CCFIL1 – AN INTERACTIVE SOFTWARE SYSTEM FOR DESIGN OPTIMIZATION OF IDEAL MULTI-COUPLED CAVITY FILTERS

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SOS-84-14-RU

September 1984

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Abstract

CCFIL1 is an interactive software system for design optimization of ideal multi-coupled cavity filters of the narrow-band lossless type with resistive load. User-oriented features for data entry, editing and storage are implemented. The engineering specifications are taken directly as the optimization objectives and the network parameters as the optimization variables. The gain and phase responses may be optimized concurrently and the variable network parameters may be subjected to any required equality or inequality linear constraints. The design solution is found in the minimax sense by the MMLC optimization package running simultaneously with a tracking algorithm which judiciously selects sample frequency points by applying a cubic interpolation routine to the gain response. The package and documentation have been developed on the DEC VAX 11/780 system with the VMS 3.6 operating system and the FORTRAN 3.5 compiler.

This work was supported in part by the Natural Sciences and Engineering Research Council of Canada under Grant G1135.

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I. INTRODUCTION

This document provides a user-oriented description of the CCFIL1 software system, which effectively implements the algorithm for an interactive computer program for design optimization of ideal multi-coupled cavity filters presented by Bandler and Chen [1]. Efficient approaches to the simulation and sensitivity evaluation of such filters have been developed and discussed in a report [2] wherein various formulas and tables are presented in detail. The CCFIL1 system applies these formulas to the case of a narrow-band lossless type filter with resistive load.

The design optimization is performed by the MMLC package [3,4] which applies a gradient-based minimax method and allows the formulation of linearly constrained design variables. A cubic interpolation technique used to improve computational efficiency has also been incorporated with the optimization procedure.

The CCFIL1 system has been developed in Fortran 77 on the DEC VAX 11/780 system. At McMaster University it is available on the Engineering VAX in the form of binary executable code as a group file under the charge ZE050. The general sequence of VMS commands to use the package can be as follows:

```
$ RUNH GR:CCFIL1
```

II. GENERAL DESCRIPTION

The network parameters that can be used as optimization variables are the coupling matrix elements, including the diagonal ones which may represent deviations from synchronous tuning, and the input and output transformer ratios. The optimization objectives are formulated directly from the gain and phase responses of the filter. The gain response is specified in terms of the reflection coefficient, or the transducer loss in units of decibels. Since the phase response of interest to the CCFIL1 system is the group delay variation within a certain frequency band, the response is specified in terms of the relative group delay in units of nanoseconds.

The general formulation of the design optimization problem has been provided by Bandler [5] and it essentially consists in minimizing a discrete set of error functions. Each error function is defined at a particular frequency as the product of a weighting factor by the net difference of the network response minus the specified response. The weighting factor is defined as being either smaller or larger than zero which corresponds to a lower or an upper specification, respectively. Hence, the specification is satisfied if the error function is less than or equal to zero, or is violated if the error function is larger than zero. For the relative group delay specification, the network response which defines the error function should be interpreted as the magnitude of the difference between the average group delay and the group delay at the particular frequency.

In conjunction with the minimization of error functions, the variable network parameters may be subjected to any required equality or inequality linear constraints. The MMLC optimization package readily accomodates such constraints and the CCFIL1 system will prompt the user for the necessary data.

The optimal design solution that can be reached by the minimax method is an equal-ripple response which meets the specifications. For the filter problem considered here, the presence of sharp ripples of the response, especially near the band edges creates a problem in the selection of representative sample frequency points. That is, the optimal solution requires the sample frequency points to present the error peaks to the minimax optimization package. The CCFIL1 system offers assistance with this task during gain response optimization by providing an algorithm to locate the peaks of the error function, that is, the error maxima w.r.t. frequency. The search procedure for a maximum starts from the lower frequency edge of a subinterval and proceeds with a given step-length to evaluate the slope of the error function. When two consecutive points yield a positive succeeded by a negative slope, it follows that at least one maximum lies between the two. If the points are close enough to exclude the existence of multiple maxima, the location of the detected maximum is estimated by a cubic interpolation formula [1]. The initial sample frequency points are then automatically changed in value to reflect the location of the detected error peak.

III. SYSTEM DATA

For simulation purposes and before optimization can be performed, the following system data is required from the user:

- the order of the coupling matrix (i.e., that of the filter)
- whether the coupling matrix is symmetrical w.r.t. its anti-diagonal (it is always symmetrical w.r.t. its diagonal)
- the value of the coupling matrix elements (only the non-zero ones need be specified)
- the synchrously tuned cavity resonant frequency (the center frequency) in units of MHz
- the bandwidth parameter in units of MHz
- the load resistance multiplied by the output-transformer ratio squared, in units of ohms
- the source resistance and reactance, in units of ohms
- the value of the input-transformer ratio squared.

IV. OPTIMIZATION DATA

Optimization Variables

The variable coupling matrix elements are identified via their row and column indexes. Symmetrical elements are automatically taken into account. Variable input and output transformer ratios may also be specified. Note that the term transformer ratio should hereafter be interpreted as transformer ratio squared.

The MMLC optimization package printouts will list these parameters under the "VARIABLES" heading. First to be listed, and in the order they were specified, are the values of the coupling matrix elements. Then, if the transformer ratios are variable, the output and then the input ratios are listed. If the transformer ratios are equal by symmetry, only one value will be listed.

Gain Response Optimization

The user begins by indicating whether the specifications will be given in terms of the reflection coefficient or the transducer loss. A table which converts between values of these terms and the return loss is contained in Appendix B. The next step consists in dividing the frequency band of interest into a number of subintervals, each characterized by the following data:

#1: the number of sample frequency points

#2: the initial value of the sample frequency points

#3: the step-length of the extrema search

#4: the specified value of the response

#5: the corresponding weighting factor

where items #4 and #5 are used to formulate the error functions to be evaluated at frequency points specified by items #1 to #3.

For any subinterval, upper or lower specifications are indicated by positive or negative weighting factors, respectively. The magnitude of the weighting factor can be used to explicitly emphasize certain specifications, or to adjust for the inherent scaling effect arising when deviations from the specified values that may be insignificant for the stopband are critical for the passband or vice-versa [1].

Two approaches may be used to select the sample frequency points at which the subinterval's error functions are to be evaluated. The first consists in having sample frequency points that remain fixed, and the second in having sample frequency points that vary according to the location of the error peaks [1]. The former option is selected by choosing an extrema search step-length of zero, and the latter by choosing a step-length larger than zero. For both cases, the number of sample frequency points and their fixed/initial values, given in increasing order, have to be specified.

If the extrema tracking algorithm is used, certain rules of thumb can be applied to the selection of the number of sample frequency points and the search step-length value. The number of sample frequency points should equal the number of error peaks that will occur in the subinterval plus two points to delimit the edge of the subinterval plus two or three or more points dispersed throughout the subinterval. The choice of the initial value of the sample frequency points is not very critical and many of them will change value as the optimization proceeds. Upon exit from the MMLC optimization package, the sample frequency points of the last iteration will be listed and the extrema pointed out.

Choosing an extrema search step-length for a subinterval involves a compromise between too fine a step, which would make the search procedure unnecessarily time consuming, and too coarse a step which may not detect an error peak. A rule of thumb is to make the step-length equal to half the distance between either the two nearest error peaks, or an error peak and a subinterval edge, whichever is the smallest.

It should now be clear that the criteria used to divide the frequency band of interest into a number of subintervals are the specification and weighting factor combination and the extrema search step-length. The last criterion is used to prevent a certain subsection of a frequency range from imposing a search step-length much finer than otherwise necessary on the remainder of the range. It should also be pointed out that, for symmetric responses, only one of the symmetrical halves need be considered throughout the response optimization.

One final word of caution for defining subintervals, is that no subintervals should usually have any points in common. This could give rise to either redundant calculations, or worse, a very ill-conditioned problem. A notable exception occurs when a frequency subinterval is specified twice, once with an upper specification and once with a lower specification.

Phase Response Optimization

The data required for flat group delay optimization are:

#1: number of sample frequency points

#2: frequencies of the fixed sample points

#3: specification for the relative delay

#4: the weighting factor

There is effectively only one subinterval of interest, namely the passband, and since its group delay response is a well-behaved function, only fixed sample frequency points are required. The number of points and their locations can easily be determined by performing a group delay simulation and noting where the undesirable peaks occur. It should also be mentioned that the group delay sample frequency points do not interfere with those specified for the gain response optimization even if they happen to cover the same frequency range.

The relative delay specification is given in units of nanoseconds. A specification of zero implies that a perfectly flat response is desired w.r.t. the sample points, whereas a value larger than zero would tolerate a finite ripple in the response at the solution. The weighting factor should always be a positive value since the error function formula interprets as an upper specification the relative group delay specification.

Constraints

The variable network parameters may be subjected to any required linear equality or inequality constraints. The generic forms of the linear constraints are:

$$C1 * X1 + \dots + Ci * Xi + \dots + Cn * Xn + B = 0$$

$$C1 * X1 + \dots + Ci * Xi + \dots + Cn * Xn + B \geq 0$$

where B is a constant, Xi are the variable network parameters and Ci their coefficients in the equation.

The CCFIL1 system will prompt the user for all the necessary data.

Optimization Control Data

The CCFIL1 system utilizes the MMLC optimization package [3,4] to reach a design solution. The following control data is required:

#1: maximum number of function evaluations

#2: initial step-length

#3: accuracy requirement

Data items #1 and #3 are used to stop the optimization algorithm if a solution has not yet been found. Item #1 limits the number of calls to the FDF subroutine (see Section VI of this report), and item #3 is used to measure if a sufficiently small change in the optimization variables is occurring. Data item #2 specifies the initial step-length of the iterative optimization algorithm. It must be positive and normally an appropriate value is ten percent of the average variable network parameter.

The step-length is adjusted by the MMLC package during the optimization and upon return from the last function evaluation its value is saved by the CCFIL1 system. If the optimization process is initited more than once, the user will be notified of the step-length value used during the last iteration. Using it for data item #2 will cause the optimization to proceed from the last function evaluation, otherwise the optimization will start anew from the specified step-length.

Apart from the optimization control data, the user will be prompted for certain printout options. One printout option is used to list the values of the optimization variables and the error functions at various stages of the optimization. The user chooses to have these values listed only at the last function evaluation, or regularly after a specified number of function evaluations. Another printout option involves the plotting of error functions as the optimization proceeds. These error functions are the ones evaluated at the search and sample frequency points and so this option does not create a computational burden for the package. This feature is offered as a matter of interest as it allows the user to observe the effects of the minimax optimization method on the error function values. The user is well forewarned that the plotting itself is time consuming and therefore slows down the optimization. It is best to test this feature when only a small number of function evaluations have been specified.

V. INTERACTIVE FEATURES

The interactive system CCFIL1 offers many practical user-oriented features so as to allow efficient and productive design sessions. See, for example, the sample session of Appendix A. Most features are described below, while others which deal with the entry of invalid data or editing changes that have secondary implications, although present in the package, are not detailed here.

A typical interactive session begins by having the program prompt the user for all of the required system and optimization data. Entered data is regularly reiterated and the user queried about its correctness. Data entry may be made by the user from the keyboard or read from a file, which has been previously saved by the CCFIL1 system. Once the system is defined, the package enters a menu-driven mode having the following options:

1) NEW COUPLING MATRIX
2) NEW VARIABLE COUPLINGS
3) NEW CENTER FREQUENCY, BANDWIDTH, TERMINATIONS
4) NEW SUBINTERVAL DATA
5) NEW CONSTRAINTS
6) OPTIMIZATION
7) SIMULATION
8) VIEW A LOCAL FILE
9) SAVE THE DESIGN DATA
10) QUIT.

Menu items 1 to 5 allow editing of all the system data. Menu item 6 will allow the optimization to start anew or to proceed from the last function evaluation stage. Menu item 7 proceeds to simulate the existing system and offers to append the plot to a local file. This allows the user to create a file, which could later be referred to for comparison purposes by specifying menu item

8. Menu item 9 will save the entire design data, including the optimization step-length at the last function evaluation, in a format compatible with subsequent initial data entry to the program. The user may then select menu item 10 with the assurance of being able to proceed with the design session at some future time.

VI. STRUCTURE OF THE PACKAGE

The CCFIL1 filter optimization system comprises the following files:

- CCFIL1 deals with the interactive features of the package
- FILOSUB implements the algorithm which solves the filter network
- LOWRPLT a low resolution plotting package
- LMMLC8D the MMLC optimization library

A block diagram of the structure is shown in Figure 1.

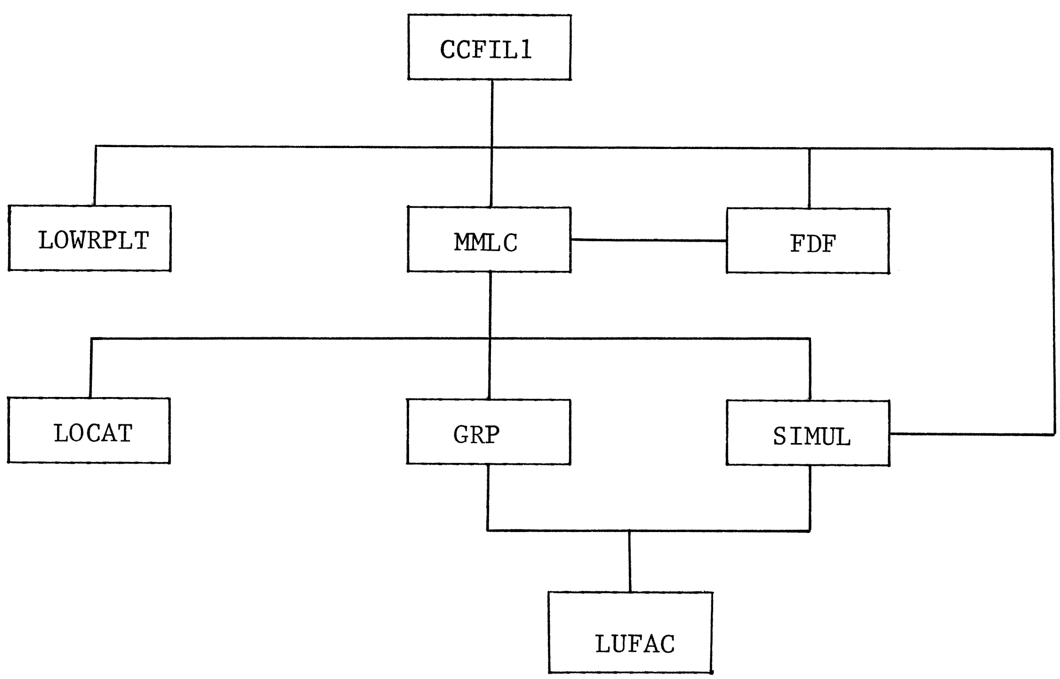


Figure 1. Structure of the CCFIL1 system.

The FILOSUB subroutines are further detailed:

- FDF interacts with the MMLC optimization package. Variable network parameters are updated and objective functions and gradients are constructed in correspondence with the subinterval specifications. Optimal selection of sample frequency points is also performed in FDF.

- LOCAT estimates the frequency point at which a maximum occurs in the error function by applying a cubic interpolation algorithm to the error function.
- SIMUL computes the gain response and its sensitivities w.r.t. the optimization variables and the frequency at a given frequency point.
- LUFAC solves the loaded filter network at a given frequency. One real LU factorization of an NxN matrix is performed. The complex original solution with or without three adjoint solutions is computed.
- GRP calculates the exact group delay and its sensitivities at a given frequency. The group delay is given in units of nanoseconds.

VII. LIMITS OF THE PACKAGE

The size of a problem that can be accomodated by the CCFIL1 system is determined by the dimension of various arrays in the CCFIL1.FOR and FILOSUB.FOR routines. The present limits are:

12 = the order of the filter

30 = the number of optimization variables in the coupling matrix

40 = the number of linear constraints

10 = the number of frequency subintervals

50 = the total number of sample frequency points

If a larger problem is to be solved, adjustments will be required in the CCFIL1.FOR and FILOSUB.FOR routines. These files will then need to be recompiled and all files re-linked. A typical sequence of VMS commands that could be used is listed in Appendix C.

APPENDIX A

A SAMPLE INTERACTIVE DESIGN OPTIMIZATION SESSION

```
                THIS IS A COMPUTER PROGRAM IMPLEMENTING AN ALGORITHM

                          FOR THE DESIGN OPTIMIZATION OF

                     NARROW-BAND MULTI-CAVITY MICROWAVE FILTERS


 IS THE INPUT DATA TO BE READ FROM A LOCAL FILE ?  Y/N
INPUT : N
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


 PLEASE ENTER:

     # 1:          ORDER OF THE  COUPLING MATRIX
INPUT : 6

     # 2:          IS THE COUPLING MATRIX SYMMETRICAL
                    W.R.T. THE ANTIDIAGONAL ?  Y/N
INPUT : Y

     # 3:          NUMBER OF NONZERO ELEMENTS OF THE COUPLING MATRIX
                    (NOT COUNTING SYMMETRICAL  OR ANTISYMMETRICAL ONES)
INPUT : 5


 RE:

     # 1:          ORDER OF THE  COUPLING MATRIX
                =       6

     # 2:          ANTISYMMETRICAL ?
                =       Y

     # 3:          NUMBER OF NONZERO ELEMENTS OF THE COUPLING MATRIX
                =       5

 DATA CORRECT ?     ANSWER  N  IF NOT
INPUT :
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


                              SET UP THE COUPLING MATRIX


               FOR ELEMENT NUMBER  " 1"
               ENTER: ROW INDEX, COLUMN INDEX, COUPLING VALUE
INPUT : 1,2,.8101

               FOR ELEMENT NUMBER  " 2"
               ENTER: ROW INDEX, COLUMN INDEX, COUPLING VALUE
INPUT : 2,3,.4894

               FOR ELEMENT NUMBER  " 3"
               ENTER: ROW INDEX, COLUMN INDEX, COUPLING VALUE
INPUT : 3,4,.8450

               FOR ELEMENT NUMBER  " 4"
               ENTER: ROW INDEX, COLUMN INDEX, COUPLING VALUE
INPUT : 1,6,.1197

               FOR ELEMENT NUMBER  " 5"
               ENTER: ROW INDEX, COLUMN INDEX, COUPLING VALUE
INPUT : 2,5,-.4010
```

CHECK YOUR COUPLING MATRIX

0.00000	0.81010	0.00000	0.00000	0.00000	0.11970
0.81010	0.00000	0.48940	0.00000	-0.40100	0.00000
0.00000	0.48940	0.00000	0.84500	0.00000	0.00000
0.00000	0.00000	0.84500	0.00000	0.48940	0.00000
0.00000	-0.40100	0.00000	0.48940	0.00000	0.81010
0.11970	0.00000	0.00000	0.00000	0.81010	0.00000

DATA CORRECT ? ANSWER N IF NOT

INPUT :

- -

V A R I A B L E   C O U P L I N G S

ENTER THE NUMBER OF OPTIMIZATION VARIABLES
IN THE COUPLING MATRIX

INPUT : 5

IDENTIFY VARIABLE NUMBER "1"
ROW INDEX, COLUMN INDEX

INPUT : 1,2

IDENTIFY VARIABLE NUMBER "2"
ROW INDEX, COLUMN INDEX

INPUT : 2,3

IDENTIFY VARIABLE NUMBER "3"
ROW INDEX, COLUMN INDEX

INPUT : 3,4

IDENTIFY VARIABLE NUMBER "4"
ROW INDEX, COLUMN INDEX

INPUT : 1,6

IDENTIFY VARIABLE NUMBER "5"
ROW INDEX, COLUMN INDEX

INPUT : 2,4

RE:

THE VARIABLE ELEMENTS OF THE COUPLING MATRIX ARE :

(1 , 2)
(2 , 3)
(3 , 4)
(1 , 6)
(2 , 4)

DATA CORRECT ? ANSWER N IF NOT

INPUT : N

PLEASE CHOOSE:

2 --- RE-KEY THIS DATA
3 --- CONTINUE

INPUT : 2

- -

```
                    V A R I A B L E     C O U P L I N G S

                ENTER THE NUMBER OF OPTIMIZATION VARIABLES
                          IN THE COUPLING MATRIX

INPUT : 5
                         IDENTIFY VARIABLE NUMBER  "1"
                          ROW INDEX,  COLUMN INDEX
INPUT : 1,2
                         IDENTIFY VARIABLE NUMBER  "2"
                          ROW INDEX,  COLUMN INDEX
INPUT : 2,3
                         IDENTIFY VARIABLE NUMBER  "3"
                          ROW INDEX,  COLUMN INDEX
INPUT : 3,4
                         IDENTIFY VARIABLE NUMBER  "4"
                          ROW INDEX,  COLUMN INDEX
INPUT : 1,6
                         IDENTIFY VARIABLE NUMBER  "5"
                          ROW INDEX,  COLUMN INDEX
INPUT : 2,5


 RE:
           THE VARIABLE ELEMENTS OF THE COUPLING MATRIX ARE :

                          ( 1 ,  2)
                          ( 2 ,  3)
                          ( 3 ,  4)
                          ( 1 ,  6)
                          ( 2 ,  5)

 DATA CORRECT ?     ANSWER  N  IF NOT

INPUT :
```

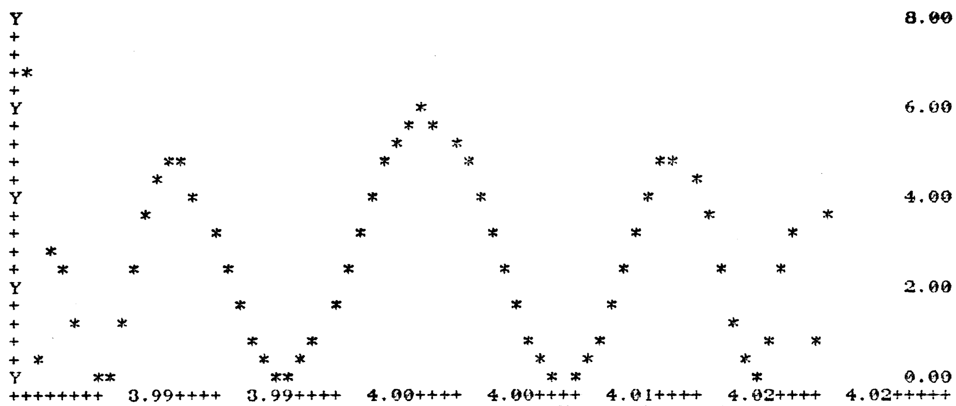
```
 PLEASE ENTER:

    # 1:          CENTER FREQUENCY

    # 2:          BANDWIDTH PARAMETER

    # 3:          RESISTANCE * OUTPUT TRANSFORMER RATIO SQUARED

    # 4:          SOURCE RESISTANCE

    # 5:          SOURCE REACTANCE

    # 6:          VALUE OF THE INPUT-TRANSFORMER  RATIO SQUARED

INPUT : 4000 40 .96 1 0 .96

    # 7:          TRANSFORMER RATIOS VARIABLE ?  Y/N

INPUT : Y
```

RE:

```
  # 1:           CENTER FREQUENCY
              =    4000.00

  # 2:           BANDWIDTH PARAMETER
              =      40.00

  # 3:           RESISTANCE * OUTPUT TRANSFORMER RATIO SQUARED
              =     0.960000

  # 4:           SOURCE RESISTANCE
              =     1.000000

  # 5:           SOURCE REACTANCE
              =     0.000000

  # 6:           VALUE OF THE INPUT-TRANSFORMER  RATIO SQUARED
              =     0.960000

  # 7:           TRANSFORMER RATIOS VARIABLE ?  Y/N
              =       Y

DATA CORRECT ?     ANSWER  N  IF NOT

INPUT :

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                  SIMULATION  ?    ANSWER  N  IF NOT

INPUT :

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                         S I M U L A T I O N

            LOWER  &  UPPER EDGES OF THE BAND  TO BE SIMULATED

            NUMBER OF FREQUENCY POINTS     AND

            RESPONSE INDICATOR  :     1 ---  REFLECTION COEF.
                                      2 ---  TRANSDUCER LOSS
                                      3 ---  GROUP  DELAY


INPUT : 3980,4020,61,2
```

```
DATA CORRECT ?      ANSWER  N   IF NOT

INPUT :
                  3980.000                0.068988
                  3980.667                0.005189
                  3981.333                0.029428
                  3982.000                0.025982
                  3982.667                0.010701
                  3983.333                0.000917
                  3984.000                0.001737
                  3984.667                0.010834
                  3985.333                0.023501
                  3986.000                0.035456
                  3986.667                0.043886
                  3987.333                0.047534
                  3988.000                0.046391
                  3988.667                0.041288
                  3989.333                0.033518
                  3990.000                0.024527
                  3990.667                0.015697
                  3991.333                0.008191
                  3992.000                0.002867
                  3992.667                0.000243
                  3993.333                0.000497
                  3994.000                0.003501
                  3994.667                0.008874
                  3995.333                0.016044
                  3996.000                0.024319
                  3996.667                0.032953
                  3997.333                0.041209
                  3998.000                0.048412
                  3998.667                0.053992
                  3999.333                0.057518
                  4000.000                0.058723
                  4000.667                0.057518
                  4001.333                0.053995
                  4002.000                0.048422
                  4002.667                0.041230
                  4003.333                0.032989
                  4004.000                0.024370
                  4004.667                0.016108
                  4005.333                0.008942
                  4006.000                0.003559
                  4006.667                0.000525
                  4007.333                0.000220
                  4008.000                0.002771
                  4008.667                0.008003
                  4009.333                0.015426
                  4010.000                0.024186
                  4010.667                0.033150
                  4011.333                0.040965
                  4012.000                0.046267
                  4012.667                0.047596
                  4013.333                0.044283
                  4014.000                0.036217
                  4014.667                0.024536
                  4015.333                0.011873
                  4016.000                0.002318
                  4016.667                0.000509
                  4017.333                0.009139
                  4018.000                0.024302
                  4018.667                0.030499
                  4019.333                0.009259
                  4020.000                0.036167

        DO YOU ALSO WANT THIS PLOT FILED (Y/N) ?
INPUT : N

DATA CORRECT ?      ANSWER  N   IF NOT

INPUT :
```

X AXIS: FREQUENCY (MHZ)
Y AXIS: TRANSDUCER LOSS (DB)



0.398E+04<= X <=0.402E+04 VS 0.220E-03<= Y <=0.690E-01

PAUSING: TYPE ANYTHING TO CONTINUE OR TYPE STOP
INPUT :

- -

SIMULATION ? ANSWER N IF NOT

INPUT :

- -

S I M U L A T I O N

LOWER & UPPER EDGES OF THE BAND TO BE SIMULATED

NUMBER OF FREQUENCY POINTS AND

RESPONSE INDICATOR : 1 --- REFLECTION COEF.
2 --- TRANSDUCER LOSS
3 --- GROUP DELAY

INPUT : 3960,3980,31,2

DATA CORRECT ? ANSWER N IF NOT

INPUT :

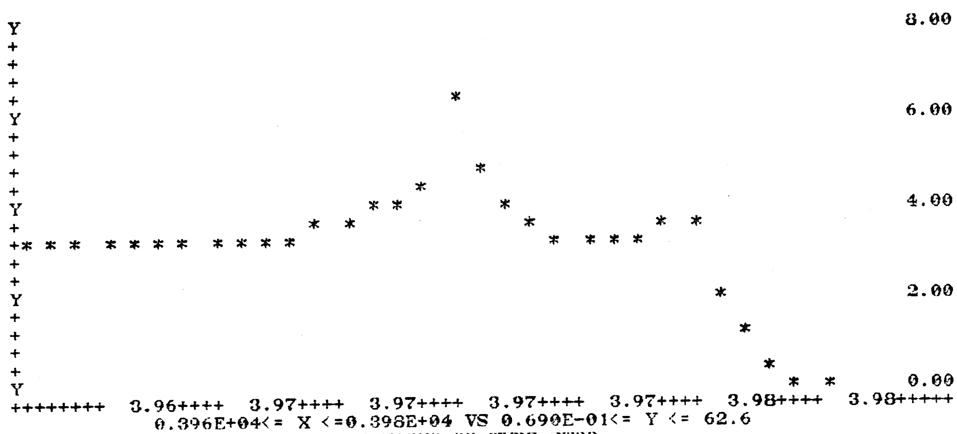
3960.000	30.991592
3960.667	31.041719
3961.333	31.122062
3962.000	31.238210
3962.667	31.397144
3963.333	31.607704
3964.000	31.881296
3964.667	32.232935
3965.333	32.682910
3966.000	33.259515
3966.667	34.003819
3967.333	34.978661
3968.000	36.287368
3968.667	38.118485
3969.333	40.877867
3970.000	45.756820
3970.667	62.616608
3971.333	47.534349
3972.000	40.348165
3972.667	36.295834
3973.333	33.562348
3974.000	31.730949
3974.667	30.825116
3975.333	31.387553
3976.000	36.225100
3976.667	35.865191
3977.333	20.944713
3978.000	11.985676
3978.667	5.041695
3979.333	1.074342
3980.000	0.068988

DO YOU ALSO WANT THIS PLOT FILED (Y/N) ?
INPUT : N

DATA CORRECT ? ANSWER N IF NOT

INPUT :

X AXIS: FREQUENCY (MHZ)
Y AXIS: TRANSDUCER LOSS (DB)



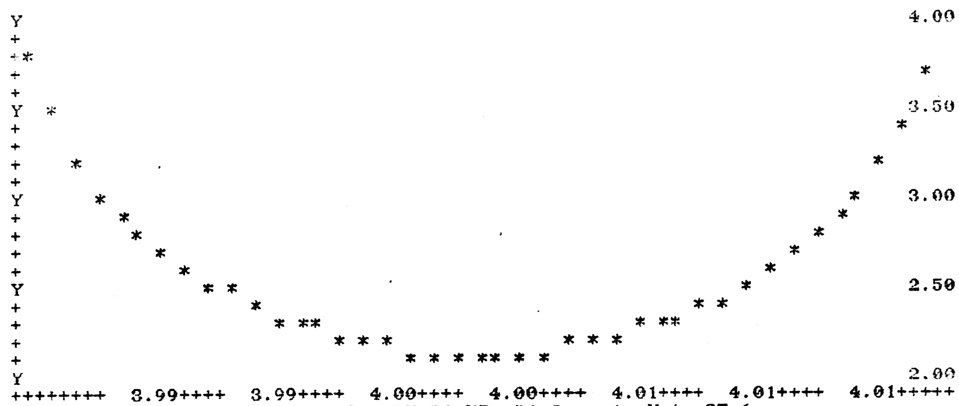
PAUSING: TYPE ANYTHING TO CONTINUE OR TYPE STOP
INPUT :

SIMULATION ? ANSWER N IF NOT

INPUT :

```
                         S I M U L A T I O N

          LOWER  &  UPPER EDGES OF THE BAND  TO BE SIMULATED

          NUMBER OF FREQUENCY POINTS       AND

          RESPONSE INDICATOR  :      1 ---  REFLECTION COEF.
                                     2 ---  TRANSDUCER LOSS
                                     3 ---  GROUP  DELAY


INPUT : 3985,4015,41,3

 DATA CORRECT ?     ANSWER  N   IF NOT

INPUT :
                    3985.000            37.576716
                    3985.750            34.662640
                    3986.500            32.321967
                    3987.250            30.449227
                    3988.000            28.948464
                    3988.750            27.735773
                    3989.500            26.740880
                    3990.250            25.907288
                    3991.000            25.191482
                    3991.750            24.561617
                    3992.500            23.995939
                    3993.250            23.481076
                    3994.000            23.010293
                    3994.750            22.581798
                    3995.500            22.197190
                    3996.250            21.860109
                    3997.000            21.575128
                    3997.750            21.346904
                    3998.500            21.179560
                    3999.250            21.076268
                    4000.000            21.038994
                    4000.750            21.068354
                    4001.500            21.163582
                    4002.250            21.322575
                    4003.000            21.542032
                    4003.750            21.817722
                    4004.500            22.144900
                    4005.250            22.518914
                    4006.000            22.936048
                    4006.750            23.394596
                    4007.500            23.896173
                    4008.250            24.447216
                    4009.000            25.060667
                    4009.750            25.757335
                    4010.500            26.568115
                    4011.250            27.534871
                    4012.000            28.711949
                    4012.750            30.166849
                    4013.500            31.980059
                    4014.250            34.243540
                    4015.000            37.058213

       DO YOU ALSO WANT THIS PLOT FILED (Y/N) ? .
INPUT : N

 DATA CORRECT ?     ANSWER  N   IF NOT

INPUT :
```

```
X AXIS: FREQUENCY (MHZ)
Y AXIS: GROUP DELAY (NSECS)
```




```
      0.399E+04<= X <=0.402E+04 VS  21.0     <= Y <= 37.6
PAUSING:  TYPE ANYTHING TO CONTINUE OR TYPE STOP
INPUT :
```

```
                      SIMULATION  ?    ANSWER  N  IF NOT

INPUT : N
```

```
PLEASE ENTER:

                        S P E C I F I C A T I O N S

     # 1:           GAIN RESPONSE INDICATOR   :
                     1 --- REFLECTION COEFFICIENT
                     2 --- TRANSDUCER LOSS


     # 2:           NUMBER OF SUBINTERVALS
INPUT : 1,3


RE:

                        S P E C I F I C A T I O N S

     # 1:           GAIN RESPONSE INDICATOR   :
                     1 --- REFLECTION COEFFICIENT
                     2 --- TRANSDUCER LOSS
                  =  1

     # 2:           NUMBER OF SUBINTERVALS
                  =  3

PLEASE CHOOSE:
                  2 --- EDIT THIS DATA
                  3 --- CONTINUE
INPUT : 3
```

```
PLEASE ENTER:

               S U B I N T E R V A L   N U M B E R   1

   # 1:            NUMBER OF SAMPLE POINTS

   # 2:            INITIAL POSITIONS OF THE SAMPLE POINTS

   # 3:            STEP-LENGTH OF EXTREMA SEARCH
                    ( ENTER 0.0  FOR FIXED POINTS )

   # 4:            THE SPECIFIED VALUE OF THE RESPONSE

   # 5:            THE CORRESPONDING WEIGHTING FACTOR
                    < 0   FOR LOWER SPECIFICATION


INPUT : 4,3950,3960,3965,3970,2,.9993,-1

RE:
               S U B I N T E R V A L   N U M B E R   1

   # 1:            NUMBER OF SAMPLE POINTS
               =   4

   # 2:            INITIAL POSITIONS OF THE SAMPLE POINTS
               =     3950.00   3960.00   3965.00   3970.00

   # 3:            STEP-LENGTH OF EXTREMA SEARCH
                    ( ENTER 0.0  FOR FIXED POINTS )
               =      2.0000

   # 4:            THE SPECIFIED VALUE OF THE RESPONSE
               =      0.999300

   # 5:            THE CORRESPONDING WEIGHTING FACTOR
                    < 0   FOR LOWER SPECIFICATION
               =    -1.000000

PLEASE CHOOSE:
                 2 --- EDIT THIS DATA
                 3 --- CONTINUE
INPUT : 3
```

```
PLEASE ENTER:

               S U B I N T E R V A L   N U M B E R   2

   # 1:            NUMBER OF SAMPLE POINTS

   # 2:            INITIAL POSITIONS OF THE SAMPLE POINTS

   # 3:            STEP-LENGTH OF EXTREMA SEARCH
                    ( ENTER 0.0  FOR FIXED POINTS )

   # 4:            THE SPECIFIED VALUE OF THE RESPONSE

   # 5:            THE CORRESPONDING WEIGHTING FACTOR
                    < 0   FOR LOWER SPECIFICATION


INPUT : 4,3970,3972,3974,3976,1,.9993,-1
```

```
RE:
                  S U B I N T E R V A L   N U M B E R   2

    # 1:             NUMBER OF SAMPLE POINTS
                 =   4

    # 2:             INITIAL POSITIONS OF THE SAMPLE POINTS
                 =     3970.00    3972.00    3974.00    3976.00

    # 3:             STEP-LENGTH OF EXTREMA SEARCH
                      ( ENTER 0.0  FOR FIXED POINTS )
                 =      1.0000

    # 4:             THE SPECIFIED VALUE OF THE RESPONSE
                 =      0.999300

    # 5:             THE CORRESPONDING WEIGHTING FACTOR
                      < 0    FOR LOWER SPECIFICATION
                 =     -1.000000

PLEASE CHOOSE:
                 2 --- EDIT THIS DATA
                 3 --- CONTINUE
INPUT : 3

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


PLEASE ENTER:

                  S U B I N T E R V A L   N U M B E R   3

    # 1:             NUMBER OF SAMPLE POINTS

    # 2:             INITIAL POSITIONS OF THE SAMPLE POINTS

    # 3:             STEP-LENGTH OF EXTREMA SEARCH
                      ( ENTER 0.0  FOR FIXED POINTS )

    # 4:             THE SPECIFIED VALUE OF THE RESPONSE

    # 5:             THE CORRESPONDING WEIGHTING FACTOR
                      < 0    FOR LOWER SPECIFICATION


INPUT : 8,3980,3982,3984,3989,3993,3995,3998,4001,.5,.1,1


RE:
                  S U B I N T E R V A L   N U M B E R   3

    # 1:             NUMBER OF SAMPLE POINTS
                 =   8

    # 2:             INITIAL POSITIONS OF THE SAMPLE POINTS
                 =     3980.00    3982.00    3984.00    3989.00    3993.00
                 =     3995.00    3998.00    4001.00

    # 3:             STEP-LENGTH OF EXTREMA SEARCH
                      ( ENTER 0.0  FOR FIXED POINTS )
                 =      0.5000

    # 4:             THE SPECIFIED VALUE OF THE RESPONSE
                 =      0.100000

    # 5:             THE CORRESPONDING WEIGHTING FACTOR
                      < 0    FOR LOWER SPECIFICATION
                 =      1.000000

PLEASE CHOOSE:
                 2 --- EDIT THIS DATA
                 3 --- CONTINUE
INPUT : 3

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
 PLEASE ENTER:

                              G R O U P     D E L A Y

      # 1:          NUMBER OF POINTS  ( ENTER  0  IF NONE )
INPUT : 0

 DATA CORRECT ?     ANSWER  N  IF NOT
INPUT :

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                               C O N S T R A I N T S
                   NUMBER OF LINEAR CONSTRAINTS (ENTER 0 IF NONE)


INPUT : 0

 DATA CORRECT ?     ANSWER  N  IF NOT
INPUT :

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


OPTIONS :  ENTER    1  ----  NEW COUPLING MATRIX
                    2  ----  NEW VARIABLE COUPLINGS
                    3  ----  NEW CENTER FREQUENCY, BANDWITH, TERMINATIONS
                    4  ----  NEW SUBINTERVAL DATA
                    5  ----  NEW CONSTRAINTS
                    6  ----  OPTIMIZATION
                    7  ----  SIMULATION
                    8  ----  VIEW A LOCAL FILE
                    9  ----  SAVE THE DESIGN DATA
                   10  ----  QUIT
INPUT : 9

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


 PLEASE ENTER THE FILE NAME
 IN WHICH THE SYSTEM STATE IS TO BE SAVED:


INPUT : INIT.PNT


SYSTEM STATE IS NOW STORED IN FILE :INIT.PNT
        TYPE ANYTHING TO CONTINUE...
INPUT :

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
OPTIONS :  ENTER   1  ----  NEW COUPLING MATRIX
                   2  ----  NEW VARIABLE COUPLINGS
                   3  ----  NEW CENTER FREQUENCY, BANDWITH, TERMINATIONS
                   4  ----  NEW SUBINTERVAL DATA
                   5  ----  NEW CONSTRAINTS
                   6  ----  OPTIMIZATION
                   7  ----  SIMULATION
                   8  ----  VIEW A LOCAL FILE
                   9  ----  SAVE THE DESIGN DATA
                  10  ----  QUIT
INPUT : 6
```

- -

```
                    OPTIMIZATION  CONTROL  DATA

 PLEASE ENTER:

    # 1:          MAXIMUM NO. OF ITERATIONS
INPUT : 50

    # 2:          INITIAL STEP-LENGTH
INPUT : .005

    # 3:          ACCURACY REQUIREMENT

INPUT : 1.E-6

   PRINTOUT CONTROL:  FUNCTION VALUES AT SOLUTION ONLY ?   Y/N

INPUT : N

        AFTER HOW MANY FUNCTION EVALUATIONS ?

INPUT : 10

        DO YOU WISH TO SEE THE ERROR FUNCTIONS PLOTTED
        AS THE OPTIMIZATION PROCEEDS ?  Y/N

(WARNING: THIS PLOTTING IS TIME CONSUMING
          AND THEREFORE SLOWS DOWNS THE OPTIMIZATION PROCESS)

INPUT : N

 DATA CORRECT ?     ANSWER  N  IF NOT

INPUT :
```

- -

```
ATE : 18-OCT-1984                 TIME :  09:06:13
INEARLY CONSTRAINED MINIMAX OPTIMIZATION (MMLC PACKAGE) (REAL*8)   (V:84.02)

INPUT DATA
----------

 NUMBER OF VARIABLES (N) . . . . . . . . . . . . . . . . . . . . . . .   6

 NUMBER OF FUNCTIONS (M) . . . . . . . . . . . . . . . . . . . . . . .  16

 TOTAL NUMBER OF LINEAR CONSTRAINTS (L)  . . . . . . . . . . . . . . .   0

 NUMBER OF EQUALITY CONSTRAINTS (LEQ)  . . . . . . . . . . . . . . . .   0

 STEP LENGTH (DX)  . . . . . . . . . . . . . . . . . . . . . . 5.000E-03

 ACCURACY (EPS)  . . . . . . . . . . . . . . . . . . . . . . . 1.000E-06

 MAX NUMBER OF FUNCTION EVALUATIONS (MAXF) . . . . . . . . . . . . . .  50

 NUMBER OF SUCCESSIVE ITERATIONS (KEQS)  . . . . . . . . . . . . . . .   3

 WORKING SPACE (IW) . . . . . . . . . . . . . . . . . . . . . . . . . 8946

 PRINTOUT CONTROL (IPR) . . . . . . . . . . . . . . . . . . . . . .  10000
```

STARTING POINT :

	VARIABLES		FUNCTION VALUES
1	8.101000000000E-01	1	-3.846836349045E-04
2	4.894000000000E-01	2	-2.993775218064E-04
3	8.450000000000E-01	3	-4.151457951448E-04
4	1.197000000000E-01	4	-6.867171602540E-04
5	-4.010000000000E-01	5	-6.867171602540E-04
6	9.600000000000E-01	6	-6.538508702268E-04
		7	-2.827413352129E-04
		8	-5.807424459313E-04
		9	2.553714130263E-02
		10	-1.553915347907E-02
		11	-8.000363508608E-02
		12	4.488379337303E-03
		13	-9.835686245257E-02
		14	-4.687239660174E-02
		15	1.588995855072E-02
		16	1.322247410953E-02

FUNCTION EVALUATION : 10 / 1

	VARIABLES		FUNCTION VALUES
1	8.201534041768E-01	1	-5.247889890181E-04
2	5.111040113576E-01	2	-5.027003561060E-04
3	8.267479102785E-01	3	-6.090597910786E-04
4	9.458781006473E-02	4	-6.937678285622E-04
5	-3.593457494794E-01	5	-6.937678285622E-04
6	9.870264259851E-01	6	-6.006983401075E-04
		7	-5.021960100974E-04
		8	-4.936119849662E-04
		9	-9.709394165884E-03
		10	-5.119351990363E-04
		11	-9.658129848684E-02
		12	-2.627209002994E-03
		13	-8.953627711734E-02
		14	-6.170063961931E-02
		15	-5.042177712500E-04
		16	-3.136655985882E-03

FUNCTION EVALUATION : 20 / 2

	VARIABLES		FUNCTION VALUES
1	8.183566074919E-01	1	-5.295407077706E-04
2	5.115146745080E-01	2	-5.082152699415E-04
3	8.242838684941E-01	3	-6.118164159783E-04
4	9.354212214981E-02	4	-6.939408656646E-04
5	-3.574834245519E-01	5	-6.939408656646E-04
6	9.856507688489E-01	6	-6.037946153604E-04
		7	-5.082125462975E-04
		8	-5.082176442507E-04
		9	-5.093942975951E-04
		10	-5.064299445283E-04
		11	-9.598340189497E-02
		12	-5.077782331604E-04
		13	-8.629493043951E-02
		14	-6.490221442620E-02
		15	-3.496121542879E-03
		16	-6.140303209929E-03

SOLUTION

	VARIABLES		FUNCTION VALUES
1	8.177562326145E-01	1	-5.312818327661E-04
2	5.110854748401E-01	2	-5.100499090424E-04
3	8.242954956108E-01	3	-6.124155349890E-04
4	9.330020381562E-02	4	-6.940881272135E-04
5	-3.571042539381E-01	5	-6.940881272135E-04
6	9.823662047636E-01	6	-6.049617180980E-04
		7	-5.100499083371E-04
		8	-5.100499090424E-04
		9	-5.100499090426E-04
		10	-5.100499090055E-04
		11	-9.649038243903E-02
		12	-5.100499090417E-04
		13	-8.802774342185E-02
		14	-6.256975104911E-02
		15	-5.100499090425E-04
		16	-3.180383321256E-03

```
TYPE OF SOLUTION (IFALL) . . . . . . . . . . . . . . . . . . . . . . . . 0
NUMBER OF FUNCTION EVALUATIONS . . . . . . . . . . . . . . . . . . . . . 26
NUMBER OF SHIFTS TO STAGE-2 . . . . . . . . . . . . . . . . . . . . . . 4
EXECUTION TIME (IN SECONDS) . . . . . . . . . . . . . . . . . . . . 11.73

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
               THE CORRESPONDING FREQUENCY POINTS ARE :

                         3950.0000
                         3956.2750          ----  EXTREMUM POINT
                         3965.0000
                         3970.0000
                         3970.0000
                         3972.0000
                         3973.7262          ----  EXTREMUM POINT
                         3976.0000
                         3980.0000
                         3981.6456          ----  EXTREMUM POINT
                         3984.0000
                         3987.9864          ----  EXTREMUM POINT
                         3993.0000
                         3995.0000
                         4000.0000          ----  EXTREMUM POINT
                         4001.0000

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

OPTIONS :  ENTER    1  ----  NEW COUPLING MATRIX
                    2  ----  NEW VARIABLE COUPLINGS
                    3  ----  NEW CENTER FREQUENCY, BANDWITH, TERMINATIONS
                    4  ----  NEW SUBINTERVAL DATA
                    5  ----  NEW CONSTRAINTS
                    6  ----  OPTIMIZATION
                    7  ----  SIMULATION
                    8  ----  VIEW A LOCAL FILE
                    9  ----  SAVE THE DESIGN DATA
                   10  ----  QUIT
INPUT : 7

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                          S I M U L A T I O N

          LOWER  &  UPPER EDGES OF THE BAND  TO BE SIMULATED

          NUMBER OF FREQUENCY POINTS      AND

          RESPONSE INDICATOR  :       1 ---  REFLECTION COEF.
                                      2 ---  TRANSDUCER LOSS
                                      3 ---  GROUP  DELAY


INPUT : 3980,4020,61,2
```

DATA CORRECT ?   ANSWER N IF NOT

INPUT :

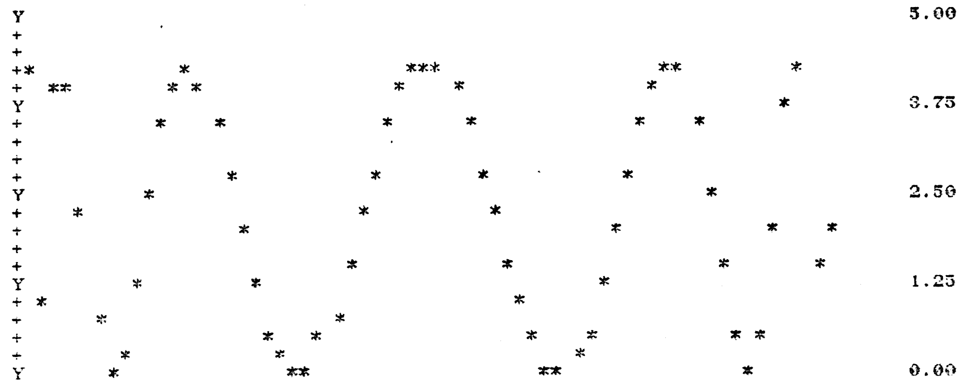
3980.000	0.043202
3980.667	0.009239
3981.333	0.039630
3982.000	0.039593
3982.667	0.022308
3983.333	0.006380
3984.000	0.000053
3984.667	0.003486
3985.333	0.013100
3986.000	0.024630
3986.667	0.034658
3987.333	0.041110
3988.000	0.043201
3988.667	0.041140
3989.333	0.035795
3990.000	0.028376
3990.667	0.020185
3991.333	0.012425
3992.000	0.006079
3992.667	0.001832
3993.333	0.000050
3994.000	0.000790
3994.667	0.003833
3995.333	0.008744
3996.000	0.014936
3996.667	0.021737
3997.333	0.028458
3998.000	0.034453
3998.667	0.039165
3999.333	0.042170
4000.000	0.043202
4000.667	0.042170
4001.333	0.039168
4002.000	0.034461
4002.667	0.028476
4003.333	0.021765
4004.000	0.014975
4004.667	0.008790
4005.333	0.003876
4006.000	0.000816
4006.667	0.000042
4007.333	0.001771
4008.000	0.005950
4008.667	0.012224
4009.333	0.019919
4010.000	0.028076
4010.667	0.035512
4011.333	0.040950
4012.000	0.043190
4012.667	0.041361
4013.333	0.035212
4014.000	0.025449
4014.667	0.014009
4015.333	0.004147
4016.000	0.000000
4016.667	0.005225
4017.333	0.020208
4018.000	0.037970
4018.667	0.041378
4019.333	0.014323
4020.000	0.020777

DO YOU ALSO WANT THIS PLOT FILED (Y/N) ?
INPUT : N

DATA CORRECT ?   ANSWER N IF NOT

INPUT :

```
X AXIS: FREQUENCY (MHZ)
Y AXIS: TRANSDUCER LOSS (DB)
```




```
++++++++  3.99++++  3.99++++  4.00++++  4.00++++  4.01++++  4.02++++  4.02+++++
          0.398E+04<= X <=0.402E+04 VS 0.358E-06<= Y <=0.432E-01
 PAUSING:  TYPE ANYTHING TO CONTINUE OR TYPE STOP
 INPUT :
```

- -

```
 OPTIONS :  ENTER   1  ----  NEW COUPLING MATRIX
                    2  ----  NEW VARIABLE COUPLINGS
                    3  ----  NEW CENTER FREQUENCY, BANDWITH, TERMINATIONS
                    4  ----  NEW SUBINTERVAL DATA
                    5  ----  NEW CONSTRAINTS
                    6  ----  OPTIMIZATION
                    7  ----  SIMULATION
                    8  ----  VIEW A LOCAL FILE
                    9  ----  SAVE THE DESIGN DATA
                   10  ----  QUIT
 INPUT : 7
```

- -

```
                         S I M U L A T I O N

          LOWER  &  UPPER EDGES OF THE BAND  TO BE SIMULATED

          NUMBER OF FREQUENCY POINTS     AND

          RESPONSE INDICATOR  :       1 ---  REFLECTION COEF.
                                      2 ---  TRANSDUCER LOSS
                                      3 ---  GROUP  DELAY


 INPUT : 3960,3980,31,2
```

DATA CORRECT ?   ANSWER N IF NOT

INPUT :

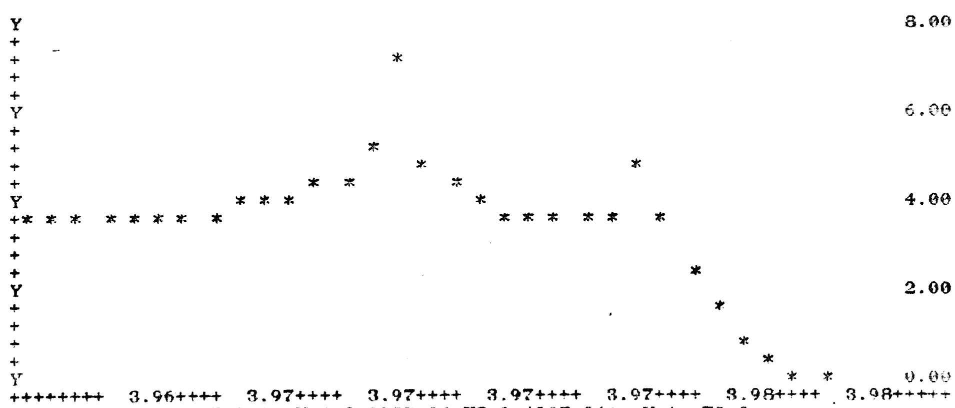
3960.000	34.553816
3960.667	34.720283
3961.333	34.933625
3962.000	35.203393
3962.667	35.541930
3963.333	35.965551
3964.000	36.496412
3964.667	37.165645
3965.333	38.018927
3966.000	39.127235
3966.667	40.609956
3967.333	42.692819
3968.000	45.892538
3968.667	51.949997
3969.333	70.031076
3970.000	49.272462
3970.667	43.347224
3971.333	39.733311
3972.000	37.210921
3972.667	35.444373
3973.333	34.400250
3974.000	34.321634
3974.667	36.150687
3975.333	46.448764
3976.000	34.203717
3976.667	23.176257
3977.333	15.438644
3978.000	8.851656
3978.667	3.560890
3979.333	0.741361
3980.000	0.043202

DO YOU ALSO WANT THIS PLOT FILED (Y/N) ?
INPUT : N

DATA CORRECT ?   ANSWER N IF NOT

INPUT :

X AXIS: FREQUENCY (MHZ)
Y AXIS: TRANSDUCER LOSS (DB)



0.396E+04<= X <=0.398E+04 VS 0.432E-01<= Y <= 70.0

PAUSING: TYPE ANYTHING TO CONTINUE OR TYPE STOP
INPUT :

```
OPTIONS :  ENTER    1  ----  NEW COUPLING MATRIX
                    2  ----  NEW VARIABLE COUPLINGS
                    3  ----  NEW CENTER FREQUENCY, BANDWITH, TERMINATIONS
                    4  ----  NEW SUBINTERVAL DATA
                    5  ----  NEW CONSTRAINTS
                    6  ----  OPTIMIZATION
                    7  ----  SIMULATION
                    8  ----  VIEW A LOCAL FILE
                    9  ----  SAVE THE DESIGN DATA
                   10  ----  QUIT
INPUT : 7

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                          S I M U L A T I O N

         LOWER  &  UPPER EDGES OF THE BAND  TO BE SIMULATED

         NUMBER OF FREQUENCY POINTS    AND

         RESPONSE INDICATOR  :      1 ---  REFLECTION COEF.
                                    2 ---  TRANSDUCER LOSS
                                    3 ---  GROUP  DELAY


INPUT : 3985,4015,41,3

 DATA CORRECT ?     ANSWER  N  IF NOT

INPUT :
                    3985.000             38.581876
                    3985.750             35.731513
                    3986.500             33.429010
                    3987.250             31.553710
                    3988.000             30.033468
                    3988.750             28.798796
                    3989.500             27.786961
                    3990.250             26.944418
                    3991.000             26.227768
                    3991.750             25.603720
                    3992.500             25.048391
                    3993.250             24.546209
                    3994.000             24.088535
                    3994.750             23.672170
                    3995.500             23.297853
                    3996.250             22.968857
                    3997.000             22.689774
                    3997.750             22.465520
                    3998.500             22.300584
                    3999.250             22.198488
                    4000.000             22.161442
                    4000.750             22.190153
                    4001.500             22.283767
                    4002.250             22.439939
                    4003.000             22.655022
                    4003.750             22.924426
                    4004.500             23.243152
                    4005.250             23.666533
                    4006.000             24.011215
                    4006.750             24.456342
                    4007.500             24.944911
                    4008.250             25.485225
                    4009.000             26.092323
                    4009.750             26.789281
                    4010.500             27.608252
                    4011.250             28.591096
                    4012.000             29.789401
                    4012.750             31.263543
                    4013.500             33.080074
                    4014.250             35.309367
                    4015.000             38.018209

      DO YOU ALSO WANT THIS PLOT FILED (Y/N) ?
INPUT : N

 DATA CORRECT ?     ANSWER  N  IF NOT

INPUT :
```

```
X AXIS: FREQUENCY (MHZ)
Y AXIS: GROUP DELAY (NSECS)

Y                                                                          4.00
+*
+                                                                            *
+
+  *
Y                                                                          *3.50
+
+    *                                                                   *
+      *
+                                                                      *
Y         *                                                           *    3.00
+          *                                                        *
+            *                                                    *
+              *                                                *
+                * *                                          *
Y                    * *                                  * *              2.50
+                        **                           * **
+                           * * *                * * *
+                                 * * * ** * *
+
Y                                                                          2.00
++++++++  3.99++++  3.99++++  4.00++++  4.00++++  4.01++++  4.01++++  4.01+++++
            0.399E+04<= X <=0.402E+04 VS  22.2     <= Y <= 38.5
 PAUSING:  TYPE ANYTHING TO CONTINUE OR TYPE STOP
 INPUT :

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 OPTIONS :  ENTER   1  ----  NEW COUPLING MATRIX
                    2  ----  NEW VARIABLE COUPLINGS
                    3  ----  NEW CENTER FREQUENCY, BANDWITH, TERMINATIONS
                    4  ----  NEW SUBINTERVAL DATA
                    5  ----  NEW CONSTRAINTS
                    6  ----  OPTIMIZATION
                    7  ----  SIMULATION
                    8  ----  VIEW A LOCAL FILE
                    9  ----  SAVE THE DESIGN DATA
                   10  ----  QUIT
 INPUT : 10
```

APPENDIX B
GAIN RESPONSE CONVERSION TABLE FOR A LOSSLESS FILTER

REFLECTION COEFFICIENT	RETURN LOSS (DB)	TRANSDUCER LOSS (DB)
0.031623	30	0.004345
0.042170	27.5	0.007730
0.056234	25	0.013755
0.074989	22.5	0.024491
0.089125	21	0.034635
0.1	20	0.043648
0.112202	19	0.055022
0.125893	18	0.069383
0.141254	17	0.087530
0.158489	16	0.110483
0.177828	15	0.139554
0.984062		15
0.989973		17
0.993685		19
0.994987		20
0.997184		22.5
0.998418		25
0.999002		27
0.999110		27.5
0.999500		30
0.999719		32.5
0.999482		35
0.999900		37
0.999911		37.5
0.999950		40
0.999972		42.5
0.999984		45
0.999990		47
0.999995		50

APPENDIX C

INCREASING THE LIMITS OF THE SYSTEM

Increasing the limits of the CCFIL1 system requires re-dimensioning of particular arrays in the CCFIL1.FOR and FILOSUB.FOR routines. These arrays are automatically dimensioned according to the MAXNT and MAXEL parameters. Hence, the only editing needed involves redefining 'ia' and 'ib' in all occurences of

PARAMETER (MAXNT=ia, MAXEL=ib)

where 'ia' is an integer value equal to the maximum order of the coupling matrix and 'ib' is an integer value equal to the maximum number of optimization variables in the coupling matrix (not counting as more than one those set equal by matrix symmetry).

The user will have to be given permission, via the master account ZE050, to read the following files:

- CCFIL1.FOR
- FILOSUB.FOR
- LOWRPLT.OBJ
- LMMLC8D.OLB.

The following sequence of VMS commands could then be used:

$COPY GR:*.* *.*	to obtain the above files
$EDIT CCFIL1.FOR ...	to edit the MAXNT, MAXEL parameters
$EDIT FILOSUB.FOR ...	to edit the MAXNT, MAXEL parameters
$FOR CCFIL1	to compile the edited file
$FOR FILOSUB	to compile the edited file
$LINK CCFIL1,FILOSUB,LOWRPLT,LMMLC8D/LIB	to re-link all files

The executable file CCFIL1.EXE is thence available and can be used:

$RUNH CCFIL1

REFERENCES

[1] J.W. Bandler and S.H. Chen, "Interactive optimization of multi-coupled cavity microwave filters", Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, Report SOS-84-13-R, 1984.

[2] J.W. Bandler, S.H. Chen and S. Daijavad, "Efficient approaches to the simulation of narrow-band multi-cavity filters", Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, Report SOS-84-9-R, 1984.

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

[4] 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-U2, 1983.

[5] J.W. Bandler, "Computer-aided circuit optimization", in Modern Filter Theory and Design, G.C. Temes and S.K. Mitra, Eds. New York: Wiley-Interscience, 1973.