NEW VERSION OF THE COCO PROGRAM

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Abstract

The new version of the COCO program enables the analysis of linear circuits in symbolical, symbolic numerical or in semi-symbolical form. Simple synthesis problems can also be solved with the aid of this program. Several examples illustrate the use of the program for circuit analysis and synthesis. Modern network elements (trans-impedance operational amplifier, current conveyors) are built in the program.

Keywords:

circuit theory, symbolical network analysis, network functions computation

1. Introduction

Originally, the program was built up for the high-order cofactor computation of an equicofactor matrix, i.e. for the analysis of networks containing only regular network-elements (having an admittance matrix). The generalized nodal voltage method was used for the scheme description. Later, we have described the network to be analysed by the **modified generalized nodal voltage method** (MGNVM) [1]. In this case, the network is described by the following matrix equation

$$\mathbf{Q} = \mathbf{R}\,\mathbf{X} \qquad (1)$$

Here the vector **Q** contains all nodal currents (exciting quantities) and any zeros, the vector **X** contains all nodal voltages and all independent currents (unknown quantities), whereas the symbol **R** denotes a hybrid network-matrix. This method allows the analysis of networks with any network elements (including multi-port immittance-converters). For the element description we can use arbitrary parameters (e.g. a resistor can be characterized either by its conductance G or by its resistance R).

The universality of the MGNVM is paid for by extending the matrix **R** (for each independent current we must add one row and one column to the matrix).

The program is an open system. Arbitrary new network- elements can be incorporated in it. It works interactively and leads the user systematically at every step of computation.

The whole program can be divided into two parts: scheme description and cofactor (network-function) computation.

2. Scheme description

All nodes of the circuit to be analysed must be interconnected. If the scheme in question consists of some separate parts (due to inductive coupling), it is necessary to interconnect arbitrary two nodes in separate subschemes. All nodes in the scheme must be denoted by arbitrary (but different) numbers. The computer itself numerates successively the scheme-nodes by numbers in natural sequence (1,2,3,...).

Each network-element is characterized by its *descriptrix* (previously "stamp"), i.e. by a special matrix indicating the position of parameters and coefficients in the resulting matrix **R**. In the descriptrix all rows and columns with zero elements are omitted. The final network-matrix **R** is obtained as a sum of descriptrices of all network-elements.

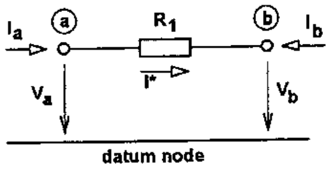

Fig.1
Resistor connected in the scheme

As an example, let us consider a resistor connected to nodes a and b and characterized by its resistance R_1 (see Fig.1). The datum node is supposed to be outside the network. In this case, we are considering one independent current I^*. Therefore it holds: $I_a = I^*$, $I_b = -I^*$ and $R_1 I^* = V_a - V_b$. According to these equations we get the conventional descriptrix in the following form:

		a	b	U+1(I*)
	a			1
R_1 =	b			-1
	U+1	-1	1	R_1

In our program each descriptrix is transformed into a special array, where every parameter or coefficient (in our case the resistance R_1 and the coefficients 1) is specified in one row having 8 columns. It is known that each parameter of a regular network-element appears in the descriptrix always in two rows and in two columns (twice with positive and twice with negative sign). In every array row we note the following quantities: parameter code, parameter subscript, row+, row-, column+, column- (for place and sign indication in the R-matrix), numerical value (or symbol specification), number of the next row for product creation.

Therefore, the equivalent array of descriptrix $\mathbf{R}_1$ (eqn.(2)) is as follows

```
R, 1: U+1, 0: U+1, 0: 1000, I+2
1, 1: U+1, 0: b   , a: 1   , I+1
---------------------------------
1, 1: a   , b: U+1, 0: 1   , I+1
```

Here the resistance value is 1 kΩ and I coresponds to the actual row number in **R**. The zero relates here to the non existing row and/or column in the **R**-matrix. The symbol U denotes the last row number of the **R**-matrix during the matrix up-building.

Let us now consider an ideal *transimpedance operational amplifier* (TIA) with accessible internal compensation pin PZ (commercially available from Analog Devices, Norwood, USA as type AD 844 or AD 846), the scheme of which is drawn in Fig.2. It is a four-port immittance-converter with two independent currents I^* and I^{**}

Using the basic equations $I_a = I^*$, $I_b = 0$, $I_c = I^*$, $I_d = -I^{**}$, $I_e = I^{**} - I^* - I^*$, $V_d - V_c = 0$ and $V_a - V_b = 0$ we get the descriptrix in conventional form

$\mathbf{R}_2 =$

	a	b	c	d	e	U+1(I*)	U+2(I**)
a						1	
b							
c						1	
d							-1
e						-1-1	1
U+1	1	-1					
U+2			-1	1			

The equivalent array descriptrix includes 5 rows:

```
1, m: U+1, 0: a   , b: 1, I+1
1, m: a   , e: U+1, 0: 1, I+2
1, m: c   , e: U+1, 0: 1, I+1
1, m: U+2, 0: d   , c: 1, I+1
1, m: c   , d: U+2, 0: 1, I+1
```

Here m is the TIA's subscript-number.

If we are not interested in the currents I* and I**, we can reduce the number of array rows using the cofactor expansion. Then we get

```
1, m: e, d: d, c: 1, I+1
------------------------
1, m: a, e: a, b: 1, I+2
1, m: c, e: a, b: 1, I+1
------------------------
```
(2)

If we delete the node *d* in Fig.2, the TIA changes to a second-generation current-conveyor (CCII+). The corresponding device is commercially available from LPT Electronics, Oxford, UK as type CCII01. Therefore, the array descriptrix of a CCII+ has only two rows

```
------------------------
1, m: a, e: a, b: 1, I+2
1, m: c, e: a, b: 1, I+1
------------------------
```
(3)

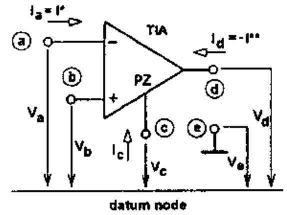

Fig.2
Transimpedance operational amplifier in the scheme

While for the CCII- it holds that $I_c = -I^*$ and $I^{**} = 0$ (Fig.2), the array descriptrix has the following form

```
------------------------
1, m: a, e: a, b: 1, I+2
1, m: e, c: a, b: 1, I+1
------------------------
```
(4)

The program COCO8 contains the following network-elements: resistors (defined by *G* or by *R*), capacitors, inductors, shorting wire, general one-port elements (defined by admittance or by impedance), high-order one-port elements ($\mathbf{Y}(s)=\mathbf{Q}s^k$ or $\mathbf{Z}(s)=\mathbf{X}s^k$), coupled inductors (transformers), ideal operational amplifiers , general two-port elements (specified by Y-, Z-, H- or A-parameters), 4 controlled sources (VCVS, VCCS, CCCS and CCVS), two-port immittance converters (incl. converting mutators, current or voltage scalors), immittance inverters (incl. inverting mutators), three-port immittance converters with one independent current (incl. current conveyor CCI), three-port immittance converters with one independent voltage, current conveyors CCII+ and CCI-, ideal transimpedance operational amplifiers, multi-input voltage sources (voltage summers), multi-input current sources (current summers), multi-ouput voltage sources, multi-output current sources and ideal transformers with n windings.

The parameters of some network-elements (namely parameters of all controlled sources, the impedance- and the admittance-function of one-port element and all two-port admittance-parameters) can be given as a fractional function of s (polynomial in s in numerator over polynomial in s in denominator). In the above case, the computer substitutes the network-element in question by a suitable model.

3. Network analysis and synthesis

Beginning the computation, we give either the network- element code or one of the following commands: H=help (survey of all element-codes), D=data (loading of the saved **R**-matrix), 0 (zero)= end of the scheme description and E=exit.

The analysed circuit can be regarded as an n-port network (n=1, 2, 3, ...). All characteristics of such a network can be computed with the aid of **R**-matrix cofactors.

With the aid of the COCO8 program we can compute directly an arbitrary high-order cofactor (we must define the desired operations with rows and columns), all two-port cofactors, 6 two-port network-functions and selected branch currents. Two-port cofactors can be used for the determination of different network characteristics (see User's manual). Loading impedance of arbitrary internal port can also be computed as well as relative or absolute sensitivities of 5 network-functions to variations of one-port element- parameters.

New is the possibility of using the COCO8 program for a simple symbolic-numerical network-synthesis. We have applied here the procedure explained in [4]. We can compute the impedance ZU(s) of a one-port element connected to a chosen network-port, if the voltage transfer function between any two ports must be equal to zero or if a two-port network-function is prescribed.

The scheme can be modified, saved and loaded again.

The basic algorithm for the cofactor-computation was described in [2] and [3]. If the cofactor in question has m rows and columns and if the **R**-matrix array has n rows, then the computer proves the existence of all possible m parameter-products which can be created from all n parameters or coefficients in the **R**-matrix array.

4. Examples

4.1 Example No 1

Let us consider the one-port network shown in Fig.3. The first transistor is characterized by its hybrid parameters $h_{11e} = 2560$, $h_{12e} = 2.43E-4$, $h_{21e} = 185.4$, $h_{22e} = 1.91E-5$, whereas for the second transistor the admittance parameters are known: $y_{11e} = 1.49E-5$, $y_{12e} = -1.376E-7$, $y_{21e} = 0.2906$, $y_{22e} = 1.777E-5$. Futher, we know $R_1 = 5E+5$, $R_2 = 2E+5$, and $R_3 = 100\ \Omega$. The network can have negative input resistance. We have to compute the resistance-value of a resistor R_4 for the desired input resistance -3 kΩ.

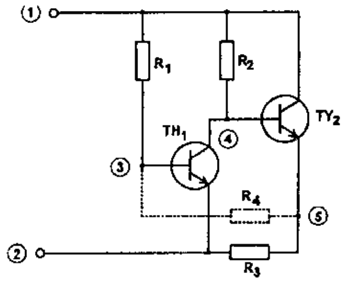

Fig.3
One-port network with negative input resistance

We choose in MENU A command 9 - impedance for the given network function.

Finally, we obtain

Input 1-2, Output 1-5, Port with unknown impedance 3-5
The actual function is: KU(s)=
Coeff. of numerator: m= 0
-3E+3
Coeff. of denominator: n= 0
1
ZU(s)=
Numerator
5.483539E+14
Denominator
3.178297E+10

Thus the chosen resistancevalue is R_4 = 17.25307 kΩ. We can prove the result correctness analysing the whole network.

4.2 Example No 2

We are interested in the input impedance of the one-port network shown in Fig.4 [5]. The circuit contains one CCII+ and one CCII-. The symbolic results are:

Input 1-5, Output 1-5
ZU(s) =
Numerator
1
Denominator
+Z3*Y1*Y2

This network can be used as an immittance converter or as an immittance inverter.

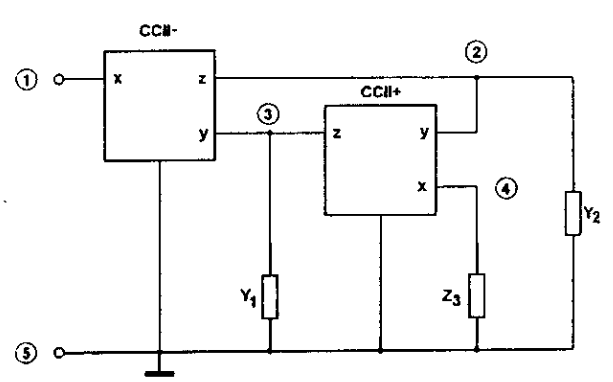

Fig.4
Special immittance converter or inverter

4.3 Example No 3

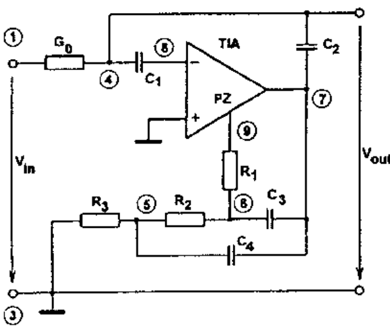

Fig.5
Fourth-order low-pass filter

The two-port network in Fig.5 [7] represents a low-pass filter with transimpedance operational amplifier. We have to compute the voltage ratio V_{out}/V_{in} in symbolical form.

The computer gives us the following result (a little rearranged):

$$V_{out} / V_{in} = G_0/\{p^4 R_1 R_2 R_3 C_1 C_2 C_3 C_4 + p^3[R_1 C_1(R_2 C_2 C_3 + R_3 C_2 C_3 + R_3 C_2 C_4) + R_2 R_3 C_1 C_2 C_4] + p^2 C_1 C_2 (R_2 + R_3) + p(C_1 + C_2) + G_0\}$$

5. Conclusion

The program COCO8 is a useful tool for research and education purposes. The use of symbolical network design seems to be still topical . About pleasures, perils and pitfalls of symbolic analysis see [6].

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