 10 I=1,N
      HRE=REAL(VL(I))
      HIM=AIMAG(VL(I))
      ANGLE(I)=ATAN2(HIM,HRE)
   10 CONTINUE
      RETURN
      END
```

Fig. 1 Listing of the subroutine PHASE.

SUBROUTINE CSOLLU

SUBROUTINE CSOLLU (M, A, B, IFALL, IPAR)

Purpose

This subroutine performs LU factorization, forward and backward substitutions in the complex mode.

Theory

The subroutines use Crout's algorithm for LU factorization. It has the capability of forward and backward substitution with or without LU factorization.

List of Arguments

M	is the order of the matrix.
A	is the matrix of coefficients on entry. It contains the LU factors on exit.
B	is the RHS vector on entry. It contains the solution vector on exit.
IFALL	is a flag set to –1 if, due to a zero on the diagonal, an indefinite value occurs in CSOLLU.
IPAR	is a flag to determine whether LU factorization together with FBS, or only FBS is to be performed. IPAR = 1 for FBS only, and IPAR ≠ 1 for both LU and FBS.

Related Software

This subroutine is called from FILTER.

```
C
      SUBROUTINE CSOLLU(M,A,B,IFALL,IPAR)
C
C     PERFORM LU FACTORIZATION, FORWARD AND BACKWARD SUBSTITUTION
C     IN THE COMPLEX MODE
C
      COMPLEX A(8,8),B(8),ZZ
C
C     CROUT'S ALGORITHM FOR LU FACTORIZATION
C
      IFALL=0
      M2=M-1
      M1=M+1
      IF(IPAR.EQ.1)GO TO 290
C
C     BEGIN FACTORIZATION
C
      DO 82 II=1,M2
      ZZ=A(II,II)
      IF(ZZ.EQ.(0.0,0.0))GO TO 100
      MM=II+1
      DO 82 J=MM,M
      A(II,J)=A(II,J)/ZZ
      DO 80 K=MM,M
   80 A(K,J)=A(K,J)-A(K,II)*A(II,J)
   82 CONTINUE
C
C     FORWARD SUBSTITUTION
C
  290 CONTINUE
      IF(A(1,1).EQ.(0.0,0.0))GO TO 100
      B(1)=B(1)/A(1,1)
      DO 88 II=2,M
      ZZ=A(II,II)
      IF(ZZ.EQ.(0.0,0.0))GO TO 100
      IM=II-1
      DO 86 K=1,IM
   86 B(II)=B(II)-A(II,K)*B(K)
      B(II)=B(II)/ZZ
   88 CONTINUE
C
C     BACKWARD SUBSTITUTION
C
      DO 92 L=2,M
      II=M1-L
      IP=II+1
      DO 90 K=IP,M
   90 B(II)=B(II)-A(II,K)*B(K)
   92 CONTINUE
      GO TO 120
  100 IFALL=-1
      WRITE 200
  200 FORMAT(/"INDEFINITE VALUE IN CSOLLU DUE TO ZERO ON THE DIAGONAL")
  120 CONTINUE
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine CSOLLU.

SUBROUTINE CONST1

SUBROUTINE CONST1 (WIDTH)

COMMON/BLK4/CBR, FCUT

Purpose

This subroutine calculates the rectangular waveguide manifold cut-off frequency.

Theory

The cut-off frequency in MHz is given by

$$f_{cut} = \frac{c}{2a} , \qquad (1)$$

where c = 11802.85 inch/μsec is the velocity of light in free space and variable a is the manifold width in inches.

List of Arguments and COMMON Blocks

WIDTH	is the manifold width a.
CBR	is the velocity of light c.
FCUT	is the cut-off frequency f_{cut}.

Related Software

This subroutine is called from the main program MXSOS2 if the junction susceptance option is selected.

```
C
      SUBROUTINE CONST1(WIDTH)
C
C     WAVEGUIDE MANIFOLD CUTOFF FREQUENCY IS CALCULATED
C
      COMMON/BLK4/CBR,FCUT
      CBR=11802.85
      FCUT=CBR/(2.0*WIDTH)
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine CONST1.

SUBROUTINE DISPAT

SUBROUTINE DISPAT (N, WO, BW, QO)

COMMON/BLK5/DISP

Purpose

This subroutine estimates the filter dissipation using the unloaded Q, bandwidth parameter and center frequency of the filter.

Theory

The filter dissipation factor d, which is added to the diagonal elements of the impedance matrix for a lossy filter, is calculated as

$$d = \frac{f_0}{\Delta f Q_0} , \quad (1)$$

where f_0 is the centre frequency, Δf is the bandwidth parameter and Q_0 is the unloaded Q.

List of Arguments and COMMON Blocks

N	is the number of channels.
WO	is the centre frequency f_0.*
BW	is the bandwidth Δf.*
QO	is the unloaded Q.*
DISP	is the dissipation d.*

Related Software

This subroutine is called from the main program MXSOS2 if the dissipation option is selected.

Footnote

For an explanation of * see FEATURES.

```
C
      SUBROUTINE DISPAT(N,WO,BW,QO)
C
C     FILTER DISSIPATION IS CALCULATED USING UNLOADED Q, BANDWIDTHS
C     AND CENTER FREQUENCIES
C
      REAL WO(16),BW(16),DISP(16),QO(16)
      COMMON/BLK3/DISP
C
      DO 10 I=1,N
      DISP(I)=WO(I)/(BW(I)*QO(I))
   10 CONTINUE
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine DISPAT

SUBROUTINE DISPER

SUBROUTINE DISPER (N, WO, BW, DIA)

COMMON/BLK6/FCNST, LAMRES, LAMDEL

Purpose

This subroutine calculates the filter constant (square of the cut-off frequency of the filter), circular guide wavelength corresponding to the filter resonant frequency and the difference in filter guide wavelengths corresponding to the band edges.

Theory

The cut-off frequency for the circular waveguide is calculated as

$$ff_{cut} = \frac{c}{1.7063\ d_f}\ , \tag{1}$$

where c = 11802.85 inch/μsec is the velocity of light in free space and d_f is the filter diameter in inches. We define filter constant f_{cst} as

$$f_{cst} \triangleq (ff_{cut})^2\ . \tag{2}$$

Using f_{cst}, we can find the guide wavelengths corresponding to the band edges, in the following way:

$$f_\ell = f_0 - \frac{\Delta f}{2}\ , \qquad f_h = f_0 + \frac{\Delta f}{2} \tag{3}$$

and

$$\lambda_{g\ell} = \frac{c}{\sqrt{(f_\ell)^2 - f_{cst}}}\ , \qquad \lambda_{gh} = \frac{c}{\sqrt{(f_h)^2 - f_{cst}}}\ , \tag{4}$$

where f_0 is the centre frequency, Δf is the bandwidth, f_ℓ and f_h are the band edges and $\lambda_{g\ell}$ and λ_{gh} are their corresponding guide wavelengths. The guide wavelength corresponding to the filter resonant frequency is defined as

$$\lambda_{res} \triangleq (\lambda_{g\ell} + \lambda_{gh})/2 \tag{5}$$

and we also define

$$\lambda_\Delta \triangleq \lambda_{g\ell} - \lambda_{gh} \,. \tag{6}$$

List of Arguments and COMMON Blocks

N	is the number of channels.
WO	is the centre frequency f_0.*
BW	is the bandwidth Δf.*
DIA	is the filter diameter d_f.*
FCNST	is the filter constant f_{cst} of (2).
LAMRES	is the guide wavelength corresponding to the filter resonant frequency λ_{res} of (5).*
LAMDEL	is the difference in filter guide wavelengths corresponding to the band edges λ_Δ of (6).*

Related Software

This subroutine is called from the main program MXSOS2 if the option of dispersion is requested.

Footnote

For an explanation of * see FEATURES.

```
C
      SUBROUTINE DISPER(N,WO,BW,DIA)
C
C     CALCULATES THE DISPERSIVE EFFECTS IN EACH FILTER
C     THE OUTPUT FROM THIS SUBROUTINE  INCLUDES  FILTER  GUIDE
C     WAVELENGTH CORRESPONDING TO THE FILTER RESONANT FREQUENCY
C     AND THE DIFFERENCE IN FILTER GUIDE WAVELENGTHS CORRESPONDING
C     TO THE BAND EDGES.
C
      REAL WO(16),BW(16),DIA(16),FCNST(16),LAMRES(16),LAMDEL(16)
      REAL LAMLOG,LAMHIG
      COMMON/BLK6/FCNST,LAMRES,LAMDEL
      CB=11802.85
      CDIA=CB*CB/(1.7063*1.7063)
C
      DO 10 I=1,N
      FCNST(I)=CDIA/(DIA(I)*DIA(I))
C
      FLO=WO(I)-BW(I)/2.0
      FHI=FLO+BW(I)
C
      LAMLOG=CB/(SQRT(FLO*FLO-FCNST(I)))
      LAMHIG=CB/(SQRT(FHI*FHI-FCNST(I)))
C
      LAMRES(I)=(LAMLOG+LAMHIG)/2.0
      LAMDEL(I)=LAMLOG-LAMHIG
C
   10 CONTINUE
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine DISPER.

SUBROUTINE SIMUL

SUBROUTINE SIMUL (OMEG, N, M, ICOUNT, IFLAGJS, IFLAGDP, IDISPER, RLOSS, INLOSS, ANGLE)

COMMON/BLK1/WO, BW, PN1, PN2, GL, VS, RS, PI2, WIDTH, NP1

COMMON/BLK2/CM, WGL

COMMON/BLK4/CBR, FCUT

COMMON/BLK6/FCNST, LAMRES, LAMDEL

COMMON/BLK7/CEL

Purpose

This subroutine sets up the complex **Z** matrix according to the options of dissipation and dispersion, calculates the nonideal junction susceptances if that option is selected and calls all subroutines required for simulation only.

Theory

If neither dissipation nor dispersion options is selected, the **Z** matrix is defined as [1]

$$\mathbf{Z} \triangleq j(s\mathbf{1} + \mathbf{M}) , \tag{1}$$

where **M** is the coupling matrix, **1** is the unit matrix of corresponding dimensions and

$$s \triangleq \frac{\omega_0}{\Delta\omega}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) = \frac{f_0}{\Delta f}\left(\frac{f}{f_0} - \frac{f_0}{f}\right), \tag{2}$$

where $f_0(\omega_0)$ is the centre frequency, $\Delta f(\Delta\omega)$ is the bandwidth parameter and $f(\omega)$ is the frequency of operation.

If the dispersion option is selected, we use f_{cst}, λ_{res} and λ_Δ as calculated in DISPER to evaluate

$$\lambda_f = \frac{c}{\sqrt{f^2 - f_{cst}}} , \tag{3}$$

$$\lambda_r = \frac{\lambda_f}{\lambda_{res}} \tag{4}$$

and

$$\lambda_x = \frac{2(\lambda_{res} - \lambda_f)}{\lambda_\Delta} \quad . \tag{5}$$

The (ℓ, k)th element of impedance matrix $\overline{\mathbf{Z}}$ is calculated as

$$\overline{Z}_{\ell k} = j[M_{\ell k} (\lambda_r)^{C_{\ell k}} + c_d], \tag{6}$$

where

$$c_d = \begin{cases} \lambda_x \ , & \text{if } \ell = k \\ 0 \ , & \text{if } \ell \neq k \end{cases} \tag{7}$$

and **C** is a matrix whose elements determine the type of coupling in the following way:

$$C_{\ell k} = \begin{cases} 1 \ , & \text{if } M_{\ell k} \text{ is screw coupled.} & \text{(8a)} \\ -1 \ , & \text{if } M_{\ell k} \text{ is iris coupled.} & \text{(8b)} \\ 0 \ , & \text{if } M_{\ell k} = 0, \text{ or } \ell = k. & \text{(8c)} \end{cases}$$

If the dissipation option is included, both matrix **Z** of (1) (no dispersion) and matrix $\overline{\mathbf{Z}}$ of (6) (dispersion included) should be updated in the following way:

$$\mathbf{Z} \leftarrow \mathbf{Z} + d\,\mathbf{1} \quad \text{and} \quad \overline{\mathbf{Z}} \leftarrow \overline{\mathbf{Z}} + d\,\mathbf{1} \ , \tag{9}$$

where d is defined in DISPAT and **1** is the unit matrix of corresponding dimensions.

In FILABCD, we named the junction series and shunt admittances as Y_c and Y_1, respectively. See Fig. 4 of FILABCD. In MXSOS2, YC is always assumed to be zero [2], however, Y_1 is zero only if the junction susceptance option is not selected. By selecting nonideal junction susceptance, Y_1 is calculated as [3]

$$Y_1 = \frac{-j f_{cut}}{\left(20\left(\frac{c}{f}\right)^2 - 1\right)\sqrt{f^2 - (f_{cut})^2}} \quad , \tag{10}$$

where f_{cut} is defined in CONST1 (1), c is the velocity of light and f is the frequency of operation.

List of Arguments and COMMON Blocks

The definition of the arguments and common blocks can be found in the main program MXSOS2 as well as in CONST1, DISPAT and DISPER.

Related Software

This subroutine is called from the main program MXSOS2 if the simulation option is selected.

References

[1] A.E. Atia and A.E. Williams, "New types of waveguide bandpass filters for satellite applications", COMSAT Technical Review, vol. 1, 1971, pp. 21-43.

[2] R. Tong and C.M. Kudsia, ComDev Ltd., Cambridge, Ontario, Canada, private discussions 1983, 1984.

[3] M.H. Chen, F. Assal and C. Mahle, "A contiguous band multiplexer", COMSAT Technical Review, vol. 6, 1976, pp. 285-306.

```
C
      SUBROUTINE SIMUL(OMEG,N,M,ICOUNT,IFLAGJS,IFLAGDP,IDISPER,
     +                  RLOSS,INLOSS,ANGLE)
C
C     THIS SUBROUTINE CALLS ALL SUBROUTINES NECESSARY FOR RESPONSE
C     CALCULATIONS ONLY
C
      COMPLEX Z(16,8,8),P(16,8),Q(16,8)
      COMPLEX Y(16,4),YP(16,4),YIN(16),Y1(16),Y3(16),YC(16)
      COMPLEX TF(16,4),TG(16,4),T(16,4),A(17,17,4),Y3SQ(16)
      COMPLEX DTG(16,4)
      COMPLEX H2(16),H3(16),H4(16),H5(16),H6(16),H7(16),H8(16)
      COMPLEX H9(16),H10(16),H13(16),H14(16)
      COMPLEX VL(16)
      COMPLEX H1,H23,ZIN,RCOEFF
      COMPLEX S,SD
      REAL WO(16),BW(16)
      REAL CM(16,8,8),PN1(16),PN2(16),PN11(16),PN12(16)
      REAL PN22(16),GL(16),WGL(16),INLOSS(16),ANGLE(16)
      REAL DISP(16),LAMR(16)
      REAL FCNST(16),LAMRES(16),LAMDEL(16),LAMFIL,LREAC
      INTEGER CEL(16,8,8)
C
      COMMON/BLK1/WO,BW,PN1,PN2,GL,VS,RS,PI2,WIDTH,NP1
      COMMON/BLK2/CM,WGL
      COMMON/BLK4/CBR,FCUT
      COMMON/BLK5/DISP
      COMMON/BLK6/FCNST,LAMRES,LAMDEL
      COMMON/BLK7/CEL
C
      IF(ICOUNT.NE.1)GO TO 5
C
      DO 100 I=1,N
      DO 100 J=1,M
      DO 100 KK=1,J
      CM(I,J,KK)=CM(I,KK,J)
  100 CONTINUE
C
      DO 99 I=1,N
      DO 99 J=1,M
      DO 99 K=1,M
      Z(I,J,K)=CMPLX(0.0,CM(I,J,K))
   99 CONTINUE
C
      C1=11802.85
      C2=4.0*WIDTH*WIDTH
C
    5 CONTINUE
C
      IF(IDISPER.NE.1)GO TO 500
C
      DO 51 I=1,N
      LAMFIL=C1/SQRT(OMEG*OMEG-FCNST(I))
      LAMR(I)=LAMFIL/LAMRES(I)
      LREAC=2.0*(LAMRES(I)-LAMFIL)/LAMDEL(I)
C
C     SET UP THE COMPLEX IMPEDANCE MATRIX OF THE FILTERS
C
      DO 52 J=1,M
      DO 52 K=1,M
      Z(I,J,K)=CMPLX(0.0,CM(I,J,K))*LAMR(I)**CEL(I,J,K)
   52 CONTINUE
C
C     SET UP DIAGONAL ELEMENTS INCLUDING FILTER DISPERSION
C
```

Fig. 1 Listing of the subroutine SIMUL.

```
      DO 53 J=1,M
      Z(I,J,J)=CMPLX(0.0,CM(I,J,J)+LREAC)
C
C     INCLUDE FILTER DISSIPATION
C
      IF(IFLAGDP.EQ.1)Z(I,J,J)=Z(I,J,J)+DISP(I)
   53 CONTINUE
   51 CONTINUE
      GO TO 75
C
  500 CONTINUE
      DO 106 I=1,N
      XR=WO(I)/BW(I)
      C3=(OMEG/WO(I))-(WO(I)/OMEG)
      S=CMPLX(0.0,C3)
      SD=S*XR
C
C     SET UP DIAGONAL ELEMENTS FOR ZERO FILTER DISPERSION
C
      DO 106 J=1,M
      Z(I,J,J)=CMPLX(0.0,CM(I,J,J))+SD
C
C     INCLUDE FILTER DISSIPATION
C
      IF(IFLAGDP.EQ.1)Z(I,J,J)=Z(I,J,J)+DISP(I)
  106 CONTINUE
C
   75 CONTINUE
      IF(IFLAGJS.EQ.1)GO TO 68
      DO 66 I=1,N
      YC(I)=CMPLX(0.0,0.0)
      Y1(I)=CMPLX(0.0,0.0)
   66 CONTINUE
      GO TO 70
C
   68 CONTINUE
C
C     THE JUNCTION SUSCEPTANCE IS CALCULATED
C
      BETAJS=FCUT/(((20.0*(CBR/OMEG)**2)-1.0)*SQRT(OMEG*OMEG-FCUT*FCUT))
      DO 69 I=1,N
      YC(I)=(0.0,0.0)
      Y1(I)=CMPLX(0.0,-BETAJS)
   69 CONTINUE
C
   70 CONTINUE
C
      CALL BETAVAL(C1,C2,OMEG,PI2,BETA)
C
      CALL FILTER(N,M,Z,P,Q)
C
      CALL FILABCD(N,M,P,Q,PN1,PN2,Y1,GL,YC,Y,YP,YIN,Y3,
     +             Y3SQ,TF,H7,H8,H13,H14,PN11,PN12,PN22)
C
      CALL WGUIDE(N,BETA,WGL,TG,DTG)
C
      DO 121 I=1,N
C
      CALL MATMUL(TF(I,1),TF(I,2),TF(I,3),TF(I,4),TG(I,1),TG(I,2),
     +         TG(I,3),TG(I,4),T(I,1),T(I,2),T(I,3),T(I,4))
C
  121 CONTINUE
C
      CALL SEQUENC(N,NP1,T,A)
C
```

Fig. 1 (continued)   Listing of the subroutine SIMUL.

```
      CALL RESPONS(N,NP1,RS,ZIN,RLOSS,VL,A,H23,H1,RO,RCOEFF,
     +            YC,YP,TG,Y1,VS,H2,H3,H4,H5,H6,H7,H9,H10)
C
      CALL INSOUT(N,VL,INLOSS)
C
      CALL PHASE(N,VL,ANGLE)
C
      RETURN
      END
C
```

Fig. 1 (continued) Listing of the subroutine SIMUL.

SUBROUTINE TOTAL2

SUBROUTINE TOTAL2 (N, IR, IRT, IPN1, IPN2, IWG)

Purpose

This subroutine calculates the total number of variables accumulated after each section.

List of Arguments

All arguments are defined in the main program except IRT, which is the total number of variables after each section.*

Related Software

This subroutine is called from the main program MXSOS2 if the options of sensitivity analysis or optimization are selected.

Footnote

For an explanation of * see FEATURES.

```
C
      SUBROUTINE TOTAL2(N, IR, IRT, IPN1, IPN2, IWG)
C
C     CALCULATE THE TOTAL NUMBER OF VARIABLES ACCUMULATED AFTER
C     EACH SECTION
C
      INTEGER IR(16),IRT(16),IPN1(16),IPN2(16),IWG(16)
      IRT(1)=IR(1)+IPN1(1)+IPN2(1)+IWG(1)
      IF(N.EQ.1)GO TO 5
      DO 15 I=2,N
      IM1=I-1
      IRT(I)=IRT(IM1)+IR(I)+IPN1(I)+IPN2(I)+IWG(I)
   15 CONTINUE
    5 CONTINUE
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine TOTAL2.

SUBROUTINE DABCDF2

SUBROUTINE DABCFD2 (N, M, IR, IRT, IPN1, IPN2, LC, KC, DYP11, DYP21, DYP22, YIN, P, Q, PN1, PN2, PN11, PN12, PN22, H7, H13, H14, Y1, TG, D, Y3SQ, YP, LAMR, IDISPER)

COMMON/BLK7/CEL

Purpose

This subroutine calculates the derivatives of the filter-junction combination ABCD matrices w.r.t. variable coupling elements and variable input-output transformer ratios. These derivatives are then stored in a designated array which contains the derivatives of the ABCD matrices of the complete sections (including waveguide spacings) w.r.t. all variables (including section lengths) contained in them.

Theory

Recalling the definitions of impedance matrix ($\mathbf{Z}$ or $\overline{\mathbf{Z}}$) from SIMUL (eqns. (1) and (6)), and denoting both matrices by $\mathbf{Z}$ for simplicity, we have

$$\frac{\partial \mathbf{Z}}{\partial M_{\ell k}} = j w_1 w_2 (\mathbf{e}_\ell \mathbf{e}_k^T + \mathbf{e}_k \mathbf{e}_\ell^T) \tag{1}$$

where

$$w_1 = \begin{cases} 1 & \text{if } \ell \neq k \\ 0.5 & \text{if } \ell = k \end{cases} \tag{2}$$

and

$$w_2 = \begin{cases} (\lambda_r)^{C_{\ell k}}, & \text{if dispersion is included,} \\ 1, & \text{if dispersion is not included.} \end{cases} \tag{3}$$

Using (10) of FILTER, we have

$$\frac{\partial y}{\partial M_{\ell k}} = - j w_1 w_2 \begin{bmatrix} 2 p_\ell p_k & p_\ell q_k + p_k q_\ell \\ p_\ell q_k + p_k q_\ell & 2 q_\ell q_k \end{bmatrix}, \tag{4}$$

and referring to (1) of FILABCD, we get [1]

$$\frac{\partial y'}{\partial \phi} = \begin{cases} \begin{bmatrix} n_1^2 \dfrac{\partial y_{11}}{\partial \phi} & n_1 n_2 \dfrac{\partial y_{21}}{\partial \phi} \\ n_1 n_2 \dfrac{\partial y_{21}}{\partial \phi} & n_2^2 \dfrac{\partial y_{22}}{\partial \phi} \end{bmatrix}, & \text{if } \phi = M_{\ell k} \\ \begin{bmatrix} 2n_1 y_{11} & n_2 y_{21} \\ n_2 y_{21} & 0 \end{bmatrix}, & \text{if } \phi = n_1 \\ \begin{bmatrix} 0 & n_1 y_{21} \\ n_1 y_{21} & 2n_2 y_{22} \end{bmatrix}, & \text{if } \phi = n_2 \end{cases} \tag{5}$$

Equations (9) of FILTER and (4) give all the terms required for evaluation of (5), once **p** and **q** of FILTER (6) and FILTER (8) are known.

Recalling (2) and (3) of FILABCD, we have

$$\frac{\partial Y_{in}}{\partial \phi} = -Y_{in}^2 \left[\frac{\partial}{\partial \phi} y'_{11} - \frac{\partial y'_{21}}{y'_{22} + G_L} \left(\frac{\partial y'_{21}}{\partial \phi} \right) + \left(\frac{y'_{21}}{y'_{22} + G_L} \right)^2 \left(\frac{\partial y'_{22}}{\partial \phi} \right) \right], \tag{6}$$

where $\phi \in \{M_{\ell k}, n_1, n_2\}$.

We can utilize (4) and (5) of FILABCD and the fact that Y_1 and Y_c are independent of ϕ, to show

$$\frac{\partial \mathbf{T}_f}{\partial \phi} = \frac{-1}{Y_3^2} \frac{\partial Y_{in}}{\partial \phi} \begin{bmatrix} Y_1 & 1 \\ Y_1^2 & Y_1 \end{bmatrix}. \tag{7}$$

At this point, we can refer to RESPONS (1)-(7) and INSOUT (2) to observe that both common port return loss and channel insertion loss sensitivity analyses require the evaluation of $\partial(\mathbf{A}_{1,N+1})/\partial\phi$. As indicated in the comments for SEQUENC, we have

$$\frac{\partial}{\partial \phi} (\mathbf{A}_{1,N+1}) = \mathbf{A}_{j+1,N+1} \left(\frac{\partial}{\partial \phi} \mathbf{T}_j \right) \mathbf{A}_{1,j}, \tag{8}$$

where ϕ is assumed to be in section j. From (1) of SEQUENC, we conclude that

$$\mathbf{D} = \frac{\partial \mathbf{T}}{\partial \phi} = \begin{cases} \left(\dfrac{\partial}{\partial \phi} \mathbf{T}_f \right) \mathbf{T}_g, & \text{if } \phi \in \{M_{\ell k}, n_1, n_2\} \\ \mathbf{T}_f \left(\dfrac{\partial}{\partial \phi} \mathbf{T}_g \right), & \text{if } \phi = \ell \end{cases} \tag{9}$$

In DABCDF2, we have calculated $(\partial \mathbf{T}_f/\partial\phi)$, hence, we fill matrix **D** partially.

List of Arguments and COMMON Blocks

N is the number of channels.

M is the order of the matrix.

IR, IPN1, IPN2, LC, KC are as defined in the main program MXSOS2.*

IRT is as defined in TOTAL2.*

DYP11 is $\partial y_{11}'/\partial \phi$ as defined in (5)

DYP21 is $\partial y_{21}'/\partial \phi$ as defined in (5).

DYP22 is $\partial y_{22}'/\partial \phi$ as defined in (5).

YIN, P, Q, PN1, PN2, PN11, PN12, PN22, H7, H13, H14, Y1, Y3SQ, YP are as defined in FILABCD.*

TG is as defined in WGUIDE.*+

LAMR is λ_r defined by (4) of SIMUL.

D is as defined by (9).*

IDISPER is as defined in the main program MXSOS2.

Related Software

This subroutine is called from SIMGRD2.

Reference

[1] J.W. Bandler, S.H. Chen, S. Daijavad and W. Kellermann, "Optimal design of multi-cavity filters and contiguous-band multiplexers", Proc. 14th European Microwave Conf. (Liège, Belgium, Sept. 1984).

Footnote

For an explanation of * and + see FEATURES.

```
C
      SUBROUTINE DABCDF2(N,M,IR,IRT,IPN1,IPN2,LC,KC,DYP11,
     +                  DYP21,DYP22,YIN,P,Q,PN1,PN2,
     +                  PN11,PN12,PN22,H7,H13,H14,Y1,TG,D,Y3SQ,YP,
     +                  LAMR,IDISPER)
C
C     CALCULATE DERIVATIVES OF THE FILTER-JUNCTION ABCD MATRICES
C     W.R.T. VARIABLE COUPLING ELEMENTS, AS WELL AS INPUT/OUTPUT
C     TRANSFORMER RATIOS, AND STORE THEM IN A DESIGNATED  ARRAY
C     FOR THE DERIVATIVES OF THE ABCD MATRICES  OF  THE SECTIONS
C     W.R.T. ALL VARIABLES CONTAINED IN THEM
C
      INTEGER IR(16),IRT(16),IPN1(16),IPN2(16),LC(16,36),KC(16,36)
      REAL PN1(16),PN2(16),PN11(16),PN12(16),PN22(16),LAMR(16)
      INTEGER CEL(16,8,8)
      COMPLEX DY11,DY21,DY22,DYP11(100),DYP21(100),DYP22(100)
      COMPLEX DYIN,DAF,DBF,DCF,DDF
      COMPLEX P(16,8),Q(16,8),Y1(16),H15,H7(16),H13(16),H14(16)
      COMPLEX TG(16,4),D(100,4),YIN(16),YINSQ,JPLX,Y3SQ(16),YP(16,4)
      COMPLEX H72
      COMMON/BLK7/CEL
      JPLX=CMPLX(0.0,1.0)
C
      DO 21 I=1,N
      YINSQ=YIN(I)*YIN(I)
      H72=2.0*YP(I,2)/H7(I)
      IM1=I-1
      IF(IR(I).EQ.0)GO TO 10
C
      KP=IR(I)
      DO 22 J=1,KP
C
      IX3=LC(I,J)
      IX4=KC(I,J)
C
      IF(I.EQ.1)GO TO 23
      IV=IRT(IM1)+J
      GO TO 24
   23 IV=J
   24 CONTINUE
C
      IF(IX3.EQ.IX4)GO TO 35
C
      DY11=-2.0*JPLX*P(I,IX3)*P(I,IX4)
      DY21=-JPLX*(P(I,IX3)*Q(I,IX4)+P(I,IX4)*Q(I,IX3))
      DY22=-2.0*JPLX*Q(I,IX3)*Q(I,IX4)
C
      IF(IDISPER.NE.1)GO TO 36
      CF=LAMR(I)**CEL(I,IX3,IX4)
      DY11=DY11*CF
      DY21=DY21*CF
      DY22=DY22*CF
      GO TO 36
C
   35 DY11=-JPLX*P(I,IX3)*P(I,IX3)
      DY21=-JPLX*P(I,IX3)*Q(I,IX3)
      DY22=-JPLX*Q(I,IX3)*Q(I,IX3)
C
   36 CONTINUE
C
      DYP11(IV)=PN11(I)*DY11
      DYP21(IV)=PN12(I)*DY21
      DYP22(IV)=PN22(I)*DY22
C
      DYIN=DYP11(IV)-DYP21(IV)*H72+DYP22(IV)*H13(I)
```

Fig. 1 Listing of the subroutine DABCDF2.

```
C
C     USE AN IMPEDANCE INVERTER
C
      DYIN=-YINSQ*DYIN
C
      H15=-DYIN/Y3SQ(I)
C
      DAF=Y1(I)*H15
      DBF=H15
      DCF=H15*H14(I)
      DDF=DAF
C
      CALL MATMUL(DAF,DBF,DCF,DDF,TG(I,1),TG(I,2),
     +            TG(I,3),TG(I,4),D(IV,1),D(IV,2),D(IV,3),D(IV,4))
C
   22 CONTINUE
C
   10 CONTINUE
      IF((IPN1(I)+IPN2(I)).EQ.0)GO TO 21
      IF(IPN1(I).EQ.0)GO TO 11
C
      J=IR(I)+1
      IF(I.EQ.1)GO TO 12
      IV=IRT(IM1)+J
      GO TO 13
   12 IV=J
   13 CONTINUE
C
      DYP11(IV)=2.0*PN1(I)*P(I,1)
      DYP21(IV)=PN2(I)*Q(I,1)
      DYP22(IV)=(0.0,0.0)
      DYIN=DYP11(IV)-DYP21(IV)*H72
      DYIN=-YINSQ*DYIN
C
      H15=-DYIN/Y3SQ(I)
      DAF=Y1(I)*H15
      DBF=H15
      DCF=H15*H14(I)
      DDF=DAF
C
      CALL MATMUL(DAF,DBF,DCF,DDF,TG(I,1),TG(I,2),TG(I,3),TG(I,4),
     +              D(IV,1),D(IV,2),D(IV,3),D(IV,4))
C
   11 CONTINUE
      IF(IPN2(I).EQ.0)GO TO 21
      J=IR(I)+IPN1(I)+1
      IF(I.EQ.1)GO TO 15
      IV=IRT(IM1)+J
      GO TO 16
   15 IV=J
   16 CONTINUE
C
      DYP11(IV)=(0.0,0.0)
      DYP21(IV)=PN1(I)*Q(I,1)
      DYP22(IV)=2.0*PN2(I)*Q(I,M)
      DYIN=-DYP21(IV)*H72+DYP22(IV)*H13(I)
      DYIN=-YINSQ*DYIN
C
      H15=-DYIN/Y3SQ(I)
      DAF=Y1(I)*H15
      DBF=H15
      DCF=H15*H14(I)
      DDF=DAF
C
      CALL MATMUL(DAF,DBF,DCF,DDF,TG(I,1),TG(I,2),TG(I,3),TG(I,4),
```

Fig. 1 (continued) Listing of the subroutine DABCDF2.

```
     +               D(IV,1),D(IV,2),D(IV,3),D(IV,4))
C
  21 CONTINUE
     RETURN
     END
C
```

Fig. 1 (continued) Listing of the subroutine DABCDF2.

SUBROUTINE DABCDG2

SUBROUTINE DABCDG2 (N, IRT, IWG, D, DG)

Purpose

In this subroutine, we store the derivatives of the ABCD matrices of the complete sections w.r.t. section lengths in the designated array which contains the derivatives w.r.t. all variables in the sections.

Theory

Recalling (9) of DABCDF2, we know that matrix **D** is only partially filled. Now, $\partial \mathbf{T}_g / \partial \ell$ which is already calculated in WGUIDE (eqn. (2)) is premultiplied by $\mathbf{T}_f$ in SIMGRD2 and the results are stored appropriately in **D** to complete the evaluation of **D**.

List of Arguments

N	is the number of channels.
IRT	is as defined in TOTAL2.*
IWG	is as defined in the main program MXSOS2.*
D	is as defined by (9) of DABCDF2.$^{+}$
DG	is $\mathbf{T}_f(\partial \mathbf{T}_g / \partial \phi)$ for $\phi = \ell$ in (9) of DABCDF2.$^{*+}$

Related Software

This subroutine is called from SIMGRD2.

Footnote

For an explanation of * and $^{+}$ see FEATURES.

```
C
      SUBROUTINE DABCDG2(N,IRT,IWG,D,DG)
C
C     STORE THE CALCULATED DERIVATIVES OF THE ABCD MATRICES OF THE
C     WAVEGUIDE SPACINGS W.R.T. SPACINGS (FROM SUBROUTINE WGUIDE)
C     IN THE DESIGNATED DERIVATIVE ARRAY OF THE ABCD MATRICES OF
C     THE SECTIONS (ONLY FOR THOSE SPACINGS WHICH ARE VARIABLES)
C
      INTEGER IRT(16),H20,IWG(16)
      COMPLEX D(100,4),DG(16,4)
C
      DO 40 I=1,N
C
      IF(IWG(I).EQ.0)GO TO 40
      H20=IRT(I)
C
      DO 42 J=1,4
      D(H20,J)=DG(I,J)
   42 CONTINUE
   40 CONTINUE
      RETURN
      END
C
```

Fig. 1   Listing of the subroutine DABCDG2.

SUBROUTINE DRLOSS2

SUBROUTINE DRLOSS2 (N, NP1, IRT, E, F, A, D, H23, RCOEFF, RO, DRTLOSS)

Purpose

This subroutine calculates the sensitivities of common port return loss w.r.t. all variables.

Theory

Having completed the evaluation of matrix **D** of (9) in DABCDF2 (completed in DABCDG2), we can calculate $\partial(\mathbf{A}_{1,N+1})/\partial\phi$ of DABCDF2 (8) in two steps:

$$\mathbf{E} = \mathbf{D}\,\mathbf{A}_{1,j} \tag{1}$$

and

$$\mathbf{F} = \frac{\partial}{\partial\phi}(\mathbf{A}_{1,N+1}) = \mathbf{A}_{j+1,N+1}\,\mathbf{E}\ . \tag{2}$$

Denoting the (1, 1), (1, 2), (2, 1) and (2, 2) elements of the 2×2 matrices $\mathbf{A}_{1,N+1}$ and **F** by superscripts 1, 2, 3 and 4, respectively, (1) of RESPONS can be rewritten as

$$Z_{in} = \frac{\mathbf{A}^2_{1,N+1}}{\mathbf{A}^4_{1,N+1}}\ , \tag{3}$$

and this gives

$$\frac{\partial Z_{in}}{\partial\phi} = \frac{\mathbf{F}^2\,\mathbf{A}^4_{1,N+1} - \mathbf{F}^4\,\mathbf{A}^2_{1,N+1}}{(\mathbf{A}^4_{1,N+1})^2}\ . \tag{4}$$

Utilizing (2) and (3) of RESPONS, we get

$$\frac{\partial\rho}{\partial\phi} = \frac{2R_S}{(Z_{in} + R_S)^2}\,\frac{\partial Z_{in}}{\partial\phi} \tag{5}$$

and

$$\frac{\partial L_R}{\partial\phi} = \frac{-20}{(\ell n\,10)|\rho|^2}\,\mathrm{Re}\left(\bar{\rho}\,\frac{\partial\rho}{\partial\phi}\right), \tag{6}$$

where $\bar{\rho}$ is the complex conjugate of ρ.

List of Arguments

N	is the number of channels.
NP1	is N + 1.
IRT	is as defined in TOTAL2.*
E	is as defined by (1).+
F	is as defined by (2).+
A	is as defined in SEQUENC.+
D	is as defined by (9) of DABCDF2.+
H23	is defined in the VARIABLES section.†
RCOEFF, RO	are as defined in RESPONS.
DRTLOSS	is the sensitivity of the common port return loss w.r.t. all variables as given by (6).

Related Software

This subroutine is called from SIMGRD2.

Footnote

For an explanation of *, + and † see FEATURES

```
C
      SUBROUTINE DRLOSS2(N,NP1,IRT,E,F,A,D,H23,RCOEFF,RO,DRTLOSS)
C
C     CALCULATE SENSITIVITIES OF COMMON PORT RETURN LOSS W.R.T.
C     ALL VARIABLES
C
      INTEGER IRT(16)
      COMPLEX E(100,4),F(100,4),A(17,17,4),D(100,4),H23,RCOEFF
      COMPLEX DZIN,H21,DRCFF,H212
      REAL DRTLOSS(100)
C
      KP=IRT(1)
C
      IF(KP.EQ.0)GO TO 10
      DO 50 J=1,KP
      DO 53 K=1,4
C
      E(J,K)=D(J,K)
   53 CONTINUE
C
      CALL MATMUL(A(2,NP1,1),A(2,NP1,2),A(2,NP1,3),A(2,NP1,4),D(J,1),
     +            D(J,2),D(J,3),D(J,4),F(J,1),F(J,2),F(J,3),F(J,4))
C
   50 CONTINUE
   10 CONTINUE
C
      IF(N.EQ.1)GO TO 54
      DO 51 I=2,N
      IM1=I-1
      IF(IRT(I).EQ.IRT(IM1))GO TO 51
      JB=IRT(IM1)+1
      JE=IRT(I)
      IP1=I+1
C
      DO 52 J=JB,JE
C
      CALL MATMUL(D(J,1),D(J,2),D(J,3),D(J,4),A(1,I,1),A(1,I,2),
     +            A(1,I,3),A(1,I,4),E(J,1),E(J,2),E(J,3),E(J,4))
C
      CALL MATMUL(A(IP1,NP1,1),A(IP1,NP1,2),A(IP1,NP1,3),A(IP1,NP1,4),
     +            E(J,1),E(J,2),E(J,3),E(J,4),F(J,1),F(J,2),F(J,3),
     +            F(J,4))
C
   52 CONTINUE
   51 CONTINUE
   54 CONTINUE
C
      H21=1.0/(A(1,NP1,4)*A(1,NP1,4))
      H211=-20.0/(ALOG(10.0)*RO*RO)
      H212=CONJG(RCOEFF)
C
      KP=IRT(N)
      DO 55 J=1,KP
C
      DZIN=H21*(A(1,NP1,4)*F(J,2)-A(1,NP1,2)*F(J,4))
      DRCFF=H23*DZIN
      DRTLOSS(J)=H211*REAL(H212*DRCFF)
   55 CONTINUE
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine DRLOSS2..

SUBROUTINE DVOLTA2

SUBROUTINE DVOLTA2 (N, IRT, IR, IPN1, IPN2, IWG, VS, H4, TG, H6, RS, DVL, F, H5, H3, H1, YC, Y1, H10, H8, H9, YP, H7, DYP21, DYP22, DYP11, DTG, A, E)

Purpose

This subroutine calculates the sensitivities of channel output voltages w.r.t. all variables.

Theory

Referring to eqn. (7) of RESPONS, we can write

$$V_L^i = \frac{jK_1}{K_2 K_3} , \tag{1}$$

where

$$K_1 = [Y_1^i \quad 1] T_g^i \mathbf{A}_{1,i} \, \mathbf{e}_2 V_S , \tag{2}$$

$$K_2 = \left(\frac{(y'_{22} + G_L)(1 + Y_c y'_{11})}{y'_{21}} - Y_c y'_{21} \right)^i , \tag{3}$$

and

$$K_3 = [1 \quad R_S] \, \mathbf{A}_{1,N+1} \, \mathbf{e}_2 . \tag{4}$$

If we assume that the variable ϕ is in section j, we can consider three different cases for evaluating sensitivitites of (1).

Case 1 Section j is to the right of section i in Fig. 2 of RESPONS, i.e., $j < i$. In this case, K_2 is independent of the variable and we have

$$\frac{\partial V_L^i}{\partial \phi} = \frac{j\left[\left(\frac{\partial K_1}{\partial \phi} \right) K_2 K_3 - \left(\frac{\partial K_3}{\partial \phi} \right) K_1 K_2 \right]}{(K_2 K_3)^2} . \tag{5}$$

We can write

$$\frac{\partial K_1}{\partial \phi} = [Y_1^i \quad 1] T_g^i \left(\frac{\partial}{\partial \phi} \mathbf{A}_{1,i} \right) \mathbf{e}_2 V_S \tag{6}$$

and

$$\begin{aligned} \frac{\partial}{\partial \phi} \mathbf{A}_{1,i} &= \mathbf{A}_{j+1,i} \left(\frac{\partial}{\partial \phi} \mathbf{T}_j \right) \mathbf{A}_{1,j} \\ &= \mathbf{A}_{j+1,i} \ \mathbf{E}_j, \end{aligned} \tag{7}$$

where **E** is defined by (1) in DRLOSS2.

Also, we have

$$\begin{aligned} \frac{\partial K_3}{\partial \phi} &= [1 \quad R_S] \frac{\partial \mathbf{A}_{1,N+1}}{\partial \phi} \mathbf{e}_2 \\ &= [1 \quad R_S] \mathbf{F}_j \ \mathbf{e}_2, \end{aligned} \tag{8}$$

where **F** is defined by (2) in DRLOSS2.

Case 2 The variable is in the same section as the output voltage, i.e., i = j. In this case, we have

$$\frac{\partial V_L^i}{\partial \phi} = \begin{cases} j\left[\dfrac{\dfrac{\partial K_1}{\partial \phi}}{K_2 K_3} - \dfrac{\left(\dfrac{\partial K_3}{\partial \phi}\right) K_1 K_2}{(K_2 K_3)^2} \right] & , \text{ if } \phi = \ell \\[2ex] \dfrac{-j\left[\left(\dfrac{\partial K_2}{\partial \phi}\right) K_1 K_3 + \left(\dfrac{\partial K_3}{\partial \phi}\right) K_1 K_2 \right]}{(K_2 K_3)^2} & , \text{ if } \phi \in \{M_{\ell k}, n_1, n_2\} \end{cases} \tag{9}$$

and

$$\frac{\partial K_1}{\partial \phi} = [Y_1^i \quad 1] \left(\frac{\partial \mathbf{T}_g^i}{\partial \phi} \right) \mathbf{A}_{1,i} \mathbf{e}_2 V_S, \tag{10}$$

where $\partial \mathbf{T}_g^i/\partial \phi$ has been calculated already in WGUIDE (eqn. (2)). Also,

$$\begin{aligned} \frac{\partial K_2}{\partial \phi} &= \frac{(y'_{22} + G_L) Y_c}{y'_{21}} \left(\frac{\partial y'_{11}}{\partial \phi} \right) + \frac{(1 + Y_c y'_{22})}{y'_{21}} \left(\frac{\partial y'_{22}}{\partial \phi} \right) \\ &\quad - \left(Y_c + \frac{(y'_{22} + G_L)(1 + Y_c y'_{11})}{(y'_{21})^2} \right) \left(\frac{\partial y'_{21}}{\partial \phi} \right), \end{aligned} \tag{11}$$

where the superscript i for y_{11}', y_{21}', y_{22}', Y_c and G_L has been omitted. $\partial K_3/\partial\phi$ is calculated as in (8).

Case 3 Section j is to the left of section i in Fig. 2, i.e., j > i. In this case, we have

$$\frac{\partial V_L^i}{\partial \phi} = \frac{-jK_1K_2\frac{\partial K_3}{\partial \phi}}{(K_2K_3)^2} \qquad (12)$$

where $\partial K_3/\partial\phi$ is calculated as in (8).

List of Arguments

N is the number of channels.

IRT is as defined in TOTAL2.*

IR, IPN1, IPN2, IWG are as defined in the main program MXSOS2.*

VS, RS are as defined in RESPONS.

TG, DTG are as defined in WGUIDE.*+

YC, Y1, YP are as defined in FILABCD.*

H4, H6, H5, H3, H1, H10, H8, H9, H7 are defined in the VARIABLES section.*

DVL is the sensitivity of channel output voltage w.r.t. all variables as given by (5), (9) and (12).*

F is as defined by DRLOSS2 (2).+

DYP11, DYP21, DYP22 are as defined in DABCDF2.

A is as defined in SEQUENC.+

E is as defined by DRLOSS2 (1).+

Related Software

This subroutine is called from SIMGRD2.

Footnote

For an explanation of * and + see FEATURES.

```
C
      SUBROUTINE DVOLTA2(N,IRT,IR,IPN1,IPN2,IWG,VS,H4,TG,H6,RS,
     + DVL,F,H5,H3,H1,YC,Y1,H10,H8,H9,YP,H7,DYP21,DYP22,DYP11,
     +             DTG,A,E)
C
C     CALCULATE SENSITIVITIES OF ALL OUTPUT VOLTAGES W.R.T. ALL
C     VARIABLES
C
      INTEGER IRT(16),IR(16),IPN1(16),IPN2(16),IWG(16),UPB,UPBP1
      COMPLEX A(17,17,4),E(100,4),DAI(100,4),Y1(16),TG(16,4)
      COMPLEX DVL(16,100),F(100,4),YC(16),YP(16,4)
      COMPLEX DH2,DYP21(100),DYP22(100),DYP11(100),DTG(16,4)
      COMPLEX H3(16),H4(16),H5(16),H6(16),H7(16),H8(16),H9(16),H10(16)
      COMPLEX JPLX,H1
      COMPLEX H29,H30,H31,H32,H35,H36,H37,H50,H51,H52,H40,H41,H42,H43
      JPLX=CMPLX(0.0,1.0)
C
      DO 60 I=1,N
C
      H29=-VS*H4(I)
      H30=(Y1(I)*TG(I,1)+TG(I,3))*H29
      H31=(Y1(I)*TG(I,2)+TG(I,4))*H29
      H32=H6(I)*RS
C
      H35=H3(I)*H1/H5(I)
      H36=H6(I)/H5(I)
      H37=H36*RS
C
      H40=(Y1(I)*DTG(I,1)+DTG(I,3))*A(1,I,2)
      H41=(Y1(I)*DTG(I,2)+DTG(I,4))*A(1,I,4)
      H42=VS*(H40+H41)
      H43=-H42/H4(I)
C
      H50=-YC(I)-H10(I)/H8(I)
      H51=H9(I)/YP(I,2)
      H52=H7(I)*YC(I)/YP(I,2)
C
      UPB=IRT(I)
      IF(UPB.EQ.0)GO TO 10
      IM1=I-1
      IF(I.EQ.1)GO TO 70
C
      LOB=IRT(IM1)
      IF(LOB.EQ.0)GO TO 70
C
      DO 62 JJ=1,IM1
      ISECT=IR(JJ)+IPN1(JJ)+IPN2(JJ)+IWG(JJ)
      IF(ISECT.EQ.0)GO TO 62
      LL=IRT(JJ)
      KK=LL-ISECT+1
C
      JJP1=JJ+1
      DO 63 J=KK,LL
C
      CALL MATMUL(A(JJP1,I,1),A(JJP1,I,2),A(JJP1,I,3),A(JJP1,I,4),
     +           E(J,1),E(J,2),E(J,3),E(J,4),DAI(J,1),DAI(J,2),
     +           DAI(J,3),DAI(J,4))
C
   63 CONTINUE
   62 CONTINUE
C
      DO 65 J=1,LOB
      DVL(I,J)=(H30*DAI(J,2)+H31*DAI(J,4)+H6(I)*F(J,2)+H32*F(J,4))/H5(I)
      DVL(I,J)=-JPLX*DVL(I,J)
   65 CONTINUE
```

Fig. 1 Listing of the subroutine DVOLTA2.

```
C
      IF(IRT(I).EQ.IRT(IM1))GO TO 10
      GO TO 72
C
   70 LOB=0
C
   72 LOB1=LOB+1
      DO 66 J=LOB1,UPB
      IF(J.NE.UPB)GO TO 30
      IF(IWG(I).NE.1)GO TO 30
C
      DVL(I,J)=H43+H36*F(J,2)+H37*F(J,4)
      DVL(I,J)=-JPLX*DVL(I,J)
C
      GO TO 66
C
   30 CONTINUE
      DH2=H50*DYP21(J)+H51*DYP22(J)+H52*DYP11(J)
C
      DVL(I,J)=H35*DH2+H36*F(J,2)+H37*F(J,4)
      DVL(I,J)=-JPLX*DVL(I,J)
   66 CONTINUE
C
   10 KP=IRT(N)
      IF(UPB.EQ.KP)GO TO 60
      UPBP1=UPB+1
      DO 67 J=UPBP1,KP
      DVL(I,J)=H36*F(J,2)+H37*F(J,4)
      DVL(I,J)=-JPLX*DVL(I,J)
C
   67 CONTINUE
   60 CONTINUE
      RETURN
      END
C
```

Fig. 1 (continued) Listing of the subroutine DVOLTA2.

SUBROUTINE INSERT

SUBROUTINE INSERT (N, VL, DVL, INLOSS, DINLOSS, IRT)

Purpose

This subroutine calculates the channel insertion loss and its sensitivities using channel output voltage and its sensitivities.

Theory

The channel insertion loss is given by (1) and (2) in INSOUT. From (2) of INSOUT, we get

$$\frac{\partial I_L^i}{\partial \phi} = \frac{-20}{(\ell n\, 10)|V_L^i|^2} \mathrm{Re}\left((\overline{V_L^i}) \frac{\partial V_L^i}{\partial \phi} \right) \tag{1}$$

where $\partial V_L{}^i/\partial\phi$ is obtained from (5), (9) and (12) of DVOLTA2 and $\overline{V_L{}^i}$ signifies the complex conjugate of $V_L{}^i$.

List of Arguments

N	is the number of channels.
VL	is the complex channel output voltage.*
DVL	is $\partial V_L/\partial\phi$.*
INLOSS	is the channel insertion loss in dB.*
DINLOSS	is the sensitivity of channel insertion loss $\partial I_L/\partial\phi$.*
IRT	is as defined in TOTAL2.

Related Software

This subroutine is called form SIMGRD2.

Footnote

For a explanation of * see FEATURES.

```
C
      SUBROUTINE INSERT(N,VL,DVL,INLOSS,DINLOSS,IRT)
C
C     CHANNEL INSERTION LOSS AND ITS SENSITIVITIES ARE CALCULATED
C
      COMPLEX VL(16),DVL(16,100),HH2
      REAL INLOSS(16),DINLOSS(16,100)
      INTEGER IRT(16)
C
C     THIS SUBROUTINE IS WRITTEN FOR VS=1.0, RS=1.0, GL(I)=1.0
C
      HH0=-20.0/ALOG(10.0)
      KP=IRT(N)
      DO 10 I=1,N
      VABS=CABS(VL(I))
      INLOSS(I)=-20.0*ALOG10(2.0*VABS)
      HH1=HH0/(VABS*VABS)
      HH2=CONJG(VL(I))
C
      DO 20 J=1,KP
      DINLOSS(I,J)=HH1*REAL(HH2*DVL(I,J))
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
C
```

Fig. 1 Listing of the subroutine INSERT.

SUBROUTINE SIMGRD2

SUBROUTINE SIMGRD2 (OMEG, RLOSS, DRTLOSS, INLOSS, DINLOSS, N, M, ICOUNT, IFLAGJS, IFLAGDP, IDISPER)

COMMON/BLK1/WO, BW, PN1, PN2, GL, VS, RS, PI2, WIDTH, NP1

COMMON/BLK2/CM, WGL

COMMON/BLK4/CBR, FCUT

COMMON/BLK5/DISP

COMMON/BLK6/FCNST, LAMRES, LAMDEL

COMMON/BLK7/CEL

COMMON/BLK8/IR, IRT, IPN1, IPN2, IWG, LC, KC

Purpose

This subroutine sets up the complex **Z** matrix and calls the subroutines necessary for a complete simulation and sensitivity analysis.

Theory

Refer to the theoretical part of SIMUL for setting up **Z** in accordance with the options of dissipation, dispersion and nonideal junction susceptances.

List of Arguments and COMMON Blocks

The definition of arguments and common blocks can be found in the main program MXSOS2, as well as CONST1, DISPAT and DISPER.

Related Software

This subroutine is called from the main program MXSOS2 and FDF2.

```
C
      SUBROUTINE SIMGRD2(OMEG,RLOSS,DRTLOSS,INLOSS,DINLOSS,N,M,
     +                  ICOUNT,IFLAGJS,IFLAGDP,IDISPER)
C
C     THIS SUBROUTINE CALLS ALL OTHER SUBROUTINES NECESSARY TO
C     CALCULATE THE RESPONSE AND EXACT SENSITIVITIES
C
      COMPLEX Z(16,8,8),P(16,8),Q(16,8)
      COMPLEX Y(16,4),YP(16,4),YIN(16),Y1(16),Y3(16),YC(16)
      COMPLEX TF(16,4),TG(16,4),T(16,4),A(17,17,4),Y3SQ(16)
      COMPLEX H2(16),H3(16),H4(16),H5(16),H6(16),H7(16),H8(16)
      COMPLEX H9(16),H10(16),H13(16),H14(16)
      COMPLEX VL(16)
      COMPLEX H1,H23,ZIN,RCOEFF
      COMPLEX S,SD
      REAL WO(16),BW(16)
      REAL CM(16,8,8),PN1(16),PN2(16),PN11(16),PN12(16)
      REAL PN22(16),GL(16),WGL(16)
      REAL INLOSS(16),DINLOSS(16,100)
      REAL DISP(16),LAMR(16)
      REAL FCNST(16),LAMRES(16),LAMDEL(16),LAMFIL,LREAC
      INTEGER IR(16),IRT(16),LC(16,36),KC(16,36),CEL(16,8,8)
      INTEGER IPN1(16),IPN2(16),IWG(16)
      COMPLEX DYP11(100),DYP21(100),DYP22(100)
      COMPLEX D(100,4)
      COMPLEX DTG(16,4),DG(16,4)
      COMPLEX E(100,4),F(100,4)
      REAL DRTLOSS(100)
      COMPLEX DVL(16,100)
C
      COMMON/BLK1/WO,BW,PN1,PN2,GL,VS,RS,PI2,WIDTH,NP1
      COMMON/BLK2/CM,WGL
      COMMON/BLK4/CBR,FCUT
      COMMON/BLK5/DISP
      COMMON/BLK6/FCNST,LAMRES,LAMDEL
      COMMON/BLK7/CEL
      COMMON/BLK8/IR,IRT,IPN1,IPN2,IWG,LC,KC
C
      IF(ICOUNT.NE.1)GO TO 5
C
      DO 100 I=1,N
      DO 100 J=1,M
      DO 100 KK=1,J
      CM(I,J,KK)=CM(I,KK,J)
  100 CONTINUE
C
      DO 99 I=1,N
      DO 99 J=1,M
      DO 99 K=1,M
      Z(I,J,K)=CMPLX(0.0,CM(I,J,K))
   99 CONTINUE
C
      C1=11802.85
      C2=4.0*WIDTH*WIDTH
C
    5 CONTINUE
C
      IF(IDISPER.NE.1)GO TO 500
C
      DO 51 I=1,N
      LAMFIL=C1/SQRT(OMEG*OMEG-FCNST(I))
      LAMR(I)=LAMFIL/LAMRES(I)
      LREAC=2.0*(LAMRES(I)-LAMFIL)/LAMDEL(I)
C
C     SET UP THE COMPLEX IMPEDANCE MATRIX OF THE FILTERS
```

Fig. 1 Listing of the subroutine SIMGRD2.

```
C
      DO 52 J=1,M
      DO 52 K=1,M
      Z(I,J,K)=CMPLX(0.0,CM(I,J,K))*LAMR(I)**CEL(I,J,K)
   52 CONTINUE
C
C     SET UP DIAGONAL ELEMENTS INCLUDING FILTER DISPERSION
C
      DO 53 J=1,M
      Z(I,J,J)=CMPLX(0.0,CM(I,J,J)+LREAC)
C
C     INCLUDE FILTER DISSIPATION
C
      IF(IFLAGDP.EQ.1)Z(I,J,J)=Z(I,J,J)+DISP(I)
   53 CONTINUE
   51 CONTINUE
      GO TO 75
C
  500 CONTINUE
      DO 106 I=1,N
      XR=WO(I)/BW(I)
      C3=(OMEG/WO(I))-(WO(I)/OMEG)
      S=CMPLX(0.0,C3)
      SD=S*XR
C
C     SET UP DIAGONAL ELEMENTS FOR ZERO FILTER DISPERSION
C
      DO 106 J=1,M
      Z(I,J,J)=CMPLX(0.0,CM(I,J,J))+SD
C
C     INCLUDE FILTER DISSIPATION
C
      IF(IFLAGDP.EQ.1)Z(I,J,J)=Z(I,J,J)+DISP(I)
  106 CONTINUE
C
   75 CONTINUE
      IF(IFLAGJS.EQ.1)GO TO 68
      DO 66 I=1,N
      YC(I)=CMPLX(0.0,0.0)
      Y1(I)=CMPLX(0.0,0.0)
   66 CONTINUE
      GO TO 70
C
   68 CONTINUE
C
C     THE JUNCTION SUSCEPTANCE IS CALCULATED
C
      BETAJS=FCUT/(((20.0*(CBR/OMEG)**2)-1.0)*SQRT(OMEG*OMEG-FCUT*FCUT))
      DO 69 I=1,N
      YC(I)=(0.0,0.0)
      Y1(I)=CMPLX(0.0,-BETAJS)
   69 CONTINUE
C
   70 CONTINUE
C
      CALL BETAVAL(C1,C2,OMEG,PI2,BETA)
C
      CALL FILTER(N,M,Z,P,Q)
C
      CALL FILABCD(N,M,P,Q,PN1,PN2,Y1,GL,YC,Y,YP,YIN,Y3,
     +                  Y3SQ,TF,H7,H8,H13,H14,PN11,PN12,PN22)
C
      CALL WGUIDE(N,BETA,WGL,TG,DTG)
C
      DO 121 I=1,N
```

Fig. 1 (continued) Listing of the subroutine SIMGRD2.

```
C
      CALL MATMUL(TF(I,1),TF(I,2),TF(I,3),TF(I,4),TG(I,1),TG(I,2),
     +            TG(I,3),TG(I,4),T(I,1),T(I,2),T(I,3),T(I,4))
C
  121 CONTINUE
C
      CALL SEQUENC(N,NP1,T,A)
C
      CALL RESPONS(N,NP1,RS,ZIN,RLOSS,VL,A,H23,H1,RO,RCOEFF,
     +             YC,YP,TG,Y1,VS,H2,H3,H4,H5,H6,H7,H9,H10)
C
      CALL DABCDF2(N,M,IR,IRT,IPN1,IPN2,LC,KC,DYP11,
     +                  DYP21,DYP22,YIN,P,Q,PN1,PN2,
     +                  PN11,PN12,PN22,H7,H13,H14,Y1,TG,D,Y3SQ,YP,
     +                  LAMR,IDISPER)
C
      DO 125 I=1,N
C
      CALL MATMUL(TF(I,1),TF(I,2),TF(I,3),TF(I,4),DTG(I,1),DTG(I,2),
     +            DTG(I,3),DTG(I,4),DG(I,1),DG(I,2),DG(I,3),DG(I,4))
C
  125 CONTINUE
C
      CALL DABCDG2(N,IRT,IWG,D,DG)
C
      CALL DRLOSS2(N,NP1,IRT,E,F,A,D,H23,RCOEFF,RO,DRTLOSS)
C
      CALL DVOLTA2(N,IRT,IR,IPN1,IPN2,IWG,VS,H4,TG,H6,RS,DVL,F,H5,
     + H3,H1,YC,Y1,H10,H8,H9,YP,H7,DYP21,DYP22,DYP11,DTG,A,E)
C
      CALL INSERT(N,VL,DVL,INLOSS,DINLOSS,IRT)
C
      RETURN
      END
C
```

Fig. 1 (continued)   Listing of the subroutine SIMGRD2.

INTERMEDIATE VARIABLES

Symbol	Mathematical Expression
H1	$[1 \quad R_S]\,\mathbf{A}_{1,N+1}\,\mathbf{e}_2$
*H2	$\dfrac{(y'_{22} + G_L)(1 + Y_c\,y'_{11})}{y'_{21}} - Y_c\,y'_{21}$
*H3	$[Y_1 \quad 1]\,\mathbf{T}_g^i\,\mathbf{A}_{1,i}\,\mathbf{e}_2\,V_S$
*H4	(H2)(H1)
*H5	$(H4)^2$
*H6	(H3)(H2)
*H7	$y'_{22} + G_L$
*H8	$(y'_{21})^2$
*H9	$1 + Y_c\,y'_{11}$
*H10	(H7)(H9)
*H13	$\left(\dfrac{y'_{21}}{y'_{21} + G_L}\right)^2$
*H14	$(Y_1)^2$

* variables which are dimensioned for the number of channels

Symbol	Mathematical Expression
H15	$-\frac{1}{(Y_3)^2}\frac{\partial Y_3}{\partial \phi}$
H20	IRT^i
H21	$1/(A^4_{1,N+1})^2$
H22	$(Z_{in}+R_S)^2$
H23	$\frac{2R_S}{(Z_{in}+R_S)^2}$
H29	$-V_S(H4)$
H30	$[Y_1 \quad 1]\,\mathbf{T}^i_g\,\mathbf{e}_1(H29)$
H31	$[Y_1 \quad 1]\,\mathbf{T}^i_g\,\mathbf{e}_2(H29)$
H32	$R_S(H6)$
H35	$(H1)(H3)/(H5)$
H36	$(H6)/(H5)$
H37	$R_S(H36)$
H40	$[Y_1 \quad 1]\,\frac{\partial T_g}{\partial \phi}\,\mathbf{e}_1\,\mathbf{e}_1^T\,\mathbf{A}_{1,i}\,\mathbf{e}_2$

Symbol	Mathematical Expression
H41	$[Y_1 \quad 1]\, \frac{\partial T_g}{\partial \phi}\, \mathbf{e}_2\, \mathbf{e}_2^T\, \mathbf{A}_{1,i}\, \mathbf{e}_2$
H42	$[Y_1 \quad 1]\, \frac{\partial T_g}{\partial \phi}\, \mathbf{A}_{1,i}\, \mathbf{e}_2 V_S$
H43	$-(H42)/(H4)$
H50	$-\left[Y_c + \frac{(y'_{22} + G_L)(1 + Y_c y'_{11})}{(y'_{21})^2} \right]$
H51	$\frac{1 + Y_c y'_{11}}{y'_{21}}$
H52	$\frac{(y'_{22} + G_L) Y_c}{y'_{21}}$
H72	$\frac{2 y'_{21}}{y'_{22} + G_L}$
H211	$\frac{-20}{(\ell n 10)\lvert\rho\rvert^2}$
H212	$\bar{\rho}$
HMX	$\mathbf{T}_g^i\, \mathbf{A}_{1,i}$