SIMULATION OPTIMIZATION SYSTEMS
Research Laboratory

FETMDL – AN INTERACTIVE SOFTWARE SYSTEM FOR MODELLING OF FETS

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Abstract

FETMDL is an interactive software system for modelling of FETs using L_1 and L_2 optimization techniques. Given a fixed topology of an equivalent circuit for the device, the objective is to achieve the best possible match between measured two-port S-parameters and the corresponding calculated S-parameters of the circuit by optimizing circuit parameters. The software package has been developed in MS-Fortran version 3.3 on the TI/PC system with the MS-DOS version 2.11 operating system.

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I. INTRODUCTION

This document provides a user-oriented description of the FETMDL software system, which implements least one (L_1) and least squares (L_2) optimization techniques in modelling of FET devices. The S-parameter sensitivities required for the gradient-based optimization methods are calculated using the formulas by Bandler, Chen and Daijavad [1]. Details of the L_1 optimization algorithm are discussed by Bandler, Kellermann and Madsen [2]. The L_2 optimization algorithm is a modification of the 1972 version of Fletcher's quasi-Newton subroutine [3].

The FETMDL package has been developed in MS-Fortran version 3.3 on the TI/PC system with the MS-DOS version 2.11 operating system.

II. FORMULATION OF THE PROBLEM

The modelling of an FET device is formulated as an optimization problem w.r.t. the equivalent circuit parameters of a fixed proposed topology. The objective is to achieve the best possible match between measured two-port S-parameters and the corresponding calculated S-parameters of the equivalent circuit.

<u>The Equivalent Circuit</u>

The proposed equivalent circuit of a carrier-mounted FET is shown in Fig. 1. As illustrated in Fig. 1, there is a total of 16 parameters which completely define the equivalent circuit at a given frequency. These parameters are $R_g(\Omega)$, $R_i(\Omega)$, $R_d(\Omega)$, G_d(mS), C_{dg}(pF), C_{gs}(pF), C_{ds}(pF), $R_s(\Omega)$, L_s(nH), C_i(pF), C_1(pF), C_2(pF), L_g(nH), L_d(nH), g_m(mS) and τ(ps), where the unit for each parameter is given in brackets. Any or all of these 16 parameters could be optimization variables with possible upper and/or lower bounds.

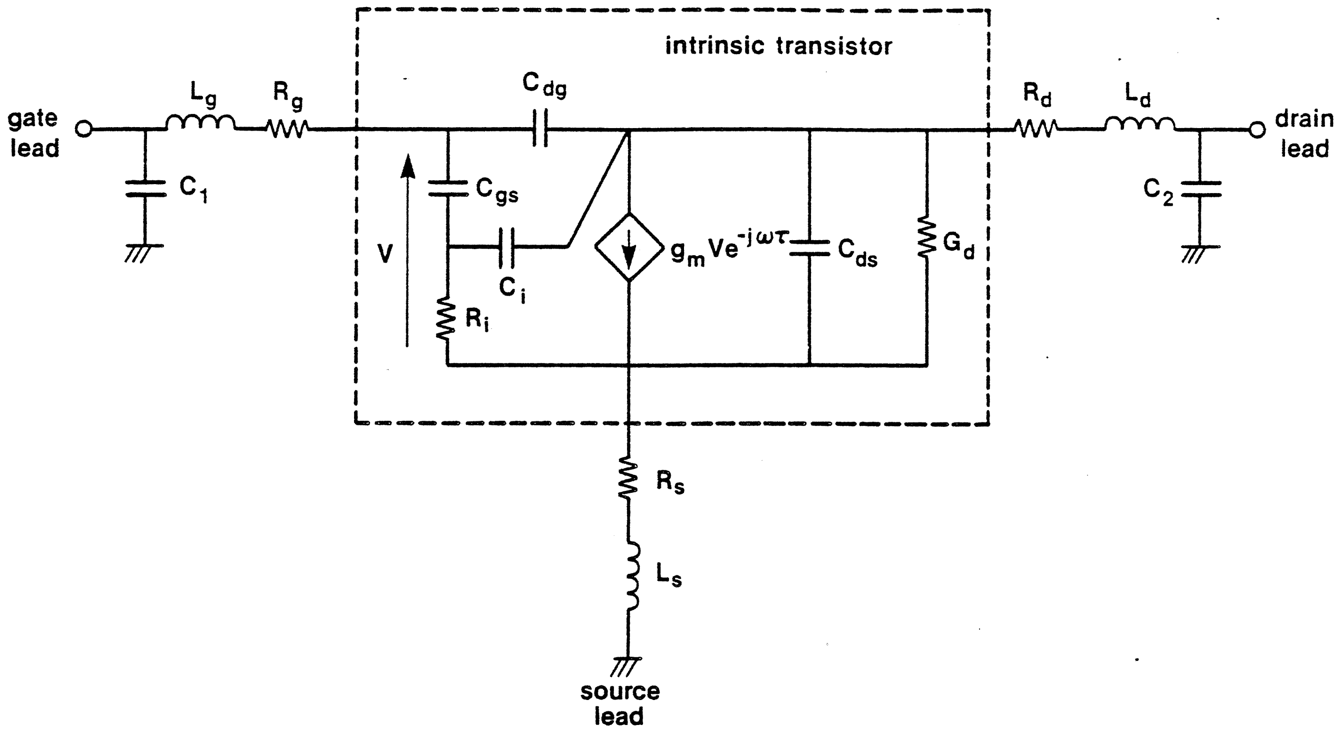

Fig. 1 The equivalent circuit of the FET.

The L_1 Optimization

Assume that measurements on all 4 complex S-parameters are available at n_f frequencies, i.e., magnitude and phase of S_{11}, S_{12}, S_{21} and S_{22} for n_f frequencies have been measured. Therefore, we have $S^m_{ij}(k)$, $i = 1,2$, $j = 1,2$, $k = 1,2,\ldots, n_f$, where S_{ij} is the complex S-parameter and m is used to denote the measured response. Similarly, we have $S^c_{ij}(k)$, where c is used to denote the calculated response using the equivalent circuit parameters. $S^c_{ij}(k)$ is a function of circuit parameters, and as mentioned before, we seek optimum circuit parameters such that $S^c_{ij}(k)$ best approximates $S^m_{ij}(k)$.

We define the unweighted error functions as

$$FR_{ij}(k) = \mathrm{Re}[S^m_{ij}(k)] - \mathrm{Re}[S^c_{ij}(k)] \qquad (1)$$

and

$$FI_{ij}(k) = Im[S^{m}_{ij}(k)] - Im[S^{c}_{ij}(k)], \tag{2}$$

where $i = 1,2$, $j = 1,2$, $k = 1,2,\ldots, n_f$. Given a weighting factor W_{ij}, $i = 1,2$, $j = 1,2$ for an S-parameter S_{ij} (these 4 weighting factors are defined by the user), the normalized weighting factors are calculated as

$$NWR_{ij} = W_{ij}/(\max_k\{Re[S^{m}_{ij}(k)]\} - \min_k\{Re[S^{m}_{ij}(k)]\}) \tag{3}$$

and

$$NWI_{ij} = W_{ij}/(\max_k\{Im[S^{m}_{ij}(k)]\} - \min_k\{Im[S^{m}_{ij}(k)]\}). \tag{4}$$

The L_1 objective function is defined as

$$U_1 = \sum_{k=1}^{n_f} \sum_{i=1}^{2} \sum_{j=1}^{2} (|NWR_{ij} * FR_{ij}(k)| + |NWI_{ij} * FI_{ij}(k)|). \tag{5}$$

Explicit bounds on variables (if desired) are handled by the L_1 optimization package internally and do not affect the objective function.

<u>The L_2 Optimization</u>

If there are no bounds on variables, the L_2 objective function is given by

$$U_2 = \sum_{k=1}^{n_f} \sum_{i=1}^{2} \sum_{j=1}^{2} [(NWR_{ij} * FR_{ij}(k))^2 + (NWI_{ij} * FT_{ij}(k))^2]. \tag{6}$$

The upper and lower bounds on variables are handled by adding a penalty function to the objective function for those variables which violate their bounds. Assuming that there are n variables x_1, $x_2, \ldots, x_n$ with lower bounds LB_t, $t = 1,2,\ldots, n$ and upper bounds UB_t, $t = 1,2,\ldots, n$, the objective function is given by

$$PU_2 = U_2 + \sum_{t=1}^{n} [WU_t(UB_t - x_t)^2] + [WL_t(x_t - LB_t)^2], \tag{7}$$

where

$$WU_t = \begin{cases} 10, & \text{if } x_t > UB_t, \\ 0, & \text{if } x_t \leqslant UB_t \end{cases} \tag{8}$$

and

$$WL_t = \begin{cases} 10, & \text{if } x_t < LB_t, \\ 0, & \text{if } x_t \geqslant LB_t. \end{cases} \tag{9}$$

III. OPERATION

In this section, the commands, data files and other details about the operation of FETCAD package are discussed.

Start the operation by keying in FETMDL. Following the initial message, which reads

FET MODELLING

Interactive Command System

a menu of commands available is automatically displayed. This menu is as follows.

```
     Commands Available
L1            start modelling using L1 optimization
L2            start modelling using least-squares optimization
STOP          stop this program and return to MS-DOS
DIR           list the file directory
HELP          display the available commands
PARAMETER     display the current model parameters
COMPARE       compare starting point with optimization solution
MDATA         display the current measurement data
USERSPEC      display user-controlled run-time specifications
ERROR         display errors in S-parameter matching
%ERROR        display percentage errors in S-parameter matching
PLOT          plot model responses and measured data
SAVE fn.ext   save current data in a file
READ fn.ext   read desired data from a file
EDIT fn.ext   edit a disk file using full screen editor

1) .ext must be .PAR, .MDA or .USE
2) only the first two characters of a command are significant
```

The menu is followed by the prompt

COMD>

which awaits the selection of any of the available commands. There are three basic commands, namely HELP, STOP and DIR, that a user should be familiar with before other commands. HELP simply displays the list of available commands (the same list which is automatically shown at the start) at any time of an interactive session. STOP terminates the program by returning to the MS-DOS operating system command level. DIR lists the files in the user directory and is particularly useful since the user may create new files as an interactive session proceeds. By using this command, the updated directory is always available to the user without stopping the program.

Data Files

.MDA Files: Three types of data files are required to run the program. The first type is the S-parameter measurement data on the device. This data which must have been stored in a file with an arbitrary name, but with the fixed extension .MDA, is available to the user in an interactive session by using the commands:

```
COMD> READ fn.MDA

COMD> MD
```

Comment: The MD command is optional and displays data on the screen.

A typical measurement data file follows.

```
C       FET  S-PARAMETERS      NEC700S.MDA
C   FREQ      MS11     AS11     MS21     AS21      MS12     AS12     MS22     AS22
     4.0     .8900   -52.00   3.2300   136.00     .0600    62.00    .6300   -26.00
     6.0     .8300   -71.00   2.9800   121.00     .0800    55.00    .5900   -36.00
     8.0     .7800   -87.00   2.5800   108.00     .0900    47.00    .5700   -42.00
    10.0     .7300  -102.00   2.2700    96.00     .1000    42.00    .5400   -49.00
    12.0     .7000  -116.00   2.1100    84.00     .1000    39.00    .4800   -56.00
    14.0     .6900  -126.00   1.7900    77.00     .1100    40.00    .5100   -70.00
    16.0     .6700  -130.00   1.6200    68.00     .1200    36.00    .5300   -75.00
    18.0     .6500  -136.00   1.5100    57.00     .1100    40.00    .5400   -77.00
```

This file consists of comment lines identified by letter C in their first columns and S-parameter data in the form of magnitude and angle. The unit for frequency is fixed (GHz) and the maximum number of frequencies allowed is 17 due to the fixed dimension of the arrays.

After an .MDA file has been read, it assumes the role of the measurement data used in the optimization and keeps this role until a new .MDA file is read. If the user wishes to edit the current measurement data (e.g., to use fewer frequency points for optimization) he/she may do so by invoking the edit command without stopping the program. The following procedure should be followed. Assume that the user has already read the file TEST.MDA and wishes to modify it. The user wants to keep the original file intact and create a new modified version under the name TESTED.MDA. The required commands are:

```
COMD> SAVE TESTED.MDA
```

Comment: The contents of TEST.MDA, which is the measurement data file, is stored in TESTED.MDA.

COMD> EDIT TESTED.MDA

Comment: At this point the ZABED full screen editor is invoked. When finished, by typing <ctrl>Z (to store the modified file) or <ctrl>Q (to abandon the modified version) , the user is back to the command level of the FETMDL package.

COMD> READ TESTED.MDA

Comment: At this point the new edited data file is read to replace the current measurement data, which is still the contents of TEST.MDA before this step.

COMD> MD

Comment: At this point, we optionally display the current measurement data which should be the contents of TESTED.MDA.

.PAR Files: The second type of data required by the program relates to the FET equivalent circuit parameters. In contrast to the measurement data, which must exist before running the program (i.e., a .MDA file at the start of a session), there is no need to create a .PAR data file before starting a session. Default values are assigned to all parameters automatically at the start of a session. These values and their default status (variable or fixed, bounded or unbounded if variable) can be displayed by using the command:

COMD> PA

The result is as follows.

```
C        FET MODEL PARAMETERS     DEFAULT VALUES
C   index =  0: constant     1: unbounded variable
C            2: bounded variable
C     value      index         bounds           name
     .04480        0                            C1   (pF)
     .00580        0                            C2   (pF)
     .10000        1                            Cdg  (pF)
     .10000        1                            Cgs  (pF)
     .10000        1                            Cds  (pF)
     .01000        0                            Ci   (pF)
    3.50000        0                            Rg   (OH)
```

2.00000	0	Rd (OH)
3.00000	1	Rs (OH)
5.00000	1	Ri (OH)
4.00000	1	Gd (mS)
.05850	0	Lg (nH)
.04960	0	Ld (nH)
.10000	1	Ls (nH)
.10000	1	gm (S)
3.00000	1	tau (ps)

Besides the comment lines, there is a column for the current values of parameters, an index column showing whether a parameter is fixed (index = 0), is an unbounded variable (index = 1) or is a bounded variable (index = 2). If a variable is bounded, the lower and upper bound values must follow the index 2, the only restriction being that at least one space exist between the numbers.

If the default values as well as their status are reasonable as initial guesses for modelling of a particular device, we can continue without operating on a .PAR data file at this time. However, it is inevitable that circuit parameters should be saved, edited or read at some point. The circuit parameters are automatically updated following an L_1 or L_2 optimization. Therefore, a useful practice is to save the parameters as well as their status in a .PAR file as a reference before performing the optimization. At any time, in a session, the command

COMD> SAVE fn.PAR

saves the current parameters and their status in the file fn.PAR. Editing a .PAR file is similar to editing an .MDA file. We may change the values, the status index and the bounds on some parameters while editing. The sequence of commands is:

COMD> SAVE TESTED.PAR

COMD> ED TESTED.PAR

Comment: Make the necessary changes using the full screen editor.

COMD> READ TESTED.PAR

COMD> PA

Comment: Optionally display the current parameters.

.USE Files: The third type of data required by the program relates to run-time specifications for optimization. Similar to circuit parameters, there are default values for these specifications which can be displayed by using the command

COMD> US

at the start of a session. The result follows.

```
C  RUN-TIME SPECIFICATIONS FOR FET MODELLING PROGRAM      DEFAULT VALUES
      8             number of frequency points
      4.0           lowest frequency (GHz)
     20.0           highest frequency (GHz)
      1.0           weighting for S11
      1.0           weighting for S21
      1.0           weighting for S12
      1.0           weighting for S22
   0.10E-04         accuracy required for the solution
    200             limit on optimization iterations
```

Editing a .USE file is similar to editing .MDA and .PAR files. It should be noted that by editing data on the number of frequency points and the lowest and highest frequencies specified in the .USE file, we can limit the number of frequencies used by the optimization without editing the .MDA file. Only frequencies in the .MDA file which are within the lower and upper limits specified in the .USE file are used for optimization. If the number of frequencies in the .MDA file which are within the required limits is more than the specified number in the .USE file, the last extra frequencies in the .MDA file are ignored.

Remaining Commands

In the context of data files, the commands PARAMETER, MDATA, USERSPEC, SAVE, READ and EDIT were discussed. Besides the basic commands, namely STOP,DIR and HELP, there are five commands which are directly related to the optimization and a command for graphical displays. These are L1, L2, COMPARE, ERROR, %ERROR and PLOT. The L1 and L2 commands are clearly used to invoke L_1 and L_2 optimizers. As the optimization proceeds, the measured and modelled responses are displayed on the screen with the modelled responses being updated at each iteration of the optimization in which the objective function decreases. The PLOT command is used to display the measured and modelled responses statically, i.e., outside an optimization loop and for the current values of parameters at any point of an interactive session. After an optimization is performed, we can compare the starting and final values for variables using the COMPARE command. The absolute and relative differences between the S-parameters of the equivalent circuit and the measured S-parameters are displayed using ERROR and %ERROR commands, respectively.

IV. EXAMPLES

S-parameter measurements on the FET NEC700 were taken from the measurement data files supplied with TOUCHSTONE [4]. Using only 8 frequency points between 4 and 18 GHz, we perform both L_1 and L_2 optimizations. Some parameters are fixed at the values reported in [1]. In a sample interactive session (Appendix A), many features of the FETMDL package are demonstrated. A detailed description of this session is as follows. Using the default values (and status) for all variables and the default values for run-time specifications which are displayed using the PA and US commands, respectively, we read (using the READ command) the measurement data file (NEC700S.MDA), display it (using the MD command) and then perform the L_1 optimization (the L1 command). As the optimization proceeds, the measured and modelled responses are displayed on the screen. Figs. 2 and 3 illustrate the responses at the start of the optimization and at the L_1 solution. Next, we compare the optimum parameters with their initial values (using the CO command) and display the percentage error in S-parameter matching (using the %ER command). The optimum parameters are then saved in a file called NEC700L1.PAR. Next, we perform the L_2 optimization using the same measurement data and starting from the optimum values obtained by the L_1 optimizer. Fig. 4 displays the responses at the L_2 solution. The L_2 solution is compared with the L_1 solution and the new optimum parameters are saved in a file named NEC700L2.PAR.

In a second example, we demonstrate the use of the package when variables are bounded. In the interactive session of Appendix B we first read the file NEC700L1.PAR which contains the unbounded L_1 solution. We save these parameters in a temporary file and edit this file by changing the index of a parameter to 2 and apply a lower bound which is larger than the current value of the parameter. An upper bound of 100 is equivalent to not having an upper bound for all practical purposes. The optimization is repeated and new values for parameters are obtained which are compared to the previous solution.

REFERENCES

[1] J.W. Bandler, S.H. Chen and S. Daijavad, "Microwave device modelling using efficient L_1 optimization: a novel approach", IEEE Trans. Microwave Theory Tech., vol.MTT-34, 1986.

[2] J.W. Bandler, W. Kellermann and K. Madsen, "A superlinearly convergent algorithm for nonlinear L_1 optimization with circuit applications", Proc. IEEE Int. Symp. Circuits and Systems (Kyoto, Japan, 1985), pp. 977-980.

[3] R. Fletcher, "FORTRAN subroutines for minimization by Quasi-Newton methods", Atomic Energy Research Establishment, Harwell, Berkshire, England, Report AERE-R7125, 1972.

[4] TOUCHSTONE, EEsof. Inc., Westlake Village, CA, 1985.

APPENDIX A

A SAMPLE INTERACTIVE SESSION

```
                         FET MODELLING

                   Interactive Command System

        Commands Available
    L1             start modelling using L1 optimization
    L2             start modelling using least-squares optimization
    STOP           stop this program and return to MS-DOS
    DIR            list the file directory
    HELP           list the available commands
    PARAMETER      display the current model parameters
    COMPARE        compare starting point with optimization solution
    MDATA          display the current measurement data
    USERSPEC       display user-controlled run-time specifications
    ERROR          display errors in S-parameter matching
    %ERROR         display percentage errors in S-parameter matching
    PLOT           plot model responses and measured data
    SAVE fn.ext    save current data in a file
    READ fn.ext    read desired data from a file
    EDIT fn.ext    edit a disk file using full screen editor

    1) .ext must be .PAR, .MDA or .USE
    2) only the first two characters of a command are significant

COMD> PA


C       FET MODEL PARAMETERS     DEFAULT VALUES
C   index =  0: constant      1: unbounded variable
C            2: bounded variable
C     value       index          bounds            name
      .04480        0                            C1  (pF)
      .00580        0                            C2  (pF)
      .10000        1                            Cdg (pF)
      .10000        1                            Cgs (pF)
      .10000        1                            Cds (pF)
      .01000        0                            Ci  (pF)
     3.50000        0                            Rg  (OH)
     2.00000        0                            Rd  (OH)
     3.00000        1                            Rs  (OH)
     5.00000        1                            Ri  (OH)
     4.00000        1                            Gd  (mS)
      .05850        0                            Lg  (nH)
      .04960        0                            Ld  (nH)
      .10000        1                            Ls  (nH)
      .10000        1                            gm  (S)
     3.00000        1                            tau (ps)
```

```
COMD> US

C   RUN-TIME SPECIFICATIONS FOR FET MODELLING PROGRAM     DEFAULT VALUES
C
      8            number of frequency points
      4.0          lowest frequency (GHz)
     20.0          highest frequency (GHz)
      1.0          weighting for S11
      1.0          weighting for S21
      1.0          weighting for S12
      1.0          weighting for S22
    .10E-04        accuracy required for the solution
    200            limit on optimization iterations


COMD> READ NEC700S.MDA
COMD> MD

C     FET  S-PARAMETERS     NEC700S.MDA
C FREQ    MS11    AS11    MS21    AS21    MS12    AS12    MS22    AS22
   4.0   .8900  -52.00  3.2300  136.00   .0600   62.00   .6300  -26.00
   6.0   .8300  -71.00  2.9800  121.00   .0800   55.00   .5900  -36.00
   8.0   .7800  -87.00  2.5800  108.00   .0900   47.00   .5700  -42.00
  10.0   .7300 -102.00  2.2700   96.00   .1000   42.00   .5400  -49.00
  12.0   .7000 -116.00  2.1100   84.00   .1000   39.00   .4800  -56.00
  14.0   .6900 -126.00  1.7900   77.00   .1100   40.00   .5100  -70.00
  16.0   .6700 -130.00  1.6200   68.00   .1200   36.00   .5300  -75.00
  18.0   .6500 -136.00  1.5100   57.00   .1100   40.00   .5400  -77.00


COMD> L1


               Optimization Completed After   8 iterations

C       FET MODEL PARAMETERS     OPTIMAL VALUES
C  index =  0: constant     1: unbounded variable
C           2: bounded variable
C    value       index         bounds          name
     .04480        0                          C1   (pF)
     .00580        0                          C2   (pF)
     .02890        1                          Cdg  (pF)
     .28337        1                          Cgs  (pF)
     .08232        1                          Cds  (pF)
     .01000        0                          Ci   (pF)
    3.50000        0                          Rg   (OH)
    2.00000        0                          Rd   (OH)
    3.58545        1                          Rs   (OH)
    7.82138        1                          Ri   (OH)
    4.81464        1                          Gd   (mS)
     .05850        0                          Lg   (nH)
     .04960        0                          Ld   (nH)
     .03790        1                          Ls   (nH)
     .05710        1                          gm   (S)
    3.45810        1                          tau  (ps)
```

COMD> CO

COMPARISON OF MODEL PARAMETERS

index=0: constant   index=1/2: variable

starting point	solution	index	name
.04480	.04480	0	C1 (pF)
.00580	.00580	0	C2 (pF)
.10000	.02890	1	Cdg (pF)
.10000	.28337	1	Cgs (pF)
.10000	.08232	1	Cds (pF)
.01000	.01000	0	Ci (pF)
3.50000	3.50000	0	Rg (OH)
2.00000	2.00000	0	Rd (OH)
3.00000	3.58545	1	Rs (OH)
5.00000	7.82138	1	Ri (OH)
4.00000	4.81464	1	Gd (mS)
.05850	.05850	0	Lg (nH)
.04960	.04960	0	Ld (nH)
.10000	.03790	1	Ls (nH)
.10000	.05710	1	gm (S)
3.00000	3.45810	1	tau (ps)

COMD> %ER

PERCENTAGE ERRORS IN S-PARAMETER MATCHING

ABS[(Model-Measurement)/Measurement] %

C FREQ	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
4.0	2.30%	2.79%	4.54%	1.53%	.90%	1.60%	.40%	2.37%
6.0	1.20%	.23%	.54%	.19%	2.68%	2.39%	.54%	1.30%
8.0	.19%	.67%	.18%	.82%	.07%	.44%	.89%	5.45%
10.0	.02%	.58%	.15%	.91%	1.99%	2.29%	.81%	6.52%
12.0	1.07%	2.63%	4.83%	.86%	3.81%	3.57%	10.52%	6.44%
14.0	3.81%	2.58%	.51%	1.93%	1.34%	2.34%	2.30%	4.68%
16.0	4.30%	.93%	.57%	1.16%	5.87%	7.33%	2.51%	1.81%
18.0	4.16%	1.94%	1.35%	4.62%	6.96%	2.91%	4.73%	4.43%

COMD> SAVE NEC700L1.PAR

COMD> L2

```
                    Optimization Completed After  38 iterations

C       FET MODEL PARAMETERS     OPTIMAL VALUES
C  index =  0: constant      1: unbounded variable
C           2: bounded variable
C     value      index         bounds            name
     .04480        0                            C1  (pF)
     .00580        0                            C2  (pF)
     .02954        1                            Cdg (pF)
     .27585        1                            Cgs (pF)
     .07943        1                            Cds (pF)
     .01000        0                            Ci  (pF)
    3.50000        0                            Rg  (OH)
    2.00000        0                            Rd  (OH)
    3.44946        1                            Rs  (OH)
    6.75736        1                            Ri  (OH)
    4.70547        1                            Gd  (mS)
     .05850        0                            Lg  (nH)
     .04960        0                            Ld  (nH)
     .03997        1                            Ls  (nH)
     .05597        1                            gm  (S)
    3.63449        1                            tau (ps)

COMD> CO

              COMPARISON OF MODEL PARAMETERS
          index=0: constant   index=1/2: variable
   starting point         solution     index        name
        .04480             .04480        0          C1  (pF)
        .00580             .00580        0          C2  (pF)
        .02890             .02954        1          Cdg (pF)
        .28337             .27585        1          Cgs (pF)
        .08232             .07943        1          Cds (pF)
        .01000             .01000        0          Ci  (pF)
       3.50000            3.50000        0          Rg  (OH)
       2.00000            2.00000        0          Rd  (OH)
       3.58545            3.44946        1          Rs  (OH)
       7.82138            6.75736        1          Ri  (OH)
       4.81464            4.70547        1          Gd  (mS)
        .05850             .05850        0          Lg  (nH)
        .04960             .04960        0          Ld  (nH)
        .03790             .03997        1          Ls  (nH)
        .05710             .05597        1          gm  (S)
       3.45810            3.63449        1          tau (ps)


COMD> SAVE NEC700L2.PAR
```

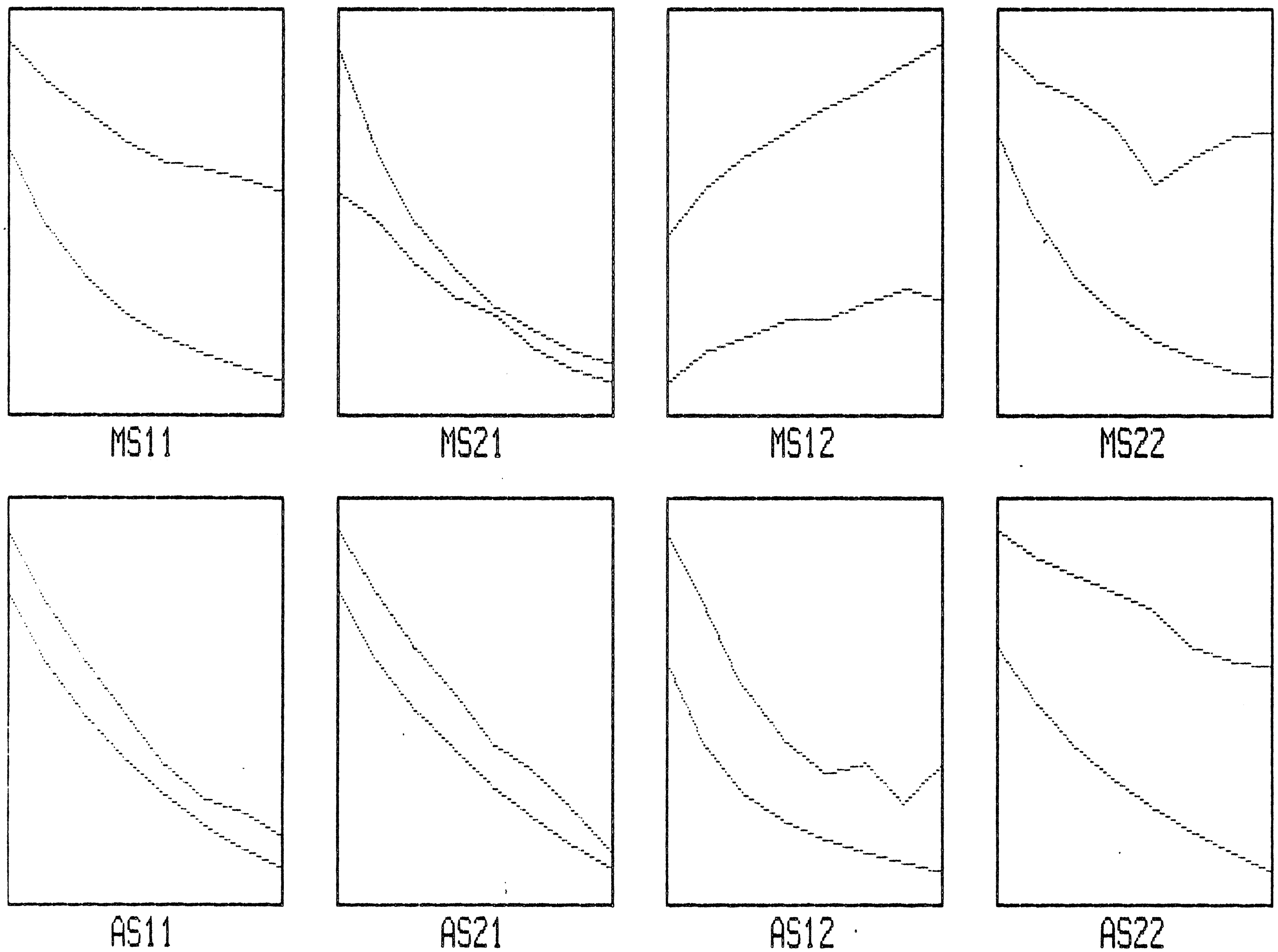

Fig. 2 Magnitude and phase of the measured and the modelled S-parameters at the start of the optimization.

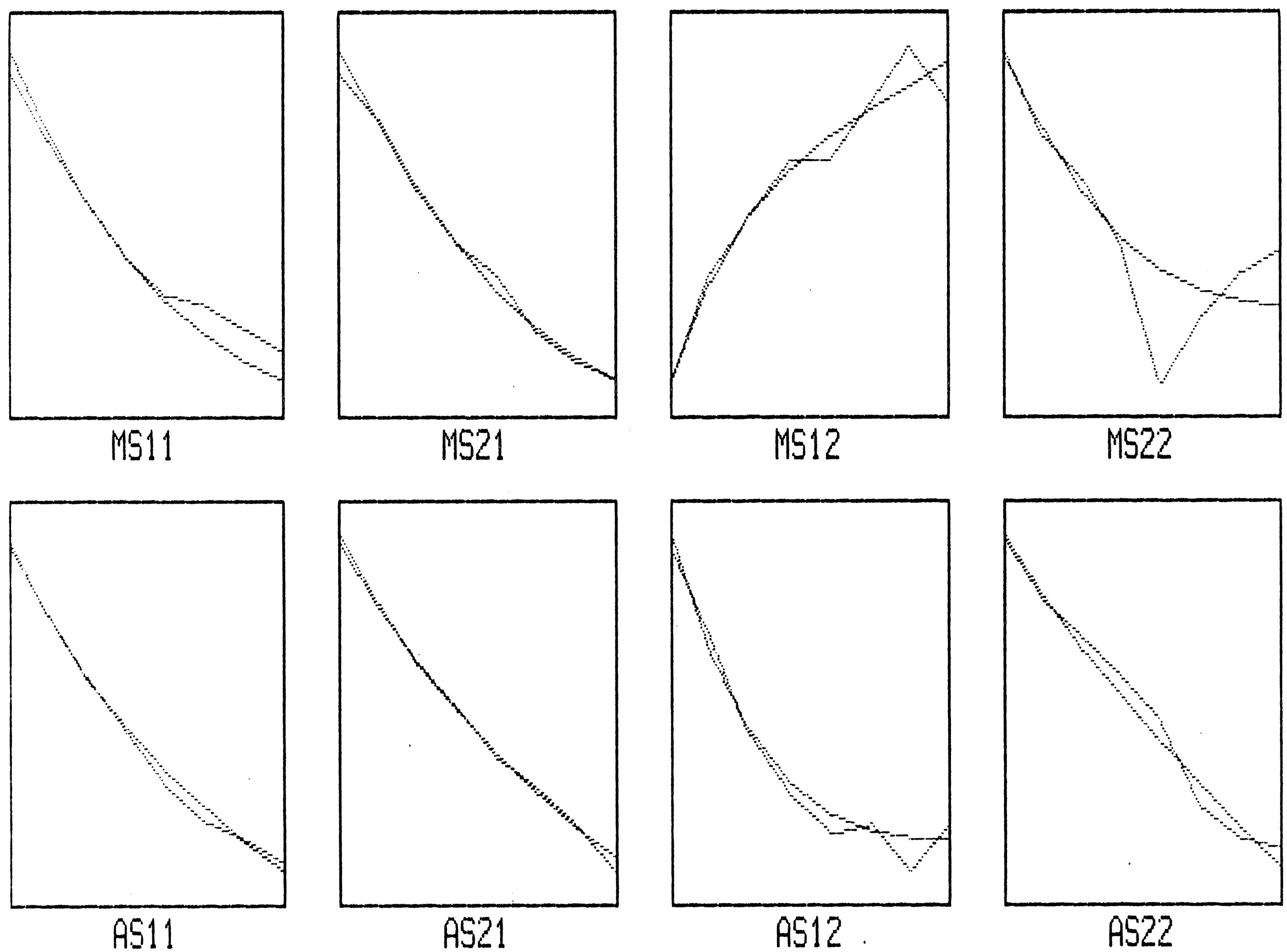

Fig. 3 Magnitude and phase of the measured and the modelled S-parameters at the L_1 solution.

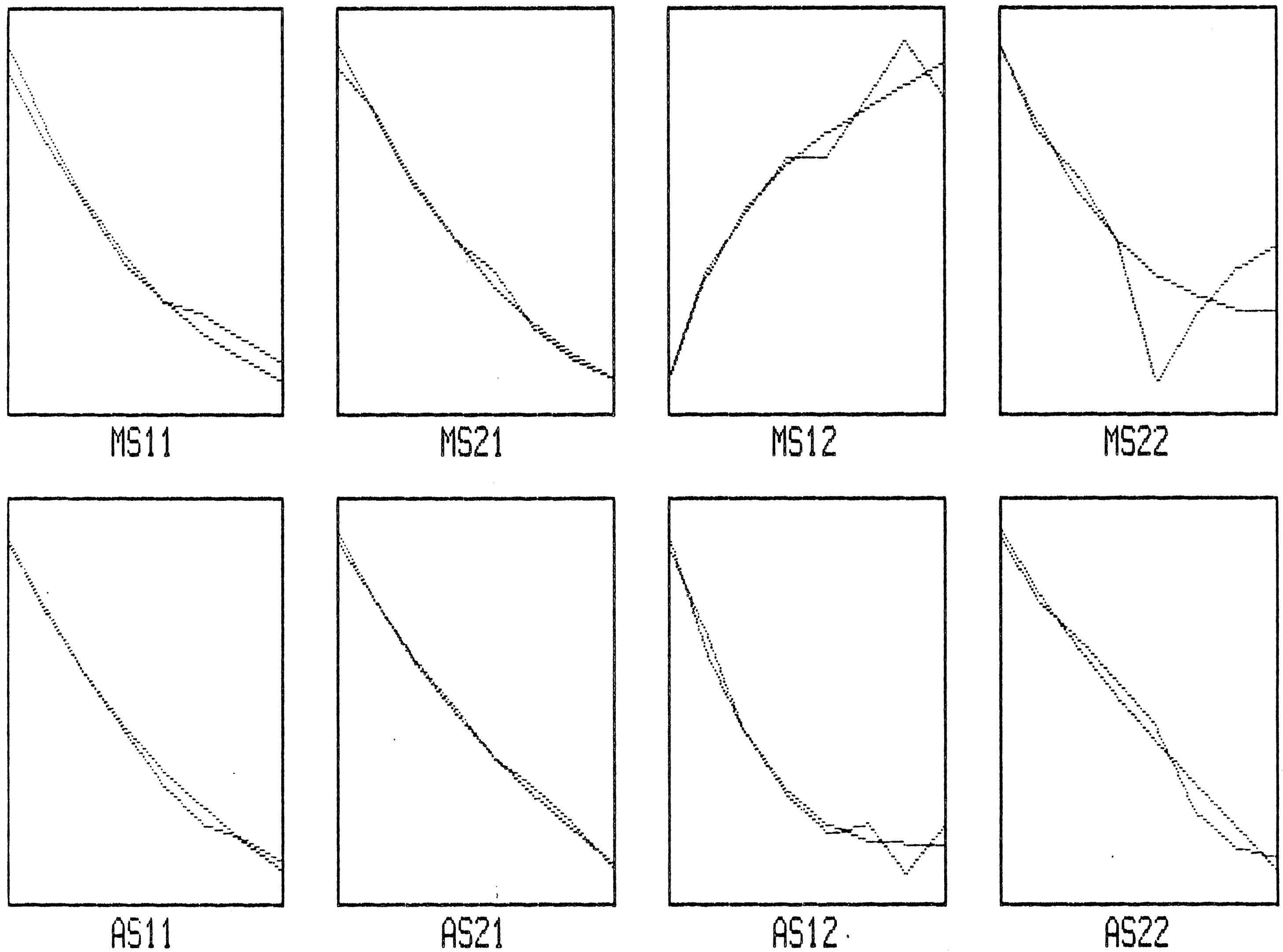

Fig. 4   Magnitude and phase of the measured and the modelled S-parameters at the L_2 solution.

APPENDIX B

AN INTERACTIVE SESSION WITH A BOUNDED VARIABLE

```
                    FET MODELLING

               Interactive Command System

     Commands Available
L1             start modelling using L1 optimization
L2             start modelling using least-squares optimization
STOP           stop this program and return to MS-DOS
DIR            list the file directory
HELP           list the available commands
PARAMETER      display the current model parameters
COMPARE        compare starting point with optimization solution
MDATA          display the current measurement data
USERSPEC       display user-controlled run-time specifications
ERROR          display errors in S-parameter matching
%ERROR         display percentage errors in S-parameter matching
PLOT           plot model responses and measured data
SAVE fn.ext    save current data in a file
READ fn.ext    read desired data from a file
EDIT fn.ext    edit a disk file using full screen editor

1) .ext must be .PAR, .MDA or .USE
2) only the first two characters of a command are significant

COMD> READ NEC700L1.PAR

COMD> READ NEC700S.MDA
COMD> PA

C        FET MODEL PARAMETERS     NEC700L1.PAR
C   index =  0: constant     1: unbounded variable
C            2: bounded variable
C     value      index          bounds            name
     .04480        0                            C1  (pF)
     .00580        0                            C2  (pF)
     .02890        1                            Cdg (pF)
     .28337        1                            Cgs (pF)
     .08232        1                            Cds (pF)
     .01000        0                            Ci  (pF)
    3.50000        0                            Rg  (OH)
    2.00000        0                            Rd  (OH)
    3.58545        1                            Rs  (OH)
    7.82138        1                            Ri  (OH)
    4.81464        1                            Gd  (mS)
     .05850        0                            Lg  (nH)
     .04960        0                            Ld  (nH)
     .03790        1                            Ls  (nH)
     .05710        1                            gm  (S)
    3.45810        1                            tau (ps)
```

```
COMD> SAVE TEMP.PAR
COMD> ED TEMP.PAR

COMD> READ TEMP.PAR
COMD> PA

C       FET MODEL PARAMETERS     TEMP.PAR
C  index =  0: constant     1: unbounded variable
C           2: bounded variable
C     value      index         bounds          name
     .04480        0                           C1  (pF)
     .00580        0                           C2  (pF)
     .02890        2        .030   100.000     Cdg (pF)
     .28337        1                           Cgs (pF)
     .08232        1                           Cds (pF)
     .01000        0                           Ci  (pF)
    3.50000        0                           Rg  (OH)
    2.00000        0                           Rd  (OH)
    3.58545        1                           Rs  (OH)
    7.82138        1                           Ri  (OH)
    4.81464        1                           Gd  (mS)
     .05850        0                           Lg  (nH)
     .04960        0                           Ld  (nH)
     .03790        1                           Ls  (nH)
     .05710        1                           gm  (S)
    3.45810        1                           tau (ps)

COMD> L1


                  Optimization Completed After   5 iterations

C       FET MODEL PARAMETERS     OPTIMAL VALUES
C  index =  0: constant     1: unbounded variable
C           2: bounded variable
C     value      index         bounds          name
     .04480        0                           C1  (pF)
     .00580        0                           C2  (pF)
     .03000        2        .030   100.000     Cdg (pF)
     .27503        1                           Cgs (pF)
     .08071        1                           Cds (pF)
     .01000        0                           Ci  (pF)
    3.50000        0                           Rg  (OH)
    2.00000        0                           Rd  (OH)
    3.29426        1                           Rs  (OH)
    7.52121        1                           Ri  (OH)
    4.62542        1                           Gd  (mS)
     .05850        0                           Lg  (nH)
     .04960        0                           Ld  (nH)
     .04143        1                           Ls  (nH)
     .05559        1                           gm  (S)
    3.26278        1                           tau (ps)

COMD> CO
```

COMPARISON OF MODEL PARAMETERS

index=0: constant   index=1/2: variable

starting point	solution	index	name
.04480	.04480	0	C1 (pF)
.00580	.00580	0	C2 (pF)
.02890	.03000	2	Cdg (pF)
.28337	.27503	1	Cgs (pF)
.08232	.08071	1	Cds (pF)
.01000	.01000	0	Ci (pF)
3.50000	3.50000	0	Rg (OH)
2.00000	2.00000	0	Rd (OH)
3.58545	3.29426	1	Rs (OH)
7.82138	7.52121	1	Ri (OH)
4.81464	4.62542	1	Gd (mS)
.05850	.05850	0	Lg (nH)
.04960	.04960	0	Ld (nH)
.03790	.04143	1	Ls (nH)
.05710	.05559	1	gm (S)
3.45810	3.26278	1	tau (ps)

```
COMD> STOP
Stop - Program terminated.
```