FAST ANALYSIS OF REAL SWITCHED NETWORKS ON PERSONAL COMPUTER

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A novel approach of linear switched networks computer simulation is described in this contribution. There are no restrictions concerning the type of passive and active components. This fact enables to extend possibilities of available programs SCSK and COCOSC, because their utilization is limited to idealized switched capacitor networks. To verify presented theory, the computer program SPIN has been developed. Its basic principles will be described.

INTRODUCTION

The program described below is a result of our development to reach following aims:

a) To create new theory how to describe real switched networks more effectively. This description has take both discrete-time and continuous-time character of phenomenon in switched networks into account. It is expedient to combine classical mathematical tools from the area of continuous-time networks (differential equation, Laplace transformation, *s*-domain transfer function, frequency response) and discrete-time networks (difference equation, *z*-transformation, *z*-domain system function, periodical frequency response).

The main idea of this "mixed" description consists in the so-called *generalized transfer function* (GTF) as a function of both well-known operators s and z. This function describes the transmission properties of switched network more complex than simple system function $K(z)$ which models only discrete-time part of behaviour. It is possible to obtain GTF in semi-symbolic form in term of operators s and z. To compute frequency response, the double substitutions $s=j\omega$ and $z=e^{j\omega T}$ must be used, where T is the switching period.

b) To create algorithmization of aforementioned approach with the final aim to make computer program for fast analysis of real linear switched networks wit two-phase switching.

The basic ideas of item **a)** are described in [3],[5] and other publications. Our contribution will be concentrated on item **b)**.

BASIC CONCEPTION

Following considerations concern the networks with the switching diagram on Fig.1. The computer simulation is subdivided to following main steps:

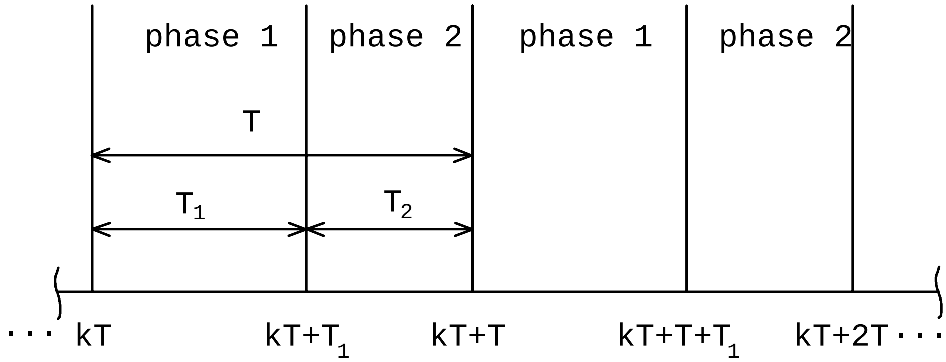

Fig.1. The switching diagram.

- *Circuit equations creation.*
- *Time-frequency pre-processing of circuit equations.*
- *Semi-symbolic computation of generalized transfer functions.*
- *Frequency analysis.*

CIRCUIT EQUATIONS CREATION

The two-graph modified nodal approach (MNA) [2] has been used as the basic method. To create minimum number of equations, our procedure is as follows:

- We find the set of independent nodal variables in each switching phase:

$$\begin{aligned} \mathbf{v}_1 &= \left[v_1^1, v_1^2, .., v_1^{n_1}\right]^T \dots \text{phase } 1, \\ \mathbf{v}_2 &= \left[v_2^1, v_2^2, .., v_2^{n_2}\right]^T \dots \text{phase } 2, \end{aligned} \tag{1}$$

where n_1 and n_2 are numbers of independent variables in phase 1 and phase 2, respectively. The algorithm how to obtain that sets is described in [4].

- It is possible to create the set of differential equations of MNA in the operator domain for independent variables:

$$\begin{aligned} \underbrace{\left(\mathbf{G}_1^M + s\mathbf{C}_1^M\right)}_{\mathbf{Y}_1^M}\mathbf{V}_1 &= \mathbf{D}_1 W_1 + \mathbf{C}_{12}^M \mathbf{v}_2(kT^-), \\ \underbrace{\left(\mathbf{G}_2^M + s\mathbf{C}_2^M\right)}_{\mathbf{Y}_2^M}\mathbf{V}_2 &= \mathbf{D}_2 W_2 + \mathbf{C}_{21}^M \mathbf{v}_1(kT + T_1^-), \end{aligned} \tag{2}$$

where $\mathbf{G}_1^M$ and $\mathbf{G}_2^M$ are modified conductance matrices of dimensions ($n_1 x\, n_1$) and ($n_2 x\, n_2$),
$\mathbf{C}_1^M$ and $\mathbf{C}_2^M$ are modified reactance matrices of dimensions ($n_1 x\, n_1$) and ($n_2 x\, n_2$),
$\mathbf{C}_{12}^M$ and $\mathbf{C}_{21}^M$ are modified transitive matrices of dimensions ($n_1 x\, n_2$) and ($n_2 x\, n_1$),
$\mathbf{D}_1$ and $\mathbf{D}_2$ are certain incidence vectors of dimensions ($n_1 x$ 1) and ($n_2 x$ 1),
W_1 and W_2 are Laplace transformations of input signals in phases 1 and 2.

Equations (2) have key significance for computer analysis. It is possible to compile them for arbitrary linear switched network no matter whether the consistent initial conditions occur in the time instances between two switching phases [1]. In practice, the simulator will produce correct results also in case of discontinuously changed nodal variables.

The circuit matrices in (2) are created in several steps:

Insertion of passive components C and R submatrices including non-zero Ron switches

The principle is indicated in Fig.2. It represents some generalization of well-known rule how to compile the admittance matrix of continuous-time network. For two-phase switched network it is necessary to compile not one but four matrices: two classical admittance matrices for each switching phase and two transitive matrices. The components of transitive matrices are the parameters of reactance elements which mediate phase-to-phase energy conversion.

The superscripts * and ** denote voltage and current coefficients of nodes in accordance with the 2-graph MNA [2].

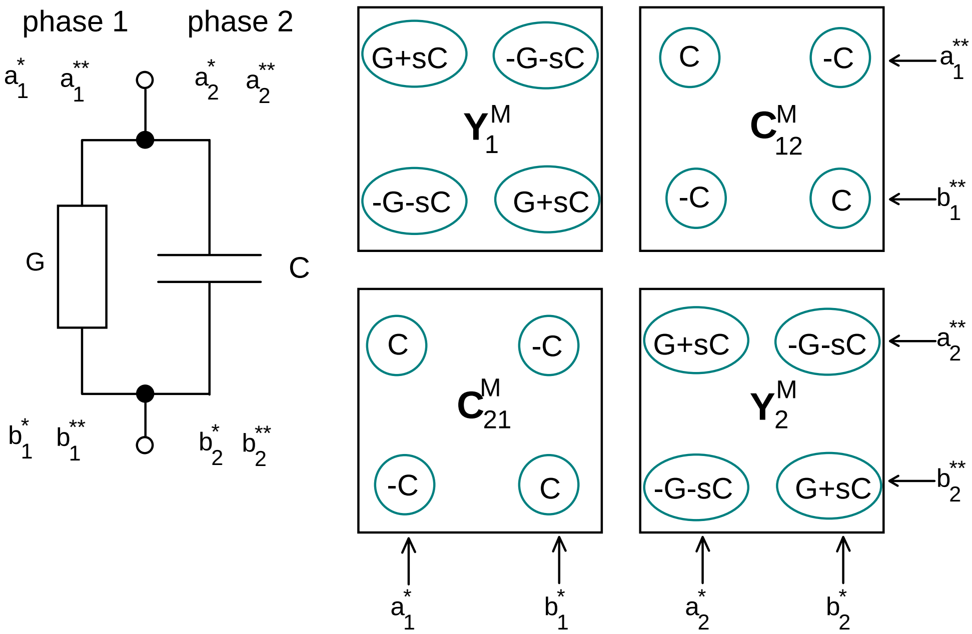

Fig.2. Insertion of conductances and capacitances to circuit matrices.

Insertion of own and mutual inductance matrices.
Insertion of real classical and transimpedance OpAmps matrices.
Circuit matrices modification in respect of input voltage sources.

That items are described in [5].

TIME-FREQUENCY PRE-PROCESSING OF CIRCUIT EQUATIONS

The circuit equations (2) must be pre-processed with the aim to derive equations for GTFs in closed form. The general solution is as follows [5]

$$\begin{aligned} \mathbf{V}_1^e(s,z) &= \mathbf{K}_{11}(s,z)W_1^e(s) + \mathbf{K}_{12}(s,z)W_2^e(s), \\ \mathbf{V}_2^e(s,z) &= \mathbf{K}_{21}(s,z)W_1^e(s) + \mathbf{K}_{22}(s,z)W_2^e(s). \end{aligned} \tag{3}$$

The so-called *equivalent signals* [5] are designated by superscript ^{e}. The generalized transfer functions $\mathbf{K}_{11}, \mathbf{K}_{12}, \mathbf{K}_{21}$ and $\mathbf{K}_{22}$ depend on the input signal character (Sample-Hold response, arbitrary response...). For more details see [5].

SEMI-SYMBOLIC AND FREQUENCY ANALYSIS

The computer algorithm for evaluation of GTFs in semi-symbolic form has been developed. However, its description is beyond the scope of this paper.

The frequency responses can be easily obtained by aforementioned double substitution.

PROPERTIES OF PROGRAM SPIN

Aforementioned theory has been verified using computer simulation. Present-day version of program SPIN enables to solve linear two-phase networks with external switching, consisting of ideal OpAmps and real OpAmps with standard gain response, transimpedance Op-Amps, ideal voltage-controlled voltage sources, capacitors, resistors and zero and nonzero-R_{on} switches. The complexity of analyzed network is limited by available memory (now approximately: 40 nodes, 30 capacitors, 30 resistors, 10 OpAmps, 50 switches). The program is in the testing stage. It computes gain and phase responses including the possibility of drawing more shapes by variation of network parameters. Also the computation of z-domain poles and system stability is available.

At present, the new version of program SPIN is prepared with not only frequency but also time - domain analysis.

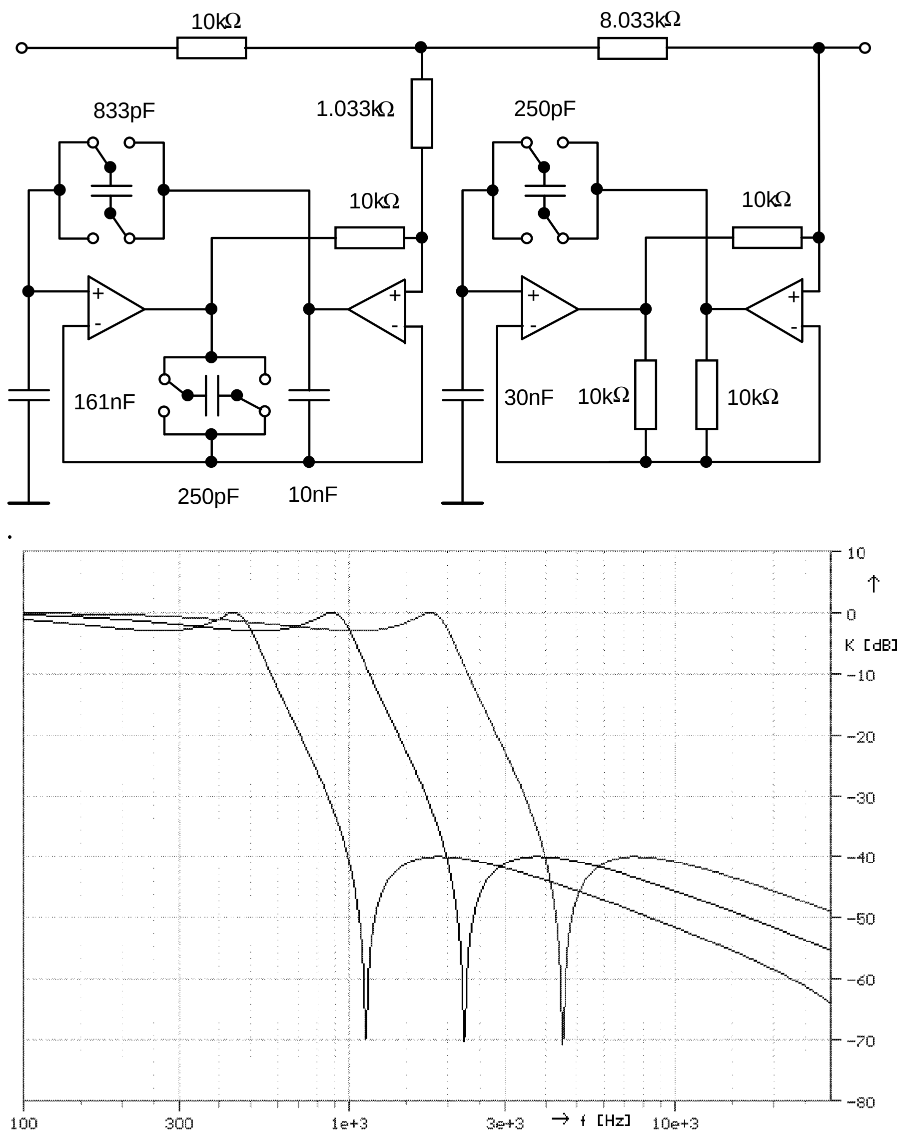

Fig.3. Example of switched network and simulation results-gain frequency response for various switching frequencies: **1.** 50kHz, **2.** 100kHz, **3.** 200kHz. OpAmps parameters: A_0=200 000, f_T =10MHz, R_{out}=0Ω. $R_{switch.ON}$ = 400Ω.

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