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**FET MODELLING USING THE FETSC
AND FETSC1 SYSTEMS, PART I: REPORT**

OSA-87-FC-3-R

February 23, 1987

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ABSTRACT

This document provides a user-oriented description of the FETSC and FETSC1 software systems. These systems implement least one (L_1) and least squares (L_2) optimization techniques in the small-signal, linear circuit modelling of FET devices. The S-parameter sensitivities required for the gradient-based optimization methods are calculated using exact formulas reported by Bandler, Chen and Daijavad.

Both the FETSC and FETSC1 systems have been developed for VAX computers with the VMS operating system. The mathematical subprograms of these systems and their PC versions, namely FETSCG and FETSCG1, are essentially the same. The main difference is that graphics features are provided for the PC versions but not for the VAX versions. The programs are dedicated to two small-signal FET models in current use at Raytheon. Their execution is not encumbered by features, options and circuit descriptions not directly necessary to the particular FET circuit description. FETSC and FETSC1 will process up to three sets of measurements at a time, matching corresponding data simultaneously to up to three model circuits by optimizing the parameters of the circuits.

All versions use the familiar SUPERCOMPACT form of user-interaction. Data files and corresponding equivalent circuit parameter files can be created, read, edited and/or saved by appropriate user-interaction.

Two versions are presented herein:

- (1) a VAX version modelling 11 parameters called FETSC
- (2) a VAX version modelling 13 parameters called FETSC1

FETSC and FETSC1 each deal with slightly different equivalent circuit models. These differences are explained and the corresponding differences in coding are highlighted. The structure of the software is described to facilitate changes in the software to enable it to deal with other desired models.

INDEX

<u>Section</u>	<u>No. of Pages</u>
ABSTRACT	2
INTRODUCTION	2
FORMULATION OF THE PROBLEM	4
SUPERCOMPACT FILE COMPATIBILITY	6
ILLUSTRATED OPERATION OF FETSC AND FETSC1	26
COMPARISON OF RESULTS BETWEEN FETSC AND COMPACT	5
PROGRAM STRUCTURE	10
DIFFERENCES BETWEEN FETSC AND FETSC1	3

INTRODUCTION

This document reports on the development of a special purpose software system for equivalent circuit representation of FETs by optimization using S-parameters. The program assumes a fixed circuit topology with specific parameter types, and good starting parameter values of the model from previous results or prior low frequency approximations. Versions of the software will run on a VAX. Data files and corresponding equivalent circuit parameter files can be created, read, edited and/or saved by appropriate user-interaction.

The programs presented are dedicated to two small-signal FET models in current use at Raytheon. They incorporate state-of-the-art features such as adjoint sensitivity calculations and efficient gradient optimization. Their execution is not encumbered by features, options and circuit descriptions not directly necessary to the particular FET circuit description. This current set of versions, named FETSC and FETSC1, will process up to three sets of measurements at a time, matching corresponding data simultaneously to up to three model circuits by optimizing the parameters of the circuits.

A user-oriented description of the FETSC and FETSC1 software systems is provided. They implement least one (L_1) and least squares (L_2) optimization techniques in the modelling process. The S-parameter sensitivities required for the gradient-based optimization methods are calculated using exact formulas by Bandler, Chen and Daijavad[1]. Details of the L_1 optimization algorithm are discussed by Bandler, Kellermann and Madsen[2].

The present document reports on a revision of previous software described in a previous report[3]. Here, FETSC and FETSC1 each deal with slightly different equivalent circuit models. These diffe-

rences are explained and the corresponding differences in coding are highlighted. The structure of the software is described to facilitate changes in the software to enable it to deal with other desired models.

The FETSC and FETSC1 systems have been developed mainly in Fortran 77 for the VAX with the VMS operating system. The mathematical subprograms of these systems and their PC versions, namely FETSCG and FETSCG1[4], are essentially the same. The main difference is that graphics features are provided for the PC versions but not for the VAX versions. All versions use the familiar SUPERCOMPACT[5] form of user-interaction.

References

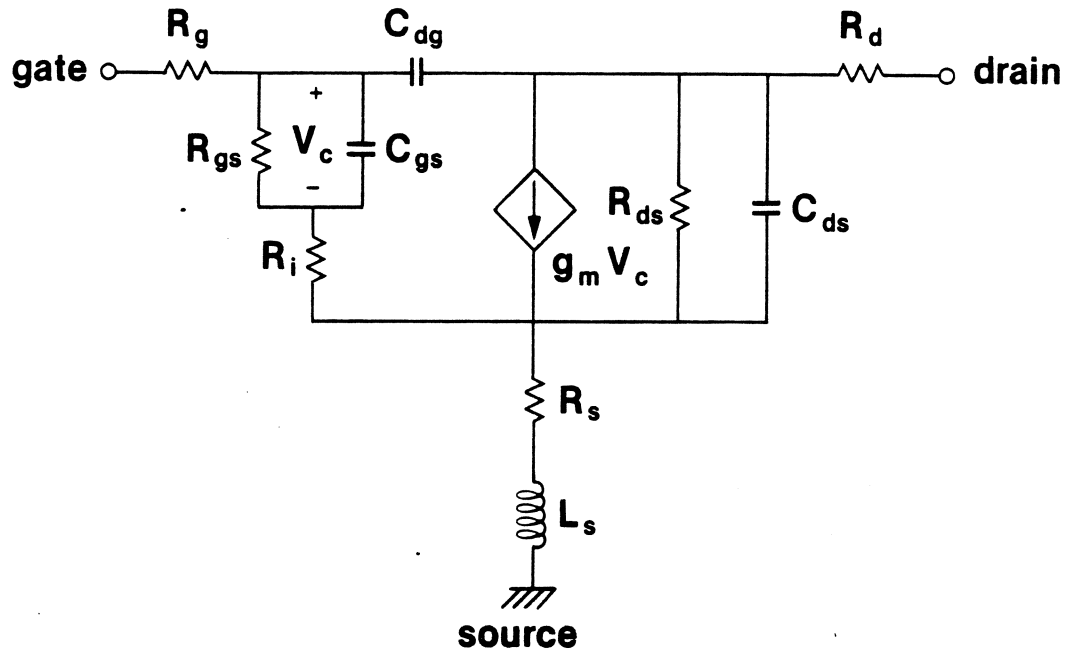
- [1] J.W. Bandler, S.H. Chen and S. Daijavad, "Microwave device modelling using efficient L_1 optimization: a novel approach", IEEE Trans. Microwave Theory Tech., vol.MTT-34, 1986, pp. 1282-1293.
- [2] J.W. Bandler, W. Kellermann and K. Madsen, "A superlinearly convergent algorithm for nonlinear L_1 optimization with circuit applications", Proc. IEEE Int. Symp. Circuits and Systems (Kyoto, Japan, 1985), pp. 977-980.
- [3] "FET modelling using the FETSC system: a user's guide," Report OSA-86-FC-7-R, October 14, 1986.
- [4] "FET modelling using the FETSCG and FETSG1 system, Part I: Report," Report OSA-87-FC-2-R, February 23, 1987.
- [5] SUPERCOMPACT User Manual, Version 1.6/1.7, July 1982, Revised 1-10-83, updated 3/1/84.

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.

The Equivalent Circuits

The two proposed equivalent circuits are shown in Figs. 1 and 2. For the model illustrated in Fig. 1, there is a total of 11



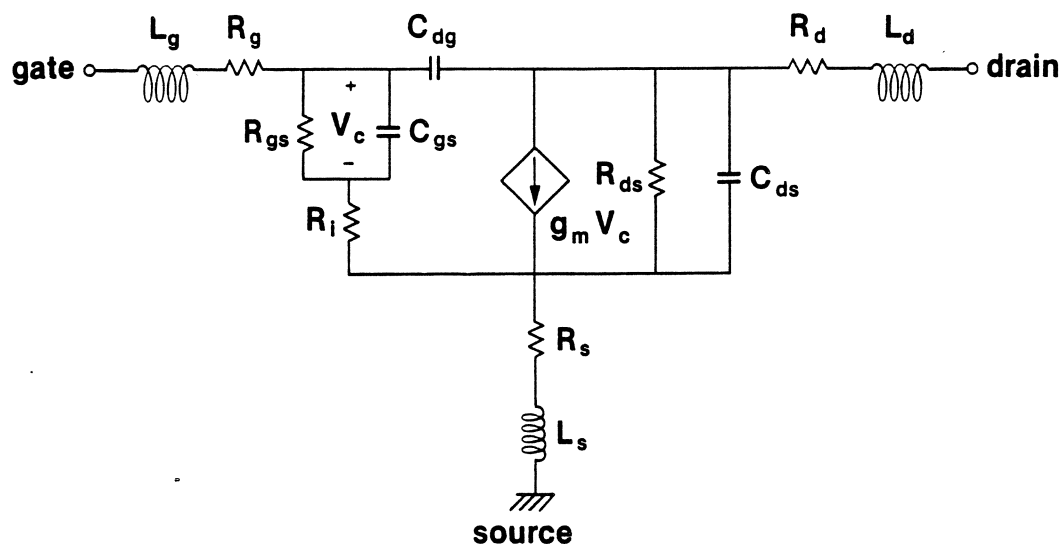
$$y_m = \frac{g_m * e^{-j2\pi f \tau}}{1 + j(f/f_{3dB})}$$

$$f_{3dB} = 1000 \text{ GHz}$$

Fig. 1 Equivalent circuit A of the FET.

parameters which completely define the equivalent circuit at a given frequency f . These parameters are $R_g(\Omega)$, $R_i(\Omega)$, $R_d(\Omega)$, $R_{ds}(\Omega)$, $C_{dg}(\text{pF})$, $C_{gs}(\text{pF})$, $C_{ds}(\text{pF})$, $R_s(\Omega)$, $L_s(\text{nH})$, $g_m(\text{mS})$ and $\tau(\text{ps})$, where the

unit for each parameter is given in brackets. For the model illustrated in Fig. 2, there is a total of 13 parameters, namely, $R_g(\Omega)$, $R_i(\Omega)$, $R_d(\Omega)$, $R_{ds}(\Omega)$, $C_{dg}(\text{pF})$, $C_{gs}(\text{pF})$, $C_{ds}(\text{pF})$, $R_s(\Omega)$, $L_s(\text{nH})$, $g_m(\text{mS})$, $\tau(\text{ps})$, $L_g(\text{nH})$ and $L_d(\text{nH})$.



$$y_m = \frac{g_m * e^{-j2\pi f \tau}}{1 + j(f/f_{3dB})}$$

$$f_{3dB} = 1000 \text{ GHz}$$

Fig. 2 Equivalent circuit B of the FET.

Any or all of these parameters could be optimization variables with possible upper and/or lower bounds on their values.

Variable Transformation

An exponential transformation is applied to all variables as follows:

$$x_t = \text{EXP}(X_t) + \text{LB}_t, \quad t=1, \dots, n \quad (1)$$

where LB_t is the lower bound on variable x_t . If not explicitly

defined by the user, $LB_t = 0$ will be assumed. Such a transformation stabilizes the optimization process and automatically ensures that the variables stay within their lower bounds.

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 $S_{ij}^m(k)$, $i = 1, 2$, $j = 1, 2$, $k = 1, 2, \dots, n_f$, where S_{ij} is the complex S-parameter and m is used to denote the measured response. Similarly, we have $S_{ij}^c(k)$, where c is used to denote the calculated response using the equivalent circuit parameters. $S_{ij}^c(k)$ is a function of circuit parameters, and as mentioned before, we seek optimum circuit parameters such that $S_{ij}^c(k)$ best approximates $S_{ij}^m(k)$.

We define the unweighted error functions as

$$FR_{ij}(k) = \text{Re}[S_{ij}^m(k)] - \text{Re}[S_{ij}^c(k)], \quad (2)$$

$$FI_{ij}(k) = \text{Im}[S_{ij}^m(k)] - \text{Im}[S_{ij}^c(k)], \quad (3)$$

where $i = 1, 2$, $j = 1, 2$, $k = 1, 2, \dots, n_f$. 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

$$NWR_{ij} = W_{ij} / (\max_k \{\text{Re}[S_{ij}^m(k)]\} - \min_k \{\text{Re}[S_{ij}^m(k)]\}) \quad (4)$$

and

$$NWI_{ij} = W_{ij} / (\max_k \{ \text{Im}[S_{ij}^m(k)] \} - \min_k \{ \text{Im}[S_{ij}^m(k)] \}). \quad (5)$$

The L_1 objective function is defined as

$$U_1 = \frac{1}{n_f} \sum_{k=1}^{n_f} \sum_{i=1}^2 \sum_{j=1}^2 (|NWR_{ij} * FR_{ij}(k)| + |NWI_{ij} * FI_{ij}(k)|). \quad (6)$$

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

The L_2 Optimization

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

$$U_2 = \frac{1}{n_f} \sum_{k=1}^{n_f} \sum_{i=1}^2 \sum_{j=1}^2 [(NWR_{ij} * FR_{ij}(k))^2 + (NWI_{ij} * FI_{ij}(k))^2]. \quad (7)$$

The lower bounds on variables are automatically enforced by the variable transformation. The upper bounds on variables are handled by adding a penalty function to the objective function for those variables which violate their bounds. In this case, the objective function is given by

$$PU_2 = U_2 + \sum_{t=1}^n [WU_t (UB_t - x_t)^2] \quad (8)$$

where

$$WU_t = \begin{cases} 10, & \text{if } x_t > UB_t, \\ 0, & \text{if } x_t \leq UB_t \end{cases} \quad (9)$$

Actually, in (8) and (9) transformed variable X_t and the transformed value of the bound are used.

SUPERCOMPACT FILE COMPATIBILITY

In this section, a description of circuit and data files which may be utilized with the FETSC and FETSC1 systems is given. The user should supply a circuit file which contains directives for a modelling process and, depending on the number of circuits to be processed, one or two or three data files containing the measured S-parameters. The reader is referred to the SUPERCOMPACT user's manual[1] for further guidelines.

Blocks

The following blocks provide information relevant both to FETSC and FETSC1 and must be defined in the circuit file:

BLK defines the variables and describes the FET models;

FREQ defines the frequency points;

OPT defines the optimization goals;

DATA specifies the measurement data files;

The OUT block is used by the PC versions to control the graphics output. A circuit file for the VAX versions may also have an OUT block, but the its contents will be ignored. The blocks LAD and NOI are not allowed since they are irrelevant.

Comments

Comments placed in a circuit file must be preceded by the special symbol '*'. For S-parameter datafiles, a comment line does not have to begin with a '*'. Any line of a datafile that does not begin with a numeral is considered as a comment line.

The BLK Block

1. Defining labels (symbolic names)

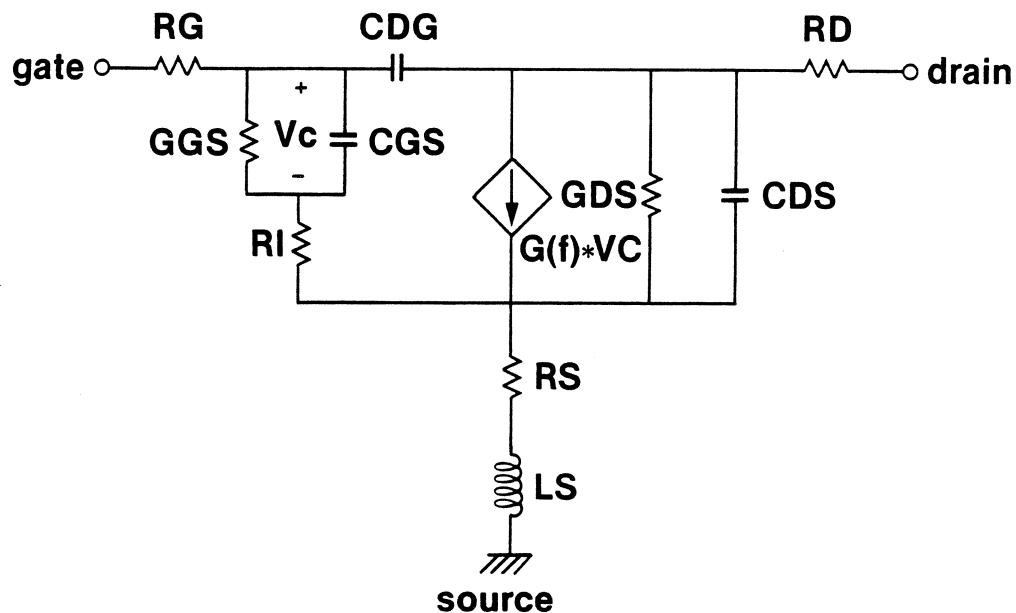
Label_name: V_string

Label_name can have 1 - 8 characters. There must not be any spaces separating the label_name and the symbol ':'. V_string is illustrated by the following examples.

VAR1: 1.2345	a constant
C2: 12.3PF	a constant with a unit
X5: ?5.1?	a variable
L3: ?1NH 10NH 100NH?	a variable with two bounds
X4: ?10% 10NH 1000%?	a variable with percentage bounds

2. Defining a FET

The FET equivalent circuit A shown in Fig. 1 is the only element type permitted in a FETSC file because it is the only device

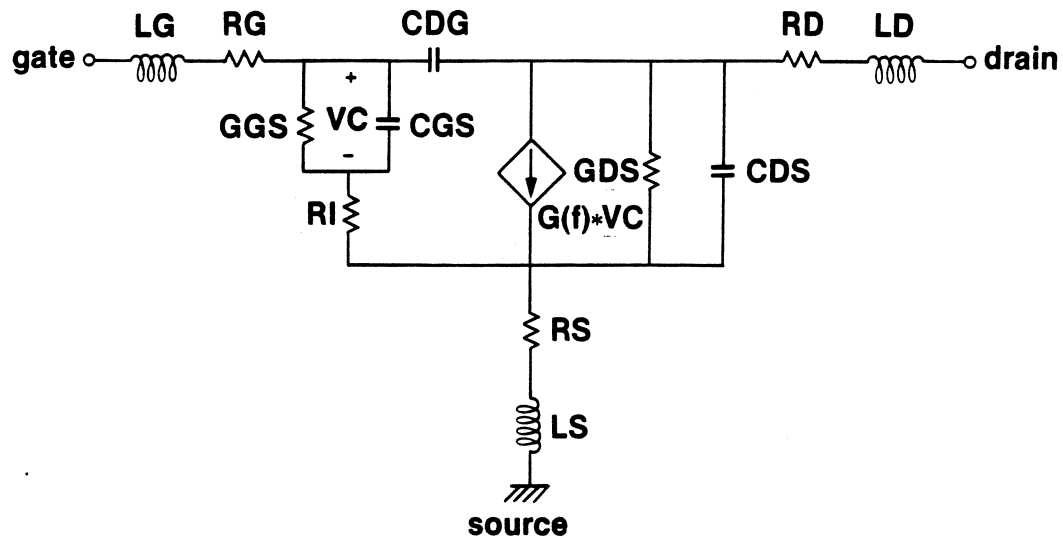


$$G(f) = \frac{G * e^{-j2\pi fT}}{1 + j(f/F)}$$

$$F = 1000 \text{ GHz}$$

Fig. 1 Equivalent circuit A of the FET.

meaningful to the program. The FET element permitted in a FETSC1 file is shown in Fig. 2.



$$G(f) = \frac{G * e^{-j2\pi fT}}{1 + j(f/F)}$$

$$F = 1000 \text{ GHz}$$

Fig. 2 Equivalent circuit B of the FET.

Defining any other elements such as RES, CAP, etc., will result in an error. The general form for FETSC is the following.

```
FET n1 n2 [0] G=x1 CGS=x2 F=x3 T=x4 GGS=x5 CDG=x6 CDS=x7 GDS=x8
+ RI=x9 RG=x10 RD=x11 RS=x12 LS=x13
```

The general form for FETSC1 is very similar:

```
FET n1 n2 [0] G=x1 CGS=x2 F=x3 T=x4 GGS=x5 CDG=x6 CDS=x7 GDS=x8
+ RI=x9 RG=x10 RD=x11 RS=x12 LG=x13 LD=x14 LS=x15
```

The n1 and n2 are node numbers. The ground node 0 is optional. The x1 to x15 are pre-defined labels or V_strings (see subsection 1

above). F is the 3 dB frequency. Neither it nor GGS can be a variable. If a component is omitted then it is assumed to be zero.

3. Defining a Two-Port

The circuit model should be defined as a two-port whose scattering parameters are to match the measurement data. Consider the following example.

```
Model_name: 2POR n1 n2 [0]
```

Model_name is an arbitrary name having 1 - 8 characters and followed immediately by ':'. The n1 and n2 are node numbers consistent with those of FET. The ground node 0 is optional.

The FREQ Block

The following is an example of the FREQ block.

```
FREQ  1GHZ 2GHZ  STEP 4GHZ 10GHZ 2GHZ
      STEP 14GHZ 17GHZ 1GHZ    20GHZ
```

The meaning of the statement is that 1GHZ, 2GHZ and 20GHZ are discrete points. Two ranges, one from 4GHZ to 10GHZ with an increment of 2GHZ and another from 14GHZ to 17GHZ with an increment of 1GHZ, are also defined. This results in a total of the 11 points:

1, 2, 4, 6, 8, 10, 14, 15, 16, 17 and 20 (GHZ).

Restriction: the total number of frequencies must not exceed 20.

The OPT Block

The format of the OPT block is the following.

```
Model_name [frequency range] S=Measure_name [W w11 w12 w21 w22]
```

'Model_name' must have been defined in the BLK block. 'Frequency range' is optional. If it is omitted then all the frequencies defined in the FREQ block will be used. It could be a single number which specifies a single frequency or it could have two entries specifying a range. In either case, the frequencies specified must be a subset of those defined in the FREQ block.

'S=' means to match scattering parameters. This is the only operation allowed by FETSC or FETSC1.

'Measure_name' is to be defined in the DATA block.

'W w11 w12 w21 w22' are optional entries defining weights. The default is unity weighting. The user is warned that the order of the S-parameters is different from that of a data file (which is S11 S21 S12 S22).

The following is an example of the OPT block.

```

OPT

MODEL1  S=MEASURE1

MODEL2  3GHZ S=MEASURE2  W 1 0 0 0

        4GHZ 10GHZ S=MEASURE2  W 1 1 1 1

END

```

The DATA Block

The measurement data (scattering parameters of the device) must be supplied through data files. The general form of specifying the name of a data file is

Measure_name: file_name

The following is an example.

DATA

MEASURE1: C85029A.DAT

MEASURE2: C85029B.DAT

END

Reference

- [1] SUPERCOMPACT User Manual, Version 1.6/1.7, July 1982, Revised 1-10-83, updated 3/1/84.

ILLUSTRATED OPERATION OF FETSC AND FETSC1

The operation of the FETSC package on a VAX computer is demonstrated with the help of two examples. The first involves a single circuit and the other involves three circuits. The operation of FETSC1 is identical in all aspects except for the definition of the circuit model.

Single Circuit Example

In this example we seek equivalent circuit parameters for the FET device C85029 under the biasing conditions

VDS=4V, VGS=0V and IDS=177mA.

The S-parameter measurement data file is called C85029A.DAT. In the following interactive session, we employ both L1 and L2 optimizations to identify the parameters and at the same time demonstrate the use of other available commands.

Starting Operation

On the VAX, the VMS operating system prompt is a dollar sign:

\$

Start the execution of the program by typing, after the system prompt,

\$RUN FETSC

Following a menu of commands available, we are at the command level of the FETSC package.

Creating a Circuit File, READ and TYPE

Using the screen editor, we create a SUPERCOMPACT compatible circuit file called ONECKT.DAT. After creating this file, we are back

at the command level of FETSC and we can use the TYPE command to inspect the contents of the file. As shown in the interactive session, the file has the format of a SUPERCOMPACT circuit file. The SUPERCOMPACT User's Manual[1] should be consulted to recall the function of each block in the circuit file. Next, we read (the READ command) the newly created file (extension DAT is assumed if no other extension is specified). If the circuit file is not SUPERCOMPACT compatible or if some of the other limitations of the package are violated by the circuit file error messages indicating the location and type of error are displayed after reading the file. For example, a limitation is that the package can handle only a prespecified topology for the equivalent circuit and not an arbitrary SUPERCOMPACT circuit file. In that case, the user must use the editor to correct the circuit file before proceeding to other operations. After a successful READ, a few lines display the status of the system in terms of the current files (the circuit file and the measurement data file(s) specified) and the number of circuits.

SWEEP, SENSITIVITY, PARAMETER, %ERROR

Next, the SWEEP command is used to evaluate the S-parameters of the model at the current values of the circuit parameters. The SENSITIVITY command displays the gradient of the least-squares objective w.r.t. the circuit parameters. The PARAMETER command summarizes the current values of parameters and %ERROR displays the percentage error between measured and modelled S-parameters.

L1 Optimization

Next, we perform the L1 optimization (the L1 command). The objective function is displayed as the optimization proceeds and the optimum parameters are displayed upon the completion of the optimization.

tion.

SAVE and COMPARE

At this time we save the optimum parameters in a file called ONECKTL1 (extension DAT) which is the same as ONECKT with the difference that the variables have been updated to their optimum values. The COMPARE command is used to show starting and final values of the circuit parameters side by side. Next in our interactive session, we use the %ERROR command to prove the success of the optimization. A sensitivity analysis is also performed at the solution. Since the sensitivities are evaluated w.r.t. the L2 objective function, displaying the sensitivities after an L2 optimization may be more appropriate. Even after an L1 optimization, however, these sensitivities can be informative.

The BRIEFING Command

Next, the BRIEFING command is used to confirm the names of the current files.

L2 Optimization

To perform the L2 optimization from the same starting values as the ones used for L1, we read ONECKT (.DAT) (using the READ command) and perform the optimization. At the solution, sensitivity analysis is performed and once more the percentage differences between measured and modelled responses are displayed.

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 VMS
DIR	list the file directory
HELP	display the available commands
PARAMETER	display the current model parameters
COMPARE	compare starting point with optimization solution
%ERROR	display percentage errors in S-parameter matching
SWEEP	generate S-parameters of the current model
SENSITIVITY	sensitivity analysis for the current model
SAVE fname	save current data in a CKT file
READ fname	read desired data from a file
EDIT fn.ext	edit a disk file using full screen editor
TYPE fn.ext	display the content of a disk file
PRESENTATION	call the user-defined routine PRESENT
BRIEFING	display the current status

COMD>

Input : ED ONECKT.DAT
V A X E D T E D I T O R

COMD>

Input : TYPE ONECKT.DAT

*Single measurement C85029A

BLK

*

G1:70.09?
T1:70.007NS?
C1:71.4PF?
C2:70.07PF?
C3:70.4PF?
G2:70.007?
R1:71?
R2:71?
R3:71?
R4:71?
L1:70.02NH?
R0:2.E-6
F0:1.E3GHz

*

FET 1 2 G=G1 CGS=C1 F=F0 T=T1 GGS=R0 CDG=C2 CDS=C3 GDS=G2 RI=R1
+ RG=R2 RD=R3 RS=R4 LS=L1
FETMDL1: 2POR 1 2

END

*

FREQ
STEP 2.0GHZ 18.0GHZ 1.0GHZ

END

*

OPT
FETMDL1 F=2.0GHZ 18.0GHZ S=FETMDA1 W 1 1 1 1

END

*

DATA
FETMDA1: C85029A.DAT
END

COMD>

Input : READ ONECKT
Reading circuit file...

Working file: ONECKT.DAT
Number of circuits: 1
Measurement files: C85029A.DAT

COMD>

Input : Sw

*

S-PARAMETERS OF MODEL FETMDL1

* Frequency

(GHZ)	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
2.0	0.9102	-90.02	4.1038	116.16	0.0489	41.02	0.4654	-47.70
3.0	0.8804	-112.39	3.1186	97.38	0.0548	29.87	0.4655	-62.14
4.0	0.8662	-126.48	2.4464	83.11	0.0559	23.49	0.4852	-73.54
5.0	0.8603	-135.94	1.9780	71.44	0.0550	20.06	0.5148	-83.03
6.0	0.8588	-142.69	1.6380	61.43	0.0530	18.75	0.5485	-91.16
7.0	0.8595	-147.76	1.3817	52.60	0.0505	19.18	0.5830	-98.24
8.0	0.8614	-151.73	1.1823	44.69	0.0481	21.15	0.6162	-104.47
9.0	0.8640	-154.94	1.0231	37.52	0.0460	24.52	0.6474	-110.00
10.0	0.8668	-157.62	0.8935	31.00	0.0445	29.07	0.6760	-114.97
11.0	0.8696	-159.91	0.7859	25.05	0.0438	34.49	0.7020	-119.43
12.0	0.8723	-161.90	0.6954	19.62	0.0440	40.37	0.7253	-123.48
13.0	0.8748	-163.65	0.6183	14.65	0.0451	46.27	0.7462	-127.16
14.0	0.8772	-165.23	0.5518	10.12	0.0471	51.81	0.7647	-130.53
15.0	0.8792	-166.65	0.4938	6.00	0.0498	56.75	0.7812	-133.62
16.0	0.8811	-167.94	0.4429	2.26	0.0531	61.00	0.7958	-136.46
17.0	0.8827	-169.14	0.3978	-1.12	0.0569	64.56	0.8087	-139.09
18.0	0.8840	-170.24	0.3576	-4.13	0.0611	67.49	0.8202	-141.52

COMD>

Input : SE

SENSITIVITY OF THE CURRENT MODEL

least-squares error: 1.43289185

FETMDL1

gradient

0.006588	RG (OH)
-0.002924	RD (OH)
-0.054016	GDS(/OH)
0.008720	RI (OH)
-0.029135	RS (OH)
0.083693	LS (nH)
0.785485	CGS (pF)
0.178493	CDG (pF)
0.846271	CDS (pF)
-0.219883	G (/OH)
0.173734	T (ps)

COMD>

Input : PA

FET MODEL PARAMETERS

FETMDL1

1.00000	RG (OH)
1.00000	RD (OH)
0.00700	GDS(/OH)
1.00000	RI (OH)
1.00000	RS (OH)
0.02000	LS (nH)
1.40000	CGS (pF)
0.07000	CDG (pF)
0.40000	CDS (pF)
0.09000	G (/OH)
7.00000	T (ps)

COMD>
Input : %ER

PERCENTAGE ERRORS IN S-PARAMETER MATCHING
ABS[(Model-Measurement)/Measurement] %

Frequency (GHZ)	model: FETMDL1				measurement: C85029A.DAT			
	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
2.0	4.65%	92.68%	1.57%	20.19%	68.04%	34.84%	22.56%	122.59%
3.0	6.27%	67.79%	13.73%	24.67%	41.15%	43.07%	19.86%	89.34%
4.0	3.15%	51.95%	26.58%	29.86%	22.16%	44.83%	15.15%	84.17%
5.0	2.11%	38.79%	33.04%	30.54%	8.42%	40.83%	9.69%	69.67%
6.0	0.12%	31.06%	38.02%	35.52%	2.24%	34.80%	5.55%	66.29%
7.0	1.60%	22.15%	39.78%	36.51%	2.26%	4.02%	2.58%	54.90%
8.0	2.70%	18.74%	43.67%	43.39%	4.35%	11.40%	5.43%	52.42%
9.0	3.60%	12.56%	46.78%	44.40%	8.87%	90.96%	10.34%	45.55%
10.0	3.81%	9.98%	50.32%	47.41%	15.21%	176.60%	11.02%	44.27%
11.0	4.44%	6.96%	50.60%	55.54%	12.23%	178.84%	13.85%	43.53%
12.0	4.77%	4.28%	53.96%	57.80%	13.26%	560.76%	14.04%	34.72%
13.0	6.74%	1.64%	55.32%	64.11%	4.69%	428.18%	16.10%	36.16%
14.0	5.67%	0.58%	57.38%	70.70%	0.97%	999.00%	15.29%	29.11%
15.0	6.68%	3.11%	57.48%	75.84%	12.61%	999.00%	16.28%	25.56%
16.0	5.74%	3.83%	60.92%	90.59%	21.82%	739.07%	16.26%	25.57%
17.0	7.77%	6.01%	57.52%	109.40%	39.56%	999.00%	14.80%	22.28%
18.0	5.32%	5.76%	63.09%	150.88%	45.57%	999.00%	15.55%	22.83%

COMD>
Input : L1

Working file: ONECKT.DAT
Number of circuits: 1
Measurement files: C85029A.DAT

Start modelling ...

You can press any key to interrupt optimization

Iteration 1	L1 error	2.4215007
Iteration 2	L1 error	1.7039427
Iteration 3	L1 error	0.7347444
Iteration 4	L1 error	0.5093994
Iteration 5	L1 error	0.4990287
Iteration 6	L1 error	0.4524295
Iteration 7	L1 error	0.4492849
Iteration 8	L1 error	0.4481698
Iteration 9	L1 error	0.4477605
Iteration 10	L1 error	0.4477171
Iteration 11	L1 error	0.4475315
Iteration 12	L1 error	0.4476416
Iteration 13	L1 error	0.4474366

Optimization Completed

13 iterations 3.13 CPU seconds

FET MODEL PARAMETERS

FETMDL1

starting	solution		
1.00000	3.06508	RG	(OH)
1.00000	3.07341	RD	(OH)
0.00700	0.00506	GDS	(/OH)
1.00000	0.01378	RI	(OH)
1.00000	0.94576	RS	(OH)
0.02000	0.00490	LS	(nH)
1.40000	0.67515	CGS	(pF)
0.07000	0.03033	CDG	(pF)
0.40000	0.22060	CDS	(pF)
0.09000	0.06727	G	(/OH)
7.00000	4.74326	T	(ps)

COMD>

Input : SAVE ONECKTL1

COMD>

Input : CO

FET MODEL PARAMETERS

FETMDL1

starting	solution		
1.00000	3.06508	RG	(OH)
1.00000	3.07341	RD	(OH)
0.00700	0.00506	GDS	(/OH)
1.00000	0.01378	RI	(OH)
1.00000	0.94576	RS	(OH)
0.02000	0.00490	LS	(nH)
1.40000	0.67515	CGS	(pF)
0.07000	0.03033	CDG	(pF)
0.40000	0.22060	CDS	(pF)
0.09000	0.06727	G	(/OH)
7.00000	4.74326	T	(ps)

COMD>
Input : %ER

PERCENTAGE ERRORS IN S-PARAMETER MATCHING								
ABS[(Model-Measurement)/Measurement] %								
Frequency	model: FETMDL1				measurement: C85029A.DAT			
(GHZ)	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
2.0	0.55%	8.21%	9.47%	2.47%	0.96%	5.34%	0.58%	12.49%
3.0	1.15%	5.15%	7.77%	2.24%	0.27%	8.80%	0.01%	3.80%
4.0	0.78%	3.68%	1.68%	4.44%	2.44%	9.43%	0.38%	6.94%
5.0	0.22%	0.89%	0.30%	0.75%	4.75%	7.82%	0.89%	2.87%
6.0	0.73%	0.13%	2.66%	3.01%	2.90%	11.45%	2.53%	4.43%
7.0	1.14%	3.55%	1.40%	1.24%	0.92%	12.96%	0.56%	0.25%
8.0	1.16%	3.64%	4.51%	3.45%	2.24%	10.01%	0.77%	1.29%
9.0	1.16%	6.70%	7.03%	2.59%	1.23%	9.51%	0.66%	0.97%
10.0	0.66%	7.28%	10.82%	6.55%	3.88%	10.57%	1.06%	0.24%
11.0	0.72%	8.61%	9.04%	0.87%	0.68%	21.76%	0.26%	1.64%
12.0	0.59%	9.91%	13.13%	10.26%	4.37%	33.68%	1.29%	2.96%
13.0	2.13%	11.39%	13.63%	12.73%	0.00%	19.58%	0.32%	0.40%
14.0	0.84%	12.67%	15.57%	18.90%	1.19%	42.57%	1.53%	4.23%
15.0	1.60%	14.36%	13.65%	46.59%	1.26%	46.37%	0.96%	5.68%
16.0	0.56%	14.54%	18.53%	33.18%	0.32%	21.85%	1.09%	4.57%
17.0	2.39%	16.11%	8.95%	133.23%	3.40%	14.63%	2.32%	6.09%
18.0	0.00%	15.55%	18.51%	191.58%	2.51%	2.55%	1.57%	4.76%

COMD>
Input : SE

SENSITIVITY OF THE CURRENT MODEL

least-squares error: 0.07406536

FETMDL1

gradient

-0.006281	RG (OH)
0.001076	RD (OH)
-0.016698	GDS(/OH)
-0.000038	RI (OH)
-0.005747	RS (OH)
-0.002337	LS (nH)
-0.075147	CGS (pF)
-0.007044	CDG (pF)
0.000188	CDS (pF)
0.048472	G (/OH)
-0.003302	T (ps)

COMD>
Input : BR

Working file: ONECKTL1.DAT

Number of circuits: 1

Measurement files: C85029A.DAT

COMD>
Input : READ ONECKT

Reading circuit file...

Working file: ONECKT.DAT

Number of circuits: 1

Measurement files: C85029A.DAT

COMD>

Input : L2

Working file: ONECKT.DAT

Number of circuits: 1

Measurement files: C85029A.DAT

Start modelling ...

You can press any key to interrupt optimization

Iteration 1	L2 error	1.4328918
Iteration 2	L2 error	0.8403827
Iteration 3	L2 error	0.2060595
Iteration 4	L2 error	0.1863935
Iteration 5	L2 error	0.0936570
Iteration 6	L2 error	0.8809951
Iteration 7	L2 error	0.0839897
Iteration 8	L2 error	0.1306155
Iteration 9	L2 error	0.0819032
Iteration 10	L2 error	0.0735486
Iteration 11	L2 error	0.0929332
Iteration 12	L2 error	0.0703869
Iteration 13	L2 error	0.0701839
Iteration 14	L2 error	0.0693486
Iteration 15	L2 error	0.0687101
Iteration 16	L2 error	0.0844100
Iteration 17	L2 error	0.0656381
Iteration 18	L2 error	0.0653310
Iteration 19	L2 error	0.0652332
Iteration 20	L2 error	0.0651622
Iteration 21	L2 error	0.0651320
Iteration 22	L2 error	0.0650604
Iteration 23	L2 error	0.0649676
Iteration 24	L2 error	0.0648164
Iteration 25	L2 error	0.0646840
Iteration 26	L2 error	0.0646226
Iteration 27	L2 error	0.0646112
Iteration 28	L2 error	0.0646054
Iteration 29	L2 error	0.0646000
Iteration 30	L2 error	0.0645970
Iteration 31	L2 error	0.0645935
Iteration 32	L2 error	0.0645874
Iteration 33	L2 error	0.0645783
Iteration 34	L2 error	0.0645692
Iteration 35	L2 error	0.0645625
Iteration 36	L2 error	0.0645594
Iteration 37	L2 error	0.0645563
Iteration 38	L2 error	0.0645509
Iteration 39	L2 error	0.0645426
Iteration 40	L2 error	0.0645339
Iteration 41	L2 error	0.0645062
Iteration 42	L2 error	0.0644917
Iteration 43	L2 error	0.0644822
Iteration 44	L2 error	0.0644768
Iteration 45	L2 error	0.0644759

Iteration 46	L2 error	0.0644750
Iteration 47	L2 error	0.0644741
Iteration 48	L2 error	0.0644712
Iteration 49	L2 error	0.0644671
Iteration 50	L2 error	0.0644613
Iteration 51	L2 error	0.0644560
Iteration 52	L2 error	0.0644522
Iteration 53	L2 error	0.0644510
Iteration 54	L2 error	0.0644480
Iteration 55	L2 error	0.0644470
Iteration 56	L2 error	0.0644462
Iteration 57	L2 error	0.0644450
Iteration 58	L2 error	0.0644438
Iteration 59	L2 error	0.0644427
Iteration 60	L2 error	0.0644416
Iteration 61	L2 error	0.0644410
Iteration 62	L2 error	0.0644404
Iteration 63	L2 error	0.0644403
Iteration 64	L2 error	0.0644400
Iteration 65	L2 error	0.0644401
Iteration 66	L2 error	0.0644401
Iteration 67	L2 error	0.0644401

Optimization Completed

67 iterations 5.85 CPU seconds

FET MODEL PARAMETERS

FETMDL1

starting	solution	
1.00000	4.94463	RG (OH)
1.00000	1.81533	RD (OH)
0.00700	0.00542	GDS(/OH)
1.00000	0.01070	RI (OH)
1.00000	1.05717	RS (OH)
0.02000	0.00448	LS (nH)
1.40000	0.73919	CGS (pF)
0.07000	0.03238	CDG (pF)
0.40000	0.21633	CDS (pF)
0.09000	0.06984	G (/OH)
7.00000	3.51992	T (ps)

COMD>

Input : SE

SENSITIVITY OF THE CURRENT MODEL

least-squares error: 0.06444001

FETMDL1

gradient

0.011226	RG (OH)
0.001489	RD (OH)
0.006218	GDS(/OH)
0.000012	RI (OH)
-0.005936	RS (OH)
-0.001443	LS (nH)
0.053245	CGS (pF)
0.019829	CDG (pF)
0.008137	CDS (pF)
-0.031499	G (/OH)
-0.009962	T (ps)

COMD>

Input : %ER

PERCENTAGE ERRORS IN S-PARAMETER MATCHING

ABS[(Model-Measurement)/Measurement] %

Frequency (GHZ)	model: FETMDL1				measurement: C85029A.DAT			
	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
2.0	1.31%	15.87%	8.92%	3.59%	6.48%	8.75%	4.44%	17.30%
3.0	4.22%	11.52%	5.28%	3.45%	3.37%	13.25%	3.99%	7.20%
4.0	3.31%	9.02%	2.15%	5.39%	0.24%	14.51%	4.13%	9.70%
5.0	4.52%	5.35%	5.10%	1.26%	3.51%	13.20%	4.16%	5.07%
6.0	4.52%	3.71%	8.08%	2.87%	2.21%	16.43%	5.19%	6.38%
7.0	4.48%	0.28%	7.42%	2.21%	0.53%	7.31%	1.60%	1.93%
8.0	4.74%	0.72%	10.72%	1.61%	2.51%	13.57%	2.35%	2.84%
9.0	4.95%	4.14%	13.33%	5.68%	1.52%	6.87%	0.44%	0.42%
10.0	5.60%	4.96%	17.05%	11.12%	3.47%	10.20%	1.69%	1.54%
11.0	5.71%	6.50%	15.53%	6.70%	0.02%	19.93%	0.49%	2.86%
12.0	5.97%	7.99%	19.41%	18.55%	3.43%	41.14%	1.16%	1.89%
13.0	4.66%	9.63%	19.93%	23.53%	1.37%	12.20%	0.12%	0.61%
14.0	5.98%	11.05%	21.76%	33.22%	0.61%	60.70%	0.82%	3.34%
15.0	5.37%	12.86%	19.99%	68.63%	3.62%	69.18%	0.01%	4.87%
16.0	6.43%	13.14%	24.51%	58.14%	2.56%	8.44%	0.07%	3.82%
17.0	4.82%	14.80%	15.60%	187.85%	6.99%	34.23%	0.99%	5.42%
18.0	7.12%	14.31%	24.42%	277.61%	1.49%	18.48%	0.05%	4.13%

COMD>

Input : SAVE ONECKTL2

COMD>

Input : STOP

Multi-Circuit Example

A powerful feature of the FETSC package is its capability of handling multiple circuits which may have common variables. Up to three circuits can be processed simultaneously. The theoretical advantages of the multi-circuit approach in modelling have been discussed by Bandler, Chen and Daijavad in a recent paper[2]. Here, we use an example to demonstrate the use of FETSC with multiple circuits. The results will prove the robustness of the package in terms of the choice of starting values and the frequency points.

S-parameter measurements on an FET device under three different biasing conditions have been provided by Raytheon. The biasing conditions and the corresponding data files are as follows.

Biasing Conditions			Measurement Data File
VDS=4V	VGS= 0V	IDS=177mA	C85029A.DAT
VDS=4V	VGS=-1.74V	IDS= 92mA	C85029B.DAT
VDS=4V	VGS=-3.10V	IDS= 37mA	C85029C.DAT

In an interactive session which follows, we simultaneously process the three sets of measurements to find parameters for the corresponding circuits. By using common variables between the circuits, we can easily force the assumption that some parameters should remain unchanged as the biasing conditions vary. In particular, parameters RGM, RD, LS and T are declared to be fixed w.r.t. the bias.

As seen from the following printout of the interactive session, we first create SUPERCOMPACT compatible file ALLTHREE.DAT. The listing of this file (obtained using the TYPE command) illustrates the way that common or noncommon variables between the three circuits are handled. The OPT block in the file specifies that each circuit

response models its corresponding measurement file.

Next, we perform the L1 optimization and obtain the parameters of the three circuits. Inspecting the parameters, we observe that the assumptions on common variables have been realized. The percentage difference between modelled and measured responses of each circuit are displayed using the %ERROR command and sensitivities of the least-squares objective are calculated using the SENSITIVITY command.

Reduced Sample Points

We now perform two tests to demonstrate the robustness of the FETSC package. In the first test, we solve the above multi-circuit problem using half the frequency points as used before, i.e., we use S-parameter measurements from 2 to 18 GHz with a 2 GHz increment. In TEST1.DAT file, only the increment in the FREQ block has been changed compared to the ALLTHREE.DAT. Consistency of the results obtained using half the frequencies with the previous results provides more confidence in the validity of circuit parameters. The reduction in CPU time is significant. We can usually expect an almost linear reduction in the CPU time as the number of frequency points is reduced.

Different Starting Points

In a second test, we examine the robustness of the package in dealing with different starting values. In TEST2.DAT file (which has been listed with the TYPE command) the starting values have been changed to the rather arbitrary numbers shown. Parameters obtained after performing the L1 optimization are consistent with the previous results. We tried at least 20 different sets of arbitrary starting

values and came up with approximately the same results in all cases except when the starting values were extremely wild. It should be mentioned that all the software packages for FET modelling that we know are sensitive (especially, some parameters such as the resistors) to the choice of starting values. We compare the performance of FETSC to the popular COMPACT software system in a separate section.

COMD>

Input : ED ALLTHREE.DAT

V A X E D T E D I T O R

COMD>

Input : TYPE ALLTHREE.DAT

*All three measurements C85029A, C85029B and C85029C

BLK

```

*      common variables
      R0:2.E-6
      F0:1.E3GHZ
      RGM:?1?
      LS:?0.02NH?
      RDD:?1?
      TAU:?0.007NS?
*      variable for the first circuit
      G1:?0.09?
      C1:?1.4PF?
      C2:?0.07PF?
      C3:?0.04PF?
      R1:?1?
      R2:?1?
      GG3:?0.007?
*      variable for the second circuit
      G2:?0.09?
      C4:?1.4PF?
      C5:?0.07PF?
      C6:?0.04PF?
      R4:?1?
      R5:?1?
      GG6:?0.007?
*      variable for the third circuit
      G3:?0.09?
      C7:?1.4PF?
      C8:?0.07PF?
      C9:?0.04PF?
      R7:?1?
      R8:?1?
      GG9:?0.007?
*
FET 1 2 G=G1 CGS=C1 F=F0 T=TAU GGS=R0 CDG=C2 CDS=C3 GDS=GG3 RI=R1 RG=RGM
+   RD=RDD RS=R2 LS=LS
FETMDL1: 2POR 1 2
FET 3 4 G=G2 CGS=C4 F=F0 T=TAU GGS=R0 CDG=C5 CDS=C6 GDS=GG6 RI=R4 RG=RGM
+   RD=RDD RS=R5 LS=LS
FETMDL2: 2POR 3 4
FET 5 6 G=G3 CGS=C7 F=F0 T=TAU GGS=R0 CDG=C8 CDS=C9 GDS=GG9 RI=R7 RG=RGM
+   RD=RDD RS=R8 LS=LS
FETMDL3: 2POR 5 6
END
*
FREQ
      STEP 2.0GHZ 18.0GHZ 1.0GHZ
END

```

*

OPT

FETMDL1 F=2.0GHZ 18.0GHZ S=FETMDA1 W 1 1 1 1

FETMDL2 F=2.0GHZ 18.0GHZ S=FETMDA2

FETMDL3 F=2.0GHZ 18.0GHZ S=FETMDA3

END

*

DATA

FETMDA1: C85029A.DAT

FETMDA2: C85029B.DAT

FETMDA3: C85029C.DAT

END

COMD>

Input : READ ALLTHREE

Reading circuit file...

Working file: ALLTHREE.DAT

Number of circuits: 3

Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

COMD>

Input : PA

FET MODEL PARAMETERS

FETMDL1	FETMDL2	FETMDL3	
1.00000	1.00000	1.00000	RG (OH)
1.00000	1.00000	1.00000	RD (OH)
0.00700	0.00700	0.00700	GDS(/OH)
1.00000	1.00000	1.00000	RI (OH)
1.00000	1.00000	1.00000	RS (OH)
0.02000	0.02000	0.02000	LS (nH)
1.40000	1.40000	1.40000	CGS (pF)
0.07000	0.07000	0.07000	CDG (pF)
0.04000	0.04000	0.04000	CDS (pF)
0.09000	0.09000	0.09000	G (/OH)
7.00000	7.00000	7.00000	T (ps)

COMD>

Input : L1

Working file: ALLTHREE.DAT

Number of circuits: 3

Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

Start modelling ...

You can press any key to interrupt optimization

Iteration 1	L1 error	2.6496809
Iteration 2	L1 error	2.0904052
Iteration 3	L1 error	1.3958710
Iteration 4	L1 error	0.7056876
Iteration 5	L1 error	0.8660346
Iteration 6	L1 error	0.5506932
Iteration 7	L1 error	0.5429597
Iteration 8	L1 error	0.5097529
Iteration 9	L1 error	0.5062686
Iteration 10	L1 error	0.5027795
Iteration 11	L1 error	0.4986020
Iteration 12	L1 error	0.4980656
Iteration 13	L1 error	0.4978623
Iteration 14	L1 error	0.4978395
Iteration 15	L1 error	0.4976631
Iteration 16	L1 error	0.4979259
Iteration 17	L1 error	0.4980634
Iteration 18	L1 error	0.4982309
Iteration 19	L1 error	0.4979310

Optimization Completed

19 iterations 43.09 CPU seconds

FET MODEL PARAMETERS

FETMDL1		FETMDL2		FETMDL3		
starting	solution	starting	solution	starting	solution	
1.0000	2.5487	1.0000	2.5487	1.0000	2.5487	RG (OH)
1.0000	3.7457	1.0000	3.7457	1.0000	3.7457	RD (OH)
0.0070	0.0050	0.0070	0.0061	0.0070	0.0061	GDS (/OH)
1.0000	0.0000	1.0000	0.1715	1.0000	0.4776	RI (OH)
1.0000	1.0042	1.0000	0.9077	1.0000	0.6243	RS (OH)
0.0200	0.0039	0.0200	0.0039	0.0200	0.0039	LS (nH)
1.4000	0.7224	1.4000	0.4414	1.4000	0.3451	CGS (pF)
0.0700	0.0306	0.0700	0.0476	0.0700	0.0610	CDG (pF)
0.0400	0.2227	0.0400	0.2227	0.0400	0.2148	CDS (pF)
0.0900	0.0698	0.0900	0.0520	0.0900	0.0409	G (pF)
7.0000	3.9600	7.0000	3.9600	7.0000	3.9600	T (ps)

COMD>
Input : %ER

PERCENTAGE ERRORS IN S-PARAMETER MATCHING
ABS[(Model-Measurement)/Measurement] %

Frequency (GHZ)	model: FETMDL1				measurement: C85029A.DAT			
	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
2.0	0.74%	14.04%	11.72%	2.99%	2.06%	6.97%	0.04%	12.93%
3.0	0.69%	10.06%	9.01%	2.83%	0.26%	10.88%	0.45%	3.88%
4.0	1.60%	7.89%	2.12%	4.95%	2.52%	12.01%	0.02%	6.89%
5.0	1.37%	4.47%	0.45%	1.12%	5.25%	10.93%	0.59%	2.82%
6.0	2.15%	2.95%	3.30%	3.13%	3.51%	14.31%	2.25%	4.41%
7.0	2.80%	0.91%	2.43%	1.45%	1.72%	8.70%	0.77%	0.33%
8.0	2.97%	1.29%	5.86%	2.87%	1.51%	12.89%	0.65%	1.44%
9.0	3.11%	4.64%	8.62%	3.71%	0.49%	4.91%	0.65%	0.73%
10.0	2.67%	5.42%	12.59%	8.33%	4.36%	6.84%	1.21%	0.55%
11.0	2.81%	6.92%	11.07%	3.26%	1.07%	26.24%	0.56%	2.01%
12.0	2.70%	8.38%	15.27%	13.79%	4.41%	26.74%	1.74%	2.57%
13.0	4.28%	10.00%	15.93%	17.47%	0.34%	23.26%	0.94%	0.03%
14.0	2.96%	11.40%	17.97%	25.37%	0.43%	36.80%	2.30%	3.80%
15.0	3.72%	13.19%	16.24%	56.79%	2.52%	40.72%	1.90%	5.24%
16.0	2.65%	13.45%	21.09%	44.99%	1.43%	25.17%	2.18%	4.13%
17.0	4.54%	15.11%	11.92%	159.57%	5.61%	2.76%	3.53%	5.66%
18.0	2.07%	14.61%	21.25%	233.79%	0.11%	14.69%	2.93%	4.33%

press <RETURN> to continue ...

PERCENTAGE ERRORS IN S-PARAMETER MATCHING
ABS[(Model-Measurement)/Measurement] %

Frequency (GHZ)	model: FETMDL2				measurement: C85029B.DAT			
	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
2.0	0.80%	6.71%	10.27%	1.70%	7.34%	4.97%	0.31%	16.17%
3.0	1.09%	3.38%	9.39%	1.38%	5.57%	7.66%	0.20%	7.42%
4.0	0.56%	3.29%	4.22%	3.38%	3.99%	9.77%	0.33%	10.23%
5.0	0.56%	0.05%	1.89%	0.37%	1.16%	8.79%	2.03%	5.61%
6.0	0.03%	0.40%	0.66%	1.70%	1.59%	13.60%	3.72%	6.85%
7.0	0.80%	4.15%	0.08%	1.56%	1.66%	2.29%	0.72%	1.82%
8.0	0.83%	3.93%	2.66%	1.45%	3.19%	16.07%	2.09%	2.98%
9.0	1.34%	7.40%	4.99%	2.94%	1.42%	2.21%	0.63%	0.11%
10.0	0.69%	8.07%	8.88%	7.43%	4.45%	3.41%	2.73%	0.04%
11.0	1.10%	9.05%	7.85%	1.66%	0.36%	28.54%	0.81%	0.16%
12.0	1.60%	10.84%	10.81%	11.34%	5.27%	316.63%	1.07%	2.90%
13.0	2.85%	11.76%	12.38%	10.68%	1.93%	2.04%	0.03%	1.81%
14.0	1.81%	13.65%	13.43%	17.55%	4.70%	63.28%	1.23%	4.75%
15.0	3.45%	15.09%	12.69%	33.38%	1.35%	49.49%	0.92%	6.80%
16.0	3.08%	15.69%	16.29%	24.81%	3.74%	36.16%	0.60%	5.20%
17.0	4.02%	16.89%	12.89%	68.44%	0.80%	43.43%	0.25%	7.51%
18.0	2.93%	16.53%	17.57%	54.59%	1.95%	37.92%	0.81%	4.14%

press <RETURN> to continue ...

PERCENTAGE ERRORS IN S-PARAMETER MATCHING

ABS[(Model-Measurement)/Measurement] %

Frequency (GHZ)	model: FETMDL3				measurement: C85029C.DAT			
	MS11	AS11	MS21	AS21	MS12	AS12	MS22	AS22
2.0	0.49%	6.40%	9.97%	1.60%	12.08%	5.46%	0.37%	18.82%
3.0	1.58%	2.72%	9.22%	1.30%	10.19%	8.40%	0.61%	9.03%
4.0	0.18%	3.29%	4.24%	3.24%	8.04%	10.59%	1.27%	12.51%
5.0	1.42%	0.31%	1.74%	0.48%	4.47%	9.78%	2.96%	7.14%
6.0	1.56%	0.58%	1.28%	1.61%	4.49%	15.70%	4.42%	8.54%
7.0	0.55%	4.56%	0.22%	1.63%	4.28%	2.86%	2.14%	2.50%
8.0	0.13%	4.15%	2.39%	1.37%	5.17%	18.99%	2.92%	4.05%
9.0	0.72%	7.84%	4.70%	2.77%	2.90%	2.87%	2.32%	0.07%
10.0	0.05%	8.59%	9.02%	7.24%	3.25%	8.51%	3.33%	0.51%
11.0	0.65%	9.27%	7.81%	1.68%	0.66%	34.41%	2.25%	0.50%
12.0	1.49%	11.45%	10.71%	11.49%	4.66%	307.50%	1.00%	2.79%
13.0	3.28%	11.96%	11.73%	10.13%	0.01%	17.51%	0.93%	4.85%
14.0	2.48%	14.24%	13.43%	16.68%	4.33%	43.85%	2.17%	7.14%
15.0	3.87%	15.54%	12.37%	30.95%	2.68%	34.82%	1.16%	7.14%
16.0	3.77%	16.37%	15.77%	24.25%	4.62%	26.53%	1.42%	5.33%
17.0	4.60%	17.34%	11.91%	63.17%	1.01%	31.77%	2.30%	7.71%
18.0	4.60%	17.38%	16.39%	54.19%	2.68%	28.28%	0.12%	4.24%

COMD>

Input : SE

SENSITIVITY OF THE CURRENT MODEL

least-squares error: 0.08651762

FETMDL1	FETMDL2	FETMDL3	
gradient	gradient	gradient	
-0.001881	-0.003091	-0.003176	RG (OH)
0.000651	-0.000476	-0.000407	RD (OH)
-0.006294	-0.007466	-0.005322	GDS(/OH)
0.000000	-0.000222	-0.000590	RI (OH)
-0.003119	-0.001239	-0.000687	RS (OH)
-0.000696	-0.000570	-0.000562	LS (nH)
-0.009661	-0.039311	-0.037724	CGS (pF)
0.000179	-0.011340	-0.015465	CDG (pF)
0.000862	0.001608	0.003444	CDS (pF)
0.022233	0.016452	0.006713	G (/OH)
-0.002111	-0.001573	-0.001323	T (ps)

COMD>

Input : SAVE ALL3L1

COMD>

Input : READ ALLTHREE

Reading circuit file...

Working file: ALLTHREE.DAT

Number of circuits: 3

Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

COMD>

Input : SAVE TEST1

COMD>

Input : ED TEST1.DAT

V A X E D T E D I T O R

COMD>

Input : TYPE TEST1.DAT

*All three measurements C85029A, C85029B and C85029C

BLK

* common variables

R0:2.E-6

F0:1.E3GHZ

RGM:?1?

LS:?0.02NH?

RDD:?1?

TAU:?0.007NS?

* variable for the first circuit

G1:?0.09?

C1:?1.4PF?

C2:?0.07PF?

C3:?0.04PF?

R1:?1?

R2:?1?

GG3:?0.007?

* variable for the second circuit

G2:?0.09?

C4:?1.4PF?

C5:?0.07PF?

C6:?0.04PF?

R4:?1?

R5:?1?

GG6:?0.007?

* variable for the third circuit

G3:?0.09?

C7:?1.4PF?

C8:?0.07PF?

C9:?0.04PF?

R7:?1?

R8:?1?

GG9:?0.007?

*

FET 1 2 G=G1 CGS=C1 F=F0 T=TAU GGS=R0 CDG=C2 CDS=C3 GDS=GG3 RI=R1 RG=RGM

+ RD=RDD RS=R2 LS=LS

FETMDL1: 2POR 1 2

FET 3 4 G=G2 CGS=C4 F=F0 T=TAU GGS=R0 CDG=C5 CDS=C6 GDS=GG6 RI=R4 RG=RGM

+ RD=RDD RS=R5 LS=LS

FETMDL2: 2POR 3 4

FET 5 6 G=G3 CGS=C7 F=F0 T=TAU GGS=R0 CDG=C8 CDS=C9 GDS=GG9 RI=R7 RG=RGM

+ RD=RDD RS=R8 LS=LS

FETMDL3: 2POR 5 6

END

*

FREQ

STEP 2.0GHZ 18.0GHZ 2.0GHZ

END

*

OPT

FETMDL1 F=2.0GHZ 18.0GHZ S=FETMDA1 W 1 1 1 1

FETMDL2 F=2.0GHZ 18.0GHZ S=FETMDA2

FETMDL3 F=2.0GHZ 18.0GHZ S=FETMDA3

END

*

DATA

FETMDA1: C85029A.DAT

FETMDA2: C85029B.DAT

FETMDA3: C85029C.DAT

END

COMD>

Input : READ TEST1

Reading circuit file...

Working file: TEST1.DAT

Number of circuits: 3

Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

COMD>

Input : L1

Working file: TEST1.DAT

Number of circuits: 3

Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

Start modelling ...

You can press any key to interrupt optimization

Iteration 1	L1 error	2.6936188
Iteration 2	L1 error	2.1329496
Iteration 3	L1 error	1.4297490
Iteration 4	L1 error	0.7262558
Iteration 5	L1 error	0.8383650
Iteration 6	L1 error	0.5615602
Iteration 7	L1 error	0.5619905
Iteration 8	L1 error	0.5394992
Iteration 9	L1 error	0.5268831
Iteration 10	L1 error	0.5189538
Iteration 11	L1 error	0.5184772
Iteration 12	L1 error	0.5115020
Iteration 13	L1 error	0.5112324
Iteration 14	L1 error	0.5111505
Iteration 15	L1 error	0.5111022
Iteration 16	L1 error	0.5110850
Iteration 17	L1 error	0.5109553

Optimization Completed

17 iterations 22.30 CPU seconds

FET MODEL PARAMETERS

FETMDL1		FETMDL2		FETMDL3			
starting	solution	starting	solution	starting	solution		
1.0000	2.2768	1.0000	2.2768	1.0000	2.2768	RG	(OH)
1.0000	3.5793	1.0000	3.5793	1.0000	3.5793	RD	(OH)
0.0070	0.0050	0.0070	0.0059	0.0070	0.0059	GDS	(/OH)
1.0000	0.0569	1.0000	0.3402	1.0000	0.5920	RI	(OH)
1.0000	0.9679	1.0000	0.4930	1.0000	0.0376	RS	(OH)
0.0200	0.0046	0.0200	0.0046	0.0200	0.0046	LS	(nH)
1.4000	0.6563	1.4000	0.4057	1.4000	0.3190	CGS	(pF)
0.0700	0.0296	0.0700	0.0492	0.0700	0.0620	CDG	(pF)
0.0400	0.2218	0.0400	0.2168	0.0400	0.2072	CDS	(pF)
0.0900	0.0633	0.0900	0.0497	0.0900	0.0394	G	(/OH)
7.0000	4.2061	7.0000	4.2061	7.0000	4.2061	T	(ps)

COMD>

Input : SAVE TEST1L1

COMD>

Input : READ ALLTHREE

Reading circuit file...

Working file: ALLTHREE.DAT

Number of circuits: 3

Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

COMD>

Input : SAVE TEST2

COMD>

Input : ED TEST2.DAT

V A X E D T E D I T O R

COMD>

Input : TYPE TEST2.DAT

*All three measurements C85029A, C85029B and C85029C

BLK

*

common variables

R0:2.E-6

F0:1.E3GHZ

RGM:? 1.00000?

LS:? 0.1000NH?

RDD:? 1.00000?

TAU:? 0.01000NS?

*

variable for the first circuit

G1:? 0.1000?

C1:? 1.0000PF?

C2:? 1.0000PF?

C3:? 1.000PF?

R1:? 1.00000?

R2:? 1.00000?

GG3:? 0.0100?

*

variable for the second circuit

G2:? 0.1000?

C4:? 1.0000PF?

```

C5:? 1.0000PF?
C6:? 1.0000PF?
R4:? 1.00000?
R5:? 1.00000?
GG6:? 0.0100?
*
variable for the third circuit
G3:? 0.10000?
C7:? 1.0000PF?
C8:? 1.0000PF?
C9:? 1.0000PF?
R7:? 1.00000?
R8:? 1.00000?
GG9:? 0.01000?
*
FET 1 2 G=G1 CGS=C1 F=F0 T=TAU GGS=R0 CDG=C2 CDS=C3 GDS=GG3 RI=R1 RG=RGM
+ RD=RDD RS=R2 LS=LS
FETMDL1: 2POR 1 2
FET 3 4 G=G2 CGS=C4 F=F0 T=TAU GGS=R0 CDG=C5 CDS=C6 GDS=GG6 RI=R4 RG=RGM
+ RD=RDD RS=R5 LS=LS
FETMDL2: 2POR 3 4
FET 5 6 G=G3 CGS=C7 F=F0 T=TAU GGS=R0 CDG=C8 CDS=C9 GDS=GG9 RI=R7 RG=RGM
+ RD=RDD RS=R8 LS=LS
FETMDL3: 2POR 5 6
END
*
FREQ
STEP 2.0GHZ 18.0GHZ 1.0GHZ
END
*
OPT
FETMDL1 F=2.0GHZ 18.0GHZ S=FETMDA1 W 1 1 1 1
FETMDL2 F=2.0GHZ 18.0GHZ S=FETMDA2
FETMDL3 F=2.0GHZ 18.0GHZ S=FETMDA3
END
*
DATA
FETMDA1: C85029A.DAT
FETMDA2: C85029B.DAT
FETMDA3: C85029C.DAT
END
COMD>
Input : READ TEST2
Reading circuit file...

Working file: TEST2.DAT
Number of circuits: 3
Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

```

COMD>

Input : Ll

Working file: TEST2.DAT

Number of circuits: 3

Measurement files: C85029A.DAT C85029B.DAT C85029C.DAT

Start modelling ...

You can press any key to interrupt optimization

Iteration 1	Ll error	6.6676922
Iteration 2	Ll error	5.6123438
Iteration 3	Ll error	4.2343659
Iteration 4	Ll error	3.0937769
Iteration 5	Ll error	1.6524744
Iteration 6	Ll error	1.1513814
Iteration 7	Ll error	0.6289817
Iteration 8	Ll error	0.8143499
Iteration 9	Ll error	0.5297607
Iteration 10	Ll error	0.5004176
Iteration 11	Ll error	0.5031931
Iteration 12	Ll error	0.4981698
Iteration 13	Ll error	0.4984140
Iteration 14	Ll error	0.4979580
Iteration 15	Ll error	0.4980265
Iteration 16	Ll error	0.4979212

Optimization Completed

16 iterations 42.72 CPU seconds

FET MODEL PARAMETERS

FETMDL1		FETMDL2		FETMDL3		
starting	solution	starting	solution	starting	solution	
1.0000	2.2309	1.0000	2.2309	1.0000	2.2309	RG (OH)
1.0000	3.7900	1.0000	3.7900	1.0000	3.7900	RD (OH)
0.0100	0.0050	0.0100	0.0061	0.0100	0.0061	GDS(/OH)
1.0000	0.3836	1.0000	0.5950	1.0000	0.9664	RI (OH)
1.0000	0.9584	1.0000	0.8376	1.0000	0.5247	RS (OH)
0.1000	0.0039	0.1000	0.0039	0.1000	0.0039	LS (nH)
1.0000	0.7191	1.0000	0.4394	1.0000	0.3434	CGS (pF)
1.0000	0.0308	1.0000	0.0478	1.0000	0.0612	CDG (pF)
1.0000	0.2226	1.0000	0.2226	1.0000	0.2145	CDS (pF)
0.1000	0.0696	0.1000	0.0518	0.1000	0.0408	G (/OH)
10.0000	3.9480	10.0000	3.9480	10.0000	3.9480	T (ps)

COMD>

Input : SAVE TEST2L1

COMD>

Input : STOP

References

- [1] SUPERCOMPACT User Manual, Version 1.6/1.7, July 1982, Revised 1-10-83, updated 3/1/84.
- [2] 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, pp. 1282-1293.

COMPARISON OF RESULTS BETWEEN FETSC AND COMPACT

The performance of FETSC is compared with COMPACT in order to establish any advantages FETSC may have over a popular and commercially available software system. Table I summarizes the results obtained using FETSC in the interactive session examples which describe the use of the package. All the results in Table I were obtained by performing two optimizations, each involving three circuits (simultaneous processing of three measurement files C85029A.DAT, C85029B.DAT and C85029C.DAT). The first optimization identified by letter A in the table corresponds to the file ALLTHREE.DAT and the second optimization (B in the table) corresponds to the file TEST2.DAT (different starting values) in the interactive session which describes a multi-circuit example.

Using data files compatible with COMPACT, such as the one shown on the next page (starting values identified as A), 6 optimizations were performed to obtain the results illustrated in Table II. Starting values for cases A and B are the same as the ones used with FETSC. In most cases the optimization is terminated after 30 iterations since the decrease in the objective function between successive iterations becomes negligible.

A careful examination of Tables I and II reveals that for all parameters except RI, the results obtained using FETSC with two different sets of starting values are more consistent with each other than the results obtained using COMPACT. The match between measured and modelled responses in all cases are excellent for both programs and the results for one program cannot be preferred to the other from the point of view of responses.

The total CPU time for obtaining the results of Table II is

TABLE I
RESULTS OBTAINED USING FETSC

Parameter	C85029A		C85029B		C85029C	
	A	B	A	B	A	B
RG	2.5487	2.2309	2.5487	2.2309	2.5487	2.2309
RD	3.7457	3.7900	3.7457	3.7900	3.74657	3.7900
GDS	0.0050	0.0050	0.0061	0.0061	0.0061	0.0061
RI	0.0000	0.3836	0.1715	0.5950	0.4776	0.9664
RS	1.0042	0.9584	0.9077	0.8376	0.6243	0.5247
LS	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039
CGS	0.7224	0.7191	0.4414	0.4394	0.3451	0.3434
CDG	0.0306	0.0308	0.0476	0.0478	0.0610	0.0612
CDS	0.2227	0.2226	0.2227	0.2226	0.2148	0.2145
G	0.0698	0.0696	0.0520	0.0518	0.0409	0.0408
T	3.9600	3.9480	3.9600	3.9480	3.9600	3.9480

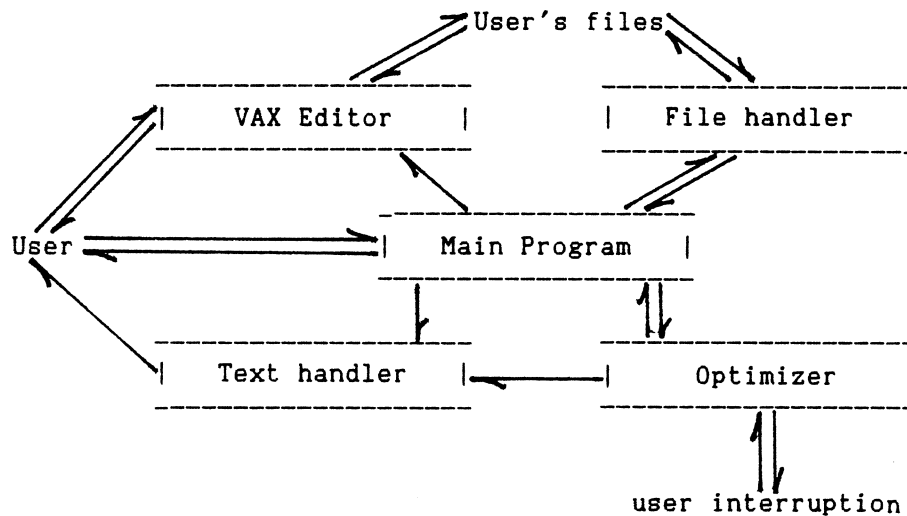
TABLE II
RESULTS OBTAINED USING COMPACT

Parameter	C85029A		C85029B		C85029C	
	A	B	A	B	A	B
RG	1.9446	1.6456	1.8780	2.0264	2.1496	2.1408
RD	0.9547	1.3896	0.8983	1.4926	0.9147	1.0759
GDS	0.0052	0.0052	0.0064	0.0064	0.0065	0.0066
RI	1.4737	1.0605	1.3875	1.1544	1.4306	1.0460
RS	0.8177	0.8417	0.8694	0.9231	0.7467	0.8622
LS	0.0043	0.0051	0.0009	0.0019	0.0017	0.0015
CGS	0.7435	0.7337	0.5125	0.5078	0.4086	0.4136
CDG	0.0319	0.0326	0.0477	0.0483	0.0610	0.0603
CDS	0.2161	0.2200	0.2139	0.2159	0.2057	0.2073
G	0.0748	0.0741	0.0568	0.0572	0.0447	0.0449
T	6.2024	6.2175	5.2949	5.1263	5.1862	5.1289
L2 objective	0.0899	0.0898	0.0857	0.0861	0.0846	0.0843
# of iterations	28	40	30	30	30	30

PROGRAM STRUCTURE

Block Structure

Main Program	solicit for user commands and direct operations accordingly
File handler	interpret a SUPERCOMPACT compatible file for circuit definition and optimization directives
Text handler	display information in text format, including menu, parameter values and simulation results
Optimizer	carry out device modelling by optimization



Subroutine Summary

FETSC or FETSC1 file - the main program itself and text handling routines:

BRIEF	display the current status (command BRIEFING)
COMPARE	compare starting point and solution (command COMPARE)
FETMDL	program entry, solicit commands, direct operations
FETSIM	organize model simulation sweeping all frequencies
GRAD	display sensitivities (command SENSITIVITY)
HEAD	clear screen, print program heading
HELP	post the main menu
OPTIMI	initiate optimization (commands L1 and L2)
PARSER	interpret commands
PASSIVE_INTERRUPT	check user interrupt without waiting
PRESENT	user's routine to respond to command PRESENTATION
SAVCKT	save data to a circuit file (command SAVE)
TAKECHAR	read a single keystroke without echo
WDA	display simulation results (commands SWEEP and %ERROR)
WPA	display parameter values (command PARAMETER)

FETFDF or FETFDF1 file - simulation handling routines:

CSOLU	solve a set of complex nodal equations
FDF	update variables, provide values of functions and derivatives for the optimizers, handle user interrupt
SIMFET	organize model simulation for one frequency

SCFILE or SCFILE1 file - file handling routines:

BLOCK DATA A	
BLKBLK	interpret BLK block
CHKTYP	check consistency of element types

DATABLK interpret DATA block

ERMSG post error messages relating to the circuit file

FERMSG post error message relating to measurement data files

FREQBLK interpret FREQ block

GETCHAR read a non-space character

GETFET read FET element data

GETFRQ read a frequency

GETINT read an integer

GETREAL read a real number

GETSYMBL detect special symbols in a line ('=', '?', etc.)

GETUNIT read data units ('KHZ', 'PF', etc.)

GETVAR read information of a designated variable

GETWRD read a word

NODUMMY detect a comment line

NOSYMBL detect special symbols in a word

OPTBLK interpret OPT block

OUTBLK interpret OUT block (retained for PC compatibility)

PAD adjust item position by adding spaces

RDCKT group organizer, also read measurement data file

RDSCF read circuit file, sort out different blocks

L1ABC file - L1 optimization handling routines:

ADDCOL

BFGS

DELCOL

HACCUM

LA1

L1B

L1C L1 optimizer

L1LP

L1STA2

LINSYS

RSOLV

UTRNS

UTTRNS

QUASI2 file - L2 optimization handling routines:

PENALTY

QUASI2 L2 optimizer

Total number of subroutines: 42

Dimensional Limits

MP model parameters

MX variables

MF frequencies per circuit

8 responses (real and imaginary parts of 4 S-parameters)

3 circuits

The first three limits are controlled by a PARAMETER statement in each subroutine. For FETSC, it is

```
PARAMETER (MP=11, MX=40, MF=20)
```

For FETSC1, it is

```
PARAMETER (MP=13, MX=40, MF=20)
```

These limits can be easily modified by editing the PARAMETER statement and the array dimensions will be adjusted automatically.

Interpreting The Circuit File

Responding to the user's command of 'READ file', subroutine RDSCF reads the specified SUPERCOMPACT compatible file as an ASCII text file and stores the content in the array TT(80,100), where TT(*,i) contains the ith line of the file. Each line may be composed of up to 80 characters and the file may contain up to 100 lines. The actual number of lines read is LINET. Subroutine RDSCF proceeds to sort out different blocks in the file in the following order: 'BLK', 'FREQ', 'OPT', 'DATA' and 'OUT'. The beginning line number of the ith block is recorded in LOCBLK(1,i) and the ending line number in LOCBLK(2,i). If a particular block is missing then LOCBLK(1,i) contains zero.

The content of these blocks are then analyzed by the subroutines in the group 'SC Filer' to produce the following information.

NCKT: total number of circuits

CKTNAME(i): symbolic name of a circuit model (e.g. 'FETMDL1')

CKTFIL(i): name of the file containing a set of measurement data

PA(MP,i): MP model parameters for the ith model

MP=11 for FETSC and MP=13 for FETSC1

NX: total number of optimization variables

X(k): value for the kth variable

INPX(j,i): model parameter PA(j,i) \Leftrightarrow variable X(INPX(j,i))

INDX(k): =1: X(k) is unbounded =2: X(k) is bounded

BND(2,k): the lower and upper bounds on X(k)

LOCX(2,k): the line and column position of X(k) in the file

NFR: total number of frequency points

FREQ(j): the jth frequency

WGT(8,j,i): user assigned weights on the 8 measurement data for the jth frequency and the ith circuit. These weights assume the order of RE[S11], IM[S11], etc., as given by the SUPERCOMPACT file specification.

ETERM: user assigned terminating condition for optimization.

Processing The Measurement Data

Having obtained all the essential information from the circuit file, subroutine RDCKT will read the measurement data files whose names have been recorded in CKTFIL(*). The data files are expected to provide 8 S-parameter data in polar form (MAG[S11], ANG[S11], etc.) at all NFR frequencies. Array DAT(8,20,3) is used to store the

measurement data. $\text{DAT}(1,j,i) - \text{DAT}(8,j,i)$ keep the data for the j th frequency and the i th circuit. This is then transformed into the rectangular form ($\text{RE}[S_{11}]$, $\text{IM}[S_{11}]$, etc.) and stored in $\text{DTM}(8,20,3)$.

Interpreting A User's Command

A user's command is read as an ASCII string. Subroutine `PARSER` compares the input the default commands 'L1', 'L2', 'STOP', 'DIR', 'HELP', 'PARAMETER', 'COMPARE', '%ERROR', 'SWEEP', 'SENSITIVITY', 'PRESENT', 'BRIEFING', 'SAVE', 'READ', 'EDIT' and 'TYPE'. Only the first two characters are significant. An index `KYCD` is returned to the main program indicating the position of the input command in the default list. If `KYCD` is between 1 - 16 then a valid command has been intercepted, e.g., `KYCD=4` indicates that the user has entered 'DIR'. `KYCD` is set to 0 if the user has simply pressed the `<ENTER>` (`<RETURN>`) key. `KYCD` is set to 17 if the user's input is not recognized. The main program acts according to the value of `KYCD`. The case of `KYCD=0` is simply ignored. A warning message is given for `KYCD=17`. Otherwise an appropriate subroutine is called for action. Such a mechanism is not hard to understand and the default command list can be modified, e.g., by changing an existing command name or adding a new command. The related subroutines will have to be modified or rewritten, of course.

Organizing Model Simulations

Two subroutines (`FETSIM` and `SIMFET`) are responsible for calculating the S-parameter responses of the circuit model. `SIMFET` accepts a set of parameters (as the formal argument array `PA`) and a single frequency (formal argument `FREQ`). In return it provides the model responses in the formal argument `F(8)` (array `F` with 8 components) and their sensitivities with respect to the MP parameters in

the formal argument DF(8,MP) (MP=11 for FETSC and MP=13 for FETSC1). FETSIM organizes simulation for all frequencies.

Feasibility of Substituting FET by Another Model

This program can certainly be modified for other device modelling. The amount of effort needed for such a modification depends on how much the new model differs from the FET model, especially in their circuit topology. The principles are not hard to understand but the actual coding may be frustrated by the requirement for SUPERCOMPACT file compatibility. Normally, the following steps will have to be taken.

- Step 1 Modify the subroutines in the group 'SC Filer' such that the contents of a circuit file relating to the new device can be properly interpreted. All the essential information described in the earlier section should be gathered. Most of the information is not device specific. But, the actual number of parameters and their meaning certainly depend on the particular device of interest.
- Step 2 Modify the subroutines responsible for circuit simulation. As explained in the previous section, subroutine SIMFET provides the critical connection. The main program and the optimizers do not know nor care to know the meaning of, say, PA(1) or PA(5). They simply pass the parameters to SIMFET and expect in return the values of the model responses and sensitivities.
- Step 3 Modify the subroutines responsible for screen output such that the correct symbols are displayed. Such symbols include phrases like 'FET MODELLING' and names of the parame-

ters ('Rgs', 'Cds', etc.). This should be easy to do.

A Gateway Reserved For the User

Command 'PRESENTATION' provides a convenient gateway for the user to implement operations that are not facilitated by the program. Responding to this command, subroutine PRESENT is called. At the present time, this routine contains nothing but a RETURN statement. To utilize this gateway, a user would substitute the dummy routine with his own subroutine that carries out whatever functions he has in his mind. The following rules must be observed.

Subroutine PRESENT must assume the form

SUBROUTINE PRESENT

Information access is facilitated through common blocks. The names and contents of various arrays have been explained in the earlier sections.

Typically, the user's routine will organize presentations of the data in some customized formats such as printed report. In any case the user must not attempt to modify the data for its consequence would be unpredictable.

The user's codes must be written in FORTRAN 77 and compiled using the VAX FORTRAN compiler. The resulting object code is then linked to the other parts of the program. These 'other parts' include:

FETSC.OBJ, SCFILE.OBJ, FETFDF.OBJ

for FETSC, or

FETSC1.OBJ, SCFILE1.OBJ, FETFDF1.OBJ

for FETSC1. The modules that are common to both versions include

L1ABC.OBJ and QUASI2.OBJ.

Start linking by typing, after the VMS system prompt,

\$LINK FETSC+SCFILE+FETFDF+L1ABC+QUASI2

or

\$LINK FETSC1+SCFILE1+FETFDF1+L1ABC+QUASI2

DIFFERENCES BETWEEN FETSC AND FETSC1

Two versions of the FET modelling program, namely FETSC and FETSC1, are described in this manual. They are implementations of the two different equivalent circuits shown in Figs. 1 and 2. Here, the differences in their actual FORTRAN codes are listed. This also serves to illustrate possible modifications by the user for other models or devices.

The basic modification from FETSC to FETSC1 is the inclusion of two inductors LG and LD. As a consequence, the total number of model parameters changes from 11 in FETSC to 13 in FETSC1. Therefore, a universal change in the FORTRAN statement

```
PARAMETER (MP=11, MX=40, MF=20)
```

to

```
PARAMETER (MP=13, MX=40, MF=20)
```

is made to each subroutine that contains the statement.

Beside this obvious modification, seven other changes take place in six subroutines as follows. In the source codes of FETSC1, all the lines that contain these changes have been marked with a special symbol 'CCC' in the first 3 columns.

Main Program

A DATA statement is changed to include indices for LG and LD.

```
FETSC:      DATA INP0/1,3,4,2,8,9,6,5,7,10,11/
FETSC1:     DATA INP0/1,3,4,2,8,9,6,5,7,10,11,12,13/
```

Subroutines WPA, CMPARE and GRAD

A DATA statement is changed to include symbols for LG and LD.

```
FETSC:
      DATA PN/'RG (OH)', 'RD (OH)', 'GDS(/OH)', 'RI (OH)', 'RS (OH)',
* 'LS (nH)', 'CGS (pF)', 'CDG (pF)', 'CDS (pF)', 'G (/OH)', 'T (ps)'/
```


FETSC1:

```
DATA PN/'RG (OH)', 'RD (OH)', 'GDS(/OH)', 'RI (OH)', 'RS (OH)',
*'LS (nH)', 'CGS (pF)', 'CDG (pF)', 'CDS (pF)', 'G (/OH)', 'T (ps)',
*'LG (nH)', 'LD (nH)'/
```

Subroutine GETFET

Two DATA statements are changed to accommodate LG and LD.

FETSC:

```
DATA IDP/10,7,6,11,6,8,6,9,3,4,1,2,5,6,6,6,6,6/
DATA ICO/2,2,1,2,-1,2,0,2,2,2,2,2,2,2,0,0,0,0,2/
```

FETSC1:

```
DATA IDP/10,7,6,11,6,8,6,9,3,4,1,2,5,6,6,12,13,6/
DATA ICO/2,2,1,2,-1,2,0,2,2,2,2,2,2,2,0,0,2,2,2/
```

Subroutine SIMFET

The most substantial changes take place in the subroutine SIMFET which is responsible for model simulation. Four groups of lines are modified. The first two groups are related to setting up the admittance matrix (from $1/R_g$ and $1/R_d$ to $1/(R_g+sL_g)$ and $1/(R_d+sL_d)$). The last two groups are related to the sensitivity calculations.

Group 1:

FETSC:

```
DO 2 I=1,4
IF(I.EQ.3)GOTO 2
IF(PAP(I).GT.1.E-6)THEN
PAP(I)=1.0/PAP(I)
ELSE
PAP(I)=1.E6
ENDIF
2 CONTINUE
```

FETSC1:

```
I=4
IF(PAP(I).GT.1.E-6)THEN
PAP(I)=1.0/PAP(I)
ELSE
PAP(I)=1.E6
ENDIF
```

Group 2:

FETSC:

```

      DO 20 I=1,4
20    Z(I)=PP(I)

```

FETSC1:

```

      Z(1)=1.0/(PP(1)+C1*PP(12))
      Z(2)=PP(2)
      Z(3)=1.0/(PP(3)+C1*PP(13))
      Z(4)=PP(4)

```

Group 3:

FETSC: none (i.e., the following lines are added to FETSC1)

FETSC1:

```

      C5=-Z(1)*Z(1)
      C6=-Z(3)*Z(3)
      DO 65 J=1,4
      DZ2P(J,1)=DZ2P(J,1)*C5
      DZ2P(J,12)=DZ2P(J,1)*C1
      DZ2P(J,3)=DZ2P(J,3)*C6
65    DZ2P(J,13)=DZ2P(J,3)*C1

```

Group 4:

FETSC:

```

      DO 140 I=1,4
      IF(I.EQ.3)GOTO 140
      PR=-PAP(I)*PAP(I)
      DO 130 J=1,8
130    DF(J,I)=DF(J,I)*PR
140    CONTINUE

```

FETSC1:

```

      I=4
      PR=-PAP(I)*PAP(I)
      DO 130 J=1,8
130    DF(J,I)=DF(J,I)*PR

```

