Sequence of Expressions Generation for the Repetitive Analysis Acceleration

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***Abstract* - A classification of Sequence of Expressions (SoE) generation is proposed. The concept of multimethodical program and testing of the symbolic methods or simulators for linear circuits are discussed. It is shown, that both analysis method and SoE generation successfully enable a choice of the minimal number of arithmetical operations during repetitive analysis of linear circuits.**

I. INTRODUCTION

Repetitive (or multivariant) analysis in frequency and/or time domains of large analogue networks is employed in the optimisation process, statistical tests, real time modelling and other cases of electronic circuits emulation. The main problem of the repetitive analysis is to obtain an acceptable time of their emulation. In spit e of technological progress in calculation and graphical resources of the present-day computers, the analysis time in optimisation process of the 100-nodes linear circuit can take a few hours. Fast calculation is also necessary for providing the real time animation of the transfer function characteristic, for example.

Nowadays symbolic analysis are more widely used due to packages of computer algebra (MAPLE, MathCAD, MATHEMATICA, etc.) However, in certain cases of considerable practical value the usage of electric circuits topology peculiarities allows one to obtain better results than with the help of computer algebra packages. For example, the author does not know of any programs of computer algebra which can obtain a linear formula of full graphs determinant [15]: with 5 nodes consisting of 50 operations of addition and 29 of multiplication, that is [+]=50,[*]=29, with 6 nodes - [+]=237, [∗]=122.

Here are some limitations of computer algebra programs for the tasks of circuit symbolic analysis:

- the use of integer fractions for symbolic-numeric operands slows down the speed of simulation, because the floating point co-processor is not used;
- linear formulae for symbolic analysis are often not good for multivariate analysis;
- peculiarities of electronic circuit matrices are not taken into account.

At present it is already difficult to determine the limitations of symbolic analysis. It includes both topological formulae and usual numeric methods with the SoE generator added. If input data are given symbolic names, then every sequence of calculations and every algorithm can be programmed as a quasi-symbolic formula which is valid for a particular circuit only.

In this paper, we continue the SoE concept [1, 2, 3, 7, 10, 13] which, in combination with the concept of multimethodical programs, most often permit achieving a maximum speed of repetitive analysis of linear circuits in frequency and time domains.

II. SEQUENCE OF EXPRESSIONS

Ordinary formulae (SoE) can have numerators and denominators, brackets and other conventional attributes. The compactness (quality) of a SoE is estimated in the first approximation by the counts of arithmetic operations needed to convert it to a real (complex) number or polynomial. It is not advisable to keep mutually cancelled members and operations leading to the calculations of small differences in large numbers, etc. All the algorithms used for SoE generation of circuit function may be divided into 16 types on the basis of 4 classifying features: the presence of two operations ('-', '/') and two attributes (branches and equations).[2, 3, 11].

In this paper a simplified classification of SoE's is proposed. It would be better to divide them into 8 groups according to three arithmetical operations: [/], [-], [//] (Table I), where [//] means division without a remainder. The types of formulae with lower numbers have higher accuracy in the calculations but they use more processor time and, on the contrary, the types with higher numbers calculate faster but with less accuracy. It should be stresses here that any allowance for sign [-] in SoE classification in general case makes sense for passive circuits only.

An important characteristic of SoE's is the potential for using them for the methods classification. It proves sufficient to generate SoE for the calculation of admittance matrix determinant for tested passive circuit. In order to determine which of the 8 groups a given method belongs to, it is sufficient to identify which arithmetical operations this SoE contains. The number of arithmetical operations contained is an indication of the efficiency of the method.

TABLE 1
THE CLASSIFICATION OF SOE AND METHOD

№ of gro-op	Attribute of SoE			Example of methods	Ope-rands
	/	-	//		
0				trees, Feussner, DTM [17],...	***c, p***
1			■	Polynomial Red. Method [12]	***c, p***
2		■		Coates [4]. Determinant according to his definition [14].	***c, p***
3		■	■	polynom. Gauss (in MAPLE)	***c,p***
4	■			Nodes Reduction Method [2]	***c***
5	■		■	?	***c***
6	■	■		Gauss, Mason Flow Graph[7]	***c***
7	■	■	■	?	***c***

where ***c*** - a complex number,
p - a polynomial

A. Subtraction

Subtraction is the main cause of numerical errors during computer calculations. Most often errors occur when calculating: c=|a|-|b|, |a|≅|b|. Subtraction operation is possible in two cases: when adding numbers with different signs and when subtracting numbers with the same signs. Of two alternative calculation formulae, that without subtraction operation is more advantageous because a significant improvement in calculation accuracy is obtained for circuits with exclusively positive admittances (no [-] sign).

Unfortunately, in most cases admittances have negative values (dependent sources etc.) and therefore even for SoE without [-] a subtraction of numbers will in fact occur and the calculation accuracy will be negatively affected.

In some cases, by combining different methods, the subtraction operations may be avoided, thus increasing the calculation accuracy. For example, a diagonal element at the elimination stage may be calculated either with Gauss formula, which has a subtraction operation, or as a sum of all elements of admittance matrix row (without subtraction operation). Depending on admittance signs, either first or the second formula may yield higher accuracy [14].

B. Division

Let us assume that the [/]sign means operation of type a/b or 1/b (b≠0). From the numerical point of view the division operation with a remainder, [/], may be as unfavourable as subtraction operation.

The [//] signs means also a division operation but one without a remainder (A/B=C+0 ⇒ C=A//B, where A, B, C are as polynomials). Division [//] enables using polynomial operations thus simplifying the symbolic analysis. Besides, in some cases the [//] operation permits reduction of the number of operations and an increase of the accuracy of floating-point calculations . In case of the [//] operation it is not possible to avoid a subtraction operation, however it is possible to correct the error resulting from the fact of remainder zeroing [14].

Division operations are several times slower than other arithmetical operations, which is a consequence of numerical coprocessor. Therefore, as far as possible, they should be avoided. Execution time of operations [/] and [//] is similar in case of complex numbers.

C. Brackets

Generating of brackets in SoE by computer in an important advantage of the method because brackets are the main source of reduction in the number of arithmetic operations.

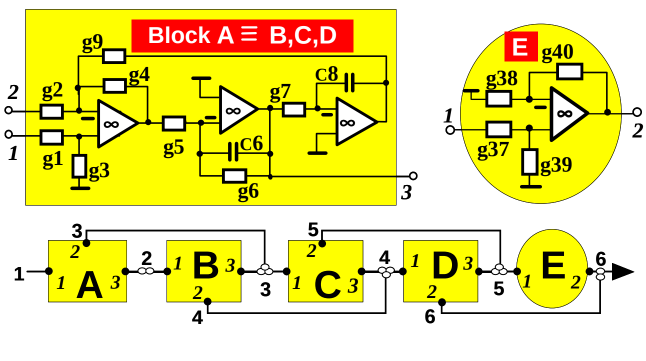


Fig. 1. An active band-pass filter for testing of symbolic methods ([6], fig.15)

TABLE II
RESULTS FROM SOE COMPARISON FOR BAND-PASS FILTER (fig.1)

METHOD	Type of generation.	Σ= 4+5+6	Number of operations				
			±	*	/	(	=
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Coates[6]	manual	**87**	26	61	-	19	25
Mason [7]	manual	**99**	30	34	35	5	52
RMNA [13]	computer (SCAPP)	**70**	24	29	17	5	54
Bisection [15]	computer(Simvol)	***65***	***26***	***30***	***8***	***16***	***19***

The [17] showed that, due to use of brackets, it was possible to reduce 8,7 times the number of multiplications.

D. Equality

The number of equality signs, [=], is determined by the number of equations in nested SoE's. Quantity of those signs does not affect the time and accuracy of calculations. Obviously, equality signs, [=], increase slightly the extent of occupied memory but it is of little significance for the sizes of memories of modern computers.

III. COMPARISON OF METODS USING SOE

Table II shows the results from SoE comparison using a popular benchmark (fig.1). According to Table I Coates method belong to the second group. MASON, RMNA and BISECTION methods belong to the 6th groop.

Knowing the groups to which SoE's belong, it is easy to characterise the numerical characteristics of the methods.

For instance the Coates enable using polynomial admittances and obtain transmittance as a ratio of polynomials. Other methods (Mason, RNMA, Bisection) operate exclusively with admittances of complex values. In Table II number of [/] is one less.

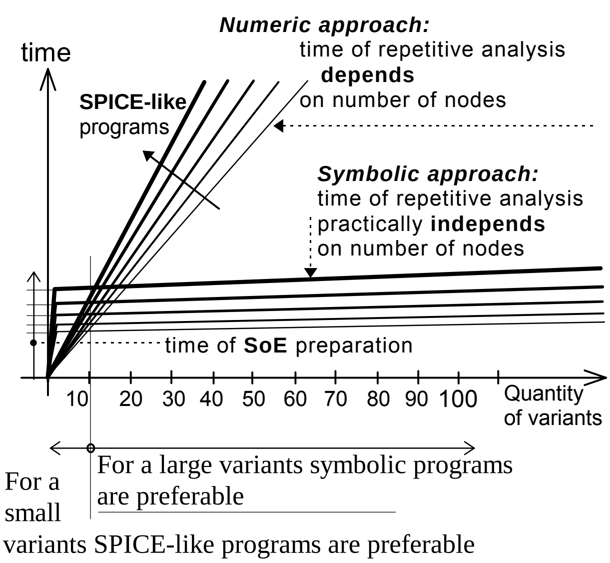


Fig.2. Comparison of two way of repetitive analysis

IV. THE MULTIMETHOD PROGRAMS

The main argument in favour of usage of different methods of generation of SoE's is the absence of a unique method which would generate efficient SoE's for different circuits and types of their analysis. The supervisor of the method analyses the structure of the circuit and selects the best model for SoE generating.

This paper examines the example of the work of the supervisor of the methods of SoE generation. The first task of the supervisor is to determine the purposefulness of using SoE. Fig. 2 shows that the most important criterion for the advisability of SoE is a number of versions of calculation of the network functions. In invariant (SPICE-like) approach, the time of multivariant calculations depends on the complexity of the circuit. In Fig.2, we can see that with the usage of SoE the time of calculation of versions is almost independent of the complexity of the circuit. The price paid for the acceleration of analysis is the necessity to create an additional program for SoE generation.

Let us analyse two cases of optimum analysis method selection, which shall be performed by the supervisor. Prior to that the notions of: bilinomial and semisymbolic matrix (SSM) require closer clarification.

The polynomials, F(y), under consideration in this paper, depend on many symbolic elements $y_1, y_2, \ldots, y_m$ exponent 0 or 1. These "electrical" polynomials F(y) will, for convenience, be called bilinomial [14]

$$F(y) = \sum_{i=0}^{2^m-1} X_i \prod_{j=1}^{m} y_j^{b_j}, \quad b_j = 0 \text{ or } 1 \qquad (1)$$

where

X_i - coefficient, which can be a real number, complex number or polynomial (subpolynomial) of s-variable (complex frequency),

b_j is equal 1 (0), if y_j exists (not exists) in the i-th item of (1) i.e.

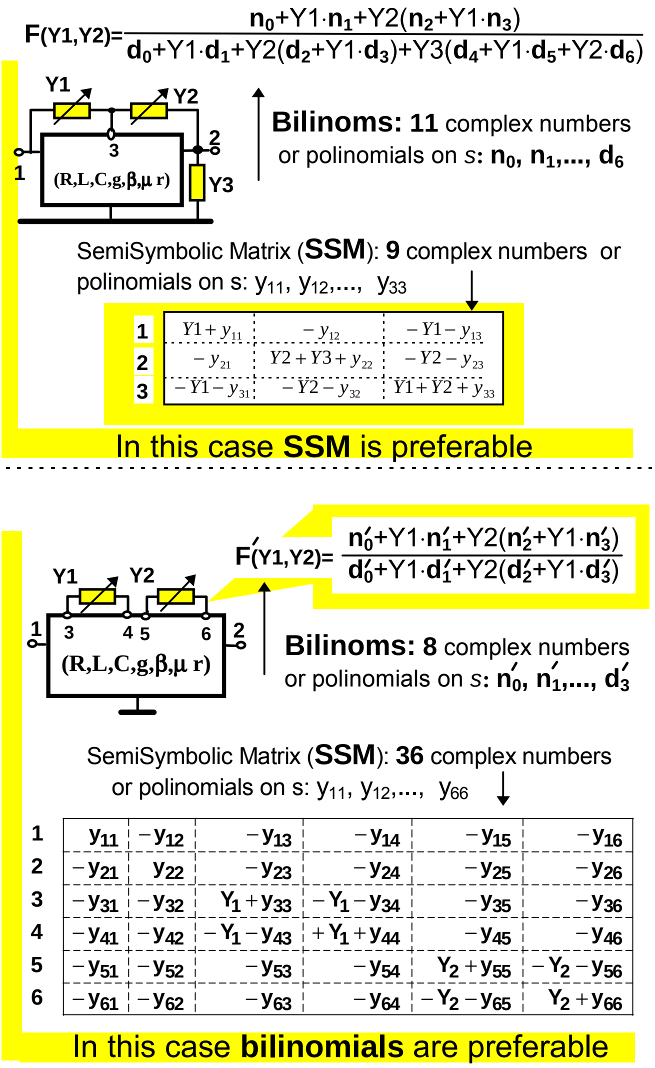
$$i = \sum_{j=1}^{m} b_j \cdot 2^{j-1}$$

The main task of symbolic methods is to obtain coefficients X_i dependent on numerical (non-symbolic) elements of the network and joining nodes of elements y_i network function is a ratio of bilinomials. For two symbolic elements, y_1, y_2 , we obtain known equation (2)

$$F(y_1,y_2) = \frac{N(y_1,y_2)}{D(y_1,y_2)} = \frac{N_0 + y_1 \cdot N_1 + y_2 \cdot N_2 + y_1 \cdot y_2 \cdot N_3}{D_0 + y_1 \cdot D_1 + y_2 \cdot D_2 + y_1 \cdot y_2 \cdot D_3} = \frac{N_0 + y_1 \cdot N_1 + y_2 \cdot (N_2 + y_1 \cdot N_3)}{D_0 + y_1 \cdot D_1 + y_2 \cdot (D_2 + y_1 \cdot D_3)} \qquad (2)$$

SSM stands for admittance matrix for a circuit in which internal nodes were reduced (Fig. 3). Characteristic feature of SSM is that matrix elements may occur as complex numbers or polinomials of complex variable s. Symbolic elements exist in the matrix as components with coefficient 1.

Fig. 4 shows second problem. Supervisor must choose one of two ways of calculating of F(y,jω) coefficients, using F(y,s) (see (4)) or directly SoE.



	1	2	3
1	$Y1+y_{11}$	$-y_{12}$	$-Y1-y_{13}$
2	$-y_{21}$	$Y2+Y3+y_{22}$	$-Y2-y_{23}$
3	$-Y1-y_{31}$	$-Y2-y_{32}$	$Y1+Y2+y_{33}$

	1	2	3	4	5	6
1	y_{11}	$-y_{12}$	$-y_{13}$	$-y_{14}$	$-y_{15}$	$-y_{16}$
2	$-y_{21}$	y_{22}	$-y_{23}$	$-y_{24}$	$-y_{25}$	$-y_{26}$
3	$-y_{31}$	$-y_{32}$	Y_1+y_{33}	$-Y_1-y_{34}$	$-y_{35}$	$-y_{36}$
4	$-y_{41}$	$-y_{42}$	$-Y_1-y_{43}$	$+Y_1+y_{44}$	$-y_{45}$	$-y_{46}$
5	$-y_{51}$	$-y_{52}$	$-y_{53}$	$-y_{54}$	Y_2+y_{55}	$-Y_2-y_{56}$
6	$-y_{61}$	$-y_{62}$	$-y_{63}$	$-y_{64}$	$-Y_2-y_{65}$	Y_2+y_{66}

Fig.3. The example of bilinomial and SSM models.

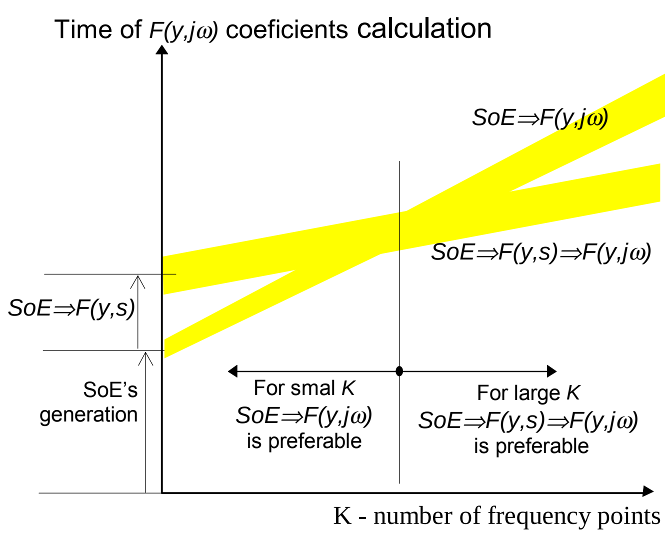


Fig. 4. Supervisor must choose between two ways of calculating of F(y,jω) coefficients.

Fig. 5 presents a general idea of symbolic analysis method selection and SoE generation for the purposes of repetitive analysis . At first the supervisor analyses the circuit structure and the type of task to be performed. On the basis of that analysis several methods most suitable for a given case are selected. SoE is being generated for each of them. Then a table of the operation quantities is created for each method (Table 2) and that SoE is selected which yields the lowest number of operations. Afterwards a repetitive analysis is performed with the use of selected SoE.

It is evident that multimethodical program is more expensive and more competitive than one with a single method, although it requires the additional dispatcher-supervisor that will select the necessary procedure of the generation of SoE as fast as possible.

V. ACCELERATION OF FREQUENCY AND TIME DOMAIN ANALYSIS

A. *Frequency domain analysis*

Traditional symbolic circuit analysis is performed in the frequency domain where the result is in the terms of the complex variable s, and symbolic elements $y_1,...y_m$

$$F(s,y)=\frac{N(s,y)}{D(s,y)} \tag{3}$$

Equation (3) is very "expensive”, because the volume of the formula depends on quantity of reactive elements. Calculation of the equation (3) needs many polynomial coefficients of very high precision. Therefore, (3) as in the past has been limited to small networks in the range of 50 nodes or less [7, 13].

In practice a set of the complex frequencies s_i=j2pf_i (i=1..k) is given in advance, hence, we propose to use system of k equations of type (4) instead of one equation (3).

$$F(j\omega,y)=\frac{N(j\omega,y)}{D(j\omega,y)} \tag{4}$$

The calculation time for (4) is independent of the quantity of nodes and the number of reactive elements, hence, the additional time needed for preliminary determination of N,D-coefficients is well recompensed by a general speedup of repetitive frequency analysis. The numerical example was performed on Pentium 120MHz with 16Mb RAM. 1000 variants of frequency characteristics with 64 frequency points for different y_1, y_2 elements take 1.76 sec. The time for one characteristic calculation is ~0.002 sec.

Structure of data in the repetitive frequency analysis is shown in Fig. 6.

B. *Time domain analysis*

Fast time domain analysis of the repetitive calculations could be performed with the utilisation of the polynomial number method [16, 18]. This method is based on Bellert’s concept of the numerical operators for Z-transform. The polynomial number plays similar role in relation to the sequence of time samples as does the complex number in relation to sinusoid signal. Hence, formula (2) could be used in this case without any modification. For one fixed sequence of samples, equation (2) needs to be used one time to obtain an answer, i.e. another sequence of the samples. The N_i,D_i coefficients are polynomial numbers in this instance.

Pentium 120MHz experiment for two symbolical variables y_1, y_2 demonstrate, that the time analysis for 1 variant of 64 time samples sequence takes about 0.05 sec. This is enough to build the computer simulator of the electrical circuit with animated answer. It means that whenever user changes several parameters, y_1, y_2, of the circuit by moving mouse pointer over y_1, y_2 plane, the characteristics are immediately shown on display in animated form (see [18])

VI. AN EXAPMLE OF REPETITIVE ANALYSIS

A RAN1 (Repetitive Analysis of Network) presentation program was created to enable presentation of the speed of multivariant analysis For a specific circuit, this program (fig.7) performs simultaneous calculation and visualisation of two diagrams - frequency characteristics A(t) and steps reaction h(t). The calculation speed A(t) and h(t) is sufficient for achieving the animation effect for those characteristics in real time at the pace of two circuit parameters being changed by mouse motions. Those any two circuit parameters are selected as symbolic variables and SoE is being generated for them.

RAN1 program was written in PASCAL language and was compiled in the DELPHI integrated environment. The user window is divided into several components. The AC and transient analysis of high order quartz filter and active filter were tested.

VII. AGAIN ABOUT THE BENCHMARKS PROBLEM

For the purpose of testing of the supervisor program in multimethodical programs a choice of certain standard test

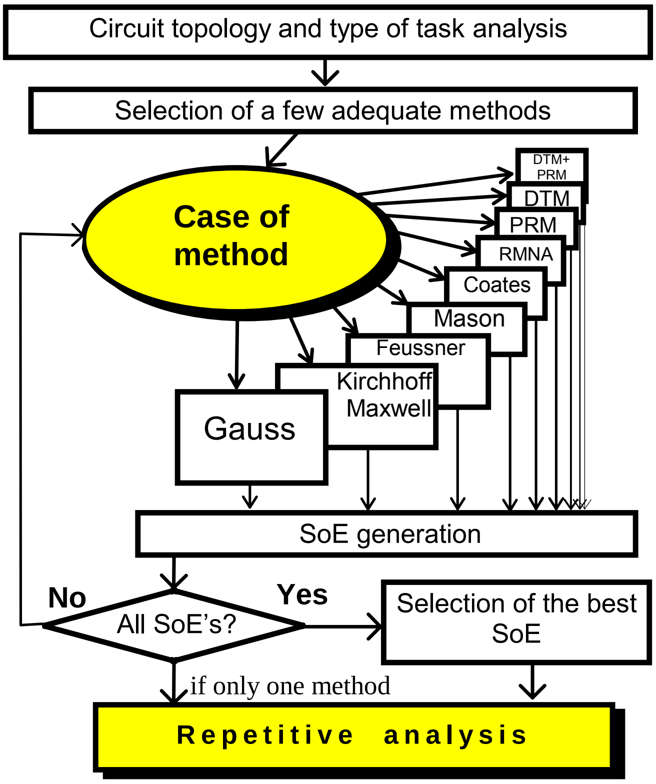


Fig. 5. An illustration of multimethodical program

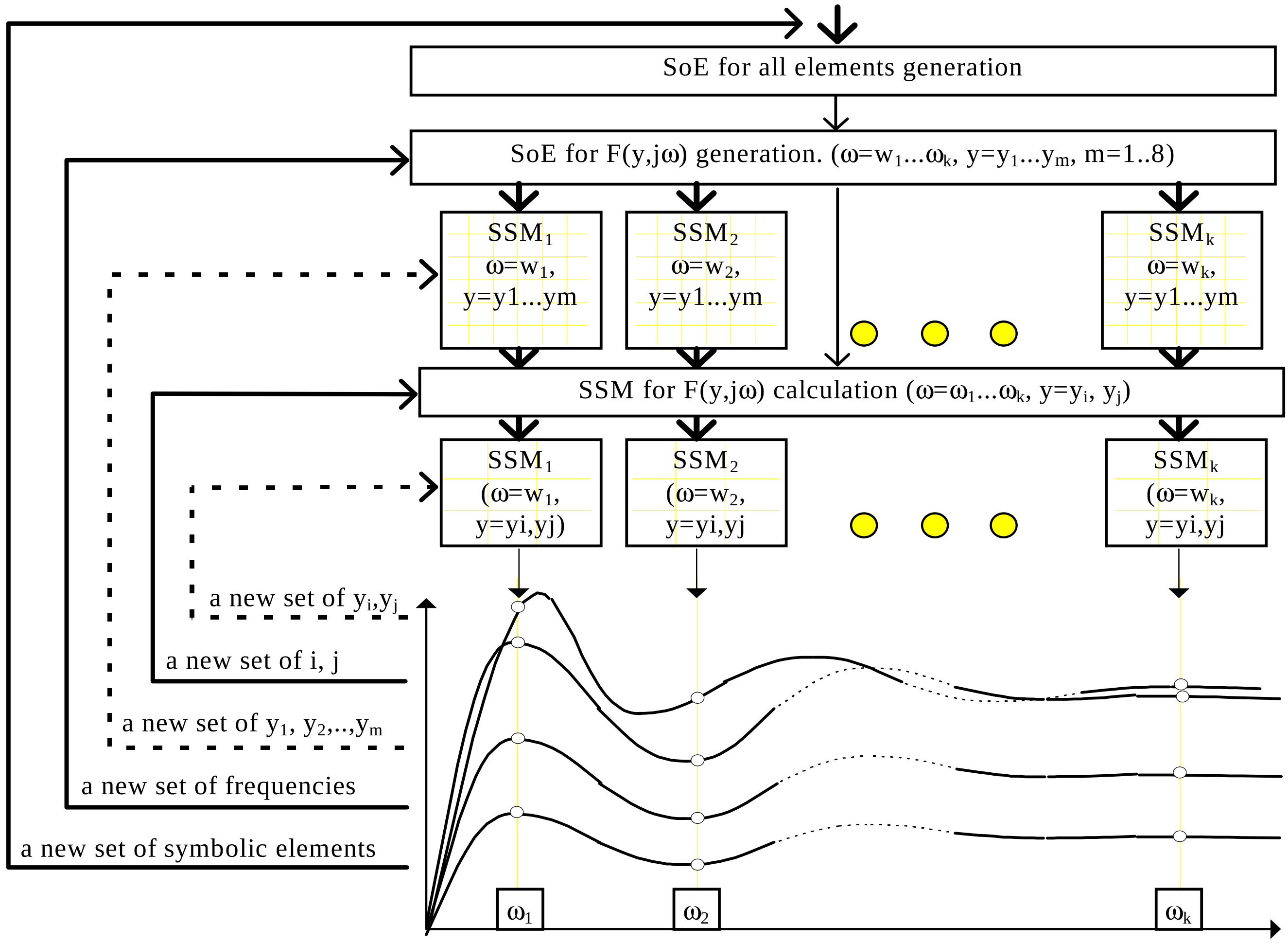


Fig. 6. An illustration of repetitive analysis

sets becomes necessary. Problem of tests for the algorithms of symbolic analysis of circuits in by no means new. [8] [1] .

A good example of testing may be that in literature [5], where a set of 37 problems to test the time domain simulators and to demonstrate the use of the performance parameters is presented.

Testing of SoE quality (e.g.. the number of arithmetical operation to perform - ref. to Table 2) offers new potential for designing benchmarks for symbolic analysis. A significant advantage of SoE analysis is the avoidance of the problem of differing speeds of various computers used during testing.

It seems that about 30 tests are needed for correct testing of various tasks of symbolic analysis (frequency and time domains, linear and nonlinear analyses etc.). A special WWW page could be utilised for their popularisation..

VIII. Conclusions

The paper shows that using of SoE's in combination with the concept of multimethodical programs quite often allows to achieve a significant increase in speed of repetitive analysis of linear circuits. The speed of the approach presented here is illustrated by an example of animation of circuit characteristics in frequency and time domains. An important feature of SoE's is the potential for using them for the classification of methods of the analysis of electric circuits.

A further improvement of the repetitive analysis becomes possible due to utilisation of symbolic expression approximation [8,9].

The authors believe that the future of symbolic analysis is a combination of work experience with polynomials in computer algebra and the experience of topology analysis and SoE generation - in electric circuits simulating.

[1] „... it is proposed to set up a standard set of benchmark circuits for all future comparisons."

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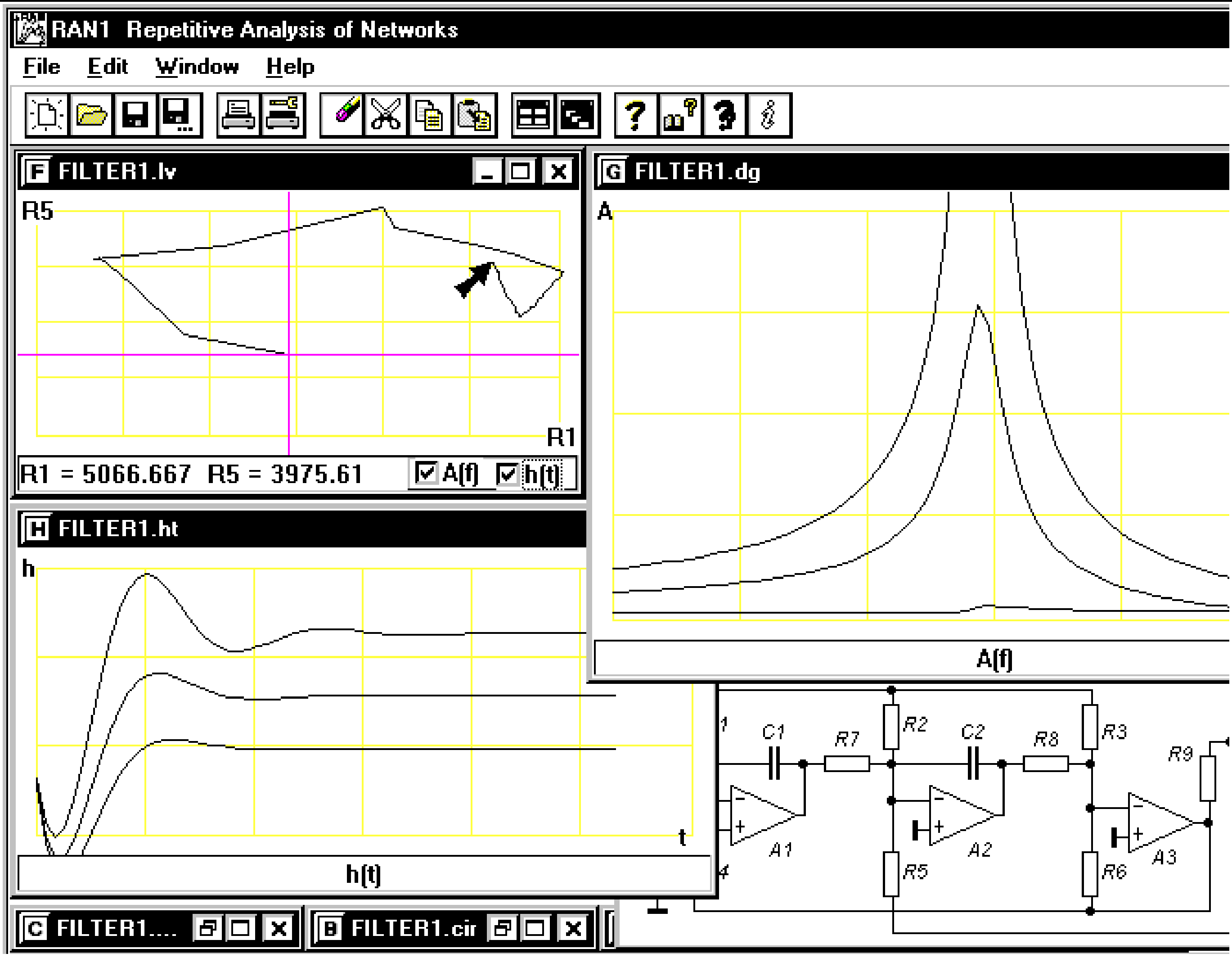

Fig. 7. View of RAN1 program

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