COMPUTER AIDED DESIGN OF A SECOND-ORDER STATE VARIABLE NETWORK

by

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STATEMENT BY AUTHOR

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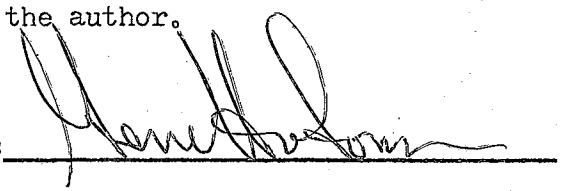
SIGNED: 

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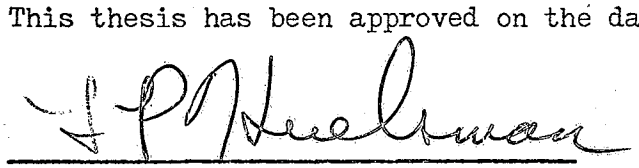

Lawrence P. Huelsman
Professor of Electrical Engineering

May 3, 1974
Date

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To my wife, Hyun Sil who typed my very rough draft and drew all the figures, a special note of thanks for her patience.

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ABSTRACT

There are several synthesis methods using operational amplifiers for realization of high-Q active RC networks. Among them, the state variable synthesis method has been proven to be a most useful realization.

Studies in the literature have indicated that the state variable network is limited in usefulness particularly for high-Q at higher frequency because for a given set of network element values, the change in the pole locations of this network is very significant to network performances when the gain bandwidth product of the operational amplifier becomes small.

This thesis finds network element values for a desired Q, in other words, for a specified voltage transfer function, taking into account the non-idealness of the amplifier. The amplifier is characterized by a one-pole rolloff model including the finite input and non-zero output impedances.

The actual realization of the network elements of this circuit is implemented by two separate computer programs which are written in Fortran. The first program is made for the analysis of both the ideal and the finite gain operational amplifier cases for the sixteen combinations of the passive elements in an equal capacitor type. The second program is made for the analysis of the non-ideal operational amplifier case for one of the combinations mentioned above.

CHAPTER 1

INTRODUCTION AND STATEMENT OF THE PROBLEM

1.1 Historical Background

Active RC networks are very often a necessity especially when the reduction in size and weight is a major concern. Since inductors are physically large and expensive at low frequencies and narrow bandwidths and since it is virtually impossible to realize practical inductors in integrated circuits, many studies have been made on synthesis methods for inductorless networks.

Owing to the advent of integrated circuit technology, the operational amplifier has been used as an economic and versatile active element in synthesis methods of high-Q active RC filters. Though several methods using operational amplifier exist, it has been proven that the state variable synthesis method is a most useful realization of high-Q active RC networks.

The state variable network is shown in Fig. 1.1. It consists of six resistors, two capacitors and three operational amplifiers. This network was presented by Kerwin, Huelsman and Newcomb (1967). The paper which introduced the network in Fig. 1.1 will be referred to the KHN paper from now on. This network is commercially available (Burr-Brown, 1973).

1.2 Statement of the Problem

Since any higher order network can be realized as a cascade of first or second-order networks, the second-order network only is taken into account here. It is shown in the KHN paper that the second-order transfer function can be obtained with low Q sensitivity to the passive elements and the active elements at Q's less than 1000. Moreover, this network may be used to obtain bandpass, high-pass and lowpass realizations simultaneously. This network is, however, limited in usefulness, particularly for high-Q at higher frequencies, because of its dependency on the gain and phase vs. frequency characteristics of the operational amplifier (Tarmy and Ghausi, 1970). These characteristics are shown in Fig. 1.2. For simplicity, only the bandpass realization of the second-order state variable network is treated in the following text.

The following questions will be studied thoroughly, resulting in two computer programs.

1. Which combination of the eight passive elements in Fig. 1.1 results in the best network performance in terms of the element spread and the sensitivities of pole, Q and center frequency to the passive elements?
2. What effects does the finite gain of the operational amplifier have on the passive element values and the limitation of realizable Q?
3. How do the passive element values vary due to the frequency dependency and the non-ideal input and output impedances of the operational amplifier?

The study for the questions 1 and 2 will result in the first computer program in Fortran which is described in Chapter 5. The second computer program in Chapter 5 is used to answer the question 3.

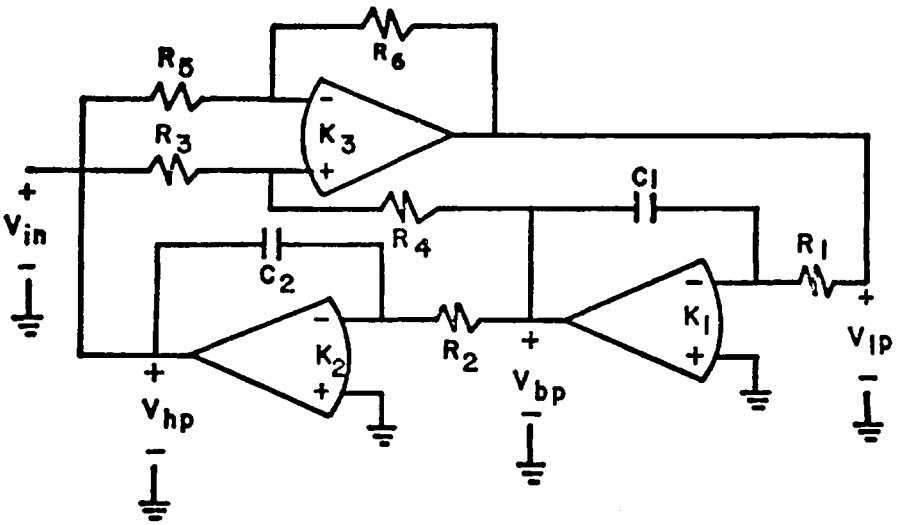


Figure 1.1. A second-order state variable network. V_{lp} is for lowpass, V_{bp} for bandpass, and V_{hp} for highpass.

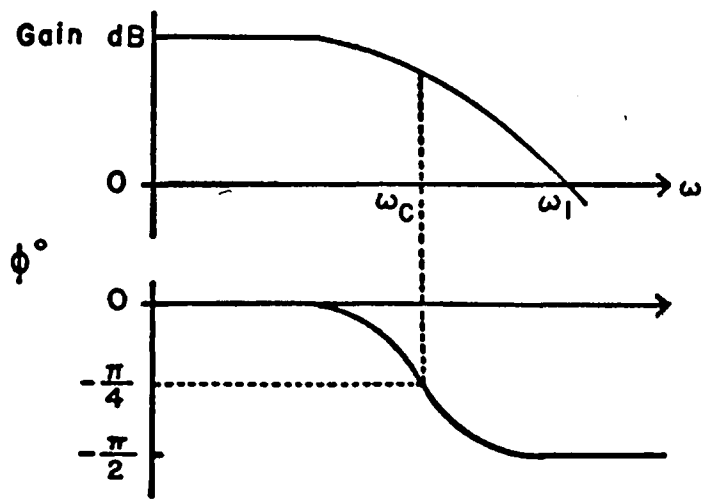


Figure 1.2. Magnitude and phase characteristics of an operational amplifier.

CHAPTER 2

THE ANALYSIS I

The analysis I in this chapter and the analysis II in Chapter 3 are based on open-circuit voltage transfer function in the complex frequency domain where s is the complex frequency variable. The coefficients of the transfer function are specified to obtain some desired network performance. The purpose of these analyses is to find the defining relations by which the given coefficients are interrelated to the network elements. These defining relations are required for the synthesis method which will be discussed in Chapter 4.

2.1 The Ideal Operational Amplifier

It is assumed here that each amplifier in Fig. 1.1 is considered as ideal, i.e., infinite gain, infinite input and zero output impedances.

In general, the transfer function for the bandpass realization of Fig. 1.1 is

$$T(s) = \frac{V_{out(s)}}{V_{in(s)}} = \frac{-Hs}{s^2 + a_1 s + a_o} \qquad (2.1)$$

The defining relations are easily derived. They are

$$a_1 = \frac{G_1 G_4 S_1 (G_5 + G_6)}{G_6 (G_3 + G_4)} \tag{2.2a}$$

$$a_o = \frac{G_1 G_2 G_5 S_1 S_2}{G_6} \tag{2.2b}$$

$$H = \frac{G_1 G_3 S_1 (G_5 + G_6)}{G_6 (G_3 + G_4)} \tag{2.2c}$$

Where the G_i are conductance and the S_i are the reciprocal of capacitance. From Eqs. (2.2a) and (2.2c) the relation between a_1 and H is

$$H = \frac{G_3}{G_4} a_1 \tag{2.3}$$

It is seen in Eqs. (2.2a), (2.2b) and (2.2c) that the eight element values must be determined from the only three equations. Thus five out of the eight unknowns may be arbitrarily set to unity. Before choosing these, it is noteworthy that an equal capacitor network has a decided cost advantage over an equal resistor type. For the equal capacitor type, there are twenty possible combinations in which three resistors may be set to unity. The sixteen cases considered here have the common characteristic that the unknowns in each case depend only on the coefficients which are specified for a desired Q. In the other four cases, at least one of the unknowns is found to be negative at Q's greater than 2.

For the sixteen cases of the equal capacitor type, the unknown resistor values are obtained as well as the value of element spread and various sensitivities. The element spread is defined as the ratio of the maximum to the minimum element value. Sensitivities will be discussed in section 2.3. An additional case, the equal resistor one, is also considered for the sake of comparison. The above analysis is implemented by the program I in Chapter 5.

2.2 Finite Gain of the Operational Amplifier

It was assumed that the amplifier was ideal in the analysis of the previous section. Such an assupmtion gives results which disagree with the actual circuit's performance particularly for the high-Q case. In actual fact, the amplifier has a finite gain. It, as well as the input and output impedances may also depend on frequency. In this section an analysis is made to find the transfer function with the assumption that the amplifier has a finite gain over all frequencies and infinite input and zero output impedances. Now the amplifier acts like an ideal voltage controlled voltage source as shown in Fig. 2.1 such that

$$V_{out} = K \cdot V_{in} \qquad (2.4)$$

where K is a negative constant.

By replacing each amplifier by the model in Fig. 2.1, the equivalent circuit of Fig. 1.1 can be redrawn as shown in Fig. 2.2. By using parallel ideal voltage sources, the circuit is now broken into three interdependent subcircuits as shown in Fig. 2.3. From the summer circuit, the following equation is obtained

$$V_{in} = \frac{(G_3 + G_4)G_5}{G_3(G_5 + G_6)} V_8 - \frac{(G_3 + G_4)\left[G_5 + G_6(1 - K_3)\right]}{G_3K_3(G_5 + G_6)} V_4 - \frac{G_4}{G_3} V_6 \tag{2.5}$$

From the integrator circuits, V_8 and V_4 can be expressed in terms of V_6 as below

$$V_4 = \frac{G_1 + (1 - K_1)C_1 s}{G_1K_1} V_6 \tag{2.6}$$

$$V_8 = \frac{G_2K_2}{G_2 + (1 - K_2)C_2 s} V_6 \tag{2.7}$$

By substituing Eqs. (2.6) and (2.7) into Eq. (2.5), the overall transfer function is obtained using V_6 as the output voltage V_{out}. The general transfer function for the network in Fig. 2.2 can now be written as

$$T(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-Hs + b_o}{s^2 + a_1 s + a_o} \tag{2.8}$$

Division of the numerator and denominator polynomials by the coefficient of the second-order term of the denominator polynomial of the overall transfer function gives defining relations between the coefficients of Eq. (2.8) and the network elements. They are

$$a_1 = \frac{1}{D} G_1 G_4 S_1 (G_5 + G_6) \left(\frac{1}{K_2} - 1\right) \tag{2.9a}$$

$$a_o = \frac{1}{D}\left\{- S_1 S_2 G_1 G_2 G_5 (G_3 + G_4) + \frac{1}{K_2} S_1 S_2 G_1 G_2 G_4 (G_5 + G_6) + \frac{1}{K_1 K_2} S_1 S_2 G_1 G_2 (G_3 + G_4) \left[\frac{G_5}{K_3} + G_6 \left(\frac{1}{K_3} - 1\right)\right]\right\} \tag{2.9b}$$

$$H = \frac{1}{D} G_1 G_3 S_1 (G_5 + G_6) \left(\frac{1}{K_2} - 1\right) \tag{2.9c}$$

$$b_o = \frac{-1}{D} G_1 G_2 G_3 S_1 S_2 (G_5 + G_6) \frac{1}{K_2} \tag{2.9d}$$

where $D = (G_3 + G_4)\left[\frac{G_5}{K_3} + G_3 \left(\frac{1}{K_3} - 1\right)\right] \left(\frac{1}{K_1} - 1\right) \left(\frac{1}{K_2} - 1\right)$,

the G_i are conductances, the S_i the reciprocal of the capacitances, and the K_i the gains of the operational amplifiers as shown in Fig. 2.2.

From Eq. (2.9d), it is obvious that consideration of finite gain of the amplifier moves the zero of the transfer function at the origin to the negative real axis. It will be shown in Chapter 5 that this movement is negligible even for high-Q case.

The simultaneous set of nonlinear equations given in (2.9) may be solved, by the use of a computer. For each of the sixteen cases of the equal capacitor type mentioned in the previous section, the above equations will be solved iteratively using the Newton-Raphson method which will be studied in Chapter 4. As in the ideal amplifier case, the element spread and the sensitivities will be obtained as well as the optimum set of network passive elements for each case. This task is also carried out by the program I in Chapter 5.

2.3 The Sensitivities

As mentioned in Chapter 1, the state variable network can be obtained with low sensitivities to passive and active elements for moderately high-Q realizations. It is, however, worthwhile to find the various sensitivities for each realization discussed in Sections 2.1 and 2.2 since such a sensitivity study will be used as a criteria by means of which the performance of each realization can be evaluated and compared with the others. It is one of the purposes of the program I in Chapter 5 to give the user as much information for each realization as possible. As for sensitivity, the following types are obtained with respect to passive and active elements: coefficient, pole, Q, and center frequency sensitivities. Each

sensitivity is generally defined as the ratio of normalized change in a network parameter y to normalized change in a network element x such that

$$S_x^y = \frac{\delta y/y}{\delta x/x} \tag{2.10}$$

In our sensitivity study, x could be any one of the passive elements and the gains of the operational amplifiers, while y could be one of the coefficients, the upper left half plane pole locations, the center frequency ω_o, or Q. It is noteworthy that at the center frequency, ω_o

$$S_x^{a_1} = - S_x^T \tag{2.11}$$

where a_1 and T are defined in Eq. (2.1) for the analysis in Sec. 2.1 and Eq. (2.8) for the analysis in Sec. 2.2. For most high-Q cases, the variation of transfer function magnitude is usually maximum at ω_o since $S_x^{T(j\omega_o)}$ is the frequency of maximum signal output. Since $S_x^T = S_x^{|T|} + jArg\ T\ S_x^{Arg\ T}$ at ω_o, the coefficient sensitivity for a_1, shows how the magnitude and phase of the transfer function is varying in response to the normalized change in x. Program I is designed to calculate all the sensitivities referred to above.

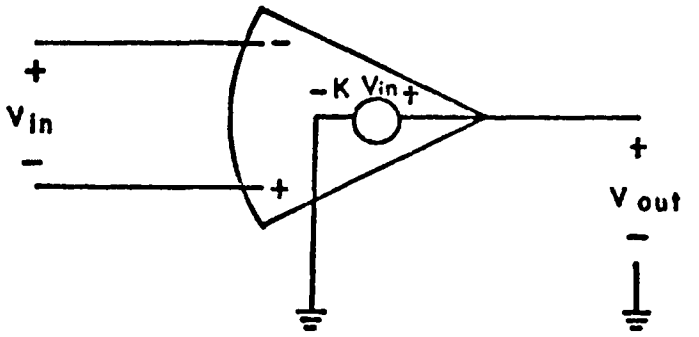


Fig. 2.1. Model for finite gain operational amplifier

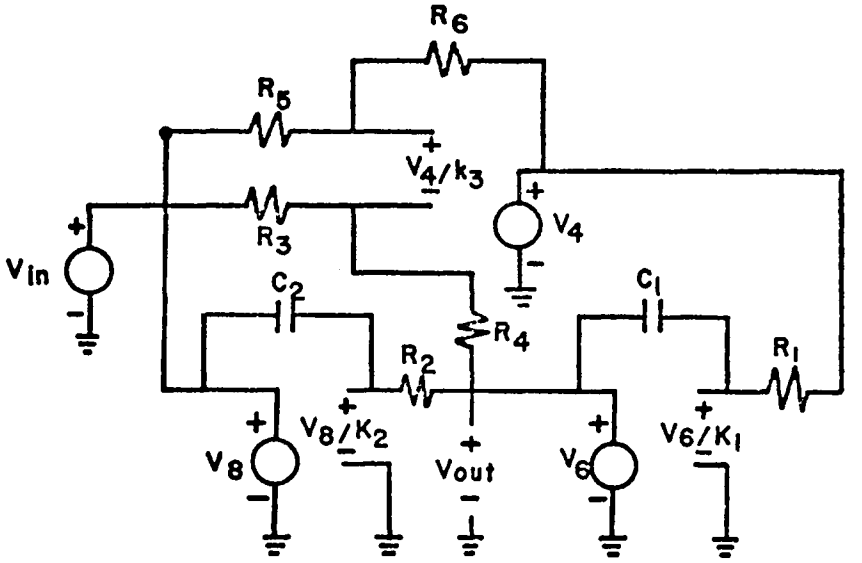
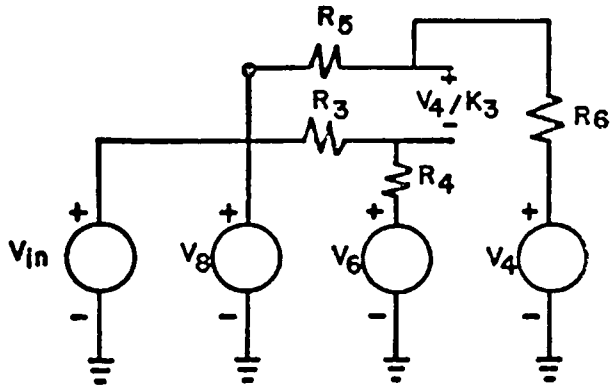
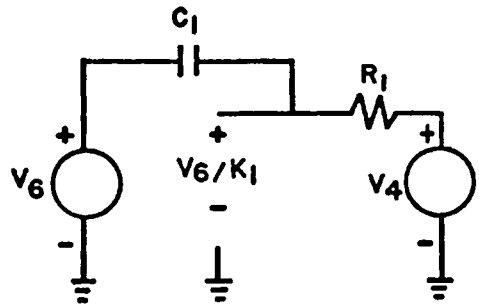


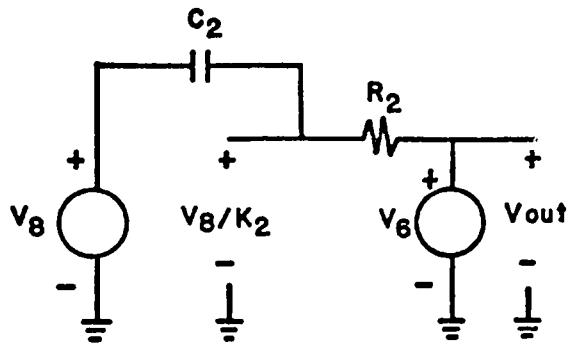
Fig. 2.2. The equivalent circuit of Fig. 1.1, redrawn using ideal voltage sources in place of the amplifiers.



The Summer Circuit



The First Integrator Circuit



The Second Integrator Circuit

Fig. 2.3. The state variable network broken into three subcircuits by the use of parallel voltage sources.

CHAPTER 3

THE ANALYSIS II

3.1 AC Characterization of the Operational Amplifier (OA)

As mentioned in Section 2.2, a real OA does not usually maintain constant gain and input and output-impedance characteristics over the frequency range of interest. This chapter discusses the frequency dependence of the open-loop gain and the impedances as well as the modifications to the analysis method due to this.

The integrated-circuit (IC) OA's have high dc gain which starts rolling off at a certain frequency. Since the high open-loop gain has to be realized by cascading several stages, a stability problem is involved. There are numerous methods avaiable to shape the frequency response so that stable operation is guaranteed. Among these single-pole compensation is widely adopted in the internally compensated IC OA's. In the present discussion, the single-pole compensation is assumed for the OA's whose characteristics are shown in Fig. 1.2. Thus, the open-loop gain K may be expressed as

$$K(s) = \frac{K_o \omega_c}{s + \omega_c} \tag{3.1}$$

where K_o is the negative open-loop dc gain and ω_c is the cut-off frequency of the compensated pole. The frequency dependency on the

voltage gain has been studied and analyzed for its effects on various networks by Budak and Petrela (1972).

Generally, there are two kinds of resistances in the model for the input circuitry of the OA. One is the differential input resistance R_{id}, and the other is the two common-mode resistances from each of the two inputs to ground. Since the common-mode resistance R_{cm} is much larger than the differential input resistance, the effect of R_{cm} can be neglected for most of the practical applications. The output resistance R_o is also seen at the output terminal of the real OA. The equivalent circuit of a non-ideal OA incorporating input resistance and output resistance is given in Fig. 3.1 where the voltage controlled voltage source has been replaced by the Norton equivalent. The effect of the input and output resistances of the OA was not studied by the Budak and Petrela paper.

Strictly speaking, the input resistance R_i and the output resistance R_o are also frequency dependent. However, this happens only near the 0-dB gain frequency and the change is usually very small. Therefore R_i and R_o are assumed to be constant. Generally, this assumption holds true if the six resistors shown in Fig. 1.1 are much larger than R_o and much smaller than R_i.

3.2 The Equivalent Circuit

When the single-pole model of the OA is used for all OA's, a fifth-order denominator polynomial results. The defining relations by which the coefficients of the fifth-order polynomial are related

to the network parameters are quite involved. As a result, it is found that the analysis method used in Sec. 2.2 becomes complicated since two resistors are added for each OA. Therefore a different analysis method is used.

The model in Fig. 3.1 is used in the place of the OA, resulting in the equivalent circuit of Fig. 1.1. This circuit is shown in Fig. 3.2 with every node numbered sequencially. Note that this circuit contains only current sources as dependent sources. Therefore, it is apparent that the nodal admittance matrix can be easily formed by finding the admittances at each node. For simplicity of the analysis, this circuit is broken into the three subcircuits exactly in the same way as was done in Sec. 2.2. These three interdependent subcircuits are shown in Fig. 3.3 with each node maintaining the same node number as in Fig, 3.2. Now the admittance matrix is obtained for each subcircuit. Since each circuit has one dependent current source, its output must be added to that of the independent current source at the same node. For the first integrator circuit, the node equations in matrix form are

$$\begin{bmatrix} I_6 \\ I_4 \\ I_5 \end{bmatrix} = \begin{bmatrix} G_{o1} + sC_1 & 0 & -sC_1 - K_1 G_{o1} \\ 0 & G_1 & -G_1 \\ -sC_1 & -G_1 & G_1 + sC_1 + G_{i1} \end{bmatrix} \begin{bmatrix} V_6 \\ V_4 \\ V_5 \end{bmatrix} \qquad (3.2)$$

Similarly, for the second integrator circuit,

$$\begin{bmatrix} I_8 \\ I_6 \\ I_7 \end{bmatrix} = \begin{bmatrix} G_{o2} + sC_2 & 0 & -sC_2 - K_2G_{o2} \\ 0 & G_2 & -G_2 \\ -sC_2 & -G_2 & G_2 + sC_2 + G_{i2} \end{bmatrix} \begin{bmatrix} V_8 \\ V_6 \\ V_7 \end{bmatrix} \qquad (3.3)$$

For the summer circuit, the node equations in matrix form can be expressed as

$$\begin{bmatrix} I_1 \\ I_6 \\ I_8 \\ I_4 \\ I_3 \\ I_2 \end{bmatrix} = \begin{bmatrix} G_3 & 0 & 0 & 0 & 0 & -G_3 \\ 0 & G_4 & 0 & 0 & 0 & -G_4 \\ 0 & 0 & G_5 & 0 & -G_5 & 0 \\ 0 & 0 & 0 & G_6+G_{o3} & -G_6-K_3G_{o3} & K_3G_{o3} \\ 0 & 0 & -G_5 & -G_6 & G_5+G_6+G_{i3} & -G_{i3} \\ -G_3 & -G_4 & 0 & 0 & -G_{i3} & G_{i3}+G_3+G_4 \end{bmatrix} \begin{bmatrix} V_1 \\ V_6 \\ V_8 \\ V_4 \\ V_3 \\ V_2 \end{bmatrix} \qquad (3.4)$$

Since there are six nodes in the circuit, the 6 by 6 admittance matrix is obtained as above. To obtain the overall node equations in matrix form, Eqs. (3.2), (3.3) and (3.4) must be added to form eight simultaneous equations in matrix form.

Now the problem is how to derive the open-circuit voltage transfer function from the 8 by 8 admittance matrix. The task is

simplified by noting that

$$I_i = 0 \quad \text{except for } i = 1 \tag{3.5}$$

The above fact is true because there is no independent source except at the input node 1 and because the output is assumed to be open-circuited. Utilization of Eq. (3.5) produces the following reduction procedure. The general node equation in matrix form is

$$\underline{I} = \underline{\underline{Y}}\,\underline{V} \tag{3.6}$$

where the bar under the letters indicates the matrix and

$\underline{I}$	n x 1	nodal independent current source vector;
$\underline{\underline{Y}}$	n x n	admittance matrix;
$\underline{V}$	n x 1	nodal voltage source vector.

Partitions of I, Y and V matrices in the following manner

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} I_1 \\ 0 \\ \vdots \\ 0 \end{bmatrix} = \left[\begin{array}{c|c} \underline{A} & \underline{B} \\ \hline \underline{C} & y'_{nn} \end{array}\right] \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} \tag{3.7}$$

give the matrix equations

$$\underline{X} = \underline{\underline{A}}\underline{Z} + \underline{B}V_n \tag{3.8a}$$

$$I_n = 0 = \underline{\underline{C}}\underline{Z} + y'_{nn}V_n \tag{3.8b}$$

where $\underline{X} = \left[I_1, I_2, \cdots, I_{n-1}\right]^t$,

$\underline{Z} = \left[V_1, V_2, \cdots, V_{n-1}\right]^t$ and t indicates the transpose.

From Eqs. (3.8a) and (3.8b)

$$\underline{X} = \left(\underline{A} - \frac{1}{y'_{nn}}\underline{\underline{BC}}\right)\underline{Z} \tag{3.9}$$

By comparing Eq. (3.6) with Eq. (3.9), it is apparent that $\underline{I}$, $\underline{Y}$ and $\underline{V}$ are corresponding to $\underline{X}$, $\left(\underline{A} - \frac{1}{y'_{nn}}BC\right)$ and $\underline{Z}$ respectively. The difference is that the orders of the latter are less by one. By repeating the above operation (n-2) times, the short-circuit y parameter matrix is obtained

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{3.10}$$

Since $I_2 = 0$, the open-circuit voltage transfer function is

$$V_{oc}(s) = \frac{V_2(s)}{V_1(s)} = \frac{-y_{21}(s)}{y_{22}(s)} \tag{3.11}$$

This iterative reduction operation is very amenable to computer implementation.

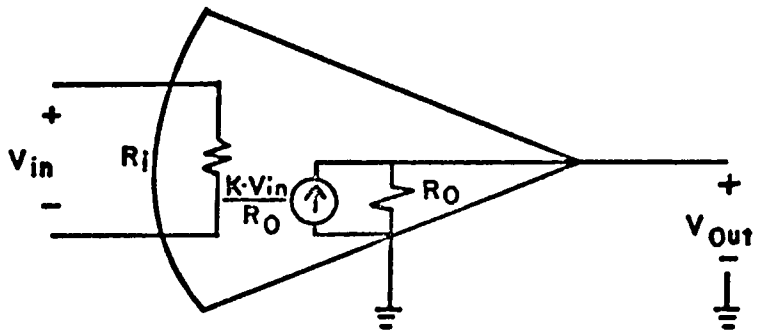


Fig. 3.1. The equivalent circuit of a non-ideal OA.

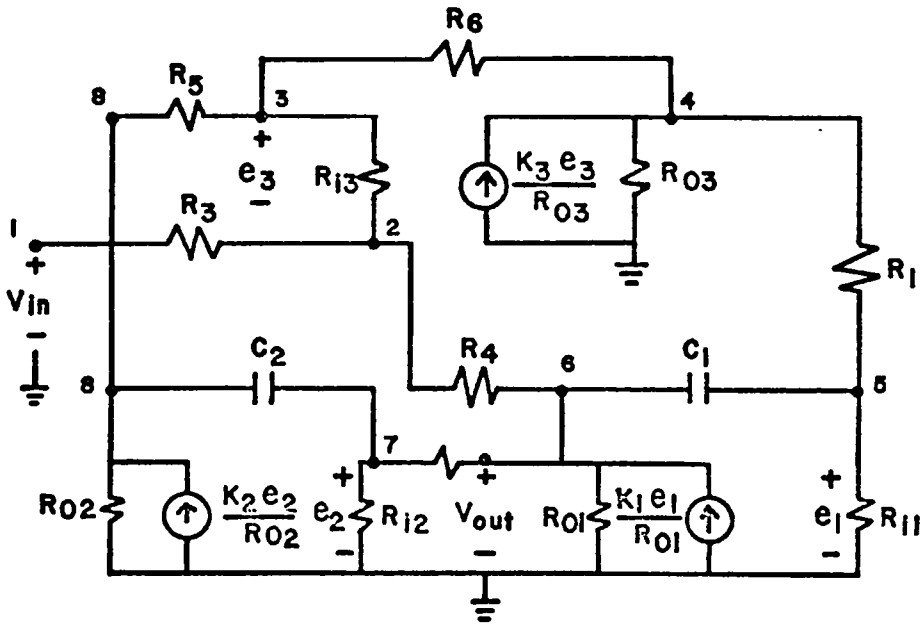
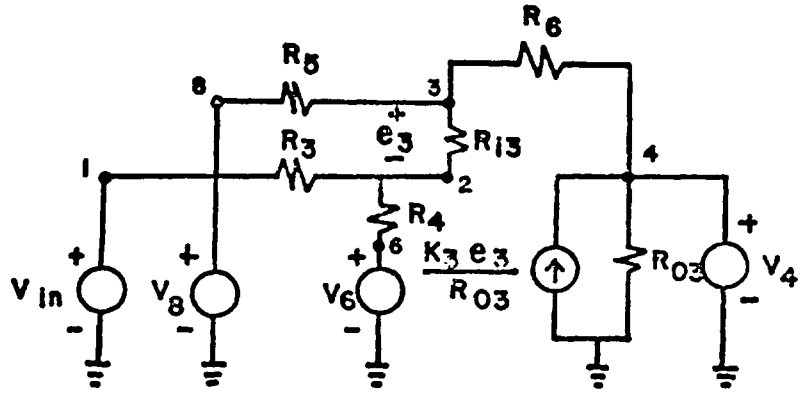
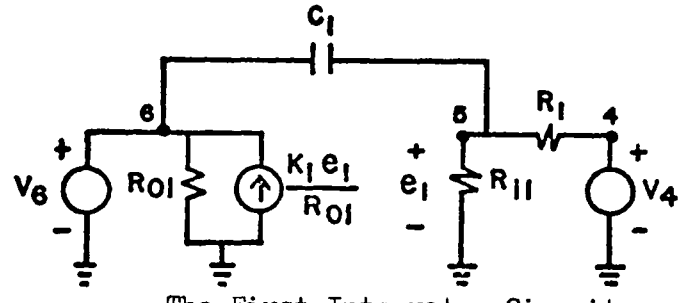


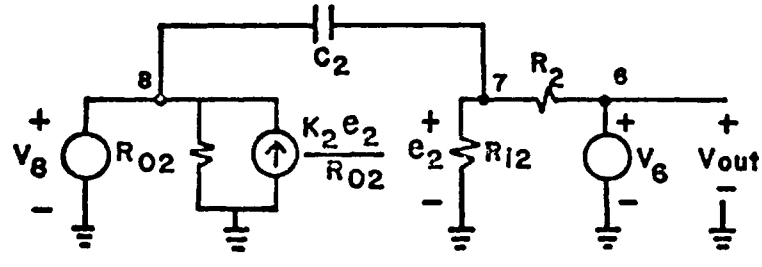
Fig. 3.2. The equivalent circuit of Fig. 1.1, redrawn using a non-ideal amplifier model.



The Summer Circuit



The First Integrator Circuit



The Second Integrator Circuit

Fig. 3.3. The three subcircuits of Fig. 3.2. divided as in Fig. 2.3.

CHAPTER 4

SYNTHESIS

The synthesis problem in this chapter is how to find the network element values from the defining relations which were obtained in Chapters 2 and 3 for the given state variable network configuration.

4.1 The Ideal OA Case

From the analysis in Section 2.1, the general defining relations, Eqs. (2.2a), (2.2b) and (2.2c) were obtained. For the equal resistor type and the sixteen cases in the equal capacitor type, the relations pertinent to each case are easily found by substituting the unity values for the specified elements into the general defining relations. They are shown in the program I by which the unknown network variables are obtained. Since these relations are linear, there is no need of a special technique to solve them.

4.2 The Finite Gain OA Case

As shown in Eqs. (2.9a), (2.9b) and (2.9c), the defining relations are a simultaneous set of nonlinear equations which must be solved for the unknown network element values. For the solution of

nonlinear equations, an optimization approach is used. To introduce this approach, the following terms are defined:

Parameters: These are the quantities whose values will be determined to satisfy the requirments as closely as possible. The symbols $x_i (i = 1,2, \cdots, n)$ are used to represent these parameters in the defining relations.

Independent Variable: The performance of a network can be described in either time domain or frequency domain through the use of an independent variable. In the complex frequency comain, a network function may be written N(s) where s is the independent variable. The symbol h is used for the independent variable. For the specific values of h, the symbol $h_i (i = 1,2, \cdots, n_h)$ are used.

Defining relations: As introduced in Chapter 2, these are functional relationships by which the parameters and the independent variable of a given network interrelate to determine the network performance. The symbol $g(h, \underline{x})$ is used, where h is the independent variable and $\underline{x}$ is the parameter vector with elements x_i, for the defining relation. For specific values of h, the symbol g_i are used such that

$$g_i = g(h_i, \underline{x}) \quad (i = 1,2, \cdots, n_h) \tag{4.1}$$

Requirements: These are the values of g_i which it is desired to match as closely as possible. The symbol r_i $(i = 1,2, \cdots, n_h)$ are used for the requirements.

Error Criteria: A positive scalar quantity which indicates how closely the optimization procedure comes to an exact sloution. The value of zero for the error means the exact solution is achieved. The error function is defined as

$$y = \sum_{i=1}^{n_h} (r_i - g_i)^2 \tag{4.2}$$

To apply the optimization technique to solve the nonlinear equations, Eqs. (2.9a), (2.9b) and (2.9c) can be rewritten using the terms defined as above. Let $g_i(x)$ represent the coefficients of the transfer function where $i = 1,2, \cdots, n_h$. Since the independent variable h is not used in this problem formulation, the constant n_h refers to the number of requirements, r_i, the desired values for the coefficients of the transfer function of Eq. (2.1) and x_i represents the network elements, namely the six resistors, the two capacitors and the three gains of the OA's such that

$$x_i = \begin{cases} R_i & \text{for} \quad i = 1,2, \cdots, 6 \\ C_1, C_2 & \text{for} \quad i = 7,8 \\ K_1, K_2, K_3 & \text{for} \quad i = 9,10,11 \end{cases} \tag{4.3}$$

Since the sixteen cases in the equal capacitor type are only considered, C_i and K_i are constant and three of the R_i are set to unity values for each case. Therefore the three unknowns will be found with the three given defining relations. Now Eqs. (2.9a), (2.9b) and (2.9c)

become the defining relations, g_i respectively

$$g_1(\underline{x}) = \frac{1}{D}\left\{x_2x_3x_8(x_5+x_6)\left(\frac{1}{x_{10}}-1\right)+(x_3+x_4)\left[\frac{x_6}{x_{11}}+x_5\left(\frac{1}{x_{11}}-1\right)\right]\right.$$

$$\left.\left[\frac{x_2x_8}{x_9}\left(\frac{1}{x_{10}}-1\right)+\frac{x_1x_7}{x_{10}}\left(\frac{1}{x_9}-1\right)\right]\right\} \qquad (4.4a)$$

$$g_2(\underline{x}) = \frac{1}{D}\left\{-x_6(x_3+x_4)+\frac{x_3}{x_{10}}(x_5+x_6)+\frac{1}{x_9x_{10}}(x_3+x_4)\right.$$

$$\left.\left[\frac{x_6}{x_{11}}+x_5\left(\frac{1}{x_{11}}-1\right)\right]\right\} \qquad (4.4b)$$

$$g_3(\underline{x}) = \frac{1}{D}\,x_2x_4x_8(x_5+x_6)\left(\frac{1}{x_{10}}-1\right) \qquad (4.4c)$$

where $D = x_1x_2x_7x_8(x_3+x_4)\left(\frac{1}{x_9}-1\right)\left(\frac{1}{x_{10}}-1\right)\left[\frac{x_6}{x_{11}}+x_5\left(\frac{1}{x_{11}}-1\right)\right]$.

And the requirements are

$$r_1 = a_1 \qquad (4.5a)$$

$$r_2 = a_o \qquad (4.5b)$$

$$r_3 = H \qquad (4.5c)$$

where a_1, a_o and H are defined in Eq. (2.1) and their values are given to specify a desired Q realization. The error function in

Eq. (4.2) becomes

$$y = \sum_{i=1}^{3} (r_i - g_i)^2 \qquad (4.6)$$

Now the optimization procedure is initiated by choosing a set of initial values for x_i and the quantities g_i are determined. The next step is to compute the error function y to see if it is less than some specified maximum allowable error. If the error is not satisfactory, the x_i are perturbed by some optimization strategy. The process is repeated until the quantities g_i agree with the requirements r_i within a preset tolerance.

Numerous optimization strategies are available to find a better set of x_i which has a lower error than the preceding set. Experience has shown than the Newton-Raphson method is a most efficient way to slove the problem at hand as long as a set of good initial points are provided. However, the choice of the initial points is not a problem here since the solutions from the ideal case in Sec. 4.1 are found to provide an excellent set of initial points for this nonlinear equation problem. To see how the Newton-Raphson strategy works, refer to (Huelsman, September 1968)

4.3 The Non-Ideal OA Case

In this section a discussion is given to show how the defining relations g_i are formulated from the network function which was derived in Sec. 3.2. The formulation technique used here is based on

the fact that the poles of the network function occur at those points in the complex frequency domain where the magnitude of the network function takes on a very large (in theory, infinite) value. Thus, the purpose of this technique is to find the network variables x_i whose values will produce as large a value of the magnitude of the network function as possible at the pole locations. This technique is called complex optimization. It is much easier to apply with numbers which get very small rather than those which get very large. Therefore, it is more convenient to minimize the reciprocal of the magnitude rather than to maximize the magnitude of the network function at the pole locations.

Now the complex optimization is applied to the problem at hand. For simplicity, one of the sixteen cases in the equal capacitor type is chosen which has the minimum value of element spread. This is the case 8 obtained by using program I. It must be noted that due to frequency dependence of the OA, each integrator now has two poles and the summing amplifier has one pole. Therefore it must be guaranteed in order to apply this optimization technique that these additional poles do not influence the pole locations which are given to realize a desired Q. They are found to be located far out in the left half plane. Since the coefficients are specified for a desired Q, the pole locations are easily calculated as the following.

$$p_{1,2} = \frac{-a_1}{2} \pm j\sqrt{a_o - \left(\frac{a_1}{2}\right)^2} \qquad (4.7)$$

where a_1 and a_o are defined in Eq. (2.1). The upper left half plane pole p_1 is separated into the real and imaginary parts which are assigned the independent variables, h_1 and h_2 respectively. In case 8, R_4 and R_6 are only the unknowns. These are assigned the symbols x_4 and x_6 respectively. Note the number of the defining relations g_i must be equal to that of the independent variables h_i. This difficulty is easily overcome by separating the real and imaginary parts of the reciprocal of the network function and assigning them as g_1 and g_2 respectively such that

$$g_1 = \text{Real} \frac{1}{V_{oc}(h_1 + jh_2, \underline{x})} \tag{4.8a}$$

$$g_2 = \text{Imag} \frac{1}{V_{oc}(h_1 + jh_2, \underline{x})} \tag{4.8b}$$

where v_{oc} is expressed in Eq. (3.11) and $\underline{x}$ is the parameter vector with elements x_4 and x_6. The requirements are

$$r_1 = r_2 = 0 \tag{4.9}$$

Now the same optimization strategy, i.e., the Newton-Raphson method, is applied to find the values of x_4 and x_6 which makes the error criteria, Eq. (4.6) as small as possible.

The complex optimization method of problem formulation has many advantages over the non-linear equation problem formulation case

(Huelsman, September 1968). Experience, however, has shown that for the problem at hand the complex optimization method is more sensitive to having a good set of initial points than in the non-linear equation method. The reason for this is that the optimization process is carried out on the defining relation which is its reciprocal instead of the network function itself. This difficulty can be, however, removed by using the solution set from the finite gain OA case in Sec. 4.2, as the initial points.

The optimization procedures in this chapter are implemented by the two programs I and II which are described in the next chapter.

CHAPTER 5

THE PROGRAMS

The purpose of this chapter is to show how the synthesis methods are carried out by the digital computer. It also includes the instructions by which the reader can use the programs which are written in Fortran.

5.1 The Program I

The program I includes a main program and eight individual subroutines. A brief description of each follows.

MAIN — The program reads two input cards:

The first card contains the variable KDB in Format (I1).

KDB = 0; The ideal OA case is only considered. Otherwise, both the ideal and finite gain OA cases are treated.

The second card includes the three coefficients of the transfer function in Eq. (2.1), the three gains of the OA's an increment for differentiation and a maximum allowable error for the

Newton-Raphson method. Format (8E10.0) is used. The variables are

A1 = the coefficient of the first order in the denominator polynomial.

A0 = the constant term in the denominator polynomial.

H = the coefficient of the negative of the first order term in the numerator polynomial.

XK1 = the negative dc gain of the OA in the first integrator.

XK2 = the negative dc gain of the OA in the second integrator.

XK3 = the negative dc gain of the OA in the summer.

DX = the incremental variation of the parameters for differentiation..

EMAX = the minimum required value for the error function y.

If no specifications are made for the variables XK1, XK2, XK3, DX and EMAX, they are given default values as follows.

$XK1 = XK2 = XK3 = -10^{8}$

$DX = 10^{-6}$

$EMAX = 10^{-12}$

SPREAD — the element spread value is found by using the library functions, AMAX nad AMIN.

PRINT1 — the values of all parameters x_i are printed for the ideal OA case. This subroutine has two entries, i.e., PRINT2 and PRINT3 for the finite gain OA case. PRINT2 calculates b_o which is the constant term in the numerator polynomial of the transfer function in Eq. (2.8). It also prints out all parameters x_i. PRINT3 finds actual value of H against the user's specified value of H.

EQNMX — These are the equations obtained by subtracting the defining relations g_i in Sec. 4.2 by the requirements r_i. Thus a solution is obtained when those equations have zero values.

NEWTMX — The Newton-Raphson method is programmed to solve the non-linear equation problem. It requires the additional subroutines, i.e., EQNMX, MXINV and MXMULT.

MXINV — The Gauss-Jordan Reduction method is used to implement the inverse of the Jacobian matrix in the implementation of the Newton-Raphson algorithm.

MXMULT — Multiplies a square matrix by a vector.

COEF1 — The coefficients of the transfer function in Eq. (2.1), are expressed in terms of the network parameters x_i. For the ideal OA case, the gains of

the OA's take on very large value such as -10^8. This subroutine has one entry whose name is COEF2 for the finite gain OA case. In addition, the real and imaginary parts of the upper left half pole and the center frequency are expressed in terms of the coefficients mentioned herein. They are stored in the array A in the same order as described.

SENS1 — The sensitivity function in Eq. (2.10) is carried out. The differentiation is calculated by

$$\frac{dA(x)}{dx} = \frac{A(x+\Delta x) - A(x-\Delta x)}{2\Delta x} \qquad (5.1)$$

where A is defined in COEF1. For the finite gain OA case, the entry, SENS2 is included which calls COEF2 as SENS1 does COEF1.

Listings of the actual programs are included in Appendix A. For more specific user's instructions and example outputs, refer to Appendix C.

5.2 The Program II

This program covers the non-ideal OA case mentioned in Sec. 4.3. Since case 8 only is considered, the related parts are extracted from the program MAIN in the previous program. Besides the slight changes in MAIN and NEWTMX, one additional subprogram, EQNMX2

must be added to the existing ones in the program I. For EQNMX2, the 8 x 8 nodal admittance matrix in Sec. 4.3 is reduced to 4 x 4 matrix to simplify the analysis. This reduced matrix is stored in the complex two-dimensional array Y1(4,4). In Appendix B, listings of the modified programs, MAIN and NEWTMX1, and the additional subprogram EQNMX2 are shown. The rest of the programs are same as in program I. The internal structure of program II is essentially the same as that of program I. Since the OA is considered as a non-ideal active element, an additional input card is required. This specifies the input and output-impedance and the cut-off frequency of the one-pole model. These are assigned to the following variables using Format (7E10.0).

XI = one-dimensional array for the input impedances. The first variable is for the first integrator, the second for the second integrator and the third for the summer.

XO = one-dimensional array for the output impedances. The entries are same as in XI.

WC = the cut-off frequency, which is assumed to be same for all OA's.

5.3 Results

This section displays a series of results which are obtained from the programs I and II.

In Table 5.1, the results are collected from the output of the program I for a realization with Q = 100. As shown in the KHN paper, the sensitivities for each case are found to be below unity

and they are not listed in the table. It is apparent that any case is not decisively superior to others in terms of the element spread and the sensitivities. In the last column of the table, note that the numerator polynomial has a constant term, b_o for the finite gain OA case while it has only the coefficient of its first order term H for the ideal OA case.

The effects of dc gain of the OA on the network variables R_4 and R_6 are investigated for various Q realizations. The results show that there is negligible increase in R_6 with Q. Thus only the variation of R_4 is taken into consideration in Fig. 5.1. It is observed from Fig. 5.1 that there is a minimum K_o which is required for a desired Q realization. Therefore, an appropriate minimum dc gain is required for the OA's corresponding to each desired Q. This observation results in Fig. 5.2

From the program II, the effects of the non-ideal OA charateristics on R_4 and R_6 are obtained to produce Table 5.2 and Fig. 5.3. As seen in the results from the program I, the effect on R_6 is again negligible. It is shown in Table 5.2 that the considerable change in R_4 occurs at extreme conditions such as $R_{in} = 10$ and $R_{out} = 10$. For the data in Table 5.2 the following conditions were assumed.

$$\begin{aligned} Q &= 500 \\ K_o &= -10^4 \\ \omega_c &= 10^6 \end{aligned} \qquad (5.2)$$

The effect of the cut-off frequency $_c$ of the OA on R_4 is shown in Fig. 5.3. As expected, the change in R_4 is apparent at the lower value of $_c$ when sufficiently high Q is realized. For Fig. 5.3, the following conditions were assumed.

$$\begin{aligned} K_o &= -10^4 \\ R_i &= 10^4 \\ R_o &= 10^{-2} \end{aligned} \qquad (5.3)$$

Table 5.1. Comparison of the results from the different combinations of the passive elements for Q = 100.

Unity Elements	Realized Elements			Element Spread		Numerator Coefficients H and b_o		
	Ideal OA Case		Finite Gain OA Case (-10^3)	Ideal OA Case	Finite Gain OA Case (-10^3)	Ideal OA Case		Finite Gain OA Case (-10^3)
Case 1 all Resistors	C_1	100.	——	10^4	——	H	0.01	——
	C_2	0.01						
Case 2	R_2	1.01	1.0100			H	2.0	2.0
$C_1 = C_2 =$	R_3	0.005	0.0040	202	253.14			
$R_1 = R_4 = R_5$	R_6	1.01	1.0141			b_o	0.0	-1.9782E-3
Case 3	R_1	1.010	0.9902			H	2.0	1.9999
$C_1 = C_2 =$	R_3	0.005	0.0040	202	250.23			
$R_2 = R_4 = R_5$	R_6	1.01	0.9941			b_o	0.0	-1.9979E-3
Case 4	R_1	0.995	0.9930			h	2.0	2.0
$C_1 = C_2 =$	R_2	1.005	1.003	201	251.82			
$R_3 = R_5 = R_6$	R_4	200.0	250.01			b_o	0.0	-1.9920E-3
Case 5	R_1	0.995	0.9930			H	2.0	2.0
$C_1 = C_2 =$	R_2	1.005	1.0030	201	250.81			
$R_4 = R_5 = R_6$	R_3	0.005	0.0040			b_o	0.0	-1.9920E-3
Case 6	R_2	1.000	0.9960			H	1.99	1.9860
$C_1 = C_2 =$	R_3	1.000	1.0000	199	249.31			
$R_1 = R_5 = R_6$	R_4	199.0	248.31			b_o	0.0	-1.9920E-3
Case 7	R_1	1.000	0.9960			H	1.99	1.9940
$C_1 = C_2 =$	R_3	1.000	1.0000	199	250.31			
$R_2 = R_5 = R_6$	R_4	199.	249.31			b_o	0.0	-1.9920E-3
Case 8	R_4	199.0	248.69			H	1.99	1.99
$C_1 = C_2 =$	R_5	1.0000	1.0000	199	248.69			
$R_1 = R_2 = R_3$	R_6	1.0000	1.0040			b_o	0.0	-1.988E-3
Case 9	R_2	1.01	1.0100			H	2.0	2.0
$C_1 = C_2 =$	R_4	200.0	249.63	200	249.63			
$R_1 = R_3 = R_5$	R_6	1.01	1.0141			b_o	0.0	-1.9782E-3
Case 10	R_2	1.01	1.0100			H	2.0	2.0
$C_1 = C_2 =$	R_4	200.0	249.63	202	253.14			
$R_1 = R_3 = R_6$	R_5	0.9901	0.9861			b_o	0.0	-1.9782E-3
Case 11	R_2	1.01	1.0100			H	2.0	2.0
$C_1 = C_2 =$	R_3	0.005	0.0040	202	252.13			
$R_1 = R_4 = R_6$	R_5	0.9901	0.9861			b_o	0.0	-1.9782E-3
Case 12	R_3	0.005	0.0040			H	1.99	1.99
$C_1 = C_2 =$	R_5	1.000	0.9960	199	248.69			
$R_1 = R_2 = R_4$	R_6	1.000	1.0000			b_o	0.0	-1.9880E-3
Case 13	R_3	0.005	0.0040			H	1.99	1.99
$C_1 = C_2 =$	R_4	1.000	1.0000	199	249.08			
$R_1 = R_2 = R_5$	R_6	1.000	1.0040			b_o	0.0	-1.9880E-3
Case 14	R_3	1.000	1.0000			H	1.99	1.99
$C_1 = C_2 =$	R_4	199.0	248.69	199	249.68			
$R_1 = R_2 = R_6$	R_5	1.000	0.9960			b_o	0.0	-1.9880E-3
Case 15	R_1	0.9901	0.9901			H	2.0	2.0
$C_1 = C_2 =$	R_4	200.0	250.25	202	252.76			
$R_2 = R_3 = R_5$	R_6	0.9901	0.9940			b_o	0.0	-1.9980E-3
Case 16	R_1	0.9901	0.9901			H	2.0	2.0
$C_1 = C_2 =$	R_4	200.0	250.25	202	252.76			
$R_2 = R_3 = R_6$	R_5	1.010	1.0080			b_o	0.0	-1.9980E-3
Case 17	R_1	1.000	0.9901			H	2.0	2.0
$C_1 = C_2 =$	R_3	0.005	0.0040	200	251.75			
$R_2 = R_4 = R_6$	R_5	1.000	1.0000			b_o	0.0	-1.9980E-3

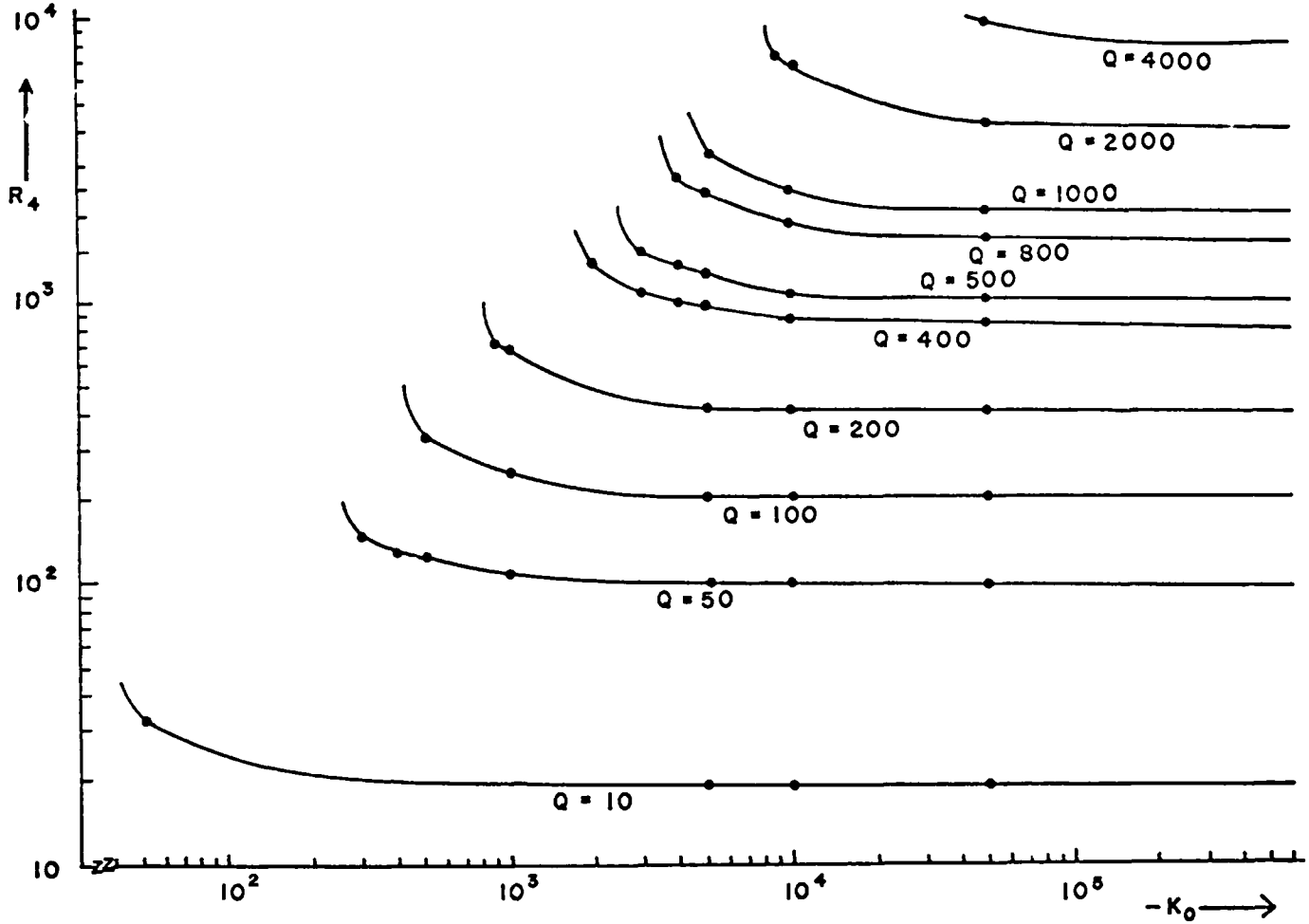


Fig. 5.1. The effect of the dc OA gain on R_4 for various Q realizations.

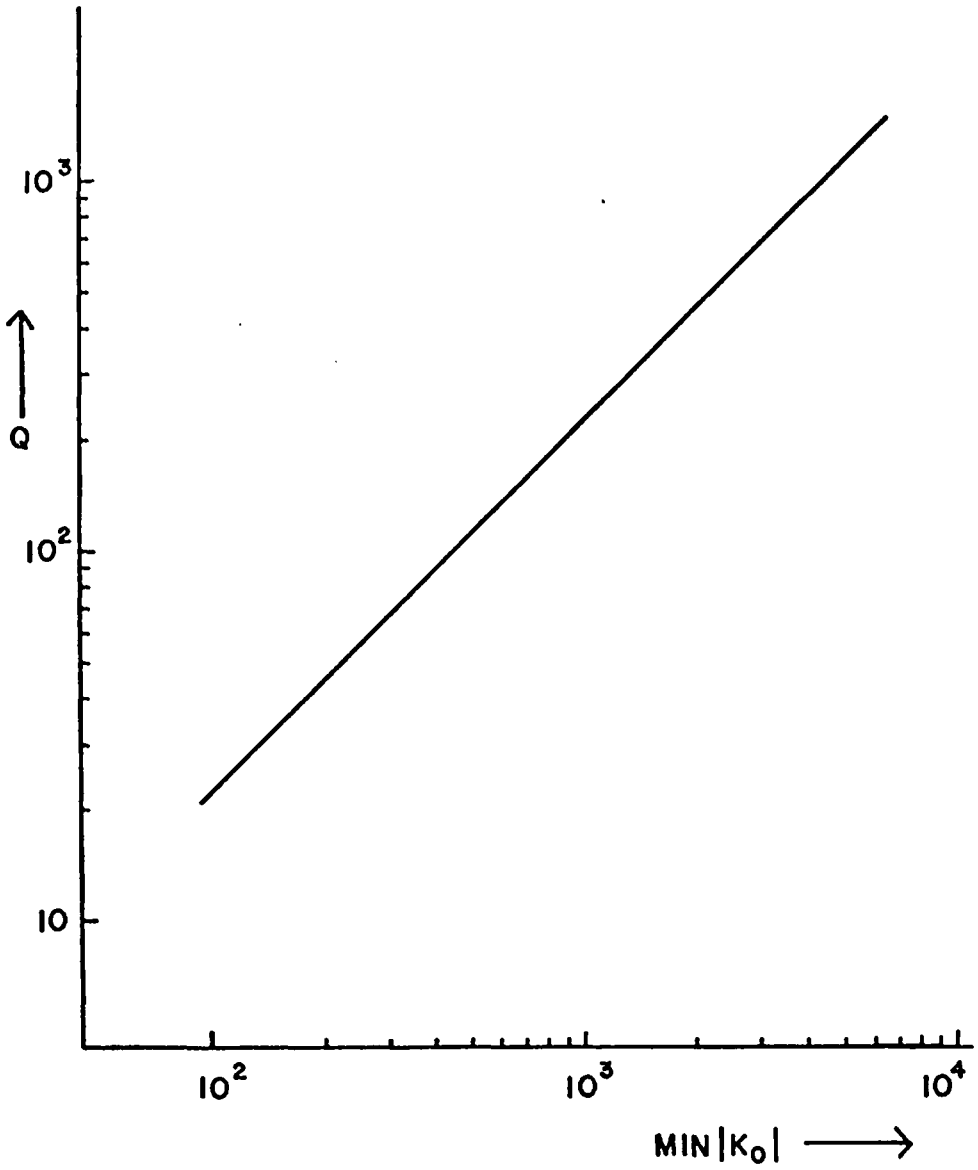


Fig. 5.2. Minimum dc OA gain required to realize a desired Q.

Table 5.2. The effect of the input and output impedances on R_4 for Q=500.

Input Impedance	Output Impedance			
	10^{-2}	10^{-1}	1	10
10^4	1.1100E+3	1.1100E+3	1.1098E+3	1.1023E+3
10^3	1.1101E+3	1.1101E+3	1.1100E+3	1.1035E+3
10^2	1.1112E+3	1.1113E+3	1.1122E+3	1.1156E+3
10	1.1224E+3	1.1235E+3	1.1344E+3	1.2531E+3

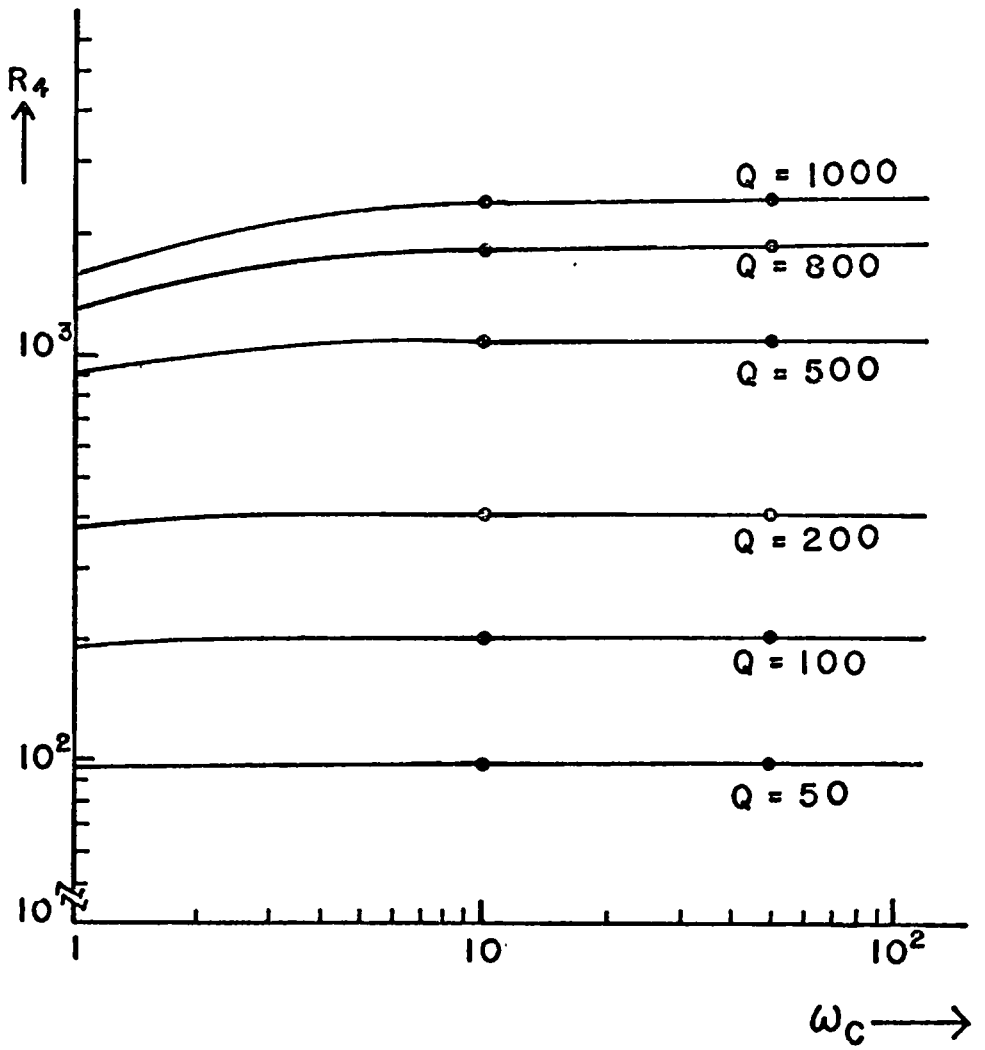


Fig. 5.3. The effect of the OA cut-off frequency on R_4 for various Q realizations.

CHAPTER 6

CONCLUSION

Although studies in the literature have indicated that the non-ideal characteristics of the OA's have considerable effect on the pole location of a KHN filter, especially for very high-Q realizations, no data has been given for the actual realization of network elements for desired pole locations, taking these effects into account. As shown in this paper, both the frequency dependency on the OA gain and phase as well as the input and output-impedance have, in fact, noticeable effects on the network element values, especially for high-Q realization. Through use of the programs I and II, an optimum set of network elements can be found which compensates for the effects of the non-idealness of the OA.

Further work on this network could be done. As mentioned in Chapter 1, the KHN filter may be used to obtain lowpass and highpass realizations besides the bandpass realization which has been considered here. The methods outlined can be readily applied to these realizations with little difficulties since the general defining relations which govern this filter configuration, have been already derived in this text. In general, the optimization techniques mentioned have been found to be very effective to study the effects of the non-idealness of

other controlled source realizations, producing an optimum set of network element values.

APPENDIX A

LISTING OF THE PROGRAM I

```
                PROGRAM MAIN(INPUT,OUTPUT,TAPE3=INPUT)
    3           DIMENSION A(7),AP(7),AM(7),S(11,7),X(11),L(3),NAME(7),F(3),FPERT(3
               $),AA(3,3),BB(3),CC(3)
    3           REAL JAC(10,10),JACINV(10,10),M(3)
    3           COMMON/COEFF/A1,A0,H/SENS/NX,DX/GAINS/XK1,XK2,XK3
    3           DATA (NAME(I),I=1,7),NV,NX,NA/2HA1,2HA0,1HH,8HREALPOLE,8HIMAGPOLE,
               $1HQ,2HWC,11,8,7/
    3           READ 18,KOB
   11       18 FORMAT(I1)
   11        1 READ 2,A1,A0,H,XK1,XK2,XK3,DX,EMAX
   35        2 FORMAT (8E10.0)
   35          IF(EOF,3) 999,4
   40        4 IF(XK1.EQ.0.) XK1=-1.E+8
   43          IF(XK2.EQ.0.) XK2=-1.E+8
   46          IF(XK3.EQ.0.) XK3=-1.E+8
   51          IF(DX.EQ.0.) DX=1.E-6
   54          IF(EMAX.EQ.0.) EMAX=1.E-12
   57          Q=(SQRT(A0))/A1
   64          PRINT 99,A1,A0,H,XK1,XK2,XK3,DX,EMAX,Q
  111       99 FORMAT(*1SPECIFIED COEFFICIENTS,GAINS OF THREE OP-AMPS,INCREMENT F
               $OR DIFFERENTIATION,MAXIMUM ERROR FROM NEWTON ALGORITHM AND Q
               $*/5X,*A1*12X,*A0*11X*H*12X*K1*12X*K2*12X*K3*12X*DX*12X*ERROR* 9X*Q
               $*/1X,9E14.4)
  111          PRINT 100
  115      100 FORMAT(///1X,*(CASE 1-1) ALL RESISTORS EQUAL TO UNITY WITH INFINIT
               $E GAIN*)
  115          X(7)=1./A1
  121          X(8)=A1/A0
  124          X(1)=X(2)=X(3)=X(4)=X(5)=X(6)=1.
  146          PRINT 101,A1
  154      101 FORMAT(1X,*A1=*,E11.4,*=ACTUAL VALUE OF H*)
  154          IF(X(7).GT.X(8)) GO TO 98
  163          SP=X(8)/X(7)
  171          GO TO 97
  171       98 SP=X(7)/X(8)
  177       97 PRINT 96,SP
  205       96 FORMAT(* SPREAD OF TWO CAPACITORS=*,E11.4)
  205          CALL PRINT1(X,NV)
  207          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
  217          IF(KOB.EQ.0) GO TO 301
  221          PRINT 105
  225      105 FORMAT(1H1,1X*(CASE 2-1) C1=C2=R1=R4=R5=1 AND INFINITE GAIN*)
  225          X(7)=X(8)=1.
  233          X(1)=X(4)=X(5)=1.
  244          X(3)=A1/H
  250          X(6)=H*A1-1.
  255          X(2)=X(6)/A0
  262          CALL SPREAD(X,NV)
  264          CALL PRINT1(X,NV)
  266          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
  276          PRINT 106
  302      106 FORMAT(///,1X,*( CASE 2-2 )  WITH FINITE GAIN*)
  302          NI=3
  304          L(1)=3
  307          L(2)=6
```

MAIN

```
      L(3)=2
      CALL NEWTMX(X,L,DX,NI,EMAX)
      CALL SPREAD(X,NV)
      CALL PRINT3(X,NV)
      CALL PRINT2(X,NV)
      CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
  301 PRINT 107
  107 FORMAT(1H1,1X,*( CASE 3-1) C1=C2=R2=R4=R5=1 AND INFINITE GAIN*)
      X(2)=X(4)=X(5)=X(7)=X(8)=1.
      X(6)=(A1-A0+H)/A0
      X(3)=A1/H
      X(1)=X(6)/A0
      CALL SPREAD(X,NV)
      CALL PRINT1(X,NV)
      CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
      IF(KDB.EQ.0) GO TO 302
      PRINT 108
  108 FORMAT(///,1X*( CASE 3-2 ) WITH FINITE GAIN*)
      L(1)=6
      L(2)=3
      L(3)=1
      CALL NEWTMX(X,L,DX,NI,EMAX)
      CALL SPREAD(X,NV)
      CALL PRINT3(X,NV)
      CALL PRINT2(X,NV)
      CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
  302 PRINT 109
  109 FORMAT(1H1,1X,*( CASE 4-1 ) C1=C2=R3=R5=R6=1. AND INFINITE GAIN *)
      X(3)=X(5)=X(6)=X(7)=X(8)=1.
      X(1)=2./(A1+H)
      X(4)=H/A1
      X(2)=(A1+H)/(2.*A0)
      CALL SPREAD(X,NV)
      CALL PRINT1(X,NV)
      CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
      IF(KDB.EQ.0) GO TO 303
      PRINT 110
  110 FORMAT(///,1X,*( CASE 4-2 ) WITH FINITE GAIN*)
      L(1)=1
      L(2)=4
      L(3)=2
      CALL NEWTMX(X,L,DX,NI,EMAX)
      CALL SPREAD(X,NV)
      CALL PRINT3(X,NV)
      CALL PRINT2(X,NV)
      CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
  303 PRINT 111
  111 FORMAT(1H1,1X*( CASE 5-1 ) C1=C2=R4=R5=R6=1 AND INFINITE GAIN*)
      X(4)=X(5)=X(6)=X(7)=X(8)=1.
      X(1)=2./(A1+H)
      X(2)=1./(A0*X(1))
      X(3)=A1/H
      CALL SPREAD(X,NV)
      CALL PRINT1(X,NV)
      CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
      IF(KDB.EQ.0) GO TO 304

MAIN
```

```
  656          PRINT 112
  662      112 FORMAT(///,1X,*(CASE 5-2 ) FINITE GAIN*)
  662          L(1)=1
  665          L(2)=2
  670          L(3)=3
  673          CALL NEWTMX(X,L,DX,NI,EMAX)
  677          CALL SPREAD(X,NV)
  701          CALL PRINT3(X,NV)
  703          CALL PRINT2(X,NV)
  705          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
  715      304 PRINT 113
  721      113 FORMAT(1H1,1X,*( CASE 6-1 ) C1=C2=R1=R5=R6=1 AND INFINITE GAIN*)
  721          PRINT 114
  725      114 FORMAT(* R4/R3=H/A1, SET R3=1.*)
  725          H6=2.-A1
  727          PRINT 115,H6
  735      115 FORMAT(* H=*,E11.4,*=ACTUAL VALUE *)
  735          X(1)=X(5)=X(6)=X(7)=X(8)=X(3)=1.
  757          X(2)=1./A0
  763          X(4)=H6/A1
  766          CALL SPREAD(X,NV)
  770          CALL PRINT1(X,NV)
  772          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
 1002          IF(KOB.EQ.0) GO TO 305
 1004          PRINT 116
 1010      116 FORMAT(///,1X,*( CASE 6-2 ) FINITE GAIN *)
 1010          NI=2
 1012          L(1)=2
 1015          L(2)=4
 1020          CALL NEWTMX(X,L,DX,NI,EMAX)
 1023          CALL SPREAD(X,NV)
 1025          CALL PRINT3(X,NV)
 1027          CALL PRINT2(X,NV)
 1031          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
 1041      305 PRINT 117
 1045      117 FORMAT(1H1,1X,*( CASE 7-1 ) C1=C2=R2=R5=R6=1 AND INFINITE GAIN*)
 1045          PRINT 118
 1051      118 FORMAT(* R4/R3=H/A1, SET R3=1.*)
 1051          H7=2.*A0-A1
 1054          PRINT 119,H7
 1062      119 FORMAT(1H ,*H=*,E11.4,*=ACTUAL VALUE*)
 1062          X(7)=X(8)=X(2)=X(5)=X(6)=X(3)=1.
 1104          X(1)=1./A0
 1110          X(4)=H7/A1
 1113          CALL SPREAD(X,NV)
 1115          CALL PRINT1(X,NV)
 1117          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
 1127          IF(KOB.EQ.0) GO TO 306
 1131          PRINT 120
 1135      120 FORMAT(///,1X,*( CASE 7-2 ) FINITE GAIN*)
 1135          NI=2
 1137          L(1)=1
 1142          L(2)=4
 1145          CALL NEWTMX(X,L,DX,NI,EMAX)
 1150          CALL SPREAD(X,NV)
 1152          CALL PRINT3(X,NV)

MAIN
```

```
1154          CALL PRINT2(X,NV)
1156          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
1166      306 PRINT 121
1172      121 FORMAT(1H1,1X,*( CASE 8-1 ) C1=C2=R1=R2=R3=1 AND INFINITE GAIN *)
1172          PRINT 122
1176      122 FORMAT(* R6/R5=A0. SET R5=1.*)
1176          H8=1.+A0-A1
1201          PRINT 123,H8
1207      123 FORMAT(* H=*,E11.4,*=ACTUAL VALUE *)
1207          X(7)=X(8)=X(1)=X(3)=X(5)=X(2)=1.
1231          X(4)=H8/A1
1235          X(6)=A0
1240          CALL SPREAD(X,NV)
1242          CALL PRINT1(X,NV)
1244          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
1254          IF(KDB.EQ.0) GO TO 307
1256          PRINT 124
1262      124 FORMAT(///,1X,*( CASE 8-2 ) FINITE GAIN *)
1262          NI=2
1264          L(1)=4
1267          L(2)=6
1272          CALL NEWTMX(X,L,DX,NI,EMAX)
1275          CALL SPREAD(X,NV)
1277          CALL PRINT3(X,NV)
1301          CALL PRINT2(X,NV)
1303          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
1313      307 PRINT 201
1317      201 FORMAT(1H1,1X,*( CASE  9-1 ) C1=C2=R1=R3=R5=1. AND INFINITE GAIN*)
1317          X(7)=X(8)=X(1)=X(3)=X(5)=1.
1336          X(4)=H/A1
1342          X(6)=H+A1-1.
1347          X(2)=X(6)/A0
1354          CALL SPREAD(X,NV)
1356          CALL PRINT1(X,NV)
1360          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
1370          IF(KDB.EQ.0) GO TO 310
1372          PRINT 202
1376      202 FORMAT(///,1X,*( CASE  9-2 ) FINITE GAIN *)
1376          NI=3
1400          L(1)=4
1403          L(2)=6
1406          L(3)=2
1410          CALL NEWTMX(X,L,DX,NI,EMAX)
1414          CALL SPREAD(X,NV)
1416          CALL PRINT3(X,NV)
1420          CALL PRINT2(X,NV)
1422          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
1432      310 PRINT 203
1436      203 FORMAT(1H1,1X,*( CASE 10-1 ) C1=C2=R1=R3=R6=1. AND INFINITE GAIN*)
1436          X(7)=X(8)=X(1)=X(3)=X(6)=1.
1455          X(4)=H/A1
1461          X(5)=1./(A1+H-1.)
1467          X(2)=1./(X(5)*A0)
1476          CALL SPREAD(X,NV)
1500          CALL PRINT1(X,NV)
1502          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)

MAIN
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```
1512          IF(KDB.EC.0) GO TO 311
1514          PRINT 204
1520      204 FORMAT(///,1X,*( CASE 10-2 ) FINITE GAIN *)
1520          NI=3
1522          L(1)=4
1525          L(2)=5
1530          L(3)=2
1532          CALL NEWTMX(X,L,DX,NI,EMAX)
1536          CALL SPREAD(X,NV)
1540          CALL PRINT3(X,NV)
1542          CALL PRINT2(X,NV)
1544          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
1554      311 PRINT 205
1560      205 FORMAT(1H1,1X,*( CASE 11-1 ) C1=C2=R1=R4=R6=1. AND INFINITE GAIN*)
1560          X(7)=X(8)=X(1)=X(4)=X(6)=1.
1577          X(3)=A1/H
1603          X(5)=X(3)/(A1+X(3)*A1-X(3))
1617          X(2)=1./(X(5)*A0)
1626          CALL SPREAD(X,NV)
1630          CALL PRINT1(X,NV)
1632          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
1642          IF(KDB.EC.0) GO TO 401
1644          PRINT 206
1650      206 FORMAT(///,1X,*( CASE 11-2 ) FINITE GAIN *)
1650          NI=3
1652          L(1)=3
1655          L(2)=5
1660          L(3)=2
1662          CALL NEWTMX(X,L,DX,NI,EMAX)
1666          CALL SPREAD(X,NV)
1670          CALL PRINT3(X,NV)
1672          CALL PRINT2(X,NV)
1674          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
1704      401 PRINT 402
1710      402 FORMAT(1H1,1X,*( CASE 12-1 ) C1=C2=R1=R2=R4=1. AND INFINITE GAIN*)
1710          PRINT 403
1714      403 FORMAT(* R6/R5=A0 AND SET R6=1.*)
1714          H14=A0+1.-A1
1717          PRINT 404,H14
1725      404 FORMAT(* H=*,E11.4,*=ACTUAL VALUE*)
1725          DO 405 I=1,8
1727      405 X(I)=1.
1734          X(3)=A1/H14
1737          X(5)=1./A0
1743          CALL SPREAD(X,NV)
1745          CALL PRINT1(X,NV)
1747          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
1757          IF(KDB.EQ.0) GO TO 406
1761          PRINT 407
1765      407 FORMAT(///,1X,* ( CASE 12-2 ) FINITE GAIN*)
1765          NI=2
1767          L(1)=3
1772          L(2)=5
1775          CALL NEWTMX(X,L,DX,NI,EMAX)
2000          CALL SPREAD(X,NV)
2002          CALL PRINT3(X,NV)

MAIN
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```
2004          CALL PRINT2(X,NV)
2006          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
2016      406 PRINT 408
2022      408 FORMAT(1H1,1X,*( CASE 13-1 ) C1=C2=R1=R2=R5=1. AND INFINITE GAIN*)
2022          PRINT 409
2026      409 FORMAT(* R3/R4=A1/H AND SET R4=1.*)
2026          H15=H14
2030          PRINT 410,H15
2035      410 FORMAT(* H=*,E11.4,*=ACTUAL VALUE*)
2035          DO 411 I=1,8
2037      411 X(I)=1.
2044          X(6)=A0
2047          X(3)=A1/H15
2052          CALL SPREAD(X,NV)
2054          CALL PRINT1(X,NV)
2056          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
2066          IF(KD8.EQ.0) GO TO 451
2070          PRINT 412
2074      412 FORMAT(///,1X,* ( CASE 13-2 ) FINITE GAIN*)
2074          NI=2
2076          L(1)=3
2101          L(2)=6
2104          CALL NEWTMX(X,L,CX,NI,EMAX)
2107          CALL SPREAD(X,NV)
2111          CALL PRINT3(X,NV)
2113          CALL PRINT2(X,NV)
2115          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
2125      451 PRINT 442
2131      442 FORMAT(1H1,1X,*( CASE 14-1 ) C1=C2=R1=R2=R6=1. AND INFINITE GAIN*)
2131          PRINT 413
2135      413 FORMAT(* R3/R4=A1/H. AND SET R3=1.*)
2135          H16=H15
2137          PRINT 414,H16
2144      414 FORMAT(* H=*,E11.4,*=ACTUAL VALUE*)
2144          DO 415 I=1,8
2146      415 X(I)=1.
2153          X(4)=H16/A1
2156          X(5)=1./A0
2162          CALL SPREAD(X,NV)
2164          CALL PRINT1(X,NV)
2166          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
2176          IF(KD8.EQ.0) GO TO 416
2200          PRINT 417
2204      417 FORMAT(///,1X,* ( CASE 14-2 ) FINITE GAIN*)
2204          NI=2
2206          L(1)=4
2211          L(2)=5
2214          CALL NEWTMX(X,L,CX,NI,EMAX)
2217          CALL SPREAD(X,NV)
2221          CALL PRINT3(X,NV)
2223          CALL PRINT2(X,NV)
2225          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
2235      416 PRINT 447
2241      447 FORMAT(1H1,1X,*( CASE 15-1 ) C1=C2=R2=R3=R5=1. AND INFINITE GAIN*
2241          DO 418 I=1,8
2243      418 X(I)=1.

MAIN
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```
2250          X(4)=H/A1
2253          X(6)=A0/(H+A1-A0)
2262          X(1)=X(6)/A0
2267          CALL SPREAD(X,NV)
2271          CALL PRINT1(X,NV)
2273          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
2303          IF(KDB.EQ.0) GO TO 419
2305          PRINT 420
2311      420 FORMAT(///,1X,* ( CASE 15-2 ) FINITE GAIN*)
2311          NI=3
2313          L(1)=1
2316          L(2)=4
2321          L(3)=6
2323          CALL NEWTMX(X,L,CX,NI,EMAX)
2327          CALL SPREAD(X,NV)
2331          CALL PRINT3(X,NV)
2333          CALL PRINT2(X,NV)
2335          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
2345      419 PRINT 421
2351      421 FORMAT(1H1,1X,*( CASE 16-1 ) C1=C2=R2=R3=R6=1. AND INFINITE GAIN*)
2351          DO 422 I=1,8
2353      422 X(I)=1.
2360          X(1)=1./(A1+H-A0)
2366          X(4)=H/A1
2372          X(5)=1./(A0*X(1))
2401          CALL SPREAD(X,NV)
2403          CALL PRINT1(X,NV)
2405          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
2415          IF(KDB.EQ.0) GO TO 423
2417          PRINT 424
2423      424 FORMAT(///,1X,* ( CASE 16-2 ) FINITE GAIN*)
2423          NI=3
2425          L(1)=1
2430          L(2)=4
2433          L(3)=5
2435          CALL NEWTMX(X,L,CX,NI,EMAX)
2441          CALL SPREAD(X,NV)
2443          CALL PRINT3(X,NV)
2445          CALL PRINT2(X,NV)
2447          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
2457      423 PRINT 444
2463      444 FORMAT(1H1,1X,*( CASE 17-1 ) C1=C2=R2=R4=R6=1. AND INFINITE GAIN*)
2463          DO 425 I=1,8
2465      425 X(I)=1.
2472          X(3)=A1/H
2475          X(1)=1./(H-A0)
2503          X(5)=1./(A0*X(1))
2512          CALL SPREAD(X,NV)
2514          CALL PRINT1(X,NV)
2516          CALL SENS1(AP,AM,A,S,NV,NA,X,NAME)
2526          IF(KDB.EQ.0) GO TO 1
2530          PRINT 427
2534      427 FORMAT(///,1X,* ( CASE 17-2 ) FINITE GAIN*)
2534          NI=3
2536          L(1)=1
2541          L(2)=3
```

MAIN

```
2544          L(3)=5
2547          CALL NEWTMX(X,L,DX,NI,FMAX)
2552          CALL SPREAD(X,NV)
2554          CALL PRINT3(X,NV)
2556          CALL PRINT2(X,NV)
2560          CALL SENS2(AP,AM,A,S,NV,NA,X,NAME)
2570          GO TO 1
2571      999 STOP
2573          END
```

MAIN

```
            SUBROUTINE SPREAD(X,NV)
  6         DIMENSION X(NV)
  6         SP=AMAX1(X(1),X(2),X(3),X(4),X(5),X(6))/AMIN1(X(1),X(2),X(3),X(4),
           .X(5),X(6))
 56         PRINT 10,SP
 63      10 FORMAT(* SPREAD OF RESISTOR VALUES=*,E11.4)
 63         RETURN
 64         END
```

SPREAD

```
            SUBROUTINE PRINT1(X,NV)
  6         DIMENSION X(NV)
  6         PRINT 105
 11     105 FORMAT (/6X*R1*13X*R2*13X*R3*13X*R4*13X*R5*13X*R6*13X*C1*13X*C2*)
 11         PRINT 106,(X(I),I=1,8)
 26     106 FORMAT(1X,8(E15.4))
 26         RETURN
 27         ENTRY PRINT2
 37         B0= -(1./X(10))*(X(5)+X(6))*X(3)*X(4)*X(5)*X(6) /(X(1)*X(2)*X(3)*
           $X(5)*X(6)*X(7)*X(8)*(X(3)+X(4))*(1./X(9)-1.)*(1./X(10)-1.)*(X(6)/X
           $(11)+X(5)*(1./X(11)-1.)))
150         PRINT 104,B0
155     104 FORMAT( 1X,*B0=*E15.4)
155         PRINT 107
161     107 FORMAT (/6X*R1*10X*R2*10X*R3*10X*R4*10X*R5*10X*R6*10X*C1*10X*C2*
           .10X*K1*10X*K2*10X*K3*)
161         PRINT 108,(X(I),I=1,NV)
201     108 FORMAT(1X,11E12.4)
201         RETURN
202         ENTRY PRINT3
212         HREAL=X(3)*X(4)*X(5)*X(6)*X(8)*(X(5)+X(6))*(1./X(10)-1.)/(X(1)*X(3
           $)*X(5)*X(6)*X(7)*X(8)*(X(3)+X(4))*(1./X(9)-1.)*(1./X(10)-1.)*(X(6)
           $/X(11)+X(5)*(1./X(11)-1.)))
321         PRINT 109,HREAL
327     109 FORMAT (* H=*E15.4*=ACTUAL VALUE*)
327         RETURN
330         END
```

PRINT1

```
                SUBROUTINE EQNMX(X,F)
      6         DIMENSION X(11),F(3)
      6         COMMON/COEFF/A1,A0,H/GAINS/XK1,XK2,XK3
      6         X(9)=XK1
     11         X(10)=XK2
     14         X(11)=XK3
     17         F(1)=A1*X(1)*X(4)*X(5)*X(6)*X(7)*X(8)*(X(3)+X(4))*(1./X(9)-1.)*(1.
               ./X(10)-1.)*(X(6)/X(11)+X(5)*(1./X(11)-1.))-X(3)*X(4)*X(5)*X(6)*X(8
               .)*(X(5)+X(6))*(1./X(10)-1.)-X(4)*X(5)*X(6)*(X(3)+X(4))*(X(6)/X(11)
               .+X(5)*(1./X(11)-1.))*((X(8)/X(9))*(1./X(10)-1.)+(X(1)*X(7)/X(2)/X(
               .10))*(1./X(9)-1.))
    224         F(2)=A0*X(1)*X(2)*X(7)*X(8)*(X(3)+X(4))*(1./X(9)-1.)*(1./X(10)-1.)
               $*(X(6)/X(11)+X(5)*(1./X(11)-1.))+X(6)*(X(3)+X(4))-(X(3)/X(10))*(X(
               $5)+X(6))-(X(3)+X(4))*(X(6)/X(11)+X(5)*(1./X(11)-1.))/X(9)/X(10)
    355         F(3)=H*X(1)*X(3)*X(5)*X(6)*X(7)*(X(3)+X(4))*(1./X(9)-1.)*(1./X(10)
               .-1.)*(X(6)/X(11)+X(5)*(1./X(11)-1.))-X(3)*X(4)*X(5)*X(6)*     (X(5
               .)+X(6))*(1./X(10)-1.)
    460         RETURN
    461         END
```

EQNMX

```
      SUBROUTINE NEWTMX(X,L,DX,NI,EMAX)
C     TO SOLVE A SIMULTANEOUS SET OF NONLINEAR EQUATIONS THE NEWTON
C     -RAPHSON ALGORITHM IS USED IN THIS SUBPROGRAM.
11    DIMENSION X(11),F(3),FPERT(3),L(3)
11    REAL JAC(10,10),JACINV(10,10),M(3)
11    ITER=0
12   2 CALL EQNMX(X,F)
C     COMPUTE THE TOTAL ERROR
14    ERROR=0.
15    DO 11 I=1,NI
22   11 ERROR=ERROR+F(I)*F(I)
32    IF (ERROR.LT.EMAX) RETURN
35    IF (ITER.GT.30) GO TO 20
40    DO 13 I=1,NI
42    K=L(I)
45    X(K)=X(K)+DX
51    CALL EQNMX(X,FPERT)
53    DO 12 J=1,NI
60   12 JAC(J,I)=(FPERT(J)-F(J))/DX
75   13 X(K)=X(K)-DX
104   CALL MXINV(JAC,NI,JACINV)
106   CALL MXMULT(JACINV,F,M,NI)
114   DO 17 I=1,NI
121   K=L(I)
124  17 X(K)=X(K)-M(I)
135   ITER=ITER+1
137   GO TO 2
137  20 PRINT 21
143  21 FORMAT(//* SUBROUTINE NEWTMX DOES NOT CONVERGE*/)
143   RETURN
144   END
```

NEWTMX

```
            SUBROUTINE MXINV (R, N, RI)
      C     SUBROUTINE TO FIND THE INVERSE OF A GIVEN MATRIX USING
      C     GAUSS-JORDAN REDUCTION.  R MATRIX IS PRESERVED
      C             R - MATRIX WHICH IS TO BE INVERTED
      C             N - ORDER OF MATRIX
      C            RI - INVERSE MATRIX (OUTPUT)
    6          DIMENSION R(10,10), RA(10,20), RI(10,10)
      C
      C     ENTER R ARRAY INTO RA ARRAY AND SET
      C     LAST N COLUMNS OF RA ARRAY TO IDENTITY MATRIX
    6          DO 26  I = 1, N
    7          DO 24  J = 1, N
   10          RA(I,J) = R(I,J)
   20          NJ = N + J
   22       24 RA(I,NJ) = 0.
   31          NI = N + I
   33       26 RA(I,NI) = 1.
      C
      C     REDUCE MATRIX RA SO THAT FIRST N COLUMNS
      C     ARE SET EQUAL TO THE IDENTITY MATRIX
   42          NP = 2 * N
   44          DO 12  I = 1, N
      C
      C     SET MAIN DIAGONAL ELEMENT TO UNITY
   45          ALFA = RA(I,I)
   51          DO  5  J = I, NP
   53        5 RA(I,J) = RA(I,J) / ALFA
      C
      C     SET ELEMENTS OF ITH COLUMN TO ZERO
   66          DO 11  K = 1, N
   67          IF (K - I) 8, 11, 8
   72        8 BETA = RA(K,I)
   77          DO 10  J = I, NP
  101       10 RA(K,J) = RA(K,J) - BETA * RA(I,J)
  121       11 CONTINUE
  124       12 CONTINUE
      C
      C     SET INVERSE MATRIX RI EQUAL TO LAST
      C     N COLUMNS OF RA ARRAY
  126          DO 33  J = 1, N
  127          JN = J + N
  130          DO 33  I = 1, N
  132       33 RI(I,J) = RA(I,JN)
  147          RETURN
  147          END
```

MXINV

```
                SUBROUTINE MXMULT(AA,BB,CC,N)
          C     SUBROUTINE FOR MATRIX MULTIPLICATION AA*BB=CC
          C     AA-INPUT NXN SQUARE MATRIX
          C     BB-INPUT NX1 COLUMN MATRIX
          C     CC-OUTPUT NX1 COLUMN MATRIX
          C     N-ORDER OF SQUARE MATRIX
    11            DIMENSION AA(10,10),BB(10),CC(10)
    11            DO 2 I=1,N
    12          2 CC(I)=0.
    17            DO 5 I=1,N
    20            DO 5 J=1,N
    21          5 CC(I)=CC(I)+AA(I,J)*BB(J)
    40            RETURN
    40            END
```

MXMULT

```
                SUBROUTINE COEF1(A,X,NA,NV)
   11           DIMENSION A(NA),X(NV)
   11           X(9)=X(10)=X(11)=-1.E+08
   22           GO TO 1
   23           ENTRY COEF2
   36         1 A(1)=(X(3)*X(4)*X(5)*X(6)*X(8)*(X(5)+X(6))*(1./X(10)-1.)+X(4)*X(5)
              $*X(6)*(X(3)+X(4))*(X(6)/X(11)+X(5)*(1./X(11)-1.))*((X(8)/X(9))*
              $(1./X(10)-1.)+(X(1)*X(7)/X(2)/X(10))*(1./X(9)-1.)))/(X(1)*X(4)*X(5
              $)*X(6)*X(7)*X(8)*(X(3)+X(4))*(1./X(9)-1.)*(1./X(10)-1.)*(X(6)/X(11
              $)+X(5)*(1./X(11)-1.)))
  251           A(2)=(-X(6)*(X(3)+X(4))+(X(3)/X(10))*(X(5)+X(6))+(1./X(9))*(1./X(1
              $0))*(X(3)+X(4))*(X(6)/X(11)+X(5)*(1./X(11)-1.)))/(X(1)*X(2)*X(7)*
              $   X(8)*(X(3)+X(4))*(1./X(9)-1.)*(1./X(10)-1.)*(X(6)/X(11)+X(5)*(1
              $./X(11)-1.)))
  411           A(3)=(X(3)*X(4)*X(5)*X(6)*X(8)*(X(5)+X(6))*(1./X(10)-1.))/(X(1)*X(
              $3)*X(5)*X(6)*X(7)*X(8)*(X(3)+X(4))*(1./X(9)-1.)*(1./X(10)-1.)*(X(6
              $)/X(11)+X(5)*(1./X(11)-1.)))
  526           A(4)=-A(1)/2.
  534           A(5)=SQRT(A(2)-(A(1)/2.)**2)
  555           A(6)=SQRT(A(2))/A(1)
  572           A(7)=SQRT(A(2))
  603           RETURN
  604           END
```

COEF1

```
                SUBROUTINE SENS1(AP,AM,A,S,NV,NA,X,NAME)
     13         DIMENSION AP(NA),AM(NA),A(NA),S(NV,NA),X(NV),NAME(NA)
     13         COMMON/SENS/NX,DX
     13         PRINT 98
     16      98 FORMAT(/1X*SENSITIVITIES FOR THE IDEAL CASE*)
     16         DO 4 I=1,NX
     23         X(I)=X(I)+DX
     31         CALL COEF1(AP,X,NA,NX)
     34         X(I)=X(I)-2.*DX
     50         CALL COEF1(AM,X,NA,NX)
     52         X(I)=X(I)+DX
     65         CALL COEF1(A,X,NA,NX)
     67         DO 4 J=1,NA
     74         S(I,J)=(X(I)/A(J))*(AP(J)-AM(J))/(2.*DX)
    121       4 CONTINUE
    126         DO 5 J=1,NA
    130         PRINT 99,NAME(J)
    142      99 FORMAT (/1X,A8)
    142         PRINT 100,(S(I,J),I=1,NX)
    166     100 FORMAT (1X,8(E15.4))
    166       5 CONTINUE
    174         RETURN
    174         ENTRY SENS2
    214         DO 7 I=1,NV
    216         X(I)=X(I)+DX
    224         CALL COEF2(AP,X,NA,NV)
    227         X(I)=X(I)-2.*DX
    243         CALL COEF2(AM,X,NA,NV)
    245         X(I)=X(I)+DX
    260         CALL COEF2(A,X,NA,NV)
    262         DO 7 J=1,NA
    267         S(I,J)=(X(I)/A(J))*(AP(J)-AM(J))/(2.*DX)
    314       7 CONTINUE
    321         PRINT 101
    324     101 FORMAT(/1X* SENSITIVITIES FOR THE NON-IDEAL CASE*)
    324         DO 8 J=1,NA
    331         PRINT 102,NAME(J)
    343     102 FORMAT(/1X,A8)
    343         PRINT 103,(S(I,J),I=1,NV)
    371     103 FORMAT(1X,11(E12.4))
    371       8 CONTINUE
    377         RETURN
    377         END
```

SENS1

APPENDIX B

LISTING OF THE PROGRAM II

The difference of the program II with the program I is that the programs MAIN and NEWTMX in the program I are slightly changed for the non-ideal OA case as well as one addition of the new subprogram, EQNMX2. Therefore, the programs, MAIN, EQNMX2 and NEWTMX1 are only included here.

```
                PROGRAM MAIN(INPUT,OUTPUT,TAPE3=INPUT)
      3         DIMENSION A(7),AP(7),AM(7),SE(11,7),X(11),L(3),NAME(7),F(3),FPERT(
                $3),AA(3,3),BB(3),CC(3),AMP0(3),GI(3),GO(3),XI(3),XO(3)
      3         COMPLEX Y1(4,4),Y2(3,3),Y3(2,2),D1,D2,S,AMP(3),RNET
      3         REAL JAC(10,10),JACINV(10,10),H(3)
      3         COMMON/EQN1/A1,A0,H/SENS/NX,DX/EQN2/GI,GO,AMP,S
      3         DATA (NAME(I),I=1,7),NV,NX,NA/2HA1,2HA0,1HH,8HREALPOLE,8HIMAGPOLE,
                $1HQ,2HH0,11,8,//
      3     100 READ 1,A1,A0,H,(AMP0(I),I=1,3),DX,EMAX
     30       1 FORMAT(8E10.0)
     30         IF(EOF,3)999,4
     33       4 READ 2,(XI(I),I=1,3),(XO(I),I=1,3),HC
     57       2 FORMAT(7E10.0)
     57         IF(DX.LE.0.) DX=1.E-06
     63         IF(EMAX.EQ.0.) EMAX=1.E-12
     66         SR=-A1/2.
     70         TEST=A1**2-4.*A0
     77         IF(TEST.GE.0) GO TO 997
    101         SI=0.5*SQRT(-TEST)
    106         S=CMPLX(SR,SI)
    115         Q=(SQRT(A0))/A1
    121         DO 55 I=1,3
    122         GI(I)=1./XI(I)
    127      55 GO(I)=1./XO(I)
    136         PRINT99,A1,A0,H,(AMP0(I),I=1,3),DX,EMAX,Q
    164      99 FORMAT(*1SPECIFIED COEFFICIENTS,GAINS OF THREE OP-AMPS,INCREMENT F
                $OR DIFFERENTIATION,MAXIMUM ERROR FROM NEWTON ALGORITHM AND Q
                $*/5X,*A1*12X,*A0*11X*H*12X*K1*12X*K2*12X*K3*12X*DX*12X*ERROR* 9X*Q
                $*/1X,9E14.4)
    164         PRINT 121
    170     121 FORMAT(*0(CASE8-1)C1=C2=R1=R2=R3=R5=1 AND INFINITE GAIN*)
    170         H8=1.+A0-A1
    173         PRINT 123,H8
    201     123 FORMAT(* H=*E11.4*=ACTUAL VALUE*)
    201         X(7)=X(8)=X(3)=X(5)=X(2)=X(1)=1.
    223         X(4)=H8/A1
    227         X(6)=A0
    232         CALL SPREAD(X,NV)
    234         CALL PRINT1(X,NV)
    236         CALL SENS1(AP,AM,A,SE,NV,NA,X,NAME)
    246         PRINT 124
    252     124 FORMAT(1H0,*(CASE8-2) FINITE GAIN*)
    252         L(1)=4
    255         L(2)=6
    260         X(9)=AMP0(1)
    265         X(10)=AMP0(2)
    272         X(11)=AMP0(3)
    277         CALL NEWTMX1(X,L,DX,EMAX)
    302         CALL SPREAD(X,NV)
    304         CALL PRINT3(X,NV)
    306         CALL PRINT2(X,NV)
    310         DO 44 I=1,8
    312      44 IF(X(I).LT.0.) PRINT 45
    323         CALL SENS2(AP,AM,A,SE,NV,NA,X,NAME)
    333         DO 5 I=1,3

MAIN
```

```
335         5 AMP(I)=AMPC(I)*WC/(S+WC)
356           PRINT 888
362       888 FORMAT(1HL,*(CASE 8-3) FREQUENCY DEPENDENT OP-AMP AND CONSTANT INP
           $UT AND OUTPUT IMPEDENCES*//)
362           PRINT 125,S,WC,(XI(I),I=1,3),(XO(I),I=1,3)
410       125 FORMAT(6X,*POLE LOCATION =*, 7X,E15.6,*+J*,E12.6/6X,*CUT-OFF FREQU
           $ENCY=*4X,E15.6,/30X,*FIRST INTEGRTOR*4X*SECOND INTEGRTOR*4X*SUMMER
           $*/6X*INPUT IMPEDENCE =*3E20.6/6X,*OUTPUT IMPEDENCE=*3E20.6/)
410           CALL NEWTMX2(X,L,DX,EMAX)
413           CALL SPREAD(X,NV)
415           CALL PRINT1(X,NV)
417        45 FORMAT(* NOT REALIZABLE. INCREASE GAIN*)
417           GO TO 100
420       997 PRINT 998
424       998 FORMAT(1HO,*UNDESIRABLE COEFFICIENTS*)
424       999 STOP
426           END
```

MAIN

```
                SUBROUTINE EQNMX2(X,F)
      6         DIMENSION F(2),X(8)
      6         COMPLEX Y1(4,4),Y2(3,3),Y3(2,2),D1,D2,S,AMP,RNET
      6         COMMON/EQN2/GI(3),GO(3),AMP(3),S
      6         X(4)=1./X(4)
     13         X(6)=1./X(6)
     20         D1=GI(1)+X(1)+S*X(7)
     33         D2=GI(2)+X(2)+S*X(8)
     47         D3=GI(3)+X(3)+X(4)
     57         D4=X(5)+X(6)+GI(3)-GI(3)**2/D3
     76         Y1(1,1)=X(3)-X(3)**2/D3-(X(3)*GI(3))**2/D3**2/D4
    132         Y1(1,2)=-X(3)*X(4)/D3-X(3)*X(4)*GI(3)**2/D3**2/D4
    163         Y1(1,3)=-X(3)*X(5)*GI(3)/D3/D4
    201         Y1(1,4)=-X(6)*X(3)*GI(3)/D3/D4
    217         Y1(2,1)=-X(3)*X(4)/D3-X(3)*X(4)*GI(3)**2/D3**2/D4
    251         Y1(2,2)=GO(1)+S*X(7)-(1./D1)*((S*X(7))**2+S*X(7)*AMP(1)*GO(1))+X(2
               $)-X(2)**2/D2+X(4)-X(4)**2/D3-(X(4)*GI(3))**2/D3**2/D4
    404         Y1(2,3)=-S*X(8)*X(2)/D2-X(4)*X(5)*GI(3)/D3/D4
    440         Y1(2,4)=-(S*X(7)*X(1)+AMP(1)*X(1)*GO(1))/D1-X(4)*X(6)*GI(3)/D3/D4
    510         Y1(3,1)=-X(5)*X(3)*GI(3)/D3/D4
    527         Y1(3,2)=-(S*X(8)*X(2)+AMP(2)*X(2)*GO(2))/D2-X(5)*X(4)*GI(3)/D3/D4
    600         Y1(3,3)=GO(2)+S*X(8)-((S*X(8))**2+S*X(8)*AMP(2)*GO(2))/D2+X(5)-X(5
               $)**2/D4
    671         Y1(3,4)=-X(5)*X(6)/D4
    704         Y1(4,1)=AMP(3)*GO(3)*X(3)/D3-X(3)*X(6)*GI(3)/D3/D4+AMP(3)*GO(3)*X(
               $3)*GI(3)*(GI(3)-D3)/D3**2/D4
    773         Y1(4,2)=-S*X(7)*X(1)/D1+AMP(3)*X(4)*GO(3)/D3-X(4)*X(6)*GI(3)/D3/D4
               $+AMP(3)*GO(3)*X(4)*GI(3)*(GI(3)-D3)/D3**2/D4
   1077         Y1(4,3)=-X(5)*X(6)/D4+AMP(3)*X(5)*GO(3)*(GI(3)-D3)/D3/D4
   1134         Y1(4,4)=X(1)-X(1)**2/D1+X(6)+GO(3)-X(6)**2/D4+AMP(3)*GO(3)*X(6)*(G
               $I(3)-D3)/D3/D4
   1217         DO 3 I=1,3
   1221         DO 3 J=1,3
   1222       3 Y2(I,J)=Y1(I,J)-(1./Y1(4,4))*Y1(I,4)*Y1(4,J)
   1275         DO 4 I=1,2
   1276         DO 4 J=1,2
   1277       4 Y3(I,J)=Y2(I,J)-(1./Y2(3,3))*Y2(I,3)*Y2(3,J)
   1352         RNET=-Y3(2,2)/Y3(2,1)
   1371         F(1)=REAL(RNET)
   1400         F(2)=AIMAG(RNET)
   1407         X(4)=1./X(4)
   1414         X(6)=1./X(6)
   1421         RETURN
   1421         END
```

EQNMX2

```
                SUBROUTINE NEWTMX1(X,L,DX,EMAX)
          C     TO SOLVE A SIMULTANEOUS SET OF NONLINEAR EQUATIONS THE NEWTON
          C     -RAPHSON ALGORITHM IS USED IN THIS SUBPROGRAM.
     11         DIMENSION X(11),F(3),FPERT(3),L(3)
     11         REAL JAC(10,10),JACINV(10,10),M(3)
     11         ITER=0
     12       2 CALL EQNMX1(X,F)
          C     COMPUTE THE TOTAL ERROR
     14         ERROR=0.
     15         DO 11 I=1,2
     21      11 ERROR=ERROR+F(I)*F(I)
     31         IF (ERROR.LT.EMAX) RETURN
     34         IF (ITER.GT.30) GO TO 20
     37         DO 13 I=1,2
     41         K=L(I)
     44         X(K)=X(K)+DX
     50         CALL EQNMX1(X,FPERT)
     52         DO 12 J=1,2
     56      12 JAC(J,I)=(FPERT(J)-F(J))/DX
     73      13 X(K)=X(K)-DX
    102         CALL MXINV(JAC,2,JACINV)
    104         CALL MXMULT(JACINV,F,M,2)
    107         DO 17 I=1,2
    113         K=L(I)
    116      17 X(K)=X(K)-M(I)
    126         ITER=ITER+1
    130         GO TO 2
    131      20 PRINT 21
    135      21 FORMAT(//* SUBROUTINE NEWTMX DOES NOT CONVERGE*/)
    135         RETURN
    136         ENTRY NEWTMX2
    151         ITER=0
    152      30 CALL EQNMX2(X,F)
          C     COMPUTE THE TOTAL ERROR
    156         ERROR=0.
    157         DO 31 I=1,2
    163      31 ERROR=ERROR+F(I)*F(I)
    173         IF (ERROR.LT.EMAX) RETURN
    176         IF (ITER.GT.30) GO TO 35
    201         DO 33 I=1,2
    203         K=L(I)
    206         X(K)=X(K)+DX
    212         CALL EQNMX2(X,FPERT)
    214         DO 32 J=1,2
    220      32 JAC(J,I)=(FPERT(J)-F(J))/DX
    235      33 X(K)=X(K)-DX
    244         CALL MXINV(JAC,2,JACINV)
    246         CALL MXMULT(JACINV,F,M,2)
    251         DO 34 I=1,2
    255         K=L(I)
    260      34 X(K)=X(K)-M(I)
    270         ITER=ITER+1
    272         GO TO 30
    273      35 PRINT 36
    277      36 FORMAT(//* SUBROUTINE NEWTMX DOES NOT CONVERGE*/)

NEWTMX1
```

APPENDIX C

USER'S INSTRUCTION AND EXAMPLE OUTPUTS

This appendix provides the user with specific instructions for using programs I and II and shows some example outputs.

As an example of using program I, a Q = 100 KHN filter is realized with the following conditions

$$\begin{aligned} XK1 &= XK2 = XK3 = -10^{3} \\ H &= 2 \\ A0 &= 1 \\ DX &= 10^{-6} \text{ (=default value)} \\ EMAX &= 10^{-12} \text{(=default value)} \end{aligned} \qquad (C.1)$$

where the above variables are again defined for the user's convenience as below.

XK1 = the negative dc gain of the OA in the first integrator.

XK2 = the negative dc gain of the OA in the second integrator.

XK3 = the negative dc gain of the OA in the summer.

DX = the incremental variation of the parameters for

differentiation

EMAX = the minimum required value for the error function y.

Since Q is 100 and the center frequency is normalized to unity, the transfer function with the multiplicative constant term, H equal to 2 is

$$T(s) = \frac{-2s}{s^2 + 0.01s + 1} \qquad (C.2)$$

Since both the ideal and finite gain OA cases are to be considered, the variable KDB is set to 1. If KDB = 0, only the ideal OA case is treated. The input data are shown in Table C.1.

For an example of using program II, additional input data are required since the OA has now frequency dependent gain and input and output-impedance. These additional data are fed in the third input data card. They are

$$XI(1) = XI(2) = XI(3) = 10^3$$
$$XO(I) = XO(2) = XO(3) = 10^{-3}$$

and

$$WC = 10 \qquad (C.3)$$

where the above variables are defined again as below.

The first variable is for the first integrator, the second for the second integrator and the third for the summer.

XO = one-dimensional array for the output impedances. The entries are same as in XI.

WC = the cut-off frequency of the one-pole rolloff model for the OA.

The input data in the first and second cards are same as in Table C.1. The input data are listed in Table C.2.

Table C.1. The input data in the program I

column	1 . . . 10 . . . 20 . . . 30 . . . 40 . . . 50 . . . 60 . . . 70 . . . 80							
card no.								
variables (I1)	KDB							
1	1							
variables (8E10.0)		A1	A0	H	XK1	XK2	XK3	DX	EMAX
2		0.01	1.	2.	-1.E+3	-1.E+3	-1.E+3		

Table C.2. The input data in the program II

column	1 . . . 10 . . . 20 . . . 30 . . . 40 . . . 50 . . . 60 . . . 70 . . . 80							
card no.								
variables (I1)	KDB							
1	1							
variables (8E10.0)		A1	A0	H	XK1	XK2	XK3	DX	EMAX
2		0.01	1.	2.	-1.E+3	-1.E+3	-1.E+3		
variables (7E10.0)		XI(1)	XI(2)	XI(3)	XO(1)	XO(2)	XO(3)	WC	
3		1.E+3	1.E+3	1.E+3	1.E-3	1.E-3	1.E-3	10.	

SPECIFIED COEFFICIENTS,GAINS OF THREE OP-AMPS,INCREMENT FOR DIFFERENTIATION,MAXIMUM ERROR FROM NEWTON ALGORITHM AND Q

A1	A0	H	K1	K2	K3	DX	ERROR	Q
1.0000E-02	1.0000E+00	2.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03	1.0000E-06	1.0000E-12	1.0000E+02

(CASE 1-1) ALL RESISTORS EQUAL TO UNITY WITH INFINITE GAIN
A1= 1.0000E-02=ACTUAL VALUE OF H
SPREAD OF TWO CAPACITORS= 1.0000E+04

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+02	1.0000E-02

SENSITIVITIES FOR THE IDEAL CASE

A1							
-9.9990E-01	-9.9991E-05	4.9995E-01	-4.9995E-01	-4.9995E-01	4.9995E-01	-9.9990E-01	-9.9990E-05
A0							
-1.0000E+00	-1.0000E+00	1.0658E-08	-1.7764E-09	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-5.0000E-01	5.0000E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	8.3267E-11
REALPOLE							
-9.9990E-01	-9.9991E-05	4.9995E-01	-4.9995E-01	-4.9995E-01	4.9995E-01	-9.9990E-01	-9.9990E-05
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-1.2497E-05	1.2502E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
4.9990E-01	-4.9990E-01	-4.9995E-01	4.9995E-01	-5.0007E-05	4.9989E-05	4.9990E-01	-4.9990E-01
WG							
-5.0000E-01	-5.0000E-01	5.3291E-09	0.	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 2-1) C1=C2=R1=R4=R5=1 AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.020GE+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0100E+00	5.0000E-03	1.0000E+00	1.0000E+03	1.0100E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1

-1.0000E+00	-9.9237E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.9365E-07

A0

-1.0000E+00	-1.0000E+00	7.1054E-11	-1.7764E-09	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00

H

-1.0000E+00	0.	-4.9751E-03	4.9751E-03	-5.0249E-01	5.0249E-01	-1.0000E+00	0.

REALPOLE

-1.0000E+00	-9.9237E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.9365E-07

IMAGPOLE

-4.9999E-01	-5.0001E-01	-2.4876E-05	2.4876E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01

Q

5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	2.4866E-03	-2.4866E-03	5.0000E-01	-5.0000E-01

W0

-5.0000E-01	-5.0000E-01	3.5527E-11	-1.7764E-09	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 2-2) WITH FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5314E+02
H= 2.0000E+00=ACTUAL VALUE
B0= -1.9782E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0100E+00	4.0060E-03	1.0000E+00	1.0000E+00	1.0141E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1

-9.0109E-01	-9.8909E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.9001E-02	-9.8810E-02	1.6154E-03

A0

-1.0000E+00	-1.0000E+00	7.8929E-06	-7.8924E-06	-9.9898E-01	9.9898E-01	-1.0000E+00	-1.0000E+00	1.0036E-03	9.9654E-04	2.0126E-03

H

-1.0000E+00	0.	-3.9900E-03	3.9900E-03	-5.0248E-01	5.0248E-01	-1.0000E+00	3.5527E-09	1.0019E-03	-3.5527E-06	2.0144E-03

REALPOLE

-9.0109E-01	-9.8909E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.9001E-02	-9.8810E-02	1.6154E-03

IMAGPOLE

-4.9995E-01	-5.0001E-01	-1.6004E-05	1.6003E-05	-4.9949E-01	4.9949E-01	-4.9999E-01	-5.0001E-01	5.0449E-04	5.0094E-04	1.0054E-03

Q

4.9109E-01	-4.9109E-01	-7.9799E-01	7.9799E-01	-9.6908E-02	9.6908E-02	4.9109E-01	-4.9109E-01	9.9503E-02	9.9310E-02	-6.0936E-04

W0

-5.0000E-01	-5.0000E-01	3.9465E-06	-3.9453E-06	-4.9949E-01	4.9949E-01	-5.0000E-01	-5.0000E-01	5.0271E-04	4.9916E-04	1.0054E-03

(CASE 3-1) C1=C2=R2=R4=R5=1 AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.02J0E+02

	R1	R2	R3	R4	R5	R6	C1	C2
	1.0100E+J0	1.0J0CE+0C	5.0000E-03	1.0000E+00	1.00J0E+00	1.0100E+00	1.0000E+00	1.0000E+0C

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.CJJ0E+0C	-1.J092E-06	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-1.0006E-06
A0							
-1.0000E+00	-1.0C00E+0J	7.1054E-11	-1.7764E-09	-1.0000F+0J	1.0000E+00	-1.0000E+00	-1.0000E+00
M							
-1.0JJ0E+00	J.	-4.9751E-03	4.9751E-03	-5.0249E-01	5.0249E-01	-1.0000E+00	5.3824E-09
REALPOLE							
-1.CJJ0E+0C	-1.0J92E-06	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-1.0006E-06
IMAGPOLE							
-4.9999E-01	-5.0J01E-01	-2.4386E-05	2.4386E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0JJCE-01	-5.0000E-01	-9.9502E-01	9.9502E-01	2.4865E-03	-2.4866E-03	5.0000E-01	-5.0000E-01
WC							
-5.00J0E-01	-5.CJJ0E-01	3.5527E-11	-1.7764E-09	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 3-2) WITH FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5023E+02
M= 1.9999E+CO=ACTUAL VALUE
90= -1.9979E-03

	R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
	9.9015E-01	1.0J00E+0C	3.9967E-03	1.0000E+00	1.0000E+00	9.9410E-01	1.0000E+00	1.0000E+00	-1.0J0JE+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.JC10E-01	-9.9897E-02	7.9603E-01	-7.9603E-01	-3.9763E-01	3.9763E-01	-9.0010E-01	-9.9897E-02	-9.9992E-02	-9.9798E-02	1.5876E-03
AC										
-1.0J0CE+CC	-1.000CE+C0	7.9526E-06	-7.9545E-06	-9.9900E-01	9.9900E-01	-1.000CE+00	-1.0000E+00	1.0019E-03	9.9121E-04	1.9877E-03
M										
-1.0000E+0C	0.	-3.9804E-03	3.9804E-03	-4.9753E-01	4.9753E-01	-1.0000E+00	-7.1057E-09	1.0037E-03	0.	1.9879E-03
REALPOLE										
-9.0010E-01	-9.9897E-02	7.9603E-01	-7.9603E-01	-3.9763E-01	3.9763E-01	-9.0010E-01	-9.9897E-02	-9.9992E-02	-9.9798E-02	1.5876E-03
IMAGPOLE										
-4.9959E-01	-5.0001E-01	-1.5926E-05	1.5925E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0272E-04	4.9916E-04	9.9300E-04
Q										
4.0010E-01	-4.0010E-01	-7.9603E-01	7.9603E-01	-1.0187E-01	1.0187E-01	4.0010E-01	-4.0010E-01	1.0049E-01	1.0030E-01	-5.9574E-04
WC										
-5.0000E-01	-5.0000E-01	3.9763E-06	-3.9773E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9960E-04	9.9298E-04

(CASE 4-1) C1=C2=R3=R5=R6=1. AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0100E+02

R1	R2	R3	R4	R5	R6	C1	C2
9.9502E-01	1.0050E+00	1.0000E+00	2.0000E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9503E-07	9.9502E-01	-9.9502E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9365E-07
A0							
-1.0000E+00	-1.0000E+00	-3.5527E-09	-7.1054E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-4.9751E-03	4.9749E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7764E-09
REALPOLE							
-1.0000E+00	-9.9503E-07	9.9502E-01	-9.9502E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9365E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4880E-05	2.4514E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	-1.0073E-06	1.0050E-06	5.0000E-01	-5.0000E-01
W0							
-5.0000E-01	-5.0000E-01	-1.7764E-09	-3.5527E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 4-2) WITH FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5102E+02
H= 2.0000E+00=ACTUAL VALUE
BG= -1.9920E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
9.9304E-01	1.0030E+00	1.0000E+00	2.5006E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0040E-01	-9.9601E-02	7.9661E-01	-7.9661E-01	-3.9910E-01	3.9910E-01	-9.0040E-01	-9.9601E-02	-9.9695E-02	-9.9504E-02	1.5987E-03
A0										
-1.0000E+00	-1.0000E+00	7.9364E-06	-6.6630E-06	-9.9900E-01	9.9900E-01	-1.0000E+00	-1.0000E+00	1.0001E-03	9.9121E-04	1.9966E-03
H										
-1.0000E+00	0.	-3.9831E-03	3.9827E-03	-4.9900E-01	4.9900E-01	-1.0000E+00	3.5527E-09	9.9831E-04	0.	1.9966E-03
REALPOLE										
-9.0040E-01	-9.9601E-02	7.9661E-01	-7.9661E-01	-3.9910E-01	3.9910E-01	-9.0040E-01	-9.9601E-02	-9.9695E-02	-9.9504E-02	1.5987E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5948E-05	1.6436E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0272E-04	4.9916E-04	9.9655E-04
Q										
4.0040E-01	-4.0040E-01	-7.9661E-01	7.9661E-01	-1.0040E-01	1.0040E-01	4.0040E-01	-4.0040E-01	1.0019E-01	9.9999E-02	-6.0027E-04
W0										
-5.0000E-01	-5.0000E-01	3.9684E-06	-3.1094E-06	-4.9953E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9960E-04	9.9831E-04

(CASE 5-1) C1=C2=R4=R5=RE=1 AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0100E+02

P1	R2	R3	R4	R5	R6	C1	C2
9.9502E-01	1.0050E+00	5.0000E-03	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9583E-07	9.9502E-01	-9.9502E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9687E-07
A0							
-1.0000E+00	-1.0000E+00	8.8818E-11	-3.5527E-09	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
M							
-1.0000E+00	0.	-4.9751E-03	4.9751E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	0.
REALPOLE							
-1.0000E+00	-9.9583E-07	9.9502E-01	-9.9502E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9687E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4876E-05	2.4875E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	-1.0118E-06	1.0004E-06	5.0000E-01	-5.0000E-01
W0							
-5.0000E-01	-5.0000E-01	4.4409E-11	-1.7764E-09	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 5-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5081E+02
M= 2.0000E+00=ACTUAL VALUE
B0= -1.5920E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
9.9304E-01	1.0033E+00	3.9990E-03	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0040E-01	-9.9601E-02	7.9661E-01	-7.9661E-01	-3.9910E-01	3.9910E-01	-9.0040E-01	-9.9601E-02	-9.9698E-02	-9.9501E-02	1.5987E-03
A0										
-1.0000E+00	-1.0000E+00	7.9343E-06	-7.9332E-06	-9.9900E-01	9.9900E-01	-1.0000E+00	-1.0000E+00	9.9831E-04	9.8765E-04	2.0002E-03
M										
-1.0000E+00	0.	-3.9831E-03	3.9831E-03	-4.9900E-01	4.9900E-01	-1.0000E+00	-5.3291E-09	1.0019E-03	0.	2.0002E-03
REALPOLE										
-9.0040E-01	-9.9601E-02	7.9661E-01	-7.9661E-01	-3.9910E-01	3.9910E-01	-9.0040E-01	-9.9601E-02	-9.9698E-02	-9.9501E-02	1.5987E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5949E-05	1.5950E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0272E-04	4.9739E-04	1.0001E-03
Q										
4.0040E-01	-4.0040E-01	-7.9661E-01	7.9661E-01	-1.0040E-01	1.0040E-01	4.0040E-01	-4.0040E-01	1.0020E-01	9.9994E-02	-6.0027E-04
W0										
-5.0000E-01	-5.0000E-01	3.9672E-06	-3.9684E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	4.9738E-04	4.9383E-04	9.9831E-04

(CASE 6-1) C1=C2=R1=R5=RE=1 AND INFINITE GAIN
R4/R3=H/A1. SET R3=1.
H= 1.9900E+00=ACTUAL VALUE
SPREAD OF RESISTOR VALUES= 1.9900E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	1.0000E+00	1.9900E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
A0							
-1.0000E+00	-1.0000E+00	1.7764E-09	3.5350E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-5.0000E-03	5.0001E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09
REALPOLE							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4876E-05	2.5098E-05	-5.0003E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9500E-01	9.9500E-01	-1.0118E-06	1.0073E-06	5.0000E-01	-5.0000E-01
W0							
-5.0000E-01	-5.0000E-01	1.7764E-09	3.5350E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 6-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.4931E+02
H= 1.9860E+00=ACTUAL VALUE
B0= -1.9920E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	9.9602E-01	1.0000E+00	2.4831E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-8.9970E-01	-1.0030E-01	7.9659E-01	-7.9659E-01	-3.9910E-01	3.9910E-01	-8.9970E-01	-1.0030E-01	-9.9001E-02	-1.0020E-01	1.5987E-03
A0										
-1.0000E+00	-1.0000E+00	7.9901E-06	-7.9397E-06	-9.9900E-01	9.9900E-01	-1.0000E+00	-1.0000E+00	9.9831E-04	9.9121E-04	1.9966E-03
H										
-1.0000E+00	0.	-4.0110E-03	4.0111E-03	-4.9900E-01	4.9900E-01	-1.0000E+00	5.3666E-09	9.9998E-04	0.	2.0000E-03
REALPOLE										
-8.9970E-01	-1.0030E-01	7.9659E-01	-7.9659E-01	-3.9910E-01	3.9910E-01	-8.9970E-01	-1.0030E-01	-9.9001E-02	-1.0020E-01	1.5987E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5922E-05	1.5880E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0094E-04	4.9739E-04	9.9833E-04
Q										
3.9970E-01	-3.9970E-01	-7.9659E-01	7.9659E-01	-1.0040E-01	1.0040E-01	3.9970E-01	-3.9970E-01	9.9499E-02	1.0070E-01	-6.0027E-04
W0										
-5.0000E-01	-5.0000E-01	3.9933E-06	-3.5288E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	4.9739E-04	4.9738E-04	9.9831E-04

(CASE 7-1) C1=C2=R2=R5=R6=1 AND INFINITE GAIN
R4/R3=H/A1. SET R3=1.
H= 1.9900E+00=ACTUAL VALUE
SPREAD OF RESISTOR VALUES= 1.9900E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	1.0000E+00	1.9900E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9620E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
AO							
-1.0000E+00	-1.0000E+00	1.7764E-09	3.5350E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-5.0000E-03	5.0001E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09
REALPOLE							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4876E-05	2.5098E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9500E-01	9.9500E-01	-1.0118E-06	1.0073E-06	5.0000E-01	-5.0000E-01
WO							
-5.0000E-01	-5.0000E-01	1.7764E-09	3.5350E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 7-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5031E+02
H= 1.994[illegible]E+00=ACTUAL VALUE
80= -1.9920E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
9.9602E-01	1.0000E+00	1.0000E+00	2.4931E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0010E-01	-9.9900E-02	7.9661E-01	-7.9661E-01	-3.9910E-01	3.9910E-01	-9.0010E-01	-9.9900E-02	-9.9401E-02	-9.9801E-02	1.5987E-03
AO										
-1.0000E+00	-1.0000E+00	7.9545E-06	-8.8573E-06	-9.9900E-01	9.9900E-01	-1.0000E+00	-1.0000E+00	9.9831E-04	9.9476E-04	2.0002E-03
H										
-1.0000E+00	0.	-3.9950E-03	3.9947E-03	-4.9900E-01	4.9900E-01	-1.0000E+00	3.5834E-09	1.0013E-03	1.7817E-06	1.9991E-03
REALPOLE										
-9.0010E-01	-9.9900E-02	7.9661E-01	-7.9661E-01	-3.9910E-01	3.9910E-01	-9.0010E-01	-9.9900E-02	-9.9401E-02	-9.9801E-02	1.5987E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5939E-05	1.5500E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0094E-04	4.9916E-04	1.0001E-03
Q										
4.0010E-01	-4.0010E-01	-7.9660E-01	7.9660E-01	-1.0040E-01	1.0040E-01	4.0010E-01	-4.0010E-01	9.9699E-02	1.0030E-01	-6.0254E-04
WO										
-5.0000E-01	-5.0000E-01	3.9790E-06	-4.4286E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	4.9738E-04	4.9738E-04	9.9831E-04

(CASE 8-1) C1=C2=R1=R2=R3=1 AND INFINITE GAIN
R6/R5=A0. SET R5=1.
H= 1.9900E+00=ACTUAL VALUE
SPREAD OF RESISTOR VALUES= 1.9900E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	1.0000E+00	1.9900E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
AO							
-1.0000E+00	-1.0000E+00	1.7764E-09	3.5350E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-5.0000E-03	5.0001E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09
REALPOLE							
-1.0000E+00	-9.9926E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4876E-05	2.5098E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9500E-01	9.9500E-01	-1.0118E-06	1.0073E-06	5.0000E-01	-5.0000E-01
WO							
-5.0000E-01	-5.0000E-01	1.7764E-09	3.5350E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 8-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.4869E+02
H= 1.9900E+00=ACTUAL VALUE
BC= -1.5698E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0000E+00	1.0000E+00	2.4869E+02	1.0000E+00	1.0040E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9700E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8999E-02	-9.9801E-02	1.6015E-03
AO										
-1.0000E+00	-1.0000E+00	7.9581E-06	-7.9516E-06	-9.9899E-01	9.9899E-01	-1.0000E+00	-1.0000E+00	1.0036E-03	9.9476E-04	2.0002E-03
H										
-1.0000E+00	0.	-4.0050E-03	4.0047E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	0.	1.0015E-03	0.	1.9995E-03
REALPOLE										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9700E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8999E-02	-9.9801E-02	1.6015E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5947E-05	1.5903E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0449E-04	5.0494E-04	9.9833E-04
Q										
4.0010E-01	-4.0010E-01	-7.9699E-01	7.9699E-01	-9.9400E-02	9.9400E-02	4.0010E-01	-4.0010E-01	9.9501E-02	1.0030E-01	-6.0027E-04
WO										
-5.0000E-01	-5.0000E-01	3.9790E-06	-3.9758E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0271E-04	4.9738E-04	9.9831E-04

(CASE 9-1) C1=C2=R1=R3=R5=1. AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0000E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0100E+00	1.0000E+00	2.0000E+02	1.0000E+00	1.0100E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.8957E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.9087E-07
AC							
-1.0000E+00	-1.0000E+00	-3.5527E-09	-7.1054E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
M							
-1.0000E+00	0.	-4.9751E-03	4.9749E-03	-5.0249E-01	5.0249E-01	-1.0000E+00	0.
REALPOLE							
-1.0000E+00	-9.8957E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.9087E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4878E-05	2.4514E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	2.4866E-03	-2.4866E-03	5.0000E-01	-5.0000E-01
WC							
-5.0000E-01	-5.0000E-01	-1.7764E-09	-3.5527E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 9-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.4963E+02
M= 2.0000E+00=ACTUAL VALUE
80= -1.9792E-03

P1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0100E+00	1.0000E+00	2.4963E+02	1.0000E+00	1.0141E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0109E-01	-9.8939E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.8996E-02	-9.8807E-02	1.6126E-03
AC										
-1.0000E+00	-1.0000E+00	7.8906E-06	-8.8686E-06	-9.9898E-01	9.9898E-01	-1.0000E+00	-1.0000E+00	1.0019E-03	9.9121E-04	2.0073E-03
M										
-1.0000E+00	0.	-3.9900E-03	3.9991E-03	-5.0248E-01	5.0248E-01	-1.0000E+00	0.	1.0019E-03	3.5527E-06	2.0108E-03
REALPOLE										
-9.0109E-01	-9.8909E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.8996E-02	-9.8807E-02	1.6126E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.6007E-05	1.5520E-05	-4.9949E-01	4.9949E-01	-4.9999E-01	-5.0001E-01	5.0272E-04	4.9739E-04	1.0037E-03
Q										
4.0109E-01	-4.0109E-01	-7.9799E-01	7.9799E-01	-9.6904E-02	9.6909E-02	4.0109E-01	-4.0109E-01	9.9496E-02	9.9303E-02	-6.6936E-04
WC										
-5.0000E-01	-5.0000E-01	3.9435E-06	-4.4343E-06	-4.9949E-01	4.9949E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9738E-04	1.0019E-03

(CASE 10-1) C1=C2=R1=R3=R6=1. AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0200E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0100E+00	1.0000E+00	2.0000E+02	9.9010E-01	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.8957E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.8810E-07
A0							
-1.0000E+00	-1.0100E+00	-3.5527E-09	-7.1054E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-4.9751E-03	4.9759E-03	-5.0249E-01	5.0249E-01	-1.0000E+00	1.7764E-09
REALPOLE							
-1.0000E+00	-9.8957E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.8810E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4878E-05	2.4514E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	2.4866E-03	-2.4866E-03	5.0000E-01	-5.0000E-01
WC							
-5.0000E-01	-5.0000E-01	-1.7764E-09	-3.5527E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 10-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5314E+02
H= 2.0000E+00=ACTUAL VALUE
BE= -1.9742E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0100E+00	1.0000E+00	2.4963E+02	9.9613E-01	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0109E-01	-9.8909E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.8999E-02	-9.8807E-02	1.6154E-03
A0										
-1.0000E+00	-1.0000E+00	7.8870E-06	-8.4252E-06	-9.9898E-01	9.9898E-01	-1.0000E+00	-1.0000E+00	9.9831E-04	9.8943E-04	2.0108E-03
H										
-1.0000E+00	0.	-3.9900E-03	3.9900E-03	-5.0248E-01	5.0248E-01	-1.0000E+00	0.	1.0001E-03	0.	2.0108E-03
REALPOLE										
-9.0109E-01	-9.8909E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.8999E-02	-9.8807E-02	1.6154E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.6007E-05	1.5520E-05	-4.9949E-01	4.9949E-01	-4.9999E-01	-5.0001E-01	5.0272E-04	4.9739E-04	1.0054E-03
Q										
4.0109E-01	-4.0109E-01	-7.9799E-01	7.9799E-01	-9.6909E-02	9.6909E-02	4.0109E-01	-4.0109E-01	9.9496E-02	9.9303E-02	-6.0936E-04
WC										
-5.0000E-01	-5.0000E-01	3.9435E-06	-3.9909E-06	-4.9949E-01	4.9949E-01	-5.0000E-01	-5.0000E-01	4.9916E-04	4.9560E-04	1.0054E-03

(CASE 11-1) C1=C2=R1=R4=R6=1. AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0200E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0100E+00	5.0000E-03	1.0000E+00	9.9010E-01	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9237E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.9365E-07
A0							
-1.0000E+00	-1.0000E+00	7.9936E-11	-1.7764E-09	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-4.9751E-03	4.9751E-03	-5.0249E-01	5.0249E-01	-1.0000E+00	-3.5527E-09
REALPOLE							
-1.0000E+00	-9.9237E-07	9.9502E-01	-9.9502E-01	-5.0249E-01	5.0249E-01	-1.0000E+00	-9.9365E-07
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4876E-05	2.4875E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	2.4866E-03	-2.4866E-03	5.0000E-01	-5.0000E-01
W0							
-5.0000E-01	-5.0000E-01	4.4409E-11	0.	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 11-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5213E+02
H= 2.0000E+00=ACTUAL VALUE
BG= -1.9782E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0100E+00	4.0064E-03	1.0000E+00	9.8613E-01	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0109E-01	-9.8909E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.8999E-02	-9.8813E-02	1.6126E-03
A0										
-1.0000E+00	-1.0000E+00	7.8929E-06	-7.8977E-06	-9.9898E-01	9.9898E-01	-1.0000E+00	-1.0000E+00	9.9831E-04	9.9121E-04	2.0108E-03
H										
-1.0000E+00	0.	-3.9900E-03	3.9900E-03	-5.0248E-01	5.0248E-01	-1.0000E+00	3.5527E-09	1.0072E-03	3.5527E-06	2.0144E-03
REALPOLE										
-9.0109E-01	-9.8909E-02	7.9799E-01	-7.9799E-01	-4.0258E-01	4.0258E-01	-9.0109E-01	-9.8909E-02	-9.8999E-02	-9.8813E-02	1.6126E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.6004E-05	1.6003E-05	-4.9949E-01	4.9949E-01	-4.9999E-01	-5.0001E-01	5.0094E-04	4.9739E-04	1.0054E-03
Q										
4.0109E-01	-4.0109E-01	-7.9799E-01	7.9799E-01	-9.6909E-02	9.6909E-02	4.0109E-01	-4.0109E-01	9.9499E-02	9.9305E-02	-6.3709E-04
W0										
-5.0000E-01	-5.0000E-01	3.9464E-06	-3.9471E-06	-4.9949E-01	4.9949E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9383E-04	1.0054E-03

(CASE 12-1) C1=C2=R1=R2=R4=1. AND INFINITE GAIN
R6/R5=A0 AND SET R6=1.
H= 1.9900E+00=ACTUAL VALUE
SPREAD OF RESISTOR VALUES= 1.9900E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	5.0251E-03	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.0020E-06
A0							
-1.0000E+00	-1.0000E+00	9.8191E-11	-1.7764E-09	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-5.0000E-03	5.0000E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	1.7853E-09
REALPOLE							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.0020E-06
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4876E-05	2.4875E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9503E-01	9.9500E-01	-1.0027E-06	1.0050E-06	5.0000E-01	-5.0000E-01
MC							
-5.0000E-01	-5.0000E-01	5.3558E-11	0.	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 12-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.4869E+02
H= 1.9900E+00=ACTUAL VALUE
BG= -1.9880E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0000E+00	4.0211E-03	1.0000E+00	9.9602E-01	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9699E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8996E-02	-9.9798E-02	1.6043E-03
A0										
-1.0000E+00	-1.0000E+00	7.9620E-06	-7.9652E-06	-9.9499E-01	9.9899E-01	-1.0000E+00	-1.0000E+00	1.0019E-03	9.9121E-04	2.0037E-03
H										
-1.0000E+00	0.	-4.0050E-03	4.0050E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09	1.0051E-03	1.7853E-06	2.0013E-03
REALPOLE										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9699E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8996E-02	-9.9798E-02	1.6043E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5944E-05	1.5943E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0449E-04	4.9916E-04	1.0019E-03
Q										
4.0010E-01	-4.0010E-01	-7.9699E-01	7.9699E-01	-9.9400E-02	9.9400E-02	4.0010E-01	-4.0010E-01	9.9496E-02	1.0029E-01	-6.0254E-04
MC										
-5.0000E-01	-5.0000E-01	3.9810E-06	-3.9826E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9560E-04	1.0019E-03

(CASE 13-1) C1=C2=R1=R2=R5=1. AND INFINITE GAIN
R3/R4=A1/H AND SET R4=1.
H= 1.9900E+00=ACTUAL VALUE
SPREAD OF RESISTOR VALUES= 1.9900E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	5.0251E-03	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0500E+00	-9.5920E-07	9.9500E-01	-9.9500E-01	-5.0300E-01	5.0000E-01	-1.0000E+00	-1.0020E-06
A0							
-1.0000E+00	-1.0000E+00	9.8191E-11	-1.7764E-09	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-5.0000E-03	5.0000E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	1.7853E-09
REALPOLE							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.0020E-06
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4876E-05	2.4875E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9500E-01	9.9500E-01	-1.0027E-06	1.0050E-06	5.0000E-01	-5.0000E-01
W0							
-5.0000E-01	-5.0000E-01	5.3558E-11	0.	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 13-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.4968E+02
H= 1.9900E+00=ACTUAL VALUE
SL= -1.9850E-33

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0000E+00	5.0211E-03	1.0000E+00	1.0000E+00	1.0040E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9699E-01	-4.5010E-01	4.5010E-01	-9.0010E-01	-9.9900E-02	-9.9001E-02	-9.9801E-02	1.5987E-03
A0										
-1.0000E+00	-1.0000E+00	7.9620E-06	-7.9616E-06	-9.9899E-01	9.9899E-01	-1.0000E+00	-1.0000E+00	1.0019E-03	9.9476E-04	2.0002E-03
H										
-1.0000E+00	0.	-4.0050E-03	4.0050E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09	9.9798E-04	-1.7853E-06	2.0013E-03
REALPOLE										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9699E-01	-4.5010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.9301E-02	-9.9801E-02	1.5987E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5944E-05	1.5947E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0301E-01	5.0272E-04	4.9916E-04	1.0001E-03
Q										
4.0010E-01	-4.0010E-01	-7.9699E-01	7.9699E-01	-9.9400E-02	9.9400E-02	4.0010E-01	-4.0010E-01	9.9501E-02	1.0030E-01	-6.0027E-04
W0										
-5.0000E-01	-5.0001E-01	3.9810E-06	-3.9826E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9738E-04	9.9831E-04

(CASE 14-1) C1=C2=R1=R2=R6=1. AND INFINITE GAIN
R3/R4=A1/H. AND SET R3=1.
H= 1.9900E+00=ACTUAL VALUE
SPREAD OF RESISTOR VALUES= 1.9900E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	1.0000E+00	1.9900E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
A0							
-1.0000E+00	-1.0000E+00	1.7764E-09	3.5350E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-5.0000E-03	5.0001E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09
REALPOLE							
-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07
IMAGPOLE							
-4.9999E-01	-5.0011E-01	-2.4876E-05	2.5094E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9500E-01	9.9500E-01	-1.0118E-06	1.0073E-06	5.0000E-01	-5.0000E-01
W0							
-5.0000E-01	-5.0000E-01	1.7764E-09	3.5350E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 14-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.4968E+02
H= 1.9900E+00=ACTUAL VALUE
DC= -1.9880E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0000E+00	1.0000E+00	2.4869E+02	9.9602E-01	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9700E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8999E-02	-9.9001E-02	1.6015E-03
A0										
-1.0000E+00	-1.0000E+00	7.9616E-06	-7.9516E-06	-9.9899E-01	9.9899E-01	-1.0000E+00	-1.0000E+00	9.9831E-04	9.8943E-04	2.0002E-03
H										
-1.0000E+00	0.	-4.0050E-03	4.0056E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09	1.0015E-03	-1.7853E-06	2.0031E-03
REALPOLE										
-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9700E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8999E-02	-9.9001E-02	1.6015E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5945E-05	1.5903E-05	-4.9953E-01	4.9950E-01	-4.9995E-01	-5.0001E-01	5.0094E-04	4.9739E-04	9.9833E-04
Q										
4.0010E-01	-4.0010E-01	-7.9699E-01	7.9699E-01	-9.9400E-02	9.9400E-02	4.0010E-01	-4.0010E-01	9.9499E-02	1.0029E-01	-6.0027E-04
W0										
-5.0000E-01	-5.0000E-01	3.9790E-06	-3.9758E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	4.9916E-04	4.9383E-04	1.0019E-03

(CASE 15-1) C1=C2=R2=R3=R5=1. AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0200E+02

R1	R2	R3	R4	R5	R6	C1	C2
9.9010E-01	1.0000E+00	1.0000E+00	2.0000E+02	1.0000E+00	9.9010E-01	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1

-1.0000E+00	-9.9920E-07	9.9502E-01	-9.9502E-01	-4.9751E-01	4.9751E-01	-1.0000E+00	-1.0020E-06

A0

-1.0000E+00	-1.0000E+00	0.	0.	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00

H

-1.0000E+00	0.	-4.9751E-03	4.9752E-03	-4.9751E-01	4.9751E-01	-1.0000E+00	0.

REALPOLE

-1.0000E+00	-9.9920E-07	9.9502E-01	-9.9502E-01	-4.9751E-01	4.9751E-01	-1.0000E+00	-1.0020E-06

IMAGPOLE

-4.9999E-01	-5.0001E-01	-2.4876E-05	2.4869E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01

Q

5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	-2.4886E-03	2.4886E-03	5.0000E-01	-5.0000E-01

W0

-5.0000E-01	-5.0000E-01	0.	0.	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 15-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5276E+02
H= 2.0000E+00=ACTUAL VALUE
90= -1.9980E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
9.9008E-01	1.0000E+00	1.0000E+00	2.5025E+02	1.0000E+00	9.9403E-01	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1

-9.0010E-01	-9.9900E-02	7.9602E-01	-7.9602E-01	-3.9761E-01	3.9761E-01	-9.0010E-01	-9.9900E-02	-1.0000E-01	-9.9901E-02	1.5932E-03

A0

-1.0000E+00	-1.0000E+00	7.9545E-06	-7.1125E-06	-9.9300E-01	9.9900E-01	-1.0000E+00	-1.0000E+00	1.0019E-03	9.9476E-04	1.9931E-03

H

-1.0000E+00	0.	-3.9801E-03	3.9804E-03	-4.9751E-01	4.9751E-01	-1.0000E+00	0.	9.9931E-04	0.	1.9931E-03

REALPOLE

-9.0010E-01	-9.9900E-02	7.9602E-01	-7.9602E-01	-3.9761E-01	3.9761E-01	-9.0010E-01	-9.9900E-02	-1.0000E-01	-9.9801E-02	1.5932E-03

IMAGPOLE

-4.9999E-01	-5.0001E-01	-1.5925E-05	1.6448E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0272E-04	4.9916E-04	9.9655E-04

Q

4.0010E-01	-4.0010E-01	-7.9601E-01	7.9601E-01	-1.0189E-01	1.0189E-01	4.0010E-01	-4.0010E-01	1.0050E-01	1.0030E-01	-5.9572E-04

W0

-5.0000E-01	-5.0000E-01	3.9755E-06	-3.5563E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9738E-04	9.9831E-04

(CASE 16-1) C1=C2=R2=R3=R6=1. AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0200E+02

R1	R2	R3	R4	R5	R6	C1	C2
9.9010E-01	1.0000E+00	1.0000E+00	2.0000E+02	1.0100E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1

-1.0000E+00	-1.0020E-06	9.9502E-01	-9.9502E-01	-4.9751E-01	4.9751E-01	-1.0000E+00	-9.9365E-07

AO

-1.0000E+00	-1.0000E+00	0.	0.	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00

M

-1.0000E+00	0.	-4.9751E-03	4.9745E-03	-4.9751E-01	4.9751E-01	-1.0000E+00	0.

REALPOLE

-1.0000E+00	-1.0020E-06	9.9502E-01	-9.9502E-01	-4.9751E-01	4.9751E-01	-1.0000E+00	-9.9365E-07

IMAGPOLE

-4.9999E-01	-5.0001E-01	-2.4875E-05	2.4869E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01

Q

5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	-2.4886E-03	2.4886E-03	5.0000E-01	-5.0000E-01

WC

-5.0000E-01	-5.0000E-01	0.	0.	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 16-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5276E+02
M= 2.0000E+00=ACTUAL VALUE
BO= -1.9990E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
9.9009E-01	1.0000E+00	1.0000E+00	2.5025E+02	1.0060E+00	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1

-9.0010E-01	-9.9900E-02	7.9602E-01	-7.9602E-01	-3.9761E-01	3.9761E-01	-9.0010E-01	-9.9900E-02	-1.0000E-01	-9.9801E-02	1.5932E-03

AO

-1.0000E+00	-1.0000E+00	7.9545E-06	-7.9571E-06	-9.9300E-01	9.9900E-01	-1.0000E+00	-1.0000E+00	9.9476E-04	9.8765E-04	1.9931E-03

M

-1.0000E+00	0.	-3.9801E-03	3.9786E-03	-4.9751E-01	4.9751E-01	-1.0000E+00	0.	1.0019E-03	-3.5527E-06	1.9931E-03

REALPOLE

-9.0010E-01	-9.9900E-02	7.9602E-01	-7.9602E-01	-3.9761E-01	3.9761E-01	-9.0010E-01	-9.9900E-02	-1.0000E-01	-9.9801E-02	1.5932E-03

IMAGPOLE

-4.9995E-01	-5.0001E-01	-1.5925E-05	1.6003E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0094E-04	4.9739E-04	9.9655E-04

Q

4.0010E-01	-4.0010E-01	-7.9601E-01	7.9602E-01	-1.0189E-01	1.0189E-01	4.0010E-01	-4.0010E-01	1.0050E-01	1.0029E-01	-5.9572E-04

WO

-5.0000E-01	-5.0000E-01	3.9755E-06	-4.0000E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	4.9738E-04	4.9383E-04	9.9831E-04

(CASE 17-1) C1=C2=R2=R4=R6=1. AND INFINITE GAIN
SPREAD OF RESISTOR VALUES= 2.0000E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	5.0000E-03	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR THE IDEAL CASE

A1							
-1.0000E+00	-1.0042E-06	9.9502E-01	-9.9502E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.0070E-06
AC							
-1.0000E+00	-1.0000E+00	8.8818E-11	-3.5527E-09	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00
H							
-1.0000E+00	0.	-4.9751E-03	4.9751E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	7.1410E-09
REALPOLE							
-1.0000E+00	-1.0042E-06	9.9502E-01	-9.9502E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.0070E-06
IMAGPOLE							
-4.9999E-01	-5.0001E-01	-2.4629E-05	2.4626E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01
Q							
5.0000E-01	-5.0000E-01	-9.9502E-01	9.9502E-01	-1.0136E-06	1.0158E-06	5.0000E-01	-5.0000E-01
WO							
-5.0000E-01	-5.0000E-01	4.4409E-11	-1.7764E-09	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE 17-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.5175E+02
H= 2.0000E+00=ACTUAL VALUE
BG= -1.9990E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
9.9008E-01	1.0000E+00	3.9960E-03	1.0000E+00	1.0060E+00	1.0000E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR THE NON-IDEAL CASE

A1										
-9.0010E-01	-9.9900E-02	7.9602E-01	-7.9602E-01	-3.9761E-01	3.9761E-01	-9.0010E-01	-9.9900E-02	-1.0000E-01	-9.9803E-02	1.5932E-03
AC										
-1.0006E+00	-1.0000E+00	7.9522E-06	-7.9510E-06	-9.9900E-01	9.9900E-01	-1.0000E+00	-1.0000E+00	9.9831E-04	9.9121E-04	1.9931E-03
H										
-1.0000E+00	0.	-3.9801E-03	3.9801E-03	-4.9751E-01	4.9751E-01	-1.0000E+00	0.	9.9831E-04	0.	1.9931E-03
REALPOLE										
-9.0010E-01	-9.9900E-02	7.9602E-01	-7.9602E-01	-3.9761E-01	3.9761E-01	-9.0010E-01	-9.9900E-02	-1.0000E-01	-9.9803E-02	1.5932E-03
IMAGPOLE										
-4.9999E-01	-5.0001E-01	-1.5925E-05	1.5925E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0094E-04	4.9739E-04	9.9655E-04
Q										
4.0010E-01	-4.0010E-01	-7.9601E-01	7.9601E-01	-1.0189E-01	1.0189E-01	4.0010E-01	-4.0010E-01	1.0050E-01	1.0030E-01	-5.9345E-04
WO										
-5.0000E-01	-5.0000E-01	3.9761E-06	-3.9755E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0093E-04	4.9383E-04	9.9831E-04

SPECIFIED COEFFICIENTS,GAINS OF THREE OP-AMPS,INCREMENT FOR DIFFERENTIATION,MAXIMUM ERROR FROM NEWTON ALGORITHM AND Q

A1	A0	M	K1	K2	K3	DX	ERROR	Q
1.0000E-02	1.0000E+00	2.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03	1.0000E-06	1.0000E-12	1.0000E+02

(CASE8-1)C1=C2=R1=R2=R3=R5=1 AND INFINITE GAIN
M= 1.9900E+00=ACTUAL VALUE
SPREAD OF RESISTOR VALUES= 1.9900E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	1.0000E+00	1.9900E+02	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

SENSITIVITIES FOR INFINITE GAIN OP-AMP

A1

-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07

A0

-1.0000E+00	-1.0000E+00	1.7764E-09	3.5350E-07	-1.0000E+00	1.0000E+00	-1.0000E+00	-1.0000E+00

M

-1.0000E+00	0.	-5.0000E-03	5.0001E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	-1.7853E-09

REALPOLE

-1.0000E+00	-9.9920E-07	9.9500E-01	-9.9500E-01	-5.0000E-01	5.0000E-01	-1.0000E+00	-9.9642E-07

IMAGPOLE

-4.9999E-01	-5.0001E-01	-2.4876E-05	2.5098E-05	-5.0000E-01	5.0000E-01	-4.9999E-01	-5.0001E-01

Q

5.0000E-01	-5.0000E-01	-9.9500E-01	9.9500E-01	-1.0118E-06	1.0073E-06	5.0000E-01	-5.0000E-01

W0

-5.0000E-01	-5.0000E-01	1.7764E-09	3.5350E-07	-5.0000E-01	5.0000E-01	-5.0000E-01	-5.0000E-01

(CASE8-2) FINITE GAIN
SPREAD OF RESISTOR VALUES= 2.4869E+02
M= 1.9900E+00=ACTUAL VALUE
BG=-1.9840E-03

R1	R2	R3	R4	R5	R6	C1	C2	K1	K2	K3
1.0000E+00	1.0000E+00	1.0000E+00	2.4869E+02	1.0000E+00	1.0040E+00	1.0000E+00	1.0000E+00	-1.0000E+03	-1.0000E+03	-1.0000E+03

SENSITIVITIES FOR FINITE GAIN OP-AMP

A1

-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9700E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8999E-02	-9.9801E-02	1.6015E-03

A0

-1.0000E+00	-1.0000E+00	7.9581E-06	-7.9516E-06	-9.9899E-01	9.9899E-01	-1.0000E+00	-1.0000E+00	1.0036E-03	9.9476E-04	2.0002E-03

M

-1.0000E+00	0.	-4.0050E-03	4.0047E-03	-5.0000E-01	5.0000E-01	-1.0000E+00	0.	1.0015E-03	0.	1.9995E-03

REALPOLE

-9.0010E-01	-9.9900E-02	7.9699E-01	-7.9700E-01	-4.0010E-01	4.0010E-01	-9.0010E-01	-9.9900E-02	-9.8999E-02	-9.9801E-02	1.6015E-03

IMAGPOLE

-4.9999E-01	-5.0001E-01	-1.5947E-05	1.5903E-05	-4.9950E-01	4.9950E-01	-4.9999E-01	-5.0001E-01	5.0449E-04	5.0094E-04	9.9833E-04

Q

4.0010E-01	-4.0010E-01	-7.9699E-01	7.9699E-01	-9.9400E-02	9.9400E-02	4.0010E-01	-4.0010E-01	9.9501E-02	1.0030E-01	-6.0027E-04

W0

-5.0000E-01	-5.0000E-01	3.9790E-06	-3.9758E-06	-4.9950E-01	4.9950E-01	-5.0000E-01	-5.0000E-01	5.0271E-04	4.9738E-04	9.9831E-04

(CASE 6-3) FREQUENCY DEPENDENT OP-AMP AND CONSTANT INPUT AND OUTPUT IMPEDENCES

POLE LOCATION = -5.000000E-03+J9.999875E-01
CUT-OFF FREQUENCY= 1.000000E+01

	FIRST INTEGRTOR	SECOND INTEGRTOR	SUMMER
INPUT IMPEDENCE =	1.000000E+03	1.000000E+03	1.000000E+03
OUTPUT IMPEDENCE=	1.000000E-03	1.000000E-03	1.000000E-03

SPREAD OF RESISTOR VALUES= 2.3682E+02

R1	R2	R3	R4	R5	R6	C1	C2
1.0000E+00	1.0000E+00	1.0000E+00	2.3682E+02	1.0000E+00	1.0042E+00	1.0000E+00	1.0000E+00

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