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ACCESSIBILITY OF LARGE-SCALE ELECTRONIC CIRCUITS.(U)

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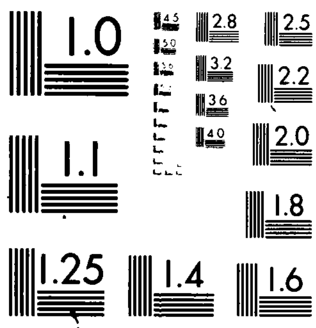

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ACCESSIBILITY OF LARGE-SCALE ELECTRONIC CIRCUITS

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ABSTRACT

The problem of fault diagnosis of large-scale analog circuit is studied. Any fault diagnosis procedure is limited by the number of circuit parameters to be diagnosed. When such limit is exceeded by large-scale circuits, some kind of tearing process has to be implemented before a fault diagnosis procedure can be applied. In this paper, a tearing process via accessibility of subnetworks is presented. The necessary and sufficient condition for accessibility is obtained. The implementation of this tearing process is discussed. The tearing process can be applied to nonlinear circuits.

I. INTRODUCTION

In the study of Large-Scale Dynamical Systems (LSDS), in order to simplify a problem we often reduce it from the level of the overall system to that of its components or subsystems. Tearing or Diakoptics [1] is such an approach for the analysis of large-scale networks. For the fault diagnosis of LSDS there is to technique which is equivalent to tearing. Existing methods of fault diagnosis (for example [3-6]) attack the problem at the LSDS level.

The easiest way to transfer the problem of fault diagnosis from the level of the overall system to that of the subsystems is to have direct access to the inputs and outputs of each subsystem. However, such direct access may not be available to us. In such a case if we can determine the inputs and outputs of the components of interest from the LSDS inputs and outputs, we have effectively accessed them. Intuitively, we can say that this would be possible if a mapping existed from the space of input-output waveforms of the LSDS to the space of input-output waveforms of the components. Such a map would be the basis of our tearing approach. In this paper, we explore these concepts and determine the necessary and sufficient conditions for the existence of such a map which takes as much advantage of the known information as possible. We then lay the intuitive basis for a strategy of tearing which simplifies the problem of fault diagnosis. The results presented are a generalization of an earlier work by Saeks, Singh and Liu [2] and Liu and Visvanathan [7].

[1]This research is supported in part by ONR Grant No. N00014-78-C-0444. N00014-75-C-0498

II. ACCESSIBILITY FROM INPUT/OUTPUT TERMINALS

The LSDS model consists of three parts, the masked subsystem, the unmasked subsystem and the connection-box as shown in Figure 1. The vectors u and y denote the input and output vectors of the LSDS, c and d of the unmasked subsystem and r and s of the masked subsystem. The connection-box consists of the connections between the above variables. The equations for the three parts are:

a) Unmasked Subsystems

We assume that the unmasked subsystem is a linear dynamical system described by:

$$\begin{aligned} \dot{x}(t) &= A\,x(t) + B\,c(t) \\ d(t) &= C\,x(t) + D\,c(t) \end{aligned} \qquad (1)$$

where A,B,C, and D are constant matrices and x is the state vector for the unmasked subsystem.

b) Connection Box

The connection box is described by [10]:

$$\begin{bmatrix} c \\ r \\ y \end{bmatrix} = \begin{bmatrix} L_{cd} & L_{cs} & L_{cu} \\ L_{rd} & L_{rs} & L_{ru} \\ L_{yd} & L_{ys} & L_{yu} \end{bmatrix} \begin{bmatrix} d \\ s \\ u \end{bmatrix} + \begin{bmatrix} R_{cc} & R_{cr} & R_{cy} \\ R_{rc} & R_{rr} & R_{ry} \\ R_{yc} & R_{yr} & R_{yy} \end{bmatrix} \begin{bmatrix} c \\ r \\ y \end{bmatrix} \qquad (2)$$

The L's and R's are constant matrices. Note that d,s and u are inputs to the connection-box and c,r and y are the outputs.

c) Masked Subsystem

The inputs and outputs of the masked subsystem are related by some functional form

$$s = f \cdot r \qquad (3)$$

which is assumed unknown. For example, the relation (3) could be a state equation or a zero-memory nonlinear function.

Equations (1), (2) and (3) completely describe the LSDS. The unmasked subsystem has been included in the LSDS model to provide us with a greater flexibility. Components that are known to be fault-free or have been independently diagnosied can be

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included as part of the unmasked subsystem. We further assume that the LSDS is well-posed, i.e., the initial value solution (x(t), c(t), d(t), r(t), s(t)) exists and is unique for all admissible inputs u(·).

Definition 1.

The masked subsystem of the LSDS is said to be accessible from input/output terminals, or simply accessible, if $\forall_t \epsilon [0,\infty)$, (r(t),s(t)) can be uniquely determined from (u(τ), y(τ)) for τε[0,t] by use of equations (1) and (2) but not (3), with the initial state x(0) = 0 of the unmasked subsystem. It is said to be anticipatively accessible if (r(t), s(t)) can be uniquely determined from (u(τ),y(τ)) for τε[0,t+δ] for some δ > 0 but not for δ = 0.

Theorem 1 [11]

The masked subsystem of the LSDS is accessible if and only if the matrix J

$$J = \begin{bmatrix} R_{cc} + L_{cd}D - I & R_{cr} & L_{cs} \\ R_{rc} + L_{rd}D & R_{rr} - I & L_{rs} \\ R_{yc} + L_{yd}D & R_{yr} & L_{ys} \end{bmatrix}$$

has full column-rank.

Note that the accessibility only depends on the memoryless part of LSDS. The application of Theorem 1 to large-scale networks is considered next.

III. ACCESSIBILITY OF SUBNETWORKS

The above result can be applied to the diagnosis of subnetworks. A given network can be decomposed into three parts as shown in Figure 2. Those R-elements, which are known to be reliable, are placed in the resistive-network box. Those L,C-elements and/or (nonlinear) devices are placed in the masked box. The last box contains all the elements to be diagnosed.

Note that (u,y) and (r,s) are the port-voltages and the port-currents of the overall network and of the subnetworks in the masked box respectively.

The unmasked part has a state-equation representation (1),

$$\dot{x} = Ax + Bc$$
$$d = Cx$$

where A = 0, C = I, and $B = \operatorname{diag}\left(\frac{1}{C_i}, \frac{1}{L_j}\right)$, $c = (i_{C_i}, v_{L_j}), d = (v_{C_i}, i_{L_j})$.

Associate each network in Figure 2, construct a LC-reduced network, or simply reduced network, by replacing each inductor by an open circuit and each capacitor by a short circuit as shown in Figure 3. Note that the reduced network is a resistive network.

Theorem 2. [11]

The masked subnetwork in Figure 2 is accessible if and only if (i_C, v_L, r, s) can be uniquely determined by (u,y) from its reduced resistive network.

IV. ACCESSIBILITY OF FURTHER REDUCED SUBNETWORK

For the purpose of testing the accessibility, it is possible to further simplify the network. In order to do this, more notations are needed. In this section, m-terminal masked box is decomposed into m-1 2-terminal X-devices and the set of X-devices-branches is denoted by G_X. Note that the knowledge of all X-devices completely describes the behavior at the terminals of the original masked box. Similarly, the set of all inductor-, capacitor-branches are denoted by G_L, G_C respectively. As for the resistor-branches, since some of them may be in a particular tree we choose in the network, we denote the set of them in the tree by G_R, and the rest in the corresponding cotree by G_G.

Now consider a network N satisfying the following assumptions.

(1) The network N is a connected graph.

(2) The sources, including voltmeters and ammeters, are considered as a set of branches with measurable voltages and currents. The symbol G_S is used to denote the set.

(3) $G_X \cup G_C$ contains no loop, otherwise ammeters are inserted to break the loops.

(4) $G_S \cup G_L$ contains no cut set.

(5) All resistors have positive resistance.

These five conditions are assumed to be satisfied in the networks considered in this section.

Under above assumptions, there exists a tree (t) which contains (G_X, G_C, G_R) and does not contain (G_S, G_L, G_G). Let the set of all such t be denoted by T. Then for each t in T, we have the following equations:

KCL:

$$\begin{bmatrix} I_X \\ I_C \\ I_R \end{bmatrix} = - \begin{bmatrix} F_{SX} & F_{SC} & F_{SR} \\ F_{LX} & F_{LC} & F_{LR} \\ F_{GX} & F_{GC} & F_{GR} \end{bmatrix}^T \begin{bmatrix} I_S \\ I_L \\ I_G \end{bmatrix} \qquad (4a)$$

KVL:

$$\begin{bmatrix} V_S \\ V_L \\ V_G \end{bmatrix} = \begin{bmatrix} F_{SX} & F_{SC} & F_{SR} \\ F_{LX} & F_{LC} & F_{LR} \\ F_{GX} & F_{GC} & F_{GR} \end{bmatrix} \begin{bmatrix} V_X \\ V_C \\ V_R \end{bmatrix} \qquad (4b)$$

Ohm's Law:

$$V_R = R\, I_R$$
$$I_G = G\, V_G \qquad (4c)$$

where R and G are diagonal matrices with positive diagonal elements.

Define

$$W = \left[\begin{array}{c|c} F_{GR}^T\, G\, F_{GX} & R^{-1} + F_{GR}^T\, G\, F_{GR} \\ \hline F_{SX} & F_{SR} \end{array}\right]$$

Then from Equation (4) and Theorem 2, the following lemma can be proved.

Lemma 1.

The X-devices in network N are accessible if and only if the associated matrix W has full column-rank.

Although the size of matrix W is smaller than the original matrices, that is only superficial because some of the submatrices cannot be determined without the knowledge of the original matrices. The following lemmas will provide a better solution.

Lemma 2.

In a network N, the associated matrix W has full column-rank in the generic sense [12] if the matrix F_{SX} has full column-rank.

Lemma 3.

The matrix F_{SX} of a network N has full column-rank if (1) there exists a tree $t \epsilon T$ such that $G_R U G_S$ contains no loop in LC-reduced network of N and (2) the matrix W associated with N has full column-rank.

The second condition in Lemma 3 will be referred as Assumption (5) in the sequent paragraphs.

Note that not only the size of the matrix F_{SX} is smaller than W but also the matrix itself can be determined by the subgraph N" constructed by shorting all resistor-branches in the particular tree and opening all resistor-branches in the corresponding cotree in the LC-reduced network N'. We call the subgraph N" RLC-reduced network. Then Theorem 3 follows.

Theorem 3.

Let N be a network satisfying Assumptions (1) to (5), then X-devices in N are generically accessible if and only if the matrix F_{SX} in RLC-reduced network associated with t has full column-rank.

Remarks

1. Theorem 3 enables us to determine the accessibility of X-devices in a network by dealing with a considerably smaller subnetwork N" with only sources and X-devices in this subnetwork.
2. From graph theory, F_{SX} has full column-rank if and only if G_S contains a tree in RLC-reduced network. Therefore, to achieve the accessibility of X-devices, we only need to add some voltmeter-branches into G_S to make it contain a tree in RLC-reduced network.
3. In this theory, in order to access all the X-devices in a network, the number of sources must be at least equal to the number of X-devices as can be seen from the required full column-rank of F_{SX}.
4. The choice of tree in a network is crucial in determining the minimalset of test points to obtain accessibility. Altough the algorithm of finding the tree is still under development, it is quite possible to pick the tree in a network of reasonable scale by inspection as shown in Example 1.

Example 1

Consider the accessibility of the two transistors in the two-stage amplifier circuit as shown in Fig. 4a. It is clear to see that (C_1, T_1, C_2, T_2, C_3) form a loop. From Assumption (2), the loop can be broken by inserting an ammeter A in series with C_2. Then, by choosing the tree consisting (X_1, X_2, X_3, X_4, R_5) in Fig. 4b, the associated RLC-reduced network is shown in Fig. 4c. Apparently, the branches (E_1, E_2, E_3, A) contains a tree in Fig. 4c. Thus, (X_1, X_2, X_3, X_4), so that (T_1, T_2), are accessible after the insertion of the ammeter.

V. APPLICATION TO TEARING PROCESS

The purpose of diakoptic or tearing process [1] is to find a way of partitioning a large-scale network into smaller subnetworks so that the solution of the large-scale network can be obtained by solving the (decoupled) subnetworks. Clearly, this represents a reduction in computation time.

If fault diagnosis is of our interest instead of the network solutions, new tearing process should be developed so that it is compatible to fault diagnosis problem. The accessibility can fulfill such purpose. Let us consider the network in Figure 2. If each masked subnetwork is diagnosable from its input/output pair (r,s) and is accessible, then the entire network is diagnosable from its input/output pair (u,y). This is because (r,s) can be obtained from (u,y) independently from the characteristics of masked subnetworks.

In summary, if accessibility is achieved, one can diagnose the entire network by diagnosing each of the (smaller and decoupled) masked subnetworks individually.

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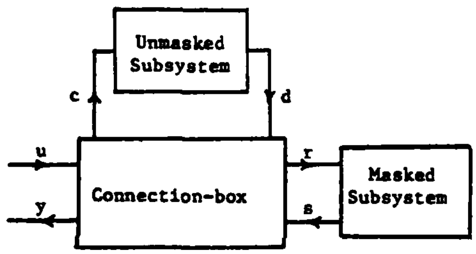

Figure 1

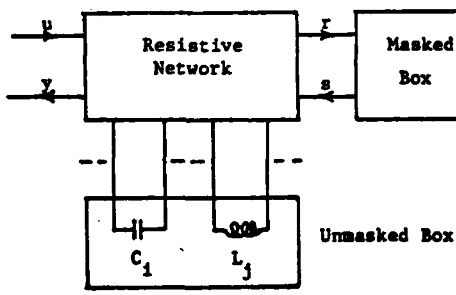

Figure 2

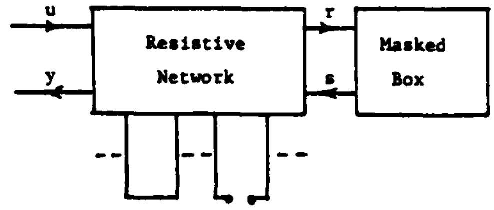

Figure 3

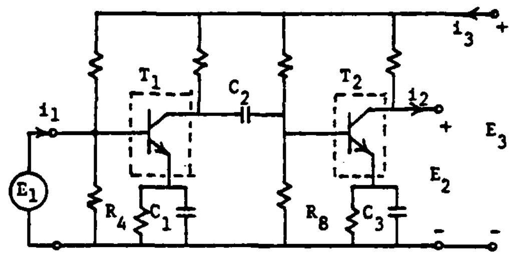

Figure 4a

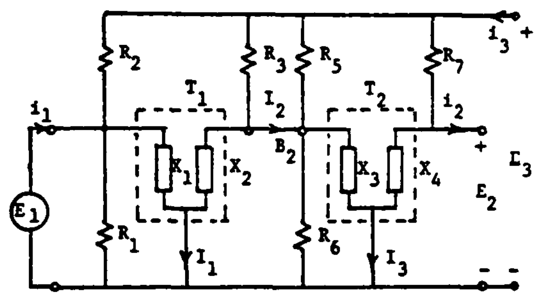

Figure 4b

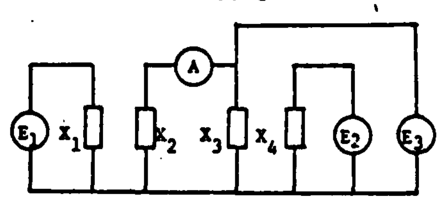

Figure 4c

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