ANALYSIS OF MULTIPHASE SWITCHED-CAPACITOR NETWORKS USING THE NODE METHOD

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Switched-capacitor networks (SC networks) deserve attention, since they provide an optimum method for implementing precision filters in a monolithic integrated circuit. Classical SC networks contain capacitors and two-phase switches (see [1-4]). In certain applications it is preferable to use multiphase networks (see [5]), but the methods for analyzing them are complex (see [1]).

The present paper proposes a comparatively simple method for the mathematical description of multiphase SC networks. It is a generalization of the method of analysis developed in [2]. Moreover, the present work emphasizes the fact that SC networks belong to a more general class of discrete time-varying networks.

The utilization of a multiphase cycling signal is of both theoretical and practical interest. Let us adopt the following constraints: 1) the commutation is periodic - the state of each switch varies with the period $t_k = kT$. The quantity t_k (or simply k for the sake of simplicity) shall be called the commutation interval. Switches whose state changes at time k belong to the k-th group of switches. 2) All switches are nonoverlapping - at any time there cannot exist two groups of closed switches. 3) Transients are ignored.

It is necessary to note that in practice SC networks are implemented in accordance with the first two constraints. However, practical transients have a certain limited although sometimes short duration. This may be the cause of the discrepancy between the actual behavior of the networks and the proposed mathematical model.

Let us analyze the network displayed in Fig. 1. We separate the switches and capacitors into two separate subnetworks - an S-network and a C-network, respectively. The S-network reflects a time-varying topology (see [2]). One may write equations which yield the relationship between the node voltages for each of the discrete times. With the switch S_0 closed, we have: $V_1 = V_1$, $V_2 = V_2$, $V_3 = V_1$, $V_4 = V_4$. One may write the matrix $[S^0]$ which represents the relationship between the node voltages at time nT = 0:

$$[S^0] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

We obtain the matrix equation

$$[V(0)] = [S^0]\,[V(0)], \qquad (1)$$

where [V(i)] is the vector representing the node voltages at time i. The equations $V_1 = V_1$, $V_2 = V_2$, $V_3 = V_3$, $V_4 = V_3$ at time nT = T are obtained similarly, and finally we obtain $V_1 = V_1$, $V_2 = V_2$, $V_3 = V_3$, $V_4 = V_2$ at time nT = 2T. In matrix form we have

$$[V(1)] = [S^1]\,[V(1)]; \qquad [V(2)] = [S^2]\,[V(2)], \qquad (2)$$

$$\text{where}\quad [S^1] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}; \qquad [S^2] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

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