SWITCHED-CURRENT FILTER DESIGN USING CASCADED SECTIONS*

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Abstract A new analogue sampled-data active device, named as a switched-current operational amplifier (SIOA), is presented. The use of active circuit elements may simplify drawing the circuit diagram significantly greatly and may permit easier analysis and synthesis of SI networks. A number of all pole and elliptic (second- or third-order) switched-current (SI) filters are derived from the switched capacitor prototypes. These can be used as simple self-contained filters or as filter sections in the cascaded realizations of a higher order transfer functions. To illustrate the approach, a fifth-order low-pass filter is designed.

Key words Circuit theory and design; Switched-Current; Active filter

I. Introduction

Recently, switched-current (SI) has been proved to be a new circuit technique for analogue sampled-data signal processing in place of the conventional switched-capacitor (SC) circuits[1]. In contrast to the SC technique, SI circuits can be integrated in standard digital CMOS process without additional operational amplifiers and processing steps to fabricate linear floating capacitors[1-4].

In this paper, the universal SI integrator presented by Hughes et al.[2] is developed. In the next section, a switched-current operational amplifier is defined in order to reduce the complexity of drawing a diagram and to simplify the analysis and synthesis of SI networks. In the third section, the general method for generation and design of SI filter circuits is described. Moreover, a number of second- or third-order SI filter circuits are derived from the SC prototypes. Finally, an example of fifth-order low-pass filter design is given.

II. Switched-Current Operational Amplifier (SIOA)

It is shown in Ref.[2] that a complex SI filter networks can be constructed by combining the universal SI integrators. Although these can readily be derived from the SC prototypes, it is redundant and complex to draw such a diagram of SI circuits. Even though a simple biquadratic is plotted, the drawing of several tens of transistors is required. This may result in complicated analysis of SI networks. To overcome this drawback, a new active device—switched-current operational amplifier (SIOA), as shown in Fig.1(a), is introduced. A possible realization for this device is shown in Fig.1(b). SIOA is defined as an analogue

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sampled-data device with multiple input and output terminals. It has three input terminals; a noninverting, an inverting and a differential input terminals. The positive output current is obtained when input current is exerted on the noninverting one, the negative output is obtained when input is exerted on the inverting one, and the differential input is obtained when input is exerted the D terminal. The terminal B is used as a feedback path which is usually connected to the noninverting terminal. The gain of the feedback current mirror realizes the damping factor of integrators. There may be several output currents, which can be obtained by the current mirrors. The terminal $S_1$ and $S_2$ represent the switches controlled by two phase non-overlapping clock pulses. Assuming that the clock phases of the switches are arranged by the way as shown in Fig.1, input and output equations expressed in the $Z$-domain of this device are given by

\[ i'(Z) = A\{A_1Z^{-1/2}i_1'(Z) - A_3i_3'(Z) - Z^{-1/2}i_3'(Z) - A_2i_2'(Z)\} + A_1i_1'(Z)Z^{-1/2} \]  \hspace{1cm} (1)

\[ i''(Z) = A_j(Z)Z^{-1/2} \]  \hspace{1cm} (2)

\[ i_j(Z) = (B/A)i''(Z) \]  \hspace{1cm} (3)

\[ i_j'(Z) = i_j(Z)Z^{-1/2} \]  \hspace{1cm} (4)

If the input signals are the sample-hold signals, then Eq.(1) yields

\[ i''(Z) = \{A_1Z^{-1}i_1''(Z) - A_3i_3''(Z)(1 - Z) - A_2i_2''(Z)\}A + A_1i_1''(Z)Z^{-1/2} \]  \hspace{1cm} (5)

It is seen that the device can realize the delayer, differentiator and inverter when the feedback path is broken off ($i_f = 0$). If the feedback terminal is connected to the noninverting one, then it is seen from Eq.(5) that the device realizes the integrator presented by Ref.[2].

Taking it in all, the SIOA can realize the forward, backward and differential integrators, differentiators, inverters and delayers etc. Therefore, it is a universal building block. SC filter networks can be constructed with the device.