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NODAL APPROACH TO MULTIPLE-FAULT LOCATION IN ANALOG CIRCUITS

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Abstract

The multiple-fault location problem for analog circuits is treated on the basis of the nodal equations. The availability of voltage measurements due to current excitations is assumed by the method. Topological restrictions on the possibility of fault location for a given set of measurements are formulated. Effects of tolerances and measurement errors are discussed in the context of a practical example. Coates flow-graph representation of a network is used for topological considerations.

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I. INTRODUCTION

Testing of analog circuits with the aim of fault location is important in network analysis. There are different approaches to the problem depending on the information available from tests conducted on the network. Generally, the network topology is known and we try to identify the faulty elements and evaluate them. If the number of measurements is large enough we can evaluate all elements and single out the faulty ones [1,2]. However, when the number of measurements is limited we can use various methods to predict regions where faults may appear [3,4]. To verify whether a predicted region contains all the faults, the multiple-fault location method based on the multiport description of a network can be used [5].

In this paper we give a method based on the nodal equations which extends the possibilities of the multiport method. Topological restrictions on multiple-fault location are discussed. Some practical remarks for effective calculations are given.

II. MULTIPLE-FAULT VERIFICATION BY NODAL EQUATIONS

In this section we discuss the method of multiple fault location on the basis of the nodal equations. The principal difference between the nodal and the multiport approach is that in the multiport approach we aim to find changes in element values whereas in the nodal method we design the changes in nodal currents only. Changes in element values can be computed by the nodal method after the network topology is considered.

Nodal Equations for Faulty Network

Let us assume that the network has (n+1) nodes, m of them accessible, and f < m is the number of faulty elements. The nodal equations for the nominal values of the elements have the form

$$\underset{\sim}{Y}\ \underset{\sim}{V} = \underset{\sim}{J}. \tag{1}$$

For the faulty network, assuming the same excitations, we obtain

$$(\underset{\sim}{Y} + \Delta\underset{\sim}{Y})(\underset{\sim}{V} + \Delta\underset{\sim}{V}) = \underset{\sim}{J}. \tag{2}$$

Thus

$$\underset{\sim}{Y}\ \Delta\underset{\sim}{V} = -\ \Delta\underset{\sim}{Y}\ \underset{\sim}{V}', \tag{3}$$

$\underset{\sim}{V}' = \underset{\sim}{V} + \Delta\underset{\sim}{V}$ is the vector of nodal voltages in the faulty network. We can compute $\Delta\underset{\sim}{V}$ assuming that $\underset{\sim}{Y}$ is nonsingular and obtain

$$\Delta\underset{\sim}{V} = -\ \underset{\sim}{Y}^{-1}\ \Delta\underset{\sim}{Y}\ \underset{\sim}{V}'. \tag{4}$$

Let us denote $\Delta\underset{\sim}{J} = -\ \Delta\underset{\sim}{Y}\ \underset{\sim}{V}'$. $\Delta\underset{\sim}{J}$ represents changes in nodal currents caused by faulty elements. The relation (4) becomes

$$\Delta\underset{\sim}{V} = \underset{\sim}{Y}^{-1}\ \Delta\underset{\sim}{J}. \tag{5}$$

We can assume that a few elements are faulty, in which case $\Delta\underset{\sim}{J}$ has the form

$$\Delta\underset{\sim}{J} = \begin{bmatrix} \underset{\sim}{0} \\ \Delta\underset{\sim}{J}^{F} \\ \underset{\sim}{0} \end{bmatrix}. \tag{6}$$

Assuming that the first m nodal voltages can be measured we obtain

$$\begin{bmatrix} \Delta\underset{\sim}{V}^{M} \\ \\ \Delta\underset{\sim}{V}^{N-M} \end{bmatrix} = \underset{\sim}{Y}^{-1} \begin{bmatrix} \underset{\sim}{0} \\ \Delta\underset{\sim}{J}^{F} \\ \underset{\sim}{0} \end{bmatrix}. \tag{7}$$

N indicates the set of all nodes, M the set of measurement nodes. Hence,

$$\Delta\underset{\sim}{V}^{M} = \underset{\sim}{Z}_{MF}\ \Delta\underset{\sim}{J}^{F}, \tag{8}$$

where

$$\underset{\sim}{Y}^{-1} = \begin{bmatrix} \underset{\sim}{Z}_{M1} & \underset{\sim}{Z}_{MF} & \underset{\sim}{Z}_{M2} \\ & & \\ \underset{\sim}{Z}_{N-M,1} & \underset{\sim}{Z}_{N-M,F} & \underset{\sim}{Z}_{N-M,2} \end{bmatrix} . \qquad (9)$$

Relation (8) has to be satisfied when the set F of network nodes includes all nodes associated with faulty elements in the network.

Reduction of the Number of Equations

It is clear from relation (8) that in order to design $\Delta\underset{\sim}{J}^F$ we must have at least 1 + card F measurement nodes. This may cause some redundancies in the case of isolated faults. If there is an isolated fault in the network it causes changes in two elements of the $\Delta\underset{\sim}{J}^F$ vector. In the example shown in Fig. 1 we have $\Delta J_k^F = - \Delta Y_e U^1 = - \Delta J_j^F$. In such a case vector $\Delta\underset{\sim}{J}^F$ will contain variables which are not independent. We can transform the equation (8) to reduce the column rank of the coefficient matrix $\underset{\sim}{Z}_{MF}$. The reduction realized depends on the location of different faults. Let us discuss the following two cases.

1) The case of isolated faults

If an isolated fault appears between nodes k and j (see Fig. 1) then equation (8) can be written in the form

$$\Delta\underset{\sim}{V}^M = [\underset{\sim}{a}_1, \ldots, \underset{\sim}{a}_k, \ldots, \underset{\sim}{a}_j, \ldots, \underset{\sim}{a}_f] \begin{bmatrix} \Delta J_1^F \\ \vdots \\ \Delta J_k^F \\ \vdots \\ -\Delta J_k^F \\ \vdots \\ \Delta J_f^F \end{bmatrix} \qquad (10)$$

or, after summing columns $\underset{\sim}{a}_k$ and $\underset{\sim}{a}_j$ and deleting column $\underset{\sim}{a}_j$,

$$\Delta \underset{\sim}{y}^M = [\underset{\sim}{a}_1, \ldots, \underset{\sim}{a}_k - \underset{\sim}{a}_j, \ldots, \underset{\sim}{a}_{j-1}, \underset{\sim}{a}_{j+1}, \ldots, \underset{\sim}{a}_f] \begin{bmatrix} \Delta J_1^F \\ \vdots \\ \Delta J_k^F \\ \vdots \\ \Delta J_{j-1}^F \\ \Delta J_{j+1}^F \\ \vdots \\ \Delta J_f^F \end{bmatrix} . \quad (11)$$

2) The case of connected faults

If connected faults form a subtree in the network then the number of variables in $\Delta \underset{\sim}{J}^F$ can be reduced by one in similar way to Case 1. The reduction holds for every connected subgraph formed by faulty elements. If the subgraph contains a circuit then the number of variables can not be reduced.

The method described has following advantages as compared with the multiport methods [5].

1. Fault regions can be located even if fault elements form a circuit or cutset.
2. We do not face the situation of block dependent systems when only one element in a circuit or cutset is not faulty.

It should be noted that the identification of faulty elements on the basis of changes in current excitations is not always possible. For example, when only one element in a circuit is not faulty, then the problem of identification is not solvable which is a simple consequence of the transformation of current excitations (cf. [6]).

The nodal approach is restricted to two-terminal elements and voltage controlled current sources only, but it can be extended to any linear active network using the modified nodal description [7].

III. TOPOLOGICAL RESTRICTIONS

In this section we will discuss the problem of the placement of measurements in the network to make possible the indentification of a certain set of faults, on the basis of network topology.

A necessary condition for solvability of equation (8) is full column rank of matrix $\underset{\sim}{Z}_{MF}$, which is equivalent to the existence of a square, nonsingular (card F) x (card F) submatrix of $\underset{\sim}{Z}_{MF}$.

Let $\underset{\sim}{Z}_{EF}$ denote a square submatrix of $\underset{\sim}{Z}_{MF}$ and $\underset{\sim}{Y}$ (E|F) denote the submatrix of $\underset{\sim}{Y}$ obtained by removing E rows and F columns. Using the equivalence

$$\det \underset{\sim}{Z}_{EF} \neq 0 \iff \det \underset{\sim}{Y}\ (E|F) \neq 0 \tag{12}$$

we can find topological restrictions for the fault location problem. We can use the approach presented in [8]. Let us assume that the topological equations for the nodal admittance matrix and Coates graph representation of network are

$$\underset{\sim}{Y} = \underset{\sim}{\lambda}_{-}\, \underset{\sim}{Y}_{e}\, \underset{\sim}{\lambda}_{+}^{T} \tag{13}$$

where the element ij of $\underset{\sim}{\lambda}_{-}$ is equal to 1 if the jth edge is directed towards the ith vertex, otherwise zero, and the element ij of $\underset{\sim}{\lambda}_{+}$ is equal to 1 if the jth edge is directed away from the ith vertex, otherwise zero and $\underset{\sim}{Y}_{e}$ is a diagonal matrix of element admittances.

The submatrix $\underset{\sim}{Y}$ (E|F) can be presented in the form [8]

$$\underset{\sim}{Y}\ (E|F) = \underset{\sim}{\lambda}_{-E}\, \underset{\sim}{Y}_{e}\, \underset{\sim}{\lambda}_{+F}^{T}, \tag{14}$$

where $\underset{\sim}{\lambda}_{-E}$ ($\underset{\sim}{\lambda}_{+F}$) is obtained from $\underset{\sim}{\lambda}_{-}$ ($\underset{\sim}{\lambda}_{+}$) by removing rows E (F), respectively.

Following Starzyk et al. [8] we can formulate the following theorem.

Theorem 1

If $\det \underset{\sim}{Y}(E|F) \neq 0$ then there exists at least one k-connection c_S in the graph G(E|F) obtained from Coates graph of the network after deleting all the edges incoming to nodes E and all the edges outgoing from nodes F, where

$$S = \{(v_s, v_e);\ v_s \in E \cap (N-F),\ v_e \in F \cap (N-E)\}, \tag{15}$$

$$\text{card } S = \text{card } (E \cap (N-F)) = \text{card } (F \cap (N-E)), \tag{16}$$

(v_s, v_e) represents a path directed from the node v_s to the node v_e, and N is the set of all graph nodes.

The condition stated in Theorem 1 is sufficient almost everywhere. As a consequence of Theorem 1 we have an important corollary.

Corollary 1

If $\det \underset{\sim}{Y}(E|F) \neq 0$ then after deleting all the edges outgoing from nodes F and incoming to nodes E there are no isolated nodes in the set $N - (E \cap F)$.

To locate the faults of elements incident with nodes F such that after deleting all the edges outgoing from nodes F some of them become isolated, we must include all of these isolated nodes in the set E, which means that all of them must be accessible nodes (i.e., the nodes at which voltages can be measured).

Following the method described in [8] we can investigate the problem of two subnetworks having c common nodes when $c < \text{card } \{F\}$. In

this case we can not identify the faults appearing in one of the subnetworks by measuring the voltages in the second only (see Fig. 2) because the k-connection required by Theorem 1 does not exist.

The restriction on the placement of measurement nodes appears also in more complex cases when faults and measurements are in different weakly connected subnetworks.

To obtain the overdetermined system of equations we should have at least two nonsingular (card F) x (card F) submatrices of $\underset{\sim}{Z}_{MF}$.

Lemma 1

If $\underset{\sim}{Z}_{EF}$ is a nonsingular submatrix of $\underset{\sim}{Z}_{MF}$ and $\underset{\sim}{z}_0^T$ is a nonzero row of $\underset{\sim}{Z}_{MF}$ not belonging to $\underset{\sim}{Z}_{EF}$ then there exists a nonsingular submatrix of $\underset{\sim}{Z}_{MF}$ that contains $\underset{\sim}{z}_0^T$.

Proof

Since rank $\underset{\sim}{Z}_{MF}$ = rank $\underset{\sim}{Z}_{EF}$ the row $\underset{\sim}{z}_0^T$ is a linear combination of rows $\underset{\sim}{z}_i^T \in \underset{\sim}{Z}_{EF}$, $i \in I$. If we remove row $\underset{\sim}{z}_k^T$, $k \in I$, then $\underset{\sim}{z}_0^T$ will be linearly independent from the rows z_i^T, $i \in I - \{k\}$, and because of the linear independency of rows $\underset{\sim}{z}_i^T$ will form a new set of linearly independent rows $\{\underset{\sim}{z}_0^T, \underset{\sim}{z}_i^T : i \in I, i \neq k\}$.

Corollary 2

If $\underset{\sim}{Z}_{MF}$ contains a zero row and the corresponding voltage $\Delta V^M \in \Delta \underset{\sim}{V}^M$ is nonzero then $\Delta \underset{\sim}{J}^F$ does not represent all the faults in the network, therefore, other candidates for faults should be considered.

A simple topological interpretation can be given to illustrate Lemma 1 and Corollary 2. Element $z_{ij} \in \underset{\sim}{Z}_{MF}$ is nonzero if and only if

det $\underset{\sim}{Y}(i|j) \neq 0$ ($i \in M$, $j \in F$). This condition is topologically equivalent to the existence of the 1-connection which contains the path directed from node i to node j in the graph G(i|j).

Graph G(i|j) is obtained from the Coates graph of the network after deleting all the edges incoming to the node i and all the edges outgoing from the node j.

To fulfill the condition stated in the Lemma 1 it is sufficient that there exists a node $i \in M-E$ which is the origin of a path incoming to one of the F nodes, and if after deleting the edges incident to this path the remaining graph contains at least one 0-connection.

Element $z_{ij} \in \underset{\sim}{Z}_{MF}$ is zero when there is no path directed from the node i to j or for every such path if I denotes the set of nodes belonging to the path det Y(I|I) = 0. This case is rare in electronic circuits.

IV. NETWORK PARTITIONING INTO FAULT REGIONS

The main problem in multiple-fault location is to guess the set F that contains all faulty elements but has a number of elements $f < m$. We discuss how to choose this proper set of elements. The aim is to improve efficiency of computations when no additional information about possible faults exist.

Every set of w elements which contains all f faults ($w \geq f$) we call a fault region and denote it by $F_{w,f}$. The fault region can be predicted or designed initially by the approximate fault isolation method described in [9]. If we have no initial information about the system we can try to guess the proper set F but then the probability of being correct is low because the number of different combinations is equal to

$\binom{p}{f}$, where p denotes the number of elements (cf. [5]). Below we describe the algorithm which can be used to detect the fault region and is very effective if the number of measurements is large.

It is evident that if we have m measurement ports then the maximum fault region we can find may have at most w = m-1 elements.

Algorithm

Step 1

We divide arbitrarily the set of all elements on k distinct subsets $S_1, \ldots, S_k$, each of them of cardinality equal to $E(\frac{m-1}{f})$. Of course, if $p/E(\frac{m-1}{f})$ is not integer the last subset has less than $E(\frac{m-1}{f})$ elements. So $k \geq p/E(\frac{m-1}{f})$.

Step 2

We can check every f from k subsets by examining the relation (8) for all combinations of subsets. The number of these combinations $\binom{k}{f}$ is usually much less than $\binom{p}{f}$ when $(m-1) \geq 2f$.

If the number of faulty elements is really f (or less) there always exists such a combination of subsets for which the relation (8) is fulfilled. The sum of the subsets of this combination is the first fault region

$$F_{w,f} = \bigcup_{i \in I} S \tag{17}$$

where $w = f.E(\frac{m-1}{f})$, and $I = \{i_1, i_2, \ldots, i_f\}$, $1 \leq i_j \leq k$, $i_j \neq i_\ell$ for $j \neq \ell$.

Step 3

In every next step of the algorithm we will find fault regions containing all the f faults but having fewer elements in the following way.

Divide the set $F_{w,f}$ arbitrarily on (f+1) subsets and then check which combination of f subsets contain all fault elements. In every stage of such a procedure, after checking f+1 combinations, we can eliminate at least $E(\frac{w}{f+1})$ elements as not belonging to the faults. We obtain a new fault region $F_{w',f}$ with $w' < w$, and repeat Step 3.

Step 4

The algorithm stops when w = f and when there is no (f-1) elements in the $F_{f,f}$ for which the relation (8) is fulfilled. If this is not the case we set $f \leftarrow f-1$ and return to Step 3.

Example 1

Let us assume that a network under consideration has p = 76, m = 39, f = 2. Then realizing the algorithm we design:

1. $k \geq \frac{p}{E(\frac{m-1}{f})} = \frac{76}{19} = 4$, for example, k = 4.

2. We check $\binom{k}{f} = \binom{4}{2} = 6$ different combinations of elements, to find the first fault region $F_{38,2}$.

3. In every step of this stage of the algorithm we check 3 combinations obtaining successively the following fault regions:

$F_{26,2}$, $F_{18,2}$, $F_{12,2}$, $F_{8,2}$, $F_{6,2}$, $F_{4,2}$, $F_{3,2}$, $F_{2,2}$.

In this example, therefore, we have to check not more than 30 combinations instead of $\binom{76}{2} = 2850$, which is much easier in spite of the higher ranks of the matrices to be computed.

Example 2

For a network having 100 elements and 4 faults, when we have 61 measurement ports, we can design all the faults by checking 112 combinations instead of $\binom{100}{4} = 3921225$ combinations, each of 4 elements.

V. SOME PRACTICAL REMARKS

Biernacki and Bandler [5] stated that condition (8) is satisfied if and only if the following relation holds

$$(\underset{\sim}{\bar{Z}}_{MF} - \underset{\sim}{1})\ \Delta\underset{\sim}{V}^{M} = \underset{\sim}{0}, \tag{18}$$

where

$$\underset{\sim}{\bar{Z}}_{MF} \triangleq \underset{\sim}{Z}_{MF}\ (\underset{\sim}{Z}^{T}_{MF}\ \underset{\sim}{Z}_{MF})^{-1}\ \underset{\sim}{Z}^{T}_{MF}. \tag{19}$$

Now we propose a simpler method which can be used to verify the condition (8).

One can prove that the solution of the equation

$$\underset{\sim}{A}\ \underset{\sim}{x} = \underset{\sim}{b}, \tag{20}$$

where $\underset{\sim}{A}$ is an (mxf) full column rank matrix ($f < m$), exists if and only if it can be transformed to the form

$$\begin{bmatrix} 1 & x & & x \\ 0 & 1 & & x \\ \cdot & & \cdot & \cdot \\ \cdot & & & \cdot \\ 0 & & & 1 \\ \hline & & \underset{\sim}{0} & \end{bmatrix} \underset{\sim}{x} = \begin{bmatrix} \underset{\sim}{b}_1 \\ -- \\ \underset{\sim}{0} \end{bmatrix} \qquad (21)$$

after row manipulation, where $\underset{\sim}{b}_1$ is a column vector having f elements. The form (21) is also more convenient to obtain the solution of the set of equations.

Example 3

To compare the two methods let us solve the overdetermined system of equations

$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \\ 4 & 3 \\ 2 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 1 \\ -1 \\ -6 \\ -4 \end{bmatrix}. \qquad (22)$$

We have

$$\underset{\sim}{A}^T \underset{\sim}{A} = \begin{bmatrix} 30 & 28 \\ 28 & 30 \end{bmatrix}, \quad (\underset{\sim}{A}^T \underset{\sim}{A})^{-1} = \frac{1}{116} \begin{bmatrix} 30 & -28 \\ -28 & 30 \end{bmatrix}$$

$$\overline{\underset{\sim}{A}} = \underset{\sim}{A}(\underset{\sim}{A}^T \underset{\sim}{A})^{-1} \underset{\sim}{A}^T = \frac{1}{116} \begin{bmatrix} 38 & 50 & -8 & -20 \\ 50 & 78 & 20 & -8 \\ -8 & 20 & 78 & 50 \\ -20 & -8 & 50 & 38 \end{bmatrix}$$

$$(\underset{\sim}{\overline{A}} - \underset{\sim}{1}) \begin{bmatrix} 1 \\ -1 \\ -6 \\ -4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}.$$

Consequently, we have checked consistency using 83 multiplications and divisions and still do not know the solution, while after transforming the system to the form

$$\left[\begin{array}{cc} 1 & 2 \\ 0 & 1 \\ \hline 0 & 0 \\ 0 & 0 \end{array}\right] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \left[\begin{array}{c} 1 \\ 2 \\ \hline 0 \\ 0 \end{array}\right]$$

we can easily compute x_1, x_2 and we used 11 multiplications and divisions only.

For ill-conditioned systems the method of Householder orthogonal transformations can be used to reduce to zero the subdiagonal elements of $\underset{\sim}{A}$ [10].

For practical situations when both measurement errors and effects of tolerances appear, the technique proposed by Bandler, Biernacki and Salama [9] can be used. In the first stage of computation we solve an optimization problem that can be stated as

$$\text{Minimize} \sum_{i=1}^{n} (|\text{Re}(\Delta J_i^F)| + |\text{Im}(\Delta J_i^F)|) \tag{23}$$

subject to linear equality constraints (8). Solution of this problem gives us the most likely faulty elements. Then the verification technique in the presence of tolerances can be used to check (8) in the way described in [9].

Example 4

Consider the network shown in Fig. 3 with nominal values of elements $G_i = 1$, $i = 0,1,2,3$, $C_1 = C_2 = 1$, $k = 1$. All elements have tolerances $\pm$ 10%. The input current excitation $J_g = 1A$. Voltage measurements for the faulty network (for which $G_2 = 0.5$, $C_1 = 0.8$, $C_2 = 0.5$) are taken as $V_1 = 0.712 - j0.0648$, $V_2 = 0.137 - j0.195$, $V_3 = 0.147 - j0.0076$, $V_4 = -0.0085 + j0.0819$. The solution of the optimization problem (23) gives us the following changes in nodal currents:

$$\Delta J_1 = 0.0288 - j0.0654, \quad \Delta J_2 = -0.1114 + j0.0049,$$

$$\Delta J_3 = -0.0407 + j0.0024, \quad \Delta J_4 = -0.1387 - j0.0709.$$

This can be solved to obtain predicted changes in element values and we find three elements whose values violate the tolerances, namely G_2, C_1, C_2. The verification technique confirms the assumption that G_2, C_1 and C_2 are faulty. We checked the remaining combinations for the triple fault hypothesis and no feasible solution was detected.

Notice that in the present case of faults which were detected in the network under test, the multiport method will not work because of the cutset formed by the faulty elements.

VI. CONCLUSIONS

The method presented extends the possibilities of multiport methods used for multiple-fault location. Topological restrictions discussed in the paper show that in some cases faults cannot be identified if the measurements are imposed in the wrong place. Multiple-fault location analysis is necessary when we want to isolate faults inside a subnetwork without a sufficient number of measurements to identify all subnetwork components.

The recommended approach to fault analysis would be realized by employing the various techniques described here and elsewhere. First, the identification of as many subnetworks or network elements as is possible, using accurate and efficient techniques [1,2] is carried out and then the further investigation of subnetworks found to be faulty may be carried out, if necessary. The latter investigation should also be performed in two stages: first predicting the faulty region using the nodal approach we have presented employing linear programming techniques, and then a more accurate localization of faults using the verification method [9] together with network partitioning into fault regions as described in Section IV.

The authors believe that their approach together with the practical remarks presented allows more opportunities to effectively solve fault location problems in linear networks.

REFERENCES

[1] T.N. Trick, W. Mayeda and A.A. Sakla, "Calculation of parameter values from node voltage measurements", IEEE Trans. Circuits and Systems, vol. CAS-26, 1979, pp. 466-474.

[2] N. Navid and A.N. Wilson, Jr., "A theory and an algorithm for analog circuit fault diagnosis", IEEE Trans. Circuits and Systems, vol. CAS-26, 1979, pp. 440-457.

[3] H.M. Merrill, "Failure diagnosis using quadratic programming", IEEE Trans. Reliability, vol. R-22, 1973, pp. 207-213.

[4] M.N. Ransom and R. Saeks, "Fault isolation with insufficient measurements", IEEE Trans. Circuit Theory, vol. CT-20, 1973, pp. 416-417.

[5] R.M. Biernacki and J.W. Bandler, "Multiple-fault location of analog circuits", IEEE Trans. Circuits Systems, vol. CAS-28, 1981, pp. 361-367.

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

[7] C.W. Ho, A.E. Ruehli and P.A. Brennan, "The modified nodal approach to network analysis", IEEE Trans. Circuits and Systems, vol. CAS-22, 1975, pp. 504-509.

[8] J.A. Starzyk, R.M. Biernacki and J.W. Bandler, "Design of tests for parameter identification by voltage measurements", Faculty of Engineering, McMaster University, Hamilton, Canada, Report SOC-266, 1981.

[9] J.W. Bandler, R.M. Biernacki and A.E. Salama, "A linear programming approach to fault location in analog circuits", Proc. IEEE Int. Symp. Circuits and Systems (Chicago, IL, 1981), pp. 256-260.

[10] J.K. Reid, Ed., Large Sparse Sets of Linear Equations. New York: Academic Press, 1971.

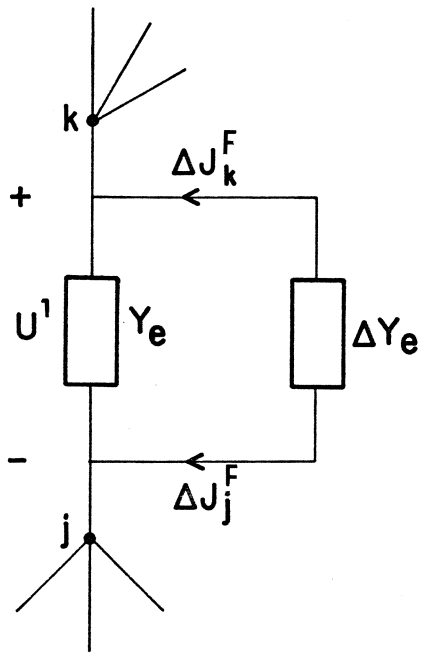

Fig. 1 Changes in nodal current caused by a single fault.

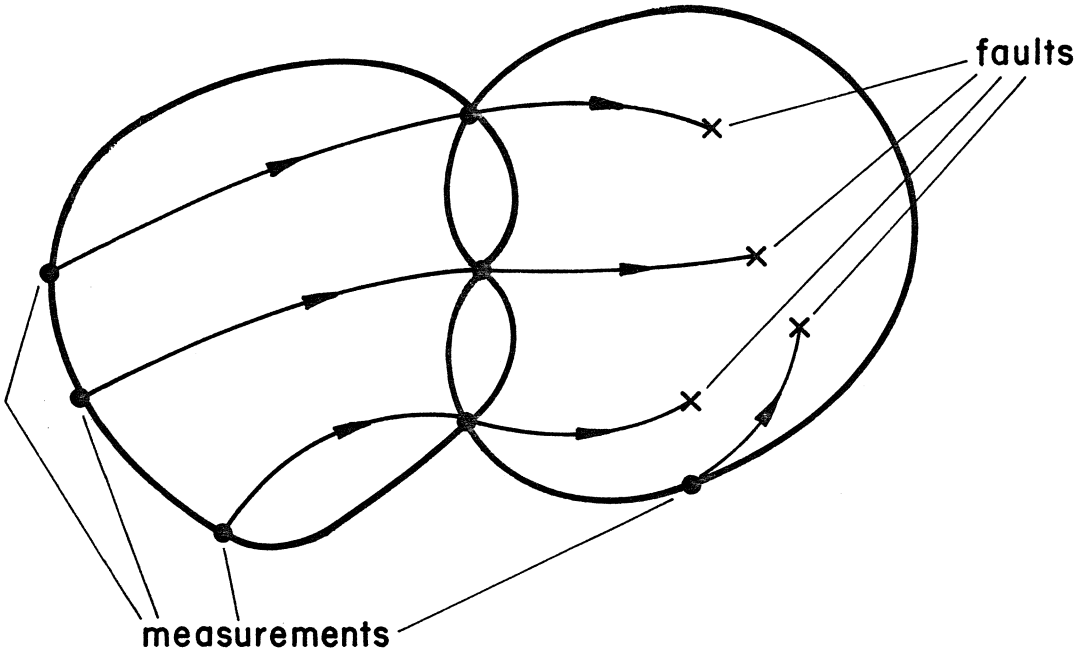

Fig. 2 Illustration of necessary connections.

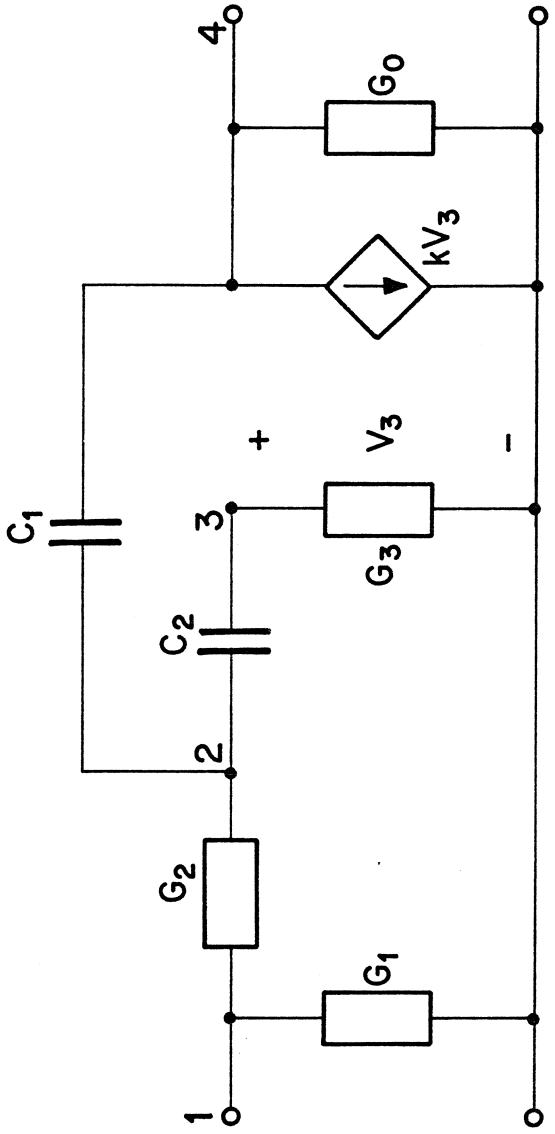

Fig. 3 Active filter example.

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