MACROMODEL APPROACH TO SEMI-SYMBOLIC ANALYSIS USING NUMERICAL CIRCUIT ANALYSIS PROGRAMS

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Abstract: A macromodel approach is proposed in the present work to determine the polynomial coefficiens of the transfer function $H(s)$ of linear circuits in semi-symbolic form using the possibilities of the general-purpose programs for numerical circuit analysis. The proposed model represents a circuit realization of an interpolation approach for semi-symbolic analysis. The transfer function determination in semi-symbolic form is reduced to a single frequency analysis of the proposed model using the *AC Sweep* option of the *PSpice* simulator. This approach enhances the possibilities of the numerical simulators such as *PSpice* with a semi-symbolic analysis, which is not implemented in the standard package. An example are given illustrating the proposed approach to semi-symbolic analysis.

I. INTRODUCTION

The determination of the circuit and system transfer functions $H(s)$ in semi-symbolic form allows to investigate automatically stability characteristics using general polynomial stability criteria. Since the general purpose *PSpice*-like analysis programs have no block incorporated for performance of symbolic and numerical-symbolic analysis, it is very useful to extend the capabilities of such numerical simulators with semi-symbolic analysis. The following possibilities of the general-purpose smulators are used for this purpose [4]:

- the possibilities of the input language for subcircuit definition;
- the extedned capabilities for the description of frequency-dependent functions.

A computer *PSpice* model is proposed in this work to obtain the polynomial coefficients of the circuit using a standard frequency analysis. The model represents a circuit realization of an interpolation approach for semi-symbolic analysis.

The expression for the transfer function of an analog circuit or system $H(s)$

$$H(s) = \frac{A(s)}{B(s)} \tag{1}$$

can be represented in the form:

$$A(s) = H(s).\ B(s) \tag{2}$$

where

$$A(s) = \sum_{i=0}^{n} a_i s^i \ ; \quad B(s) = 1 + \sum_{i=1}^{n} b_i s^i \tag{3}$$

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n is the number of the reactive elements, determining the maximum power of the polynomials in the nominator and in the denominator of the transfer function.

Similarly, the transfer function in the z-domain of discrete and analog-discrete circuits has the form:

$$H(z) = \frac{A(z)}{B(z)}, \tag{4}$$

where

$$A(z) = \sum_{i=0}^{n} a_i z^{-i} \; ; \quad B(z) = 1 + \sum_{i=1}^{n} b_i z^{-i} \tag{5}$$

for digital filters, and

$$A(z) = \sum_{i=0}^{n} a_i z^{-i/p} \; ; \quad B(z) = 1 + \sum_{i=1}^{n} b_i z^{-i/p} \tag{6}$$

for switched-capacitor and switched-current circuits;

p - number of the phases.

The corresponding basic digital filter building blocks, applicable to the frequency analysis using *PSpice*-like simulators, are presented in Fig. 1a for cascade-form and in Fig. 1b for wave digital filters [1]. The models describing *SC*- and *SI*-circuits in the z-domain, are presented in Fig. 2 and in Fig. 3 correspondingly [2].

II. POLYNOMIAL COEFFICIENTS DETERMINATION

Replacing $s=s_j=2\pi f_j$ in (2), j=1,2,...,2n+1, we obtain:

$$A(s_j) = H(s_j).\, B(s_j) \tag{7}$$

and

$$\sum_{i=0}^{n} a_i s_j^i \;= H(s_j).(1 + \sum_{i=1}^{n} b_i s_j^i) \;, \quad j=1,2,...,2n+1 \tag{8}$$

The nullator-norator equivalent circuit N_{sym}, shown in Fig. 4, corresponding to the interpolation in the points s_1, s_2, ... , s_{2n+1} , represents a circuit realization of equations (8). The circuit N_{sym} consists of n one-type blocks S_i, i=1,2,...,2n+1, obtained in the following way:

1. The subcircuits S_1, S_2, ... , S_{2n+1} model the nominal circuit for the corresponding frequencies f_1,f_2, ...,f_{2n+1}.

2. The subcircuit S_p models equations (8). The unknown coefficients a_j, b_l are represented by node voltages of subcircuit S_p:

$$V_{a_j} \Leftrightarrow a_j \;\text{ and }\; V_{b_l} \Leftrightarrow b_l \;, \; j=0, 1, ...,n \;; \; l=1, 2, ..., n. \tag{9}$$

The relations (11) are defined by dependent voltage sources

$$V_A(s_i) = A(s_i) \text{ and } V_B(s_i) = B(s_i)\,, \quad i= 1, 2, ...,2n+1. \tag{10}$$

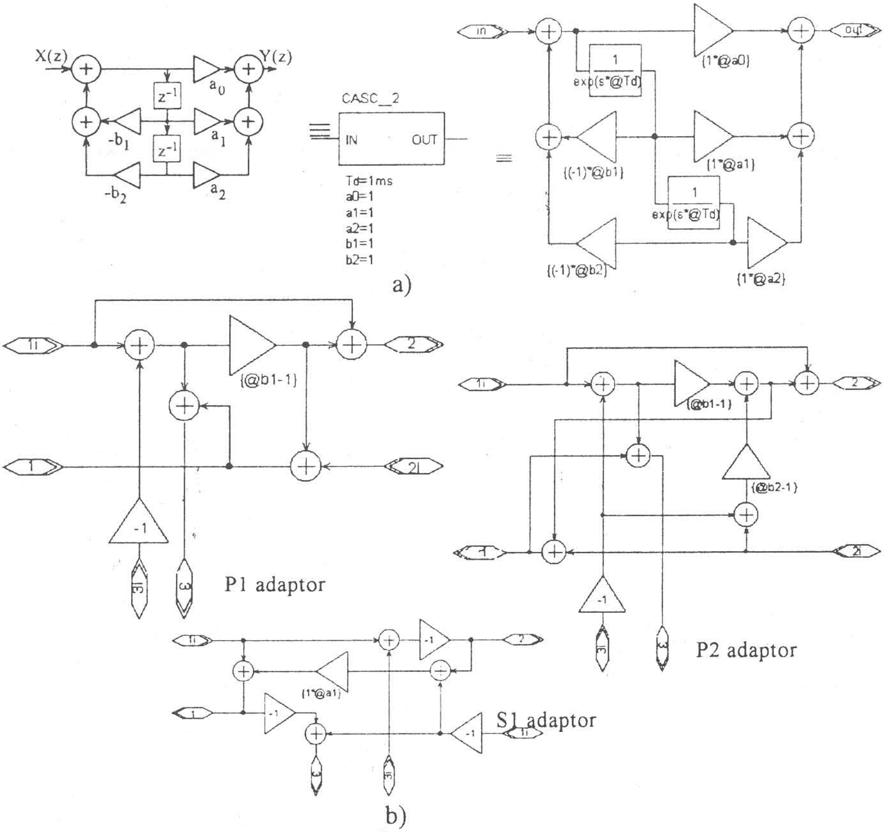


Fig. 1

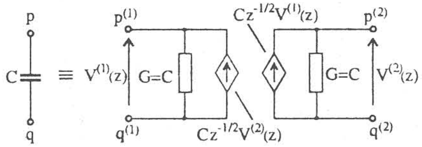
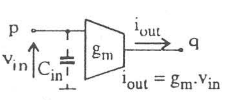


Fig. 2



$g_c^j = C'_{in}$; ; $g_m^j = g_m$;

$C'_{in} = \frac{C_{in}.2}{T}$; $j,\ t = 1,\ j \neq t$;

$R_j = 1$

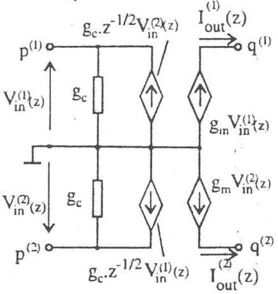


Fig. 3

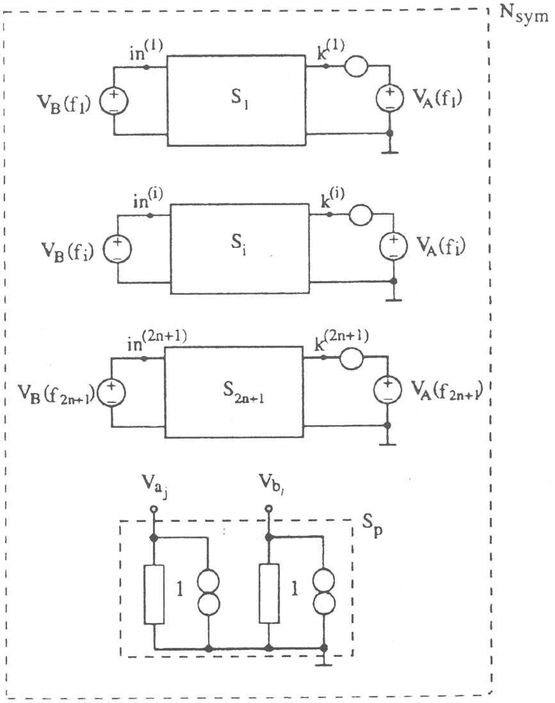


Fig. 4

It is very important to determine automatically the coefficients a_i, b_i using standard analysis programs in the frequency domain. In order to achieve the necessary accuracy, *complex interpolation* is used [3]. The interpolation nodes are placed equidistantly on the unit circle in the complex plane:

$$z_k = e^{j\frac{2\pi k}{2n+1}}\ ;\ k = 1,2,\ldots,2n+1 \tag{11}$$

and

$$z_i = z^*_{2n-i+1}\ ,\ i=1,2,\ldots,n.$$

The polynomial coefficients are obtained using the equations:

$$A(z_i) = H(z_i).\ B(z_i)$$

$$\sum_{j=0}^{n} a_j z_i{}^j = H(z_i).(1+\sum_{j=1}^{n} b_j z_i{}^j),\quad i=1,2,\ldots,2n+1 \tag{12}$$

III. COMPUTER REALIZATION

The enhanced possibilities of the *PSpice* simulator for subcircuit definition allow to obtain easily the transfer function in semi-symbolic form.

The user has to describe the circuit in a standard way. The blocks for $A(s)$ and $B(s)$ determihation are included in the library.

In order to achieve a higher accuracy:

1. Scaling of the circuit parameter values is introduced;

2. A smaler absolute error of the voltages and currents is defined by the **OPTION** statements: **VNTOL**=$1E^{-12}$ and **ABSTOL**=$1E^{-12.}$

In order to illustrate the proposed approach, the transfer function of the circuit shown in Fig. 5 is obtained in semi-symbolic form using the *PSpice* simulator. The library models for the numerator and denominator determination have the form:

Numerator determination: $A(z_k)$

```
.subckt sa_n1 a0 a1 a2 nom ref params:pk={pk} pn={pn}
ga0 ref nom value {V(a0,ref)*1}
ga1 ref nom laplace {V(a1,ref)} {exp(s*pk/pn)}
ga2 ref nom laplace {V(a2,ref)} {exp(2*s*pk/pn)}
ra1 nom ref 1
.ends sa_n1
```

Denominator determination: $B(z_k)$

```
.subckt sa_d1 b1 b2 den ref params: pk={pk}  pn={pn}
eed den ref d ref 1
id1 ref d ac 1
gb1 ref d laplace {V(b1,ref)} {exp(s*pk/pn)}
gb2 ref d laplace {V(b2,ref)} {exp(2*s*pk/pn)}
rd1 d ref 1
.ends sa_d1
```

Options

```
.options reltol=0.001 VNTOL=1E-12 ABSTOL=10E-12
```

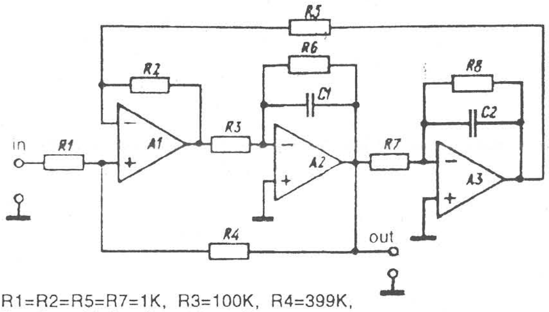
Analysis setup

```
.ac lin 2 1.0 1.0
.print ac Vr([a0]) Vr([a1]) Vr([a2]) Vr([b1])  Vr([b2])
```

The calculated polynomial coefficients,obtained in the output file, are:

```
                     AC ANALYSIS
   Vr(a0)           Vr(a1)         Vr(a2)
  1.291E+02        1.190E+03     1.252E+03

   Vr(b1)           Vr(b2)
  1.506E+04        5.648E+04
```



R1=R2=R5=R7=1K, R3=100K, R4=399K,
R6=R8=5M, C1=C2=159.16nF

Fig. 5

As a result

$$H(s)=\frac{a_0+a_1.s+a_2.s^2}{1+b_1.s+b_2.s^2}$$

where $a_0=1.291\text{x}10^2$; $a_1=1.19\text{x}10^3$; $a_2=1.252\text{x}10^3$; $b_1=1.506\text{x}10^4$; $b_2=5.648\text{x}10^4$.

CONCLUSIONS

An unified approach has been proposed to semi-symbolic analysis using the possibilities of numerical *PSpice*-like simulators reducing the problem to the standard analysis in the frequency domain. Polynomial coefficients a_i , i=0, 1, ..., n and b_i, i=1, 2,..., n of the corresponding transfer function $H(s)$ for analog circuits and $H(z)$ for analog-discrete circuits (SC- and SI-circuits), as well as for discrete-type circuits (digital filters). The user has to describe the circuit in the standard way using the graphical editor (.sch input file) or by the text editor (.cir input file). The interpolation model is extracted from the library.The polynomial coefficients are obtained from the output text file. The proposed approach enlarges the possibilities of the PSpice-like simulators for additional investigations which require polynolial representation of the analog, *SC*- and *SI*-circuit characteristics, such as stability investigation, etc.

REFERENCES

[1] Gadjeva, E., M. Marinov, T. Djamijkov, T. Kouyoumdjiev, Application of Macronodels for Computer Simulation of Digital Filters, X Intern. Symp. on Theoretical Electrical Engineering, Magdeburg, Germany, 6-9 Sept. 1999, pp. 311-314.

[2] Farchy, S., E. Gadzheva, T. Kouyoumdjiev, Switched-Capacitor and Digital Filter Modeling Using General-Purpose Analysis Programs, 39 Intern. Wissenschaftliches Kolloquium 27-30.09.1994, pp. 80-85, vol. 3.

[3] Vlach, J., K.Singhal, Computer Methods for Circuit Analysis and Design, Van Nostrand Reinhold, Nerw York, 1994.

[4] PSpice, Circuit Analysis User's Guide, *Microsim Co.*, Irvine, 1991.