Multi-Loop Filter Structures in current mode using multi-output transconductors.

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Abstract: - Universal multifunctional (low-pass, high-pass, band-pass, and band-reject) n^{th}-order active RC filters in current mode are presented in this paper. The filters are based on several state-variable multi-loop feedback structures. Their modification and implementation using single-input multi-output transconductors and current-differencing multi-output transconductors are given.

Key-Words: - Analogue filters, current mode, transconductors.

1. Introduction

Continuous-time active filters in current mode (CM) have recently found considerable attention. This stems from inherent advantages of the CM over the classical VM, namely high frequency range, simple circuitry, low power consumption. There are simple current replicas, simplicity in current summation, subtraction and in current integration.

New active devices and functional blocks are there used. Multi-loop filters with current followers and conveyors ware shown in the last time in [1]. Now we should like to turn your attention on transconductors (OTA), namely on the OTA with multi current outputs (SIMO-OTA) and on the other one with differencing current inputs (CDTA), which was introduced in [2].

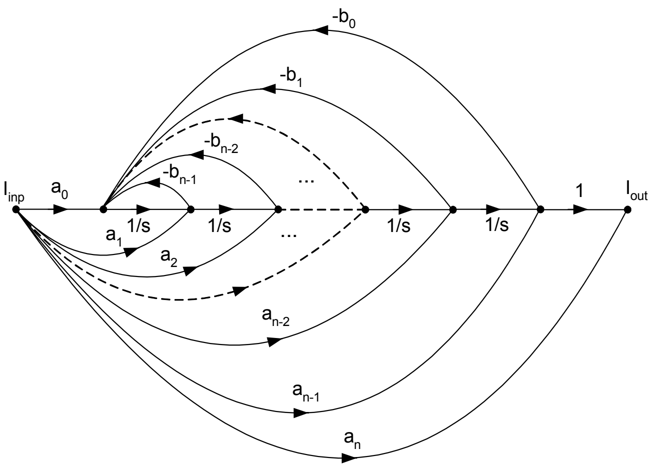

Fig. 1. Signal flow graph of the basic multi-loop structure (FLF-ID) in current mode.

In recent years the standard OTA-C filters have received particular interest [3], investigating them by Sun, Y. and Fidler J. K. [5], [6], Acar, C., Anday, F. and Kuntman, H. [7], Sun, Y., Jefferies, B. and Teng, J. [8] etc. There the standard SISO or DISO - OTA's ware used.

In this paper the classical state variable model using signal flow graph (SFG) of the universal multifunctional (LP, BP, HP, APF) n^{th}-order filter in standard voltage mode is modified and transformed to the CM and non-conventionally realized using SIMO-OTA's or CDTA. These filters have advantageous over the cascade and ladder structures, namely in universality of function, simplicity in direct design and independently adjustable coefficients.

2. Canonical state-variable multi-loop structures in current mode

The current transfer function of any n^{th}-order filter can be generally expressed as

$$K = \frac{I_{out}}{I_{inp}} = \frac{a_n s^n + a_{n-1} s^{n-1} + \ldots + a_1 s + a_0}{s^n + b_{n-1} s^{n-1} + \ldots + b_1 s + b_0} \quad . \tag{1}$$

The state-variable multi-loop feedback structure producing the transfer function (1) in classical voltage mode (VM) is well known [3], [4]. Recall that this structure can be in the following form: the follow the leader feedback (FLF) or the inverse one (IFLF) and both with the input distribution (ID) or with the output summation (OS) respectively.

The SFG of the basic FLF-ID structure in the CM is shown in Fig.1. This graph can be directly implemented using current integrators, current amplifiers (multipliers by constant), current summers and current distributors, what is a little complicated. It is the reason of modification given in Fig. 2. There B_i has the value B_i = -1, 0, +1, what depends on the type of desired filter. Note that the SFG's of other structures (FLF-OS, IFLF-ID and IFLF-OS) can be similarly modified too.

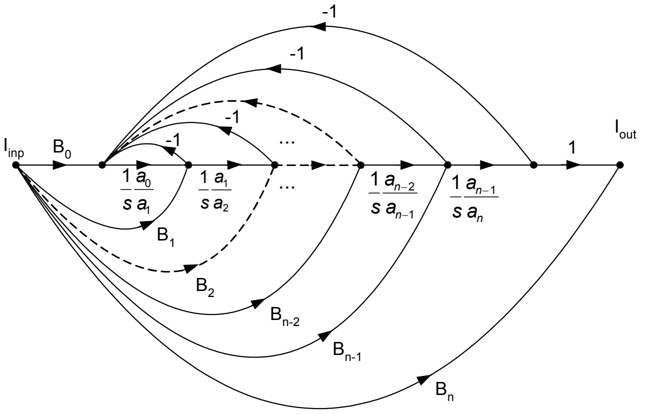

Fig. 2. Modification of the SFG of the structure FLF-ID (Fig. 1).

3. Circuit realizations by SIMO-OTA

Circuit realization of the given SFG (Fig. 2) requires current summers, current distributors and current integrators. Easy can be realized the current summer, namely by the single node only.

The current integrator with the transfer function

$$K_i = \frac{I_{out}}{I_{inp}} = \frac{1}{s}\frac{a_n}{a_{n+1}}, \qquad (2)$$

can be implemented by the SISO-OTA and capacitor as was shown in [1]. But in this case, here in Fig. 3, the OTA(n) are with single input and double output.

The current distributor (OTA(n+1), in Fig. 3) is corresponding with the first node in the SFG (Fig. 2). This subcircuit is producing (n+1) current replicas of the input current, to obtain the designed type of the filter, what is given by particular B_i (1, 0, -1).

The resulting circuit diagram of the universal filter based on the FLF-OS structure has the form given in Fig. 4. There the virtual gains (B_n) of some branches determine a type of the designed filter, summing some output currents. In the real filter of the concrete type, there is short or open circuit only. It is dual to the distribution of input currents in the Fig. 3. Similarly the circuit diagram of the IFLF-ID and IFLF-OS structures can be obtained. Furthermore using the same way the nth-order all-pass filters can be implemented too, but there some currents must be inverted to obtain desired transfer function.

4. Circuit realizations by CDTA

The other functional block, which is very suitable for the multi-loop structures in the CM, is the six-port CDTA, given in [2]. General circuit diagram of the current mode n^{th}-order universal filter based on the FLF-OS structure is shown in Fig. 5. There the desired type of this filter is given by the gains B_i of certain branches, similarly as above. Note that if B_0 = 0 the structure (Fig. 5) can be simplified, namely the last CDTA (n+1) can de omitted.

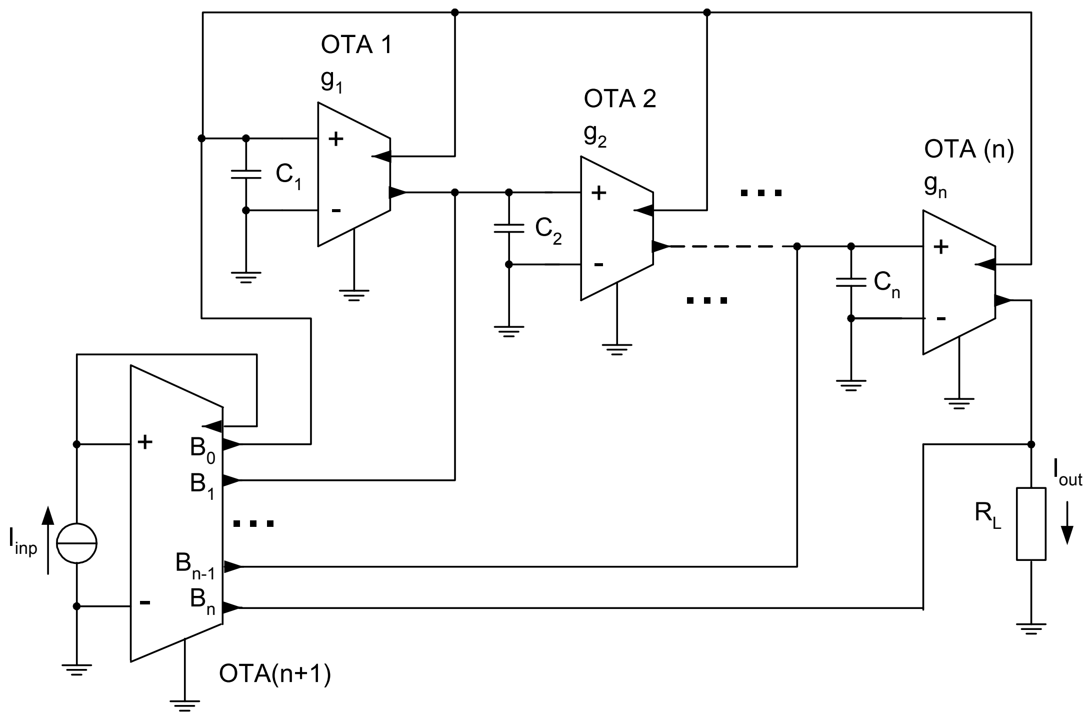

Fig. 3. Circuit diagram of the filter based on the FLF-ID structure, corresponding with the SFG given in Fig.2.

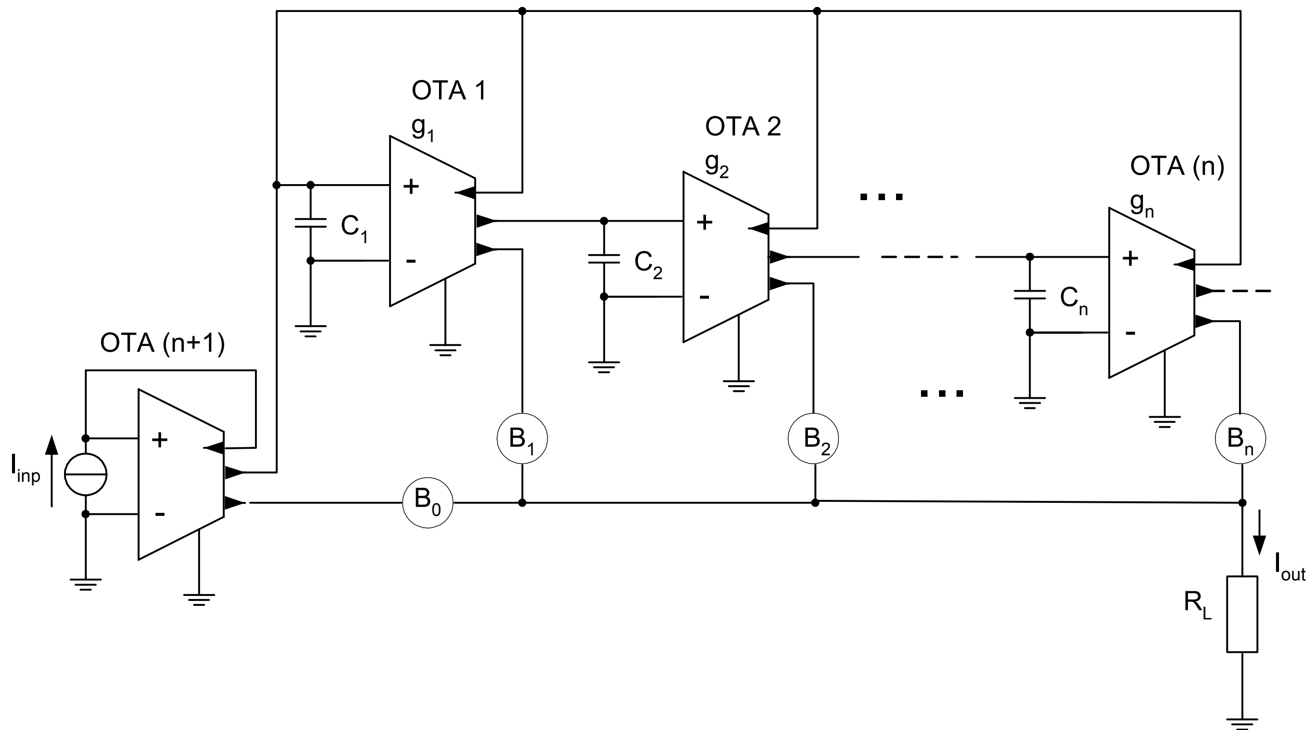

Fig. 4. General circuit diagram of the filter based on the FLF-OS structure in the CM using the SIMO-OTA.

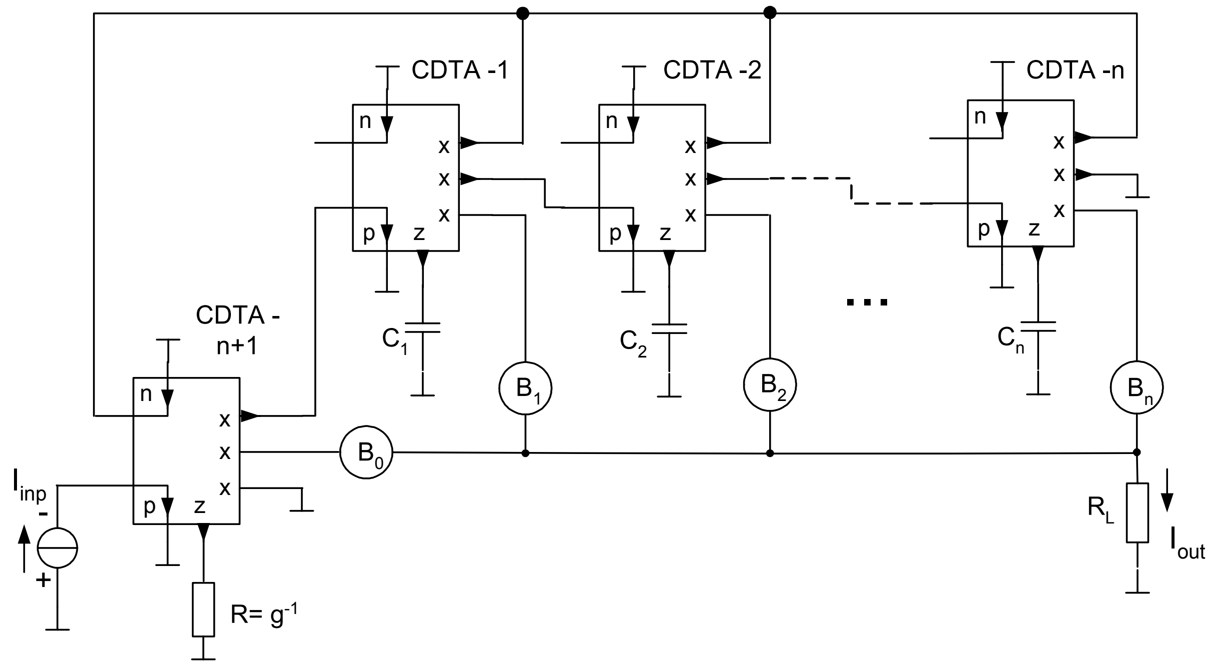

Fig. 5. General circuit diagram of the filter based on the FLF-OS structure in the CM using the six-port CDTA

5. Illustrative example

To illustrate the above structure FLF-OS in the CM (Fig. 5), the band-pass filter is designed with this specification: Butterworth approximation, center frequency f_o = 1 MHz, ripple in the pass-band K_c = - 3 dB, stop-band frequency f_s = 3 MHz, for desired attenuation K_s = - 35 dB. Then the desired 3rd-order transfer function has the following coefficients:

a_0 = 2,48640 E20, a_1 = 7,90819 E13,
a_2 = 1,25763 E7, a_3 = 1, (3)

Modifying the general circuit (Fig. 5), as mentioned above, the circuit diagram of the 3th-order band-pass filter in the CM, based on the FLF-OS is given in Fig. 6. It consists of three CDTA, with parameters g_1, g_2, g_3 and three capacitors (C_1, C_2, C_3) only. This circuit (Fig. 6) has been symbolically analyzed by computer tool SNAP, to obtained the denominator $D(s) = a_0 + sa_1 + s^2 a_2 + s^3 a_3 =$

$$= \frac{g_1 g_2 g_3}{C_1 C_2 C_3} + s\frac{g_1 g_2}{C_1 C_2} + s^2 \frac{g_1}{C_1} + s^3 \qquad (4)$$

and the numerator

$$N(s) = s^2 b_2 = s^2 \frac{g_1}{C_1} \qquad (5)$$

Substituting the desired coefficients a_i (3) into the eq. (4), following design eq's are obtained

$$a_0 = \frac{g_1 g_2 g_3}{C_1 C_2 C_3} = 2.48640E20,\ a_1 = \frac{g_1 g_2}{C_1 C_2} = 7.90819E13,$$

$$a_2 = \frac{g_1}{C_1} = 1.25763E7.$$

Then choosing $C_1 = C_2 = C_3 = 100$ pF the resulting values of the transconductances are: $g_1 = 1.26$ mS, $g_2 = 628$ μS and $g_3 = 314$ μS.

The proposed filter was simulated by PSpice. The resulting magnitude response of this filter confirms the theoretical assumptions.

6. Conclusions

The SFG of the universal n[th]-order filter in standard state variable based voltage form is modified and transformed to the current mode and realized by the multi-output transcoductors. This filter has advantage in universality of the type or function, simplicity in direct uniform design and independently adjustable coefficients.

Acknowledgments
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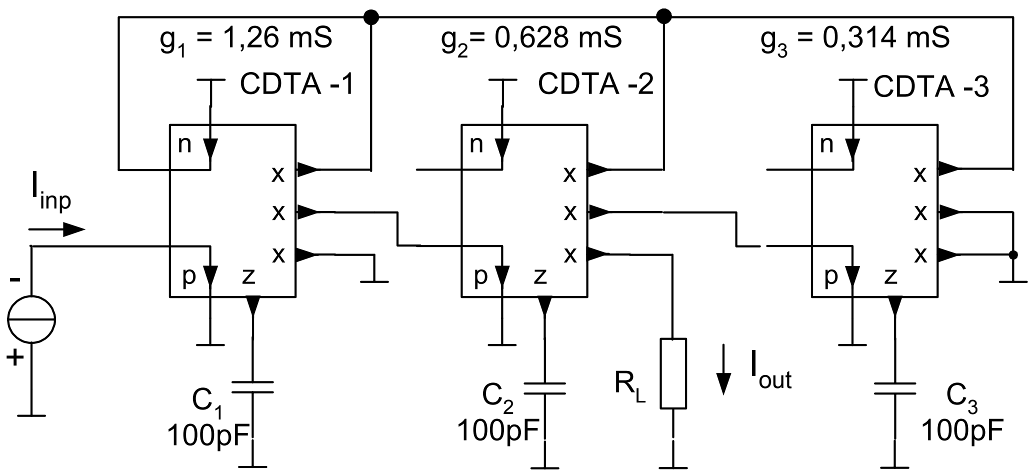

Fig. 6. Circuit diagram of the 3th-order band-pass filter in the CM, based on the FLF-OS structure.