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STATE EQUATION ANALYSIS AND COMPUTER PROGRAM

FOR A CURRENT SWITCH EMITTER FOLLOWER

H.L. Abdel-Malek and J.W. Bandler

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FACULTY OF ENGINEERING

McMASTER UNIVERSITY

HAMILTON, ONTARIO, CANADA

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Abstract

The analysis of a current switch emitter follower (CSEF) circuit originally given by Ho is described. State equations in conjunction with Gear's integration method are used to obtain the output response.

I. INTRODUCTION

A current switch emitter follower circuit which was previously investigated by Ho [1] in the context of sensitivity calculation is described in detail.

The circuit is depicted in Fig. 1. The decoupled equivalent circuit of the transmission line is used [2]. Considering a lossless transmission line and the charge-control model of the transistors as well as the diode the equivalent circuit is shown in Fig. 2. The definitions of the model parameters are given in Table I.

The following two equations are used for the transmission line model, taking Z_0 as characteristic impedance and τ as delay time:

$$u_i(t) = [e_0(t-\tau) + Z_0 i_0(t-\tau)]U(t-\tau) + \phi_i(t) , \qquad (1)$$

$$u_r(t) = [e_\ell(t-\tau) + Z_0 i_\ell(t-\tau)]U(t-\tau) + \phi_r(t) , \qquad (2)$$

where U is the step function given by

$$U(t-\tau) = \begin{cases} 0 & t < \tau , \\ \\ 1 & t \geq \tau . \end{cases} \qquad (3)$$

The parameter ϕ represents the initial voltage distribution stored on the transmission line. Thus, we take

$$\phi_i(t) = \phi_r(t) = 0 \qquad \text{for } t \geq \tau . \qquad (4)$$

The steady state solution is obtained using the Newton-Raphson algorithm as shown in Section II. The state equations are formulated in Section III. The subroutine DVOGER [3] based on Gear's integration algorithm [4] is used. The algorithm has a variable step and hence interpolation was used to find the values of $u_i(t)$ and $u_r(t)$ if $t-\tau$ falls between time steps. Alternatively, τ/n, where n is an integer can
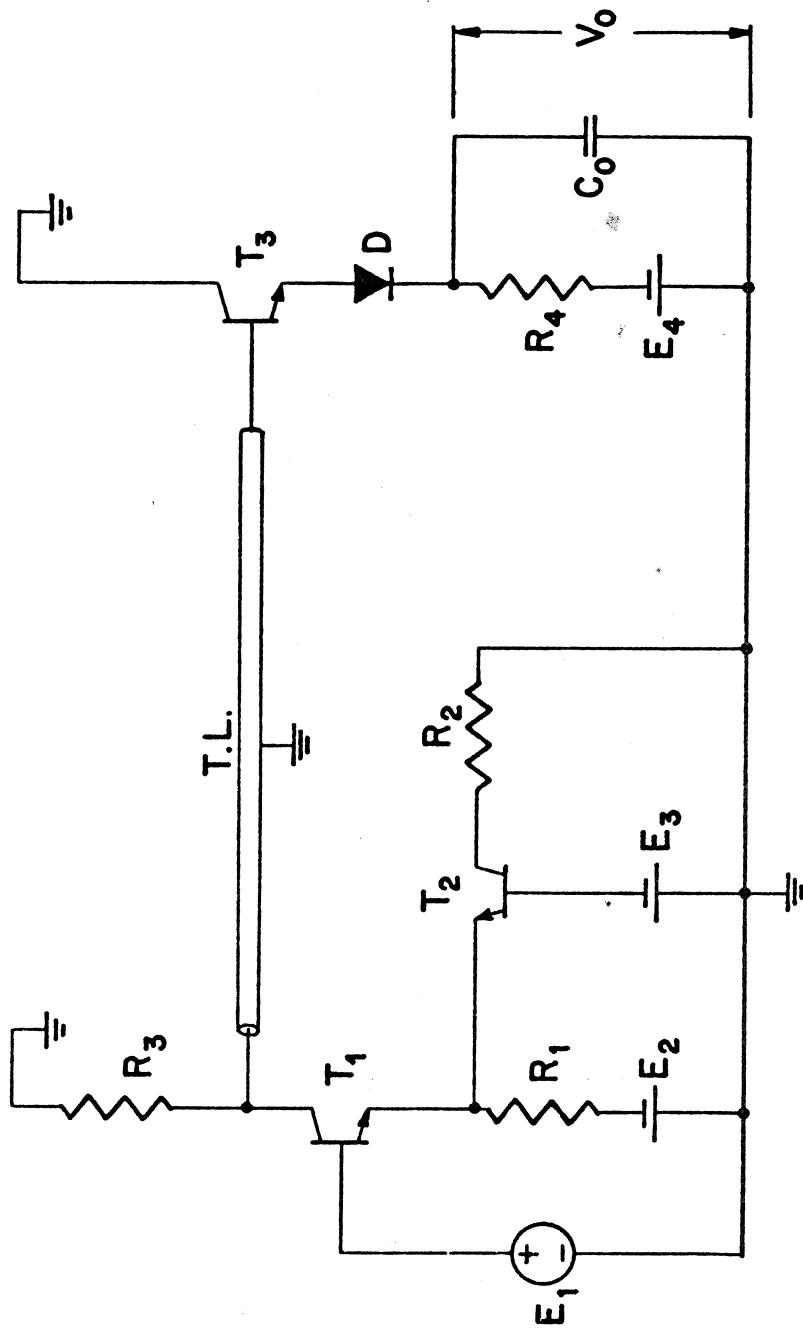
Fig. 1   The CSEF circuit [1].
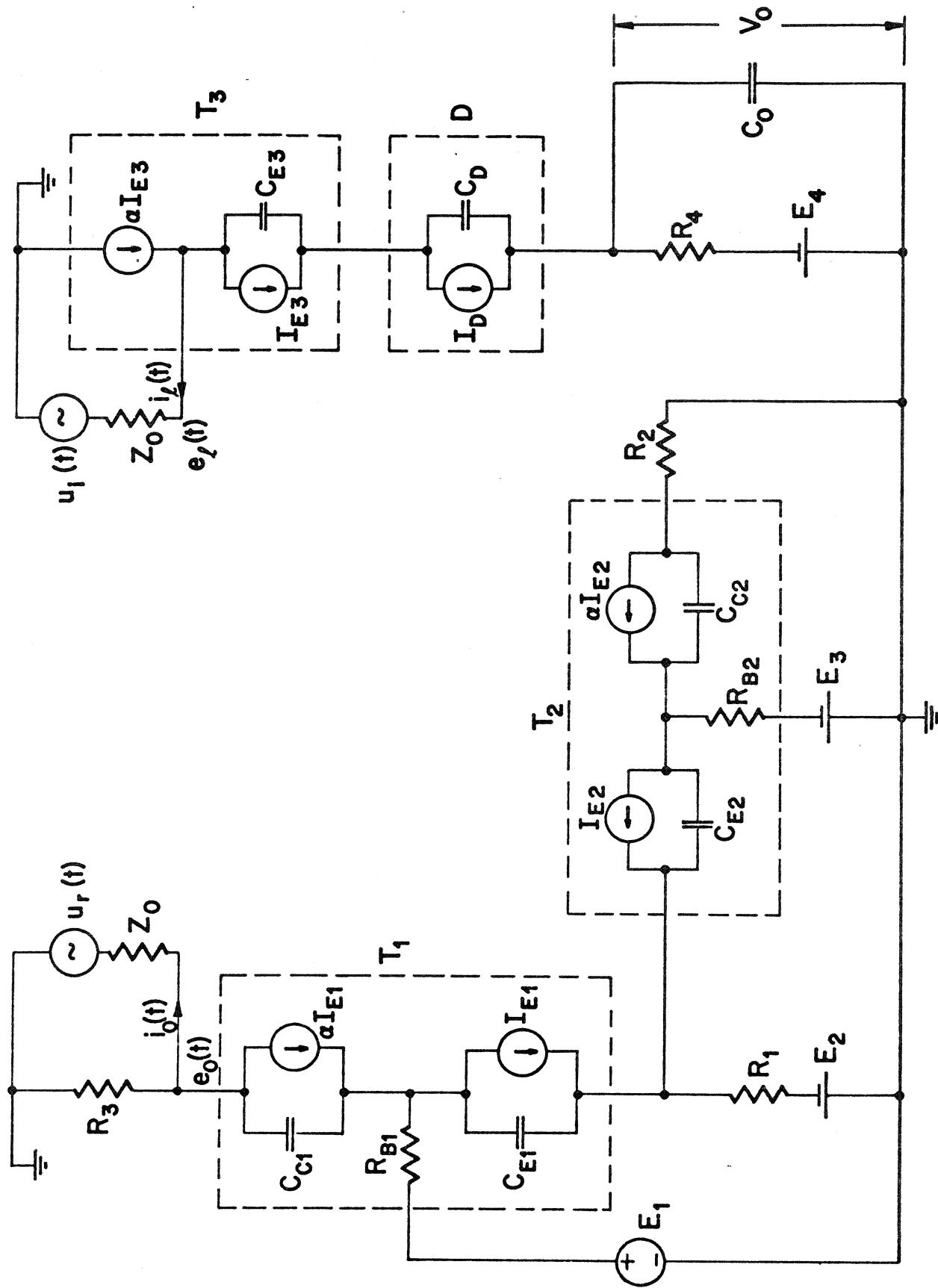
Fig. 2   The CSEF equivalent circuit used, indicating transmission-line, transistor and diode models.

TABLE I(a)
DIODE MODEL PARAMETERS

I_{SD} diode saturation current

C_{JD} depletion layer capacitance

TT_D transit time

θ inverse of thermal potential

$$I_D = I_{SD}(\exp(\theta V_D)-1)$$

$$C_D = C_{JD} + TT_D \frac{dI_D}{dV_D}$$

TABLE I(b)
TRANSISTOR MODEL PARAMETERS

I_S saturation current

α common base current gain

R_B base resistance

C_C collector junction capacitance

C_{JE} emitter junction depletion
layer capacitance

TT base transit time

θ inverse of thermal potential

$$I_E = I_S (\exp(\theta V_{BE})-1)$$

$$I_C = \alpha I_E$$

$$C_E = C_{JE} + TT \frac{dI_E}{dV_{BE}}$$

R_B and C_C are assumed zero for transistor T_3

---

be used as a fixed step, however, integration will be expensive.

A FORTRAN listing of the program is given in the appendix. Library subroutines DVOGER [3] and GELG [5] are used.

II. DC ANALYSIS OF THE CSEF CIRCUIT

The DC equivalent circuit is shown in Fig. 3. Loops 1 and 2 will lead to the following two KVL equations.

$$V_{BE1} + I_{E1}(R_1 + R_{B1}) + I_{E2}R_1 - E_2 - E_1 = 0 , \qquad (5)$$

$$V_{BE2} + I_{E2}(R_1 + R_{B2}) + I_{E1}R_1 - E_2 + E_3 = 0 , \qquad (6)$$

where

$$I_{E1} = I_{S1} (\exp(\theta V_{BE1})-1) , \qquad (7)$$

$$I_{E2} = I_{S2} (\exp(\theta V_{BE2})-1) . \qquad (8)$$

The two simultaneous nonlinear equations (5) and (6) in V_{BE1} and V_{BE2} are solved using the Newton-Raphson algorithm.

Knowing that the transmission line will have zero length for DC analysis, the base voltage of the output transistor T_3 is

$$V_{B3} = - R_3(\alpha I_{E1} + (1-\alpha)I_{E3}) . \qquad (9)$$

Since

$$I_{E3} = I_D = I_{SD}(\exp(\theta V_D)-1) , \qquad (10)$$

then

$$V_D = \ln(1 + I_{E3}/I_D)/\theta , \qquad (11)$$

where

$$I_{E3} = I_{S3}(\exp(\theta V_{BE3})-1) . \qquad (12)$$

But

$$V_{B3} = V_{BE3} + V_D + I_{E3} R_4 - E_4 . \qquad (13)$$

Accordingly, (9) and (13) lead to the nonlinear equation
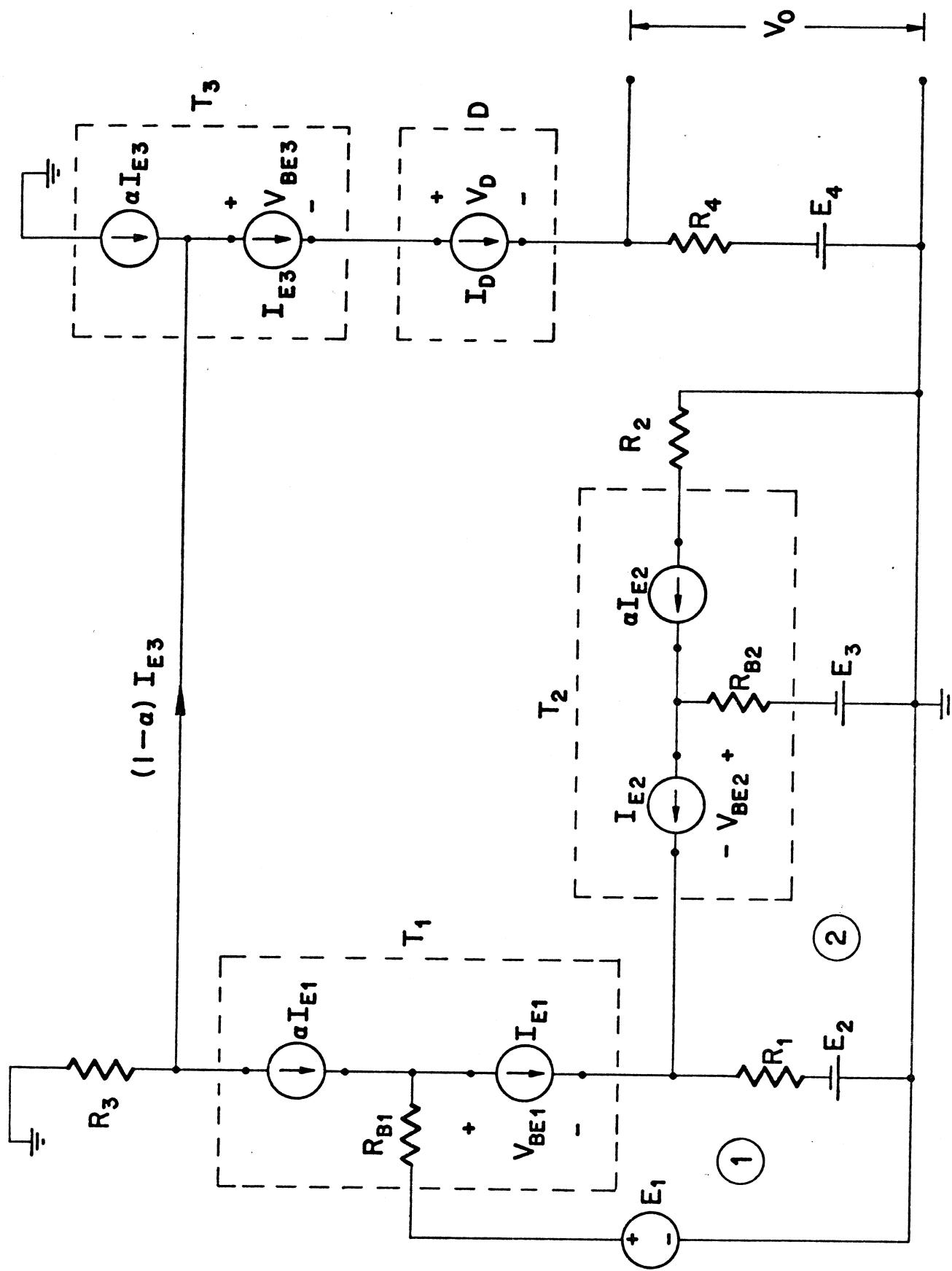
Fig. 3   The DC equivalent circuit of the CSEF.

$$V_{BE3} + \frac{1}{\theta} \ell n(1 + \frac{I_{E3}}{I_{SD}}) + I_{E3}R_4 - E_4 + R_3[\alpha I_{E1} + (1-\alpha)I_{E3}] = 0 \qquad (14)$$

in V_{BE3}, where I_{E3} is given by (12).

Having V_{BE1}, V_{BE2} and V_{BE3} all other potentials can be obtained in a simple manner.

III. TOPOLOGICAL FORMULATION OF THE STATE EQUATIONS

The basic steps required in the formulation of the state equations for nonlinear networks are sketched out. For further details see Chua and Lin [6].

Step 1   Formation and characterization of network branches

This step involves the characterization of linear and nonlinear elements, controlled and independent sources and tree and cotree (link) branches. The choice of the tree branches is based upon

(i)   all independent and controlled voltage sources,

(ii)   as many capacitors as possible,

(iii)   as many resistors as possible,

(iv)   as few inductors as possible,

(v)   no independent current sources.

Step 2   Solving the resistive nonlinear subnetwork

We solve for the voltages across the nonlinear resistors in the tree as well as the currents in the nonlinear resistors in the cotree.

Step 3   Solving the loops which include capacitors only and the cutsets which include inductors only

- 9 -

In this step we express the currents in the cotree capacitors and the voltages across the tree inductors in terms of the derivatives (w.r.t. time) of the tree capacitor voltages and the cotree inductor currents. Also, they may well be functions of the derivatives of voltages of the tree independent voltage sources and derivatives of currents of cotree independent current sources (if these derivatives exist).

Step 4   Collecting relationships derived so far to formulate the state equations.

Regarding the CSEF circuit shown in Fig. 2, the input and output circuits can be treated independently.

Formulation of the State Equations for the Input Circuit

The tree chosen according to the priorities mentioned before is shown in Fig. 4. According to this tree, the set of independent KCL equations is

$$\underset{\sim}{D}\,\underset{\sim}{i} = \underset{\sim}{0}\,,\tag{15}$$

where

$$\underset{\sim}{i} = \begin{bmatrix} \underset{\sim}{I}_{ET} \\ \underset{\sim}{I}_{CT} \\ \underset{\sim}{I}_{RT} \\ \underset{\sim}{I}_{RL} \\ \underset{\sim}{I}_{JL} \end{bmatrix}\,,\tag{16}$$
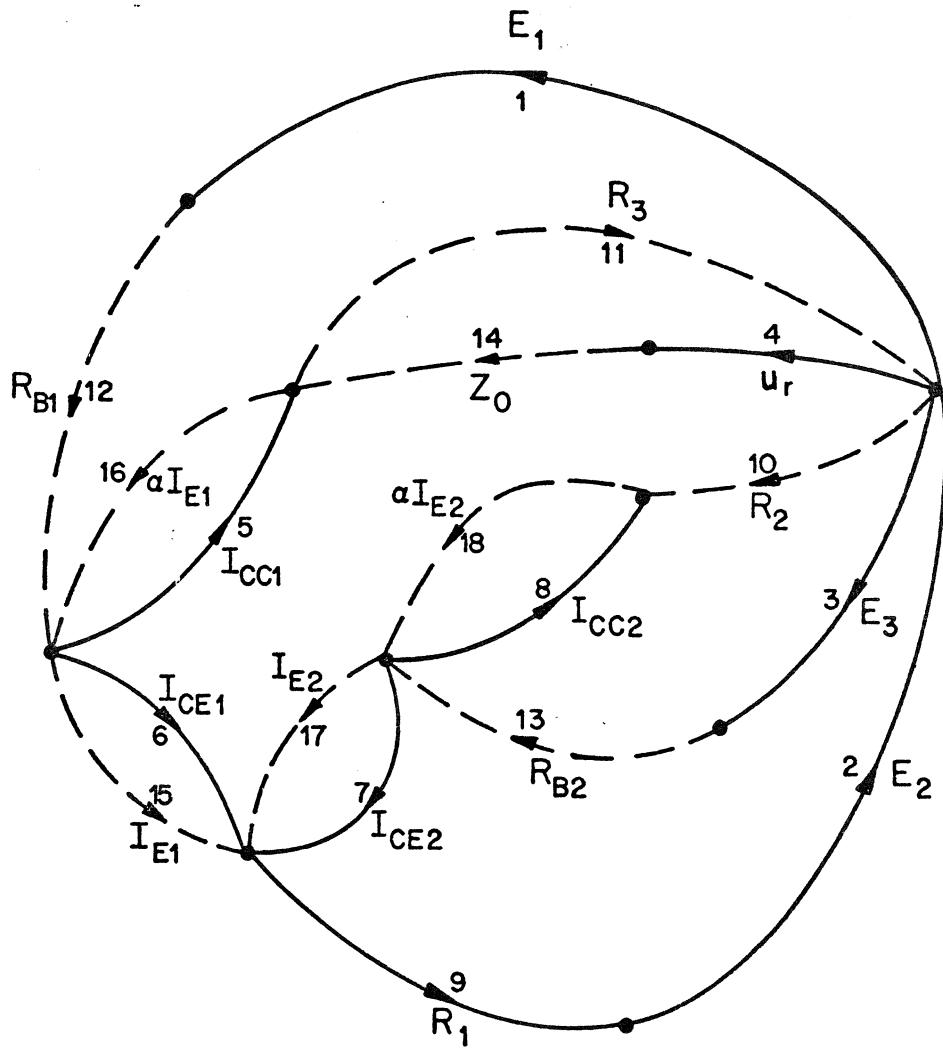
Fig. 4 Directed graph of the input circuit and branch numbering.

—— Tree chosen

——— Corresponding link

$$I_{ET} \overset{\Delta}{=} \text{Tree voltage source currents} = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} , \qquad (17)$$

$$I_{CT} \overset{\Delta}{=} \text{Tree capacitor currents} = \begin{bmatrix} I_5 \\ I_6 \\ I_7 \\ I_8 \end{bmatrix} , \qquad (18)$$

$$I_{RT} \overset{\Delta}{=} \text{Tree resistor currents} = [I_9] , \qquad (19)$$

$$I_{RL} \overset{\Delta}{=} \text{Link resistor currents} = \begin{bmatrix} I_{10} \\ I_{11} \\ I_{12} \\ I_{13} \\ I_{14} \end{bmatrix} , \qquad (20)$$

$$I_{JL} \overset{\Delta}{=} \text{Link current sources} = \begin{bmatrix} I_{15} \\ I_{16} \\ I_{17} \\ I_{18} \end{bmatrix} \qquad (21)$$

and where

$$\underset{\sim}{D} = \left[\begin{array}{ccccc|ccccc|ccc} 1 & & & & & & & -1 & & & & & \\ & 1 & & & & -1 & 1 & -1 & -1 & -1 & & & \\ & & \cdot & & & & & -1 & & & & & \\ & & & \cdot & & & & & -1 & & & & \\ \hline & & & & & -1 & & & 1 & & -1 & & \\ & & & & & 1 & -1 & & -1 & & 1 & & \\ & & & & & -1 & & -1 & & & & 1 & \\ & & & & & 1 & & & & & & -1 \\ \hline & & & & 1 & -1 & 1 & -1 & -1 & -1 & & & \end{array} \right] . \qquad (22)$$

Hence, we can write (15) as

$$
\left[\begin{array}{c|cc}
 & D_{11} & D_{12} \\
\mathbb{1}_9 & D_{21} & D_{22} \\
 & D_{31} & D_{32}
\end{array}\right]
\left[\begin{array}{c}
I_{ET} \\
I_{CT} \\
I_{RT} \\
I_{RL} \\
I_{JL}
\end{array}\right] = 0 \ , \tag{23}
$$

where

$$
D_{11} = \left[\begin{array}{ccccc}
 & & -1 & & \\
-1 & 1 & -1 & -1 & -1 \\
 & & & -1 & \\
 & & & & -1
\end{array}\right] \ , \tag{24}
$$

$$
D_{12} = 0 \ , \tag{25}
$$

$$
D_{21} = \left[\begin{array}{ccccc}
 & -1 & & & 1 \\
 & 1 & -1 & & -1 \\
-1 & & & -1 & \\
1 & & & &
\end{array}\right] \ , \tag{26}
$$

$$
D_{22} = \left[\begin{array}{ccc}
 & -1 & \\
1 & & \\
 & & 1 \\
 & & -1
\end{array}\right] \ , \tag{27}
$$

$$
D_{31} = \left[\begin{array}{ccccc} -1 & 1 & -1 & -1 & -1 \end{array}\right] \ , \tag{28}
$$

$$
D_{32} = 0 \ . \tag{29}
$$

and $\mathbb{1}_9$ is the identity matrix of order 9. The KVL equations can be written as

$$
\left[\begin{array}{ccc|c}
D_{11}^T & D_{21}^T & D_{31}^T & \\
 & & & -\mathbb{1}_9 \\
D_{12}^T & D_{22}^T & D_{32}^T &
\end{array}\right]
\left[\begin{array}{c}
V_{ET} \\
V_{CT} \\
V_{RT} \\
V_{RL} \\
V_{JL}
\end{array}\right] = 0 \ , \tag{30}
$$

where superscript T denotes transposition.

It is required to represent the link currents I_{RL} in terms of V_{ET} and V_{CT}. We have

$$V_{RL} = R_L \, I_{RL}$$

$$= D_{11}^T \, V_{ET} + D_{21}^T \, V_{CT} + D_{31}^T \, V_{RT} \, , \tag{31}$$

where

$$R_L = \begin{bmatrix} R_2 & & & & \\ & R_3 & & & \\ & & R_{B1} & & \\ & & & R_{B2} & \\ & & & & Z_0 \end{bmatrix} . \tag{32}$$

Using (23) and (29) we can write

$$I_{RT} = -D_{31} \, I_{RL} - D_{32} \, I_{JL}$$

$$= -D_{31} \, I_{RL} \, . \tag{33}$$

Thus,

$$V_{RT} = R_T \, I_{RT} = - R_T \, D_{31} \, I_{RL} \, , \tag{34}$$

where

$$R_T = [R_1] \, . \tag{35}$$

Substituting for V_{RT} in (31) and with some manipulations, we obtain

$$I_{RL} = R^{-1} \, [D_{11}^T \, V_{ET} + D_{21}^T \, V_{CT}] \, , \tag{36}$$

where

$$R = R_L + D_{31}^T \, R_T \, D_{31} \, . \tag{37}$$

From (23), we have

$$I_{CT} = -D_{21} \, I_{RL} - D_{22} \, I_{JL} \, .$$ (38)

Substituting for I_{RL} from (36), the state equations are

$$I_{CT} = -D_{21} \, R^{-1} \, [D_{11}^T \, V_{ET} + D_{21}^T \, V_{CT}] - D_{22} \, I_{JL} \, .$$ (39)

More explicitly, they can be written as

$$\begin{bmatrix} C_{C1} & dV_{C1}/dt \\ C_{E1} & dV_{BE1}/dt \\ C_{E2} & dV_{BE2}/dt \\ C_{C2} & dV_{C2}/dt \end{bmatrix} = -D_{21} \, R^{-1} \left[D_{11}^T \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ u_r \end{bmatrix} + D_{21}^T \begin{bmatrix} V_{C1} \\ V_{BE1} \\ V_{BE2} \\ V_{C2} \end{bmatrix} \right] + \begin{bmatrix} I_{16} \\ -I_{15} \\ -I_{17} \\ I_{18} \end{bmatrix},$$ (40)

where

$$C_{E1} = C_{JE} + TT \; \theta \; I_S \; \exp(\theta \, V_{BE1}) \, ,$$ (41)

$$C_{E2} = C_{JE} + TT \; \theta \; I_S \; \exp(\theta \, V_{BE2}) \, ,$$ (42)

$$I_{15} = I_S(\exp(\theta \, V_{BE1})-1) \, ,$$ (43)

$$I_{16} = \alpha \, I_{15} \, ,$$ (44)

$$I_{17} = I_S(\exp(\theta \, V_{BE2})-1) \, ,$$ (45)

$$I_{18} = \alpha \, I_{17} \, .$$ (46)

Formulation of the State Equations for the Output Circuit

Fig. 5 shows the chosen tree and branch numbering. The set of independent KCL equations is

$$D \, i = 0 \, ,$$ (47)
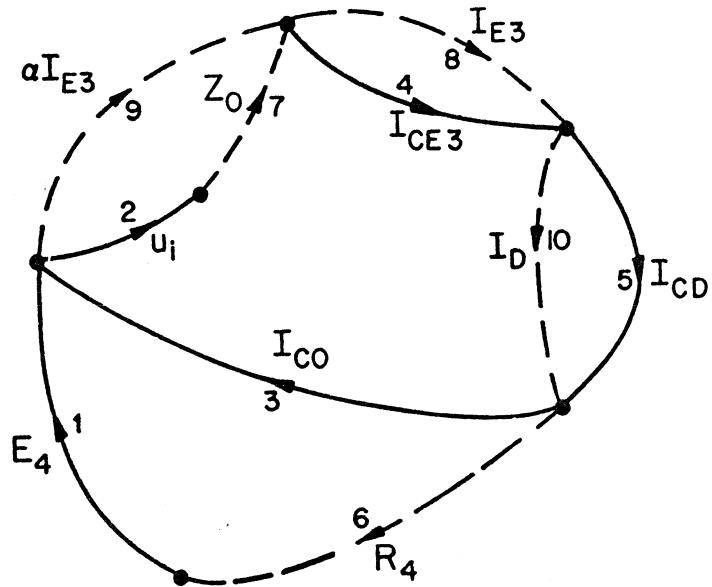
Fig. 5   Directed graph **of** the output circuit and branch numbering.

—— Tree chosen

– – – Corresponding link

where

$$
\underset{\sim}{D} = \begin{bmatrix} 1 & & & & \vdots & -1 & & & \\ & 1 & & & \vdots & & -1 & & \\ & & 1 & & \vdots & 1 & -1 & & -1 \\ & & & 1 & \vdots & & -1 & 1 & -1 \\ & & & & 1 & \vdots & -1 & & -1 & 1 \end{bmatrix} , \tag{48}
$$

$$
\underset{\sim}{i} = \begin{bmatrix} I_{\sim ET} \\ I_{\sim CT} \\ I_{\sim RL} \\ I_{\sim JL} \end{bmatrix} , \tag{49}
$$

$$
I_{\sim ET} \overset{\Delta}{=} \text{Tree voltage source currents} = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} , \tag{50}
$$

$$
I_{\sim CT} \overset{\Delta}{=} \text{Tree capacitor currents} = \begin{bmatrix} I_3 \\ I_4 \\ I_5 \end{bmatrix} , \tag{51}
$$

$$
I_{\sim RL} \overset{\Delta}{=} \text{Link resistor currents} = \begin{bmatrix} I_6 \\ I_7 \end{bmatrix} , \tag{52}
$$

$$
I_{\sim JL} \overset{\Delta}{=} \text{Link current sources} = \begin{bmatrix} I_8 \\ I_9 \\ I_{10} \end{bmatrix} . \tag{53}
$$

The KVL equations are

$$
\begin{bmatrix} -1 & & 1 & & \vdots & -1 & & & \\ & -1 & -1 & -1 & -1 & \vdots & & -1 & & \\ & & & 1 & \vdots & & & -1 & \\ & -1 & -1 & -1 & \vdots & & & & -1 \\ & & & 1 & \vdots & & & & -1 \end{bmatrix} \begin{bmatrix} V_{\sim ET} \\ V_{\sim CT} \\ V_{\sim RL} \\ V_{\sim JL} \end{bmatrix} = \underset{\sim}{0} , \tag{54}
$$

Hence,

$$V_{RL} = R_L I_{RL}$$

$$= D_{11}^T V_{ET} + D_{21}^T V_{CT} \, , \tag{55}$$

where

$$R_L = \begin{bmatrix} R_4 & \\ & Z_0 \end{bmatrix} , \tag{56}$$

$$D_{11} = \begin{bmatrix} -1 & \\ & -1 \end{bmatrix} , \tag{57}$$

$$D_{21} = \begin{bmatrix} 1 & -1 \\ & -1 \\ & -1 \end{bmatrix} . \tag{58}$$

Thus,

$$I_{RL} = R_L^{-1} [D_{11}^T V_{ET} + D_{21}^T V_{CT}] \, . \tag{59}$$

From (47), we have

$$I_{ET} = -D_{11} I_{RL} \tag{60}$$

and

$$I_{CT} = -D_{21} I_{RL} - D_{22} I_{JL} \, . \tag{61}$$

Substituting for I_{RL} from (59) into (60), the state equations are

$$I_{CT} = -D_{21} R_L^{-1} [D_{11}^T V_{ET} + D_{21}^T V_{CT}] - D_{22} I_{JL} \, . \tag{62}$$

Or, more explicitly, the state equations are

$$\begin{bmatrix} C_0 & dV_0/dt \\ C_{E3} & dV_{BE3}/dt \\ C_D & dV_D/dt \end{bmatrix} = -D_{21} \begin{bmatrix} 1/R_4 & \\ & 1/Z_0 \end{bmatrix} [D_{11}^T \ D_{21}^T] \begin{bmatrix} E_4 \\ u_i \\ V_0 \\ V_{BE3} \\ V_D \end{bmatrix} + \begin{bmatrix} I_9 \\ I_9 - I_8 \\ I_9 - I_{10} \end{bmatrix}, \qquad (63)$$

where

$$C_{E3} = C_{JE} + TT \ \theta \ I_S \ \exp(\theta \ V_{BE3}) \ , \qquad (64)$$

$$C_D = C_{JD} + TT_D \ \theta \ I_{SD} \ \exp(\theta \ V_D) \ , \qquad (65)$$

$$I_8 = I_S \ (\exp(\theta \ V_{BE3})-1) \ , \qquad (66)$$

$$I_9 = \alpha \ I_8 \ , \qquad (67)$$

$$I_{10} = I_{SD} \ (\exp(\theta \ V_D)-1) \ . \qquad (68)$$

If the diode is similar to the transistor base emitter junction, then

$$V_D = V_{BE3} \qquad (69)$$

and

$$I_{10} = I_8 \ . \qquad (70)$$

Hence, the three state equations (63) can be reduced to the following two equations

$$
\begin{bmatrix} C_0 & dV_0/dt \\ C_{E3} & dV_{BE3}/dt \end{bmatrix} = \begin{bmatrix} -1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1/R_4 & \\ & 1/Z_0 \end{bmatrix} + \begin{bmatrix} -1 & & 1 \\ & -1 & -1 & -2 \end{bmatrix} \begin{bmatrix} E_4 \\ u_i \\ V_0 \\ V_{BE3} \end{bmatrix} + \begin{bmatrix} I_9 \\ I_9 - I_8 \end{bmatrix} \quad . \qquad (71)
$$

REFERENCES

[1]   C.W. Ho, "Time-domain sensitivity computation for networks containing transmission lines", *IEEE Trans. Circuit Theory*, vol. CT-18, Jan. 1971, pp. 114-122.

[2]   D.A. Calahan, *Computer-aided Network Design* (Revised Edition). New York: McGraw-Hill, 1972.

[3]   Subroutine DVOGER, International Mathematical and Statistical Libraries, IMSL Library 3, Edition 5, (FORTRAN) CDC 6000/7000, 1975.

[4]   C.W. Gear, "The automatic integration of differential equations", *Comm. ACM.*, vol. 14, March 1971, pp. 176-179.

[5]   Subroutine GELG, System/360 Scientific Subroutine Package, Version III, IBM Programmer's Manual Number 360A-CM-03x, p. 121.

[6]   L.O. Chua and P.M. Lin, *Computer-aided Analysis of Electronic Circuits*. Englewood Cliffs, NJ: Prentice-Hall, 1975.

APPENDIX

FORTRAN LISTING OF THE CSEF ANALYSIS SUBROUTINES

The subroutine CSEF supplies the values of the output response V_0 in the array F(121) for a given value of the parameter vector

$$\underset{\sim}{x} = \begin{bmatrix} E_4 \\ Z_0 \\ R_4 \\ C_0 \\ \alpha_3 \\ I_{S3} \\ C_{JE3} \\ TT_3 \end{bmatrix}.$$

The parameter vector $\underset{\sim}{x}$ may be scaled by values given in the array SCALE(8).

For program notation and associated text notation, see Table A.

TABLE A
RELATION BETWEEN TEXT AND PROGRAM NOTATIONS

Description	Text Notation	Program Notation	
	R_1	R1	*
	R_2	R2	*
Circuit	R_3	R3	*
Parameters	R_4	R4	*
	E_1	E(1)	***
	E_2, E_3 and E_4	E(I), I = 2,3,4	*
	C_0	CO	*
	V_D	VD	**
	I_{SD}	SATD	*
Diode	$\theta\, I_{SD}\, TT_D$	TSD	**
Parameters	TT_D	TTD	*
	C_{JD}	CD	*
	I_S	SATC(I), I = 1,2,3	*
	TT	TT	*
	θ	THETA	*
Transistor	α	ALPHA(I), I = 1,2,3	*
Parameters	$\theta\, I_S\, TT$	TST(I), I = 1,2,3	**
	$\alpha\, I_S$	ASAT(I), I = 1,2,3	**
	C_{JE}	CEJ(I), I = 1,2,3	*
	C_C	CC(I), I = 1,2,3	*
	R_B	RB(I), I = 1,2	*
Transmission-Line	Z_0	ZO	*
Parameters	τ	TD	*

---

*   Supplied by user.

**   Working variable.

*** E_1 is defined as a function of time in Subroutine DFUNI.

```
SUBROUTINE CSEF(X,F)                                             CSE   10
====================                                            
C                                                                CSE   20
C                                                                
C     * * * * * * * * * * * * * * * *                            CSE   30
C     *                             *                            CSE   40
C     *   CURRENT SWITCH EMITTER FOLLOWER   *                    CSE   50
C     *                             *                            CSE   60
C     * * * * * * * * * * * * * * * *                            CSE   70
C                                                                CSE   80
C   --SUBROUTINES CALLED                                         CSE   90
C        DVOGER     AN IMSLIB    SUBROUTINE                      CSE  100
C        GEARSI   IS THE SAME AS DVOGER BUT WITH DIFFERENT NAME  CSE  110
C        GELG     AN  SSPLIB SUBROUTINE FOR SOLVING SYSTEMS OF LINEAR  CSE  120
C                 EQUATIONS                                      CSE  130
C        DCAN     A SUBROUTINE WHICH FINDS THE DC STEADY STATE SOLUTION CSE 140
C                                                                CSE  150
C     DFUNI AND DFUNO ARE THE TWO SUBROUTINES SUPPLYING THE      CSE  160
C     DERIVATIVES OF THE INPUT AND OUTPUT STATE VARIABLES NECESSARY  CSE 170
C     FOR INTEGRATION                                            CSE  180
C                                                                CSE  190
C     X = ARRAY OF VARIABLES   THEY ARE SCALED BY THE VECTOR SCALE  CSE 200
C         IN THIS SUBROUTINE THEY ARE E(4), ZO, R4, CO, ALPHA(3),  CSE 210
C         SATC(3),  CEJ(3)  AND TT(3)                            CSE  220
C                                                                CSE  230
C     F = ARRAY OF RESPONSE AT EQUAL TIME STEPS GIVEN BY TMAX/120  CSE 240
C                                                                CSE  250
C     FF = ARRAY IN WHICH THE RESPONSE IS STORED AND THE MAXIMUM  CSE 260
C          NUMBER OF THE INTEGRATION STEPS IS LIMITED TO 1500    CSE  270
C                                                                CSE  280
C     R = WORKING AREA TO STORE THE R MATRIX                     CSE  290
C                                                                CSE  300
C     YI,  YIMAX,  ERI  AND  WKI ARE THE WORKING ARRAYS REQUIRED BY  CSE 310
C         THE INTEGRATION SUBROUTINE FOR THE 4 STATE VARIABLES INPUT  CSE 320
C         CIRCUIT                                                CSE  330
C                                                                CSE  340
C     YO,  YOMAX,  ERO  AND  WKO ARE CORRESPONDING ARRAYS FOR THE 3  CSE 350
C         STATE VARIABLES OUTPUT CIRCUIT                         CSE  360
C                                                                CSE  370
C     ID1 = D21(IN TEXT)                ARE DEFINED IN           CSE  380
C     ID2 = D11(IN TEXT)                THE FOLLOWING            CSE  390
C     ID3 = D31(IN TEXT)                DATA STATEMENTS          CSE  400
C                                                                CSE  410
C     AV,  AC,  B  AND V  ARE WORKING ARRAYS                     CSE  420
C                                                                CSE  430
C     UI = WORKING ARRAY TO STORE INCIDENT VOLTAGES FOR THE T.L.  CSE 440
C     UR = WORKING ARRAY TO STORE REFLECTED VOLTAGES FOR THE T.L.  CSE 450
C     UITD  AND  URTD ARE CORRESPONDING VALUES OBTAINED BY LINEAR  CSE 460
C         INTERPOLATION BETWEEN THE DISCRETE VALUES IN UI AND UR  CSE 470
C         AT CERTAIN TIMES DETERMINED BY THE DELAY TIME TD       CSE  480
C     TIME  AND TIMEI   ARE ARRAYS TO STORE THE TIMES FOR THE OUTPUT  CSE 490
C         AND INPUT CIRCUITS, RESPECTIVELY, AT WHICH THE RESPONSES ARE CSE 500
C         OBTAINED                                               CSE  510
C                                                                CSE  520
C     /MIMC/   CIRCUIT PARAMETERS                                CSE  530
C                                                                CSE  540
C     /MIMT/   TRANSISTOR PARAMETERS                             CSE  550
C                                                                CSE  560
C     /MIMD/   DIODE PARAMETERS                                  CSE  570
C                                                                CSE  580
C     /MIMTL/  TRANSMISSION-LINE PARAMETERS      M, MS, MK, MI, MSI  CSE 590
C                                                AND MKI ARE COUNTERS CSE 600
C                                                TO TRACK THE DELAY  CSE 610
C                                                                CSE  620
C     /MIME/   VOLTAGES DEFINING THE SHAPE OF THE INPUT E(1)     CSE  630
C              EU     UPPER VALUE OF E(1)                        CSE  640
C              EB     LOWER VALUE OF E(1)                        CSE  650
C              SL     SLOPE                                      CSE  660
C                                                                CSE  670
C     /MIMINT/         VARIABLES REQUIRED FOR THE INTEGRATION    CSE  680
C              HI       INPUT CIRCUIT INTEGRATION STEP           CSE  690
C              HO       OUTPUT CIRCUIT INTEGRATION STEP          CSE  700
C              HMIN     MINIMUM STEP ALLOWED                     CSE  710
C              HMAX     MAXIMUM STEP ALLOWED                     CSE  720
C              EPSI     AN ERROR CRITERION TO CHANGE THE ORDER OF  CSE 730
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C                          THE  STEP  IN  THE  INTEGRATION                    CSE 740
C           SCALE          A VECTOR OF SCALING FACTORS FOR THE X VECTOR       CSE 750
C           TMAX           THE  UPPER  BOUND  ON  TIME  UNTIL  WHICH  OUTPUT  CSE 760
C                          RESPONSE  IS  REQUIRED                             CSE 770
C           MOI            MAXIMUM  ORDER  ALLOWED  TO  BE  USED  IN  THE      CSE 780
C                          INTEGRATION                                        CSE 790
C                                                                             CSE 800
C           -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -      CSE 810
C                                                                             CSE 820
C           *******        E X A M P L E         *******                      CSE 830
C                                                                             CSE 840
C                THIS EXAMPLE ILLUSTRATES THE EVALUATION AND PLOTTING OF      CSE 850
C           OUTPUT RESPONSE                                                   CSE 860
C                                                                             CSE 870
C           PROGRAM MIM ( INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)              CSE 880
C           DIMENSION X(8),F(121)                                             CSE 890
C           COMMON/MIMT/ SATC(3),TT(3),THETA,TST(3),ALPHA(3),ASAT(3),CEJ(3)   CSE 900
C          +,CC(3),RB(2)                                                      CSE 910
C           COMMON/MIMC/ R1,R2,R3,R4,E(4),CO                                  CSE 920
C           COMMON/MIMTL/ Z0,TD,M,MS,MK,MI,MSI,MKI                            CSE 930
C           COMMON/MIMD/ VD,SATD,TSD,TTD,CD                                   CSE 940
C           COMMON/MIME/ EU,EB,SL                                             CSE 950
C           COMMON/MIMINT/ HI,HO,HMIN,HMAX,EPSI,SCALE(8),TMAX,MOI             CSE 960
C           DATA SATD,TTD,CD/0.6E-9,1.E-11,0.12E-12/                          CSE 970
C           DATA SATC(1),SATC(2),TT(1),TT(2),THETA,ALPHA(1),ALPHA(2),CEJ(1),  CSE 980
C          +CEJ(2),CC,RB/2*0.6E-9,2*1.E-11,38.668,0.99,0.99,2*0.12E-12,       CSE 990
C          +3*0.5E-12,2*50.0/                                                 CSE1000
C           DATA R1,R2,R3,E(2),E(3)/281.33,75.,78.24,-4.03,1.13/              CSE1010
C           DATA EU,EB,SL/0.776,1.552,-5.173333333333E9/                      CSE1020
C           DATA TD/0.25E-9/                                                  CSE1030
C           DATA SCALE/-1.7,50.,50.,1.5E-12,0.99,0.6E-9,0.12E-12,1.E-11/      CSE1040
C           DATA X/0.97377,1.8401,0.910653,0.832065,4*1.0/                    CSE1050
C           MOI=2                                                             CSE1060
C           TMAX=1.44E-9                                                      CSE1070
C           EPSI=0.005                                                        CSE1080
C           HMAX=1.E-11                                                       CSE1090
C           HMIN=1.E-17                                                       CSE1100
C           HI=1.E-13                                                         CSE1110
C           CALL CSEF(X,F)                                                    CSE1120
C           DDT=TMAX/120.                                                     CSE1130
C           WRITE(6,100) (F(I),I=1,121)                                       CSE1140
C           DO 50 I=1,121                                                     CSE1150
C           T=DDT*FLOAT(I)                                                    CSE1160
C           ZZ=F(I)                                                           CSE1170
C           CALL PLOTPT(T,ZZ,4)                                               CSE1180
C       50  CONTINUE                                                          CSE1190
C           CALL OUTPLT                                                       CSE1200
C      100  FORMAT(10(2X,F8.4))                                               CSE1210
C           STOP                                                              CSE1220
C           END                                                              CSE1230
C                                                                             CSE1240
C           ---------------------------------------------------------------   CSE1250
C                                                                             CSE1260
            EXTERNAL DFUNI,DFUNO                                              CSE1270
C                                                                             CSE1280
            DIMENSION X(8),F(121),FF(1500)                                    CSE1290
C                                                                             CSE1300
            DIMENSION R(5,5),YI(8,4),YO(8,3),YIMAX(4),YOMAX(3),ERI(4),ERO(3), CSE1310
           +WKI(84),WKO(60)                                                   CSE1320
C                                                                             CSE1330
            COMMON/MIMA/ ID1(4,5),  ID2(4,5),  ID3(5),                        CSE1340
           +             AV(4,4),   AC(4,4),   B(5,4),   V(5),                CSE1350
           +             UI(1500),  UR(1500),  UITD,URTD,TIME(1500),TIMEI(1500)CSE1360
C                                                                             CSE1370
            COMMON/MIMC/ R1,R2,R3,R4,E(4),CO                                  CSE1380
C                                                                             CSE1390
            COMMON/MIMT/ SATC(3),TT(3),THETA,TST(3),ALPHA(3),ASAT(3),CEJ(3)   CSE1400
           +,CC(3),RB(2)                                                      CSE1410
C                                                                             CSE1420
            COMMON/MIMD/ VD,SATD,TSD,TTD,CD                                   CSE1430
C                                                                             CSE1440
            COMMON/MIMTL/ Z0,TD,M,MS,MK,MI,MSI,MKI                            CSE1450
C                                                                             CSE1460
            COMMON/MIME/ EU,EB,SL                                             CSE1470
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C                                                                    CSE1480
       COMMON/MIMINT/ HI,HO,HMIN,HMAX,EPSI,SCALE(8),TMAX,MOI         CSE1490
C                                                                    CSE1500
C                                                                    CSE1510
       DATA ID1/0,0,-1,1,-1,1,3*0,-1,4*0,-1,0,1,-1,0,0/             CSE1520
       DATA ID2/0,-1,3*0,1,0,0,2*-1,3*0,2*-1,0,0,-1,0,-1/           CSE1530
       DATA ID3/ -1,1,3*-1/                                          CSE1540
C                                                                    CSE1550
C          ---  SCALING  ---                                         CSE1560
C                                                                    CSE1570
       E(4)=X(1)*SCALE(1)                                           CSE1580
       Z0=X(2)*SCALE(2)                                             CSE1590
       R4=X(3)*SCALE(3)                                             CSE1600
       CO=X(4)*SCALE(4)                                             CSE1610
       ALPHA(3)=X(5)*SCALE(5)                                       CSE1620
       SATC(3)=X(6)*SCALE(6)                                        CSE1630
       CEJ(3)=X(7)*SCALE(7)                                         CSE1640
       TT(3)=X(8)*SCALE(8)                                          CSE1650
C                                                                    CSE1660
       DO 5 I=1,3                                                   CSE1670
       TST(I)=TT(I)*SATC(I)*THETA                                   CSE1680
       ASAT(I)=ALPHA(I)*SATC(I)                                     CSE1690
     5 CONTINUE                                                      CSE1700
       TSD=TTD*SATD*THETA                                           CSE1710
C                                                                    CSE1720
C     ---   INPUT CIRCUIT (EVALUATION OF REQUIRED COEFFICIENTS)  --- CSE1730
C                                                                    CSE1740
       DO 10 I=1,5                                                  CSE1750
       DO 10 J=1,I                                                  CSE1760
       R(I,J)=R(J,I)=R1*ID3(I)*ID3(J)                               CSE1770
    10 CONTINUE                                                      CSE1780
       R(1,1)=R(1,1)+R2                                             CSE1790
       R(2,2)=R(2,2)+R3                                             CSE1800
       R(3,3)=R(3,3)+RB(1)                                          CSE1810
       R(4,4)=R(4,4)+RB(2)                                          CSE1820
       R(5,5)=R(5,5)+Z0                                             CSE1830
C                                                                    CSE1840
C          SOLVING R(TRANS.)B=-D21(TRANS.)                          CSE1850
C                                                                    CSE1860
       DO 20 I=1,4                                                  CSE1870
       DO 20 J=1,5                                                  CSE1880
       B(J,I)=-FLOAT(ID1(I,J))                                      CSE1890
    20 CONTINUE                                                      CSE1900
       NR=5                                                         CSE1910
       NC=4                                                         CSE1920
       EP=1.E-7                                                     CSE1930
       CALL CELG(B,R,NR,NC,EP,IER)                                  CSE1940
       DO 30 I=1,4                                                  CSE1950
       DO 30 J=1,4                                                  CSE1960
       AC(I,J)=0.0                                                  CSE1970
       AV(I,J)=0.0                                                  CSE1980
       DO 30 K=1,5                                                  CSE1990
       AV(I,J)=AV(I,J)+B(K,I)*ID2(J,K)                             CSE2000
       AC(I,J)=AC(I,J)+B(K,I)*ID1(J,K)                             CSE2010
    30 CONTINUE                                                      CSE2020
C                                                                    CSE2030
C     ---   OUTPUT CIRCUIT (EVALUATION OF REQUIRED COEFFICIENTS)  --- CSE2040
C                                                                    CSE2050
C     STORING IN B(TRANS.)   THE MATRIX  D R(INV.) D1               CSE2060
C                                                                    CSE2070
       ZIN=-1./Z0                                                   CSE2080
       DO 35 I=2,5                                                  CSE2090
       DO 35 J=1,3                                                  CSE2100
       B(I,J)=ZIN                                                   CSE2110
    35 CONTINUE                                                      CSE2120
       B(1,1)=1./R4                                                 CSE2130
       B(3,1)=-B(1,1)+ZIN                                           CSE2140
       B(1,2)=B(1,3)=0.0                                            CSE2150
C                                                                    CSE2160
C     ---   THE STEADY STATE DC VALUES  ---                         CSE2170
C                                                                    CSE2180
       E(1)=0.776                                                   CSE2190
       VE1=0.430                                                    CSE2200
       VE2=0.081                                                    CSE2210
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      VE3=0.403
      CALL DCAN(VE1,VE2,VE3,VC1,VC2,VO,UII,URI)                    CSE2220
C                                                                  CSE2230
C     --- T.L.   INITIAL   CONDITION ---                           CSE2240
C                                                                  CSE2250
      UI(1)=UII                                                    CSE2260
      UR(1)=URI                                                    CSE2270
      URTD=URI                                                     CSE2280
      UITD=UII                                                     CSE2290
C                                                                  CSE2300
C     ---   INITIALIZATION OF INTEGRATION FOR INPUT CIRCUIT ---    CSE2310
C                                                                  CSE2320
      MTI=1                                                        CSE2330
      HO=HI                                                        CSE2340
      MOO=MOI                                                      CSE2350
      MTO=MTI                                                      CSE2360
      EPSO=EPSI                                                    CSE2370
      TI=0.0                                                       CSE2380
      MI=1                                                         CSE2390
      TIMEI(MI)=TI                                                 CSE2400
      NI=4                                                         CSE2410
      YI(1,1)=VC1                                                  CSE2420
      YI(1,2)=VE1                                                  CSE2430
      YI(1,3)=VE2                                                  CSE2440
      YI(1,4)=VC2                                                  CSE2450
      DO 40 I=1,NI                                                 CSE2460
      YIMAX(I)=1.0                                                 CSE2470
   40 CONTINUE                                                     CSE2480
      JI=0                                                         CSE2490
      CALL GEARSI(DFUNI, YI, TI, NI, MTI, MOI, JI, HI, HMIN, HMAX, CSE2500
     +            EPSI, YIMAX,.ERI, WKI, IERI)                     CSE2510
C                                                                  CSE2520
C     ---   INITIALIZATION FOR INTEGRATION FOR OUTPUT CIRCUIT ---  CSE2530
C                                                                  CSE2540
      TO=0.0                                                       CSE2550
      M=1                                                          CSE2560
      TIME(M)=TO                                                   CSE2570
      FF(1)=VO                                                     CSE2580
      YO(1,1)=VO                                                   CSE2590
      YO(1,2)=VE3                                                  CSE2600
      YO(1,3)=VD                                                   CSE2610
      NO=3                                                         CSE2620
      DO 50 I=1,NO                                                 CSE2630
      YOMAX(I)=1.0                                                 CSE2640
   50 CONTINUE                                                     CSE2650
      JO=0                                                         CSE2660
      CALL DVOGER(DFUNO, YO, TO, NO, MTO, MOO, JO, HO, HMIN, HMAX, CSE2670
     +            EPSO, YOMAX, ERO, WKO, IERO)                     CSE2680
C                                                                  CSE2690
      MSI=2                                                        CSE2700
      MS=2                                                         CSE2710
C                                                                  CSE2720
C         CHECK IF TMAX HAS BEEN REACHED                           CSE2730
C                                                                  CSE2740
   55 IF(TO.GT.TMAX) GO TO 70                                      CSE2750
C                                                                  CSE2760
C         CHECK IF AN INTEGRATION FOR INPUT CIRCUIT IS REQUIRED    CSE2770
C         (IN ORDER TO FIND THE INCIDENT VOLTAGE UI)               CSE2780
C                                                                  CSE2790
   60 IF(TI.LT.(TO+HMAX-TD)) GO TO 65                              CSE2800
C                                                                  CSE2810
C     SOLUTION OF OUTPUT CIRCUIT                                   CSE2820
C                                                                  CSE2830
      MK=MS                                                        CSE2840
      M=M+1                                                        CSE2850
      TIME(M)=TO                                                   CSE2860
      FF(M)=YO(1,1)                                                CSE2870
      IF(IERO.EQ.34.OR.IERO.EQ.35) CALL EXIT                      CSE2880
      JO=1                                                         CSE2890
      CALL DVOGER(DFUNO, YO, TO, NO, MTO, MOO, JO, HO, HMIN, HMAX, CSE2900
     +            EPSO, YOMAX, ERO, WKO, IERO)                     CSE2910
      GO TO 55                                                     CSE2920
C                                                                  CSE2930
C     SOLUTION OF INPUT CIRCUIT                                    CSE2940
                                                                   CSE2950
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C                                                                       CSE2960
   65 MKI=MSI                                                           CSE2970
      MI=MI+1                                                           CSE2980
      TIMEI(MI)=TI                                                      CSE2990
      IF(IERI.EQ.34.OR.IERI.EQ.35) CALL EXIT                           CSE3000
      JI=1                                                              CSE3010
      CALL GEARSI(DFUNI, YI, TI, NI, MTI, MOI, JI, HI, HMIN, HMAX,     CSE3020
     +            EPSI, YIMAX, ERI, WKI, IERI)                         CSE3030
      GO TO 60                                                         CSE3040
C                                                                       CSE3050
C  ---   LINEAR INTERPOLATION TO FIND RESPONSE AT INTERMEDIATE TIMES  --- CSE3060
C            TIME POINTS ARE EQUALLY SPACED BY DDT = TMAX/120         CSE3070
C                                                                       CSE3080
   70 MS=2                                                             CSE3090
      M=M+1                                                            CSE3100
      TIME(M)=TO                                                       CSE3110
      FF(M)=YO(1,1)                                                    CSE3120
      DDT=TMAX/120.                                                    CSE3130
      DO 90 I=1,121                                                    CSE3140
      T=DDT*(I-1)                                                      CSE3150
      DO 75 J=MS,M                                                     CSE3160
      JMS=J                                                            CSE3170
      IF(TIME(J).GT.T) GO TO 80                                        CSE3180
   75 CONTINUE                                                         CSE3190
   80 MS=JMS-1                                                         CSE3200
      F(I)=(FF(JMS)*(T-TIME(MS))+FF(MS)*(TIME(JMS)-T))/               CSE3210
     +     (TIME(JMS)-TIME(MS))                                        CSE3220
   90 CONTINUE                                                         CSE3230
C                                                                       CSE3240
      RETURN                                                           CSE3250
      END                                                              CSE3260
```

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       SUBROUTINE DFUNI(Y,T,MZM,DY,PW,IND)                              DFU   10
C      =====================================
C                                                                       DFU   20
C         THIS SUBROUTINE IS CALLED BY GEARS INTEGRATION SUBROUTINE     DFU   30
C         IT SUPPLIES THE VALUES OF THE DERIVATIVES (DY) THE JACOBIAN   DFU   40
C         (PW) FOR A POINT(Y,T)    FOR THE INPUT CIRCUIT                DFU   50
C                                  ---------------------                DFU   60
C         FOR FURTHER DETAILS, SEE COMMENTS IN THE INTEGRATION SUBROUTINE DFU 70
C                                                                       DFU   80
C      ---------------------------------------------------------------- DFU   90
C                                                                       DFU  100
       DIMENSION Y(8,4),DY(4),W(2,4),PW(MZM,MZM)                        DFU  110
       COMMON/MIMA/ ID1(4,5),  ID2(4,5),  ID3(5),                      DFU  120
      +             AV(4,4),   AC(4,4),   B(5,4),   V(5),              DFU  130
      +             UI(1500),  UR(1500), UITD,URTD,TIME(1500),TIMEI(1500) DFU 140
       COMMON/MIMT/ SATC(3),TT(3),THETA,TST(3),ALPHA(3),ASAT(3),CEJ(3)  DFU  150
      +,CC(3),RB(2)                                                     DFU  160
       COMMON/MIMC/ R1,R2,R3,R4,E(4),CO                                 DFU  170
       COMMON/MIME/ EU,EB,SL                                            DFU  180
       COMMON/MIMTL/ Z0,TD,M,MS,MK,MI,MSI,MKI                          DFU  190
C                                                                       DFU  200
       W(1,1)=THETA*Y(1,2)                                              DFU  210
       W(2,1)=THETA*Y(1,3)                                              DFU  220
       DO 10 I=1,2                                                      DFU  230
       W(I,2)=EXP(W(I,1))                                               DFU  240
       W(I,3)=SATC(I)*(W(I,2)-1.0)                                      DFU  250
       W(I,4)=CEJ(I)+TST(I)*W(I,2)                                      DFU  260
   10  CONTINUE                                                         DFU  270
       PT=T-TD                                                          DFU  280
       IF(PT.LT.0.0) GO TO 55                                           DFU  290
       DO 50 I=MK,M                                                     DFU  300
       IMS=I                                                            DFU  310
       IF(TIME(I).GT.PT) GO TO 52                                       DFU  320
   50  CONTINUE                                                         DFU  330
   52  MS=IMS-1                                                         DFU  340
       RATIO=(PT-TIME(MS))/(TIME(IMS)-TIME(MS))                         DFU  350
       URTD=RATIO*(UR(IMS)-UR(MS))+UR(MS)                               DFU  360
C                                                                       DFU  370
C         ---  THE INPUT VOLTAGE E(1)  ---                             DFU  380
C                                                                       DFU  390
   55  IF(T.LE.0.05E-9) E(1)=EU                                         DFU  400
       IF(T.GT.0.05E-9.AND.T.LT.0.2E-9) E(1)=EU-SL*(T-0.05E-9)          DFU  410
       IF(T.GE.0.2E-9.AND.T.LE.0.45E-9) E(1)=EB                         DFU  420
       IF(T.GT.0.45E-9.AND.T.LT.0.6E-9) E(1)=EB+SL*(T-0.45E-9)          DFU  430
       IF(T.GE.0.6E-9.AND.T.LE.0.85E-9) E(1)=EU                         DFU  440
       IF(T.GT.0.85E-9.AND.T.LT.1.E-9) E(1)=EU-SL*(T-0.85E-9)           DFU  450
       IF(T.GE.1.E-9.AND.T.LE.1.25E-9) E(1)=EB                          DFU  460
       IF(T.GT.1.25E-9.AND.T.LT.1.4E-9) E(1)=EB+SL*(T-1.25E-9)          DFU  470
       IF(T.GE.1.4E-9) E(1)=EU                                          DFU  480
       DO 20 I=1,3                                                      DFU  490
       V(I)=E(I)                                                        DFU  500
   20  CONTINUE                                                         DFU  510
       V(4)=-URTD                                                       DFU  520
       DO 30 I=1,4                                                      DFU  530
       DY(I)=0.0                                                        DFU  540
       DO 30 J=1,4                                                      DFU  550
       DY(I)=DY(I)+AV(I,J)*V(J)+AC(I,J)*Y(1,J)                          DFU  560
   30  CONTINUE                                                         DFU  570
       DY(1)=DY(1)+ALPHA(1)*W(1,3)                                      DFU  580
       DY(2)=DY(2)-W(1,3)                                               DFU  590
       VL=-Y(1,1)-RB(1)*((1.-ALPHA(1))*W(1,3)+DY(1)+DY(2))-E(1)         DFU  600
       CIZ=VL/R3+ALPHA(1)*W(1,3)-DY(1)                                  DFU  610
       UI(MI)=VL-CIZ*Z0                                                 DFU  620
C                                                                       DFU  630
       DY(1)=DY(1)/CC(1)                                                DFU  640
       DY(2)=DY(2)/W(1,4)                                               DFU  650
       DY(3)=(DY(3)-W(2,3))/W(2,4)                                      DFU  660
       DY(4)=(DY(4)+ALPHA(2)*W(2,3))/CC(2)                              DFU  670
       IF(IND.NE.1) RETURN                                              DFU  680
       PW(1,1)=AC(1,1)/CC(1)                                            DFU  690
       PW(1,2)=(AC(1,2)+ASAT(1)*THETA*W(1,2))/CC(1)                     DFU  700
       PW(1,3)=AC(1,3)/CC(1)                                            DFU  710
       PW(1,4)=AC(1,4)/CC(1)                                            DFU  720
       PW(2,1)=AC(2,1)/W(1,4)                                           DFU  730
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PW(2,2)=(AC(2,2)-THETA*W(1,2)*(SATC(1)+TST(1)*DY(2)))/W(1,4)      DFU 740
PW(2,3)=AC(2,3)/W(1,4)                                            DFU 750
PW(2,4)=AC(2,4)/W(1,4)                                            DFU 760
PW(3,1)=AC(3,1)/W(2,4)                                            DFU 770
PW(3,2)=AC(3,2)/W(2,4)                                            DFU 780
PW(3,3)=(AC(3,3)-THETA*W(2,2)*(SATC(2)+TST(2)*DY(3)))/W(2,4)      DFU 790
PW(3,4)=AC(3,4)/W(2,4)                                            DFU 800
PW(4,1)=AC(4,1)/CC(2)                                             DFU 810
PW(4,2)=AC(4,2)/CC(2)                                             DFU 820
PW(4,3)=(AC(4,3)+ASAT(2)*THETA*W(2,2))/CC(2)                      DFU 830
PW(4,4)=AC(4,4)/CC(2)                                             DFU 840
RETURN                                                            DFU 850
END                                                              DFU 860
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      SUBROUTINE DFUNO(Y,T,MZM,DY,PW,IND)                              DFU  10
C     =====================================                           
C                                                                     DFU  20
C         THIS SUBROUTINE IS CALLED BY GEARS INTEGRATION SUBROUTINE   DFU  30
C         IT SUPPLIES THE VALUES OF THE DERIVATIVES (DY) THE JACOBIAN DFU  40
C         (PW) FOR A POINT(Y,T)     FOR THE OUTPUT CIRCUIT            DFU  50
C                                   -----------------------           DFU  60
C         FOR FURTHER DETAILS, SEE COMMENTS IN THE  INTEGRATION SUBROUTINE DFU 70
C                                                                     DFU  80
C     ---------------------------------------------------------------- DFU  90
C                                                                     DFU 100
      DIMENSION Y(8,3),DY(3),W(4),PW(MZM,MZM),WD(4)                   DFU 110
      COMMON/MIMA/  ID1(4,5),  ID2(4,5),  ID3(5),                     DFU 120
     +              AV(4,4),   AC(4,4),   B(5,4),   V(5),             DFU 130
     +              UI(1500),  UR(1500), UITD,URTD,TIME(1500),TIMEI(1500) DFU 140
      COMMON/MIMT/  SATC(3),TT(3),THETA,TST(3),ALPHA(3),ASAT(3),CEJ(3) DFU 150
     +,CC(3),RB(2)                                                    DFU 160
      COMMON/MIMC/  R1,R2,R3,R4,E(4),CO                               DFU 170
      COMMON/MIMTL/ Z0,TD,M,MS,MK,MI,MSI,MKI                          DFU 180
      COMMON/MIMD/  VD,SATD,TSD,TTD,CD                                DFU 190
C                                                                     DFU 200
      W(1)=THETA*Y(1,2)                                               DFU 210
      W(2)=EXP(W(1))                                                  DFU 220
      W(3)=SATC(3)*(W(2)-1.0)                                         DFU 230
      W(4)=CEJ(3)+TST(3)*W(2)                                         DFU 240
      WD(1)=THETA*Y(1,3)                                              DFU 250
      WD(2)=EXP(WD(1))                                                DFU 260
      WD(3)=SATD*(WD(2)-1.0)                                          DFU 270
      WD(4)=CD+TSD*WD(2)                                              DFU 280
      PT=T-TD                                                         DFU 290
      IF(PT.LT.0.0) GO TO 30                                          DFU 300
      DO 10 I=MKI,MI                                                  DFU 310
      IMS=I                                                           DFU 320
      IF(TIMEI(I).GT.PT) GO TO 20                                     DFU 330
   10 CONTINUE                                                        DFU 340
   20 MSI=IMS-1                                                       DFU 350
      RATIO=(PT-TIMEI(MSI))/(TIMEI(IMS)-TIMEI(MSI))                   DFU 360
      UITD=UI(MSI)+RATIO*(UI(IMS)-UI(MSI))                            DFU 370
C                                                                     DFU 380
   30 V(1)=E(4)                                                       DFU 390
      V(2)=-UITD                                                      DFU 400
      V(3)=Y(1,1)                                                     DFU 410
      V(4)=Y(1,2)                                                     DFU 420
      V(5)=Y(1,3)                                                     DFU 430
      DY(1)=ALPHA(3)*W(3)                                             DFU 440
      CIZ=W(3)-DY(1)                                                  DFU 450
      DY(2)=-CIZ                                                      DFU 460
      DY(3)=DY(1)-WD(3)                                               DFU 470
      DO 40 I=1,3                                                     DFU 480
      DO 40 J=1,5                                                     DFU 490
      DY(I)=DY(I)+B(J,I)*V(J)                                         DFU 500
   40 CONTINUE                                                        DFU 510
      VL=V(3)+V(4)+V(5)                                               DFU 520
      CIZ=CIZ+DY(2)                                                   DFU 530
      UR(M)=VL-CIZ*Z0                                                 DFU 540
      DY(1)=DY(1)/CO                                                  DFU 550
      DY(2)=DY(2)/W(4)                                                DFU 560
      DY(3)=DY(3)/WD(4)                                               DFU 570
      IF(IND.NE.1) RETURN                                            DFU 580
C                                                                     DFU 590
      PW(1,1)=B(3,1)/CO                                               DFU 600
      PW(1,2)=(B(4,1)+ASAT(3)*THETA*W(2))/CO                          DFU 610
      PW(1,3)=B(5,1)/CO                                               DFU 620
      PW(2,1)=B(3,2)/W(4)                                             DFU 630
      PW(2,2)=(B(4,2)-THETA*W(2)*(SATC(3)-ASAT(3)+TST(3)*DY(2)))/W(4) DFU 640
      PW(2,3)=B(5,2)/W(4)                                             DFU 650
      PW(3,1)=B(3,3)/WD(4)                                            DFU 660
      PW(3,2)=(B(4,3)+ASAT(3)*THETA*W(2))/WD(4)                       DFU 670
      PW(3,3)=(B(5,3)-THETA*WD(2)*(SATD+TSD*DY(3)))/WD(4)             DFU 680
      RETURN                                                          DFU 690
      END                                                             DFU 700
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      SUBROUTINE DCAN(VE1,VE2,VE3,VC1,VC2,VO,UI,UR)                    DCA   10
C     ==================================================              DCA   20
C                                                                     DCA   30
C         THIS SUBROUTINE EVALUATES THE STEADY STATE VALUES OF        DCA   40
C         VE1,VE2,VE3,   VC1,VC2,   VO,       UI, UR.                 DCA   50
C                                                                     DCA   60
C            AN INITIAL GUESS FOR  VE1, VE2  AND VE3 SHOULD BE SUPPLIED DCA 70
C            ALL CIRCUIT AND MODEL PARAMETERS ARE ALSO SUPPLIED THROUGH DCA 80
C            THE COMMON STATEMENTS                                    DCA   90
C         THEY ARE CIRCUIT PARAMETERS IN /MIMC/, TRANSISTOR PARAMETERS IN DCA 100
C         /MIMT/, TRANS. LINE PARAMETERS IN /MIMTL/ AND DIODE PARAMETERS DCA 110
C         IN /MIMD/                                                   DCA  120
C                                                                     DCA  130
C         -------------------------------------------------------------- DCA 140
C                                                                     DCA  150
      DIMENSION TX(2),EX(2),G(2,2),GINV(2,2),DX(2)                    DCA  160
      COMMON/MIMT/ SATC(3),TT(3),THETA,TST(3),ALPHA(3),ASAT(3),CEJ(3) DCA  170
     +,CC(3),RB(2)                                                    DCA  180
      COMMON/MIMC/ R1,R2,R3,R4,E(4),CO                                DCA  190
      COMMON/MIMTL/ Z0,TD,M,MS,MK,MI,MSI,MKI                          DCA  200
      COMMON/MIMD/ VD,SATD,TSD,TTD,CD                                 DCA  210
C                                                                     DCA  220
C         STEADY STATE SOLUTION FOR INPUT                             DCA  230
C                                                                     DCA  240
      B1=SATC(1)*R1                                                   DCA  250
      B2=SATC(2)*R1                                                   DCA  260
      A1=B1+(1.-ALPHA(1))*SATC(1)*RB(1)                               DCA  270
      A2=B2+(1.-ALPHA(2))*SATC(2)*RB(2)                               DCA  280
      NIT=0                                                           DCA  290
   10 TX(1)=THETA*VE1                                                 DCA  300
      TX(2)=THETA*VE2                                                 DCA  310
      DO 20 I=1,2                                                     DCA  320
      EX(I)=EXP(TX(I))                                                DCA  330
   20 CONTINUE                                                        DCA  340
      F1=A1*(EX(1)-1.)+B2*(EX(2)-1.)+VE1+E(2)+E(1)                    DCA  350
      F2=A2*(EX(2)-1.)+B1*(EX(1)-1.)+VE2+E(2)+E(3)                    DCA  360
      G(1,1)=A1*THETA*EX(1)+1.0                                       DCA  370
      G(1,2)=B2*THETA*EX(2)                                           DCA  380
      G(2,1)=B1*THETA*EX(1)                                           DCA  390
      G(2,2)=A2*THETA*EX(2)+1.0                                       DCA  400
      DET=G(1,1)*G(2,2)-G(1,2)*G(2,1)                                 DCA  410
      GINV(1,1)=G(2,2)/DET                                            DCA  420
      GINV(2,1)=-G(2,1)/DET                                           DCA  430
      GINV(1,2)=-G(1,2)/DET                                           DCA  440
      GINV(2,2)=G(1,1)/DET                                            DCA  450
      DO 30 I=1,2                                                     DCA  460
      DX(I)=-GINV(I,1)*F1-GINV(I,2)*F2                                DCA  470
   30 CONTINUE                                                        DCA  480
      VE1=VE1+DX(1)                                                   DCA  490
      VE2=VE2+DX(2)                                                   DCA  500
      NIT=NIT+1                                                       DCA  510
      IF(NIT.GT.1000) GO TO 90                                        DCA  520
      IF(ABS(DX(1)).GT.1.E-10.OR.ABS(DX(2)).GT.1.E-10) GO TO 10       DCA  530
      GO TO 100                                                       DCA  540
   90 WRITE(6,300)                                                    DCA  550
      CALL EXIT                                                       DCA  560
  100 CONTINUE                                                        DCA  570
      CE1=SATC(1)*(EXP(THETA*VE1)-1.0)                                DCA  580
      CC1=ALPHA(1)*CE1                                                DCA  590
      CE2=SATC(2)*(EXP(THETA*VE2)-1.0)                                DCA  600
      CC2=ALPHA(2)*CE2                                                DCA  610
      VC2=R2*CC2-E(3)-RB(2)*(CE2-CC2)                                 DCA  620
C                                                                     DCA  630
C         STEADY STATE SOLUTION FOR OUTPUT                            DCA  640
C                                                                     DCA  650
      A=R4+R3*(1.-ALPHA(3))                                           DCA  660
      B=R3*CC1+E(4)                                                   DCA  670
      NIT=0                                                           DCA  680
      CT=SATC(3)/SATD                                                 DCA  690
      Y=VE3                                                           DCA  700
   40 EY=EXP(THETA*Y)                                                 DCA  710
      CE3=SATC(3)*(EY-1.0)                                            DCA  720
      VD=ALOG(CT*(EY-1.0)+1.0)/THETA                                 DCA  730
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      DY=-(A*CE3+B+Y+VD)/(A*THETA*EY*SATC(3)+1.+CT*(EY*EXP(-THETA*VD)))    DCA 740
      Y=Y+DY                                                               DCA 750
      NIT=NIT+1                                                            DCA 760
      IF(NIT.GT.1000) GO TO 190                                           DCA 770
      IF(ABS(DY).GT.1.E-10) GO TO 40                                      DCA 780
      GO TO 200                                                           DCA 790
  190 WRITE(6,400)                                                         DCA 800
      CALL EXIT                                                            DCA 810
  200 CONTINUE                                                             DCA 820
      EY=EXP(THETA*Y)                                                      DCA 830
      VE3=Y                                                                DCA 840
      CE3=SATC(3)*(EY-1.)                                                  DCA 850
C                                                                          DCA 860
C        CALCULATION OF VC1, VC2, VO, UI, AND UR                          DCA 870
C                                                                          DCA 880
      VD=ALOG(CT*(EY-1.)+1.)/THETA                                        DCA 890
      VO=R4*CE3+E(4)                                                       DCA 900
      VR=Y+VD+VO                                                           DCA 910
      VI=VR                                                                DCA 920
      DELTA=Z0*(1.-ALPHA(3))*CE3                                          DCA 930
      UI=VI+DELTA                                                          DCA 940
      UR=VR-DELTA                                                          DCA 950
      VC1=-(1.-ALPHA(1))*RB(1)*CE1-E(1)-VI                                DCA 960
  300 FORMAT(//,5X,*DC SOLUTION ONE WAS NOT OBTAINED*)                    DCA 970
  400 FORMAT(//,5X,*DC SOLUTION TWO WAS NOT OBTAINED*)                    DCA 980
      RETURN                                                              DCA 990
      END                                                                 DCA1000
```

SOC-192

STATE EQUATION ANALYSIS AND COMPUTER PROGRAM FOR A CURRENT SWITCH
EMITTER FOLLOWER

H.L. Abdel-Malek and J.W. Bandler

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Revised:

Key Words: Nonlinear circuit analysis, state equation formulation,
                  integraton methods

Abstract: The analysis of a current switch emitter follower (CSEF)
circuit originally given by Ho is described.   State equations in
conjunction with Gear's integration method are used to obtain the output
response.

Description: Contains Fortran listing, user's manual.
                  The listing contains 586 cards, of which 235 are
                  comment cards.

Related Work: SOC-182, SOC-184, SOC-185.

Price: $15.00.