Unified Methodology for Realizing Fully-Differential Current-Mode Filters

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Abstract: Using the concept of nullors, an unified methodology is presented which can be used for realizing fully differential current mode filters using a variety of building blocks which can be represented by nullators and norators. The workability of the proposed approach is verified by the SPICE simulation results of an exemplary universal biquad made from multiple-output-current-conveyors. This exemplary filter can realize low pass (LP), high pass (HP), band pass (BP), band elimination (BE) and all pass filters-all in fully differential form, from the same topology. The angular frequency and ω_0/Q_0 or Q_0 of the realized filters are orthogonally controllable. The applicability of the developed approach to derive a variety of biquads as well as higher order FD CM filters (including the electronically-tunable ones), using a number of other building blocks such as FTFNs, Current Conveyors, Controlled Current Conveyors and OTAs, is conceptualized.

*Key-Words***:** nullors, fully differential filters, current-mode circuits, current conveyors, operational transconductance amplifiers.

1. Introduction

Fully differential circuits have the advantages of immunity from common mode noise signals, enhanced dynamic range, lower harmonic distortion etc. A number of fully-differential active building blocks (FDABB) and fully differential circuits have recently received attention of analog circuit designers. In fact, a wide variety of FDABBs have been employed to realize RC active filters in both current mode (CM) and voltage mode (VM), for instance, see [1]-[16] and those cited therein. Out of the quoted works only those of [1]-[3], [5] and [6] have VM output in fully differential form. Similarly only the circuits of [3], [4] and [7] have fully differential CM output.

Recently Chang, Al-Hashmi and Ross [8] have presented a unified approach for realizing CM biquadratic filters but their approach is applicable to derive single-ended filters only. By contrast, in this paper, we present a unified approach to the realization of fully-differential CM filters. The kernel of the proposed approach is a fully-differential formulation using the concept of nullators and norators which can be used as a basic block to synthesize universal CM biquads as well as higher order filters such that practical implementations of the resulting configurations can be obtained in terms of a variety of active elements. The approach is illustrated by an exemplary implementation of a fully differential universal CM biquad using multiple output CCIIs.

2. The Unified approach to realize Fully Differential Current mode Filters

Consider now the formulation of Fig. 1. By routine analysis, the output currents of the configuration are given by

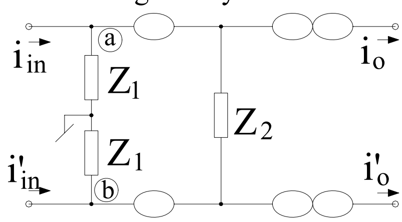

Fig 1. Fully differential CM building block

$$i_o = -i_0^{'} = \frac{Z_1}{Z_2}\left(i_{in} - i_{in}^{'}\right) \qquad (1)$$

Thus, depending upon the choice (resistive/capacitive) of the impedances Z_1 and Z_2, this block can realize fully differential scalar, integrator or differentiator. With both impedances as resistors and summing nodes created at nodes **'a'** and **'b',** the configuration can realize fully differential current mode summer.

It is known that nullors are useful in realizing and unifying circuit structures using all such different active elements which can be represented by nullors. Since it is known that an ideal BJT, an ideal FET, a CCII- and an OTA all can be represented by nullors whose most universal form is an FTFN, it turns out that the nullor-based configuration of Fig. 1 should lead to a number of practical implementations using a various building blocks.

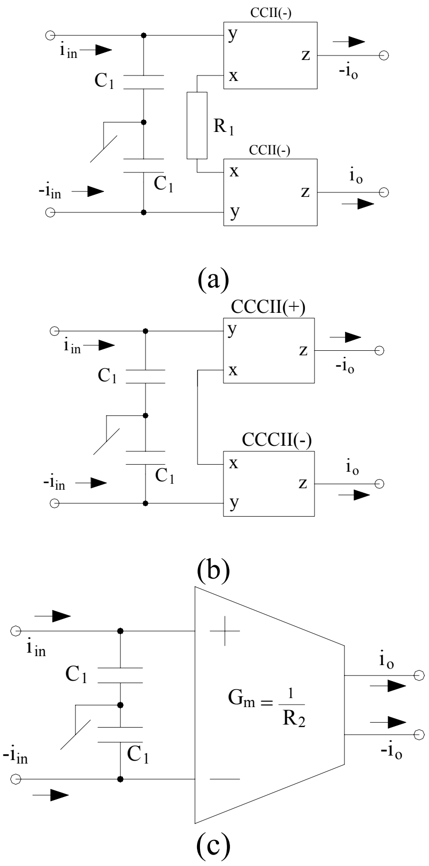

Fig 2. Various realizations of the fully differential CM integrators (a) using CCII-, (b) using CCCII- and (c) using DOTA

Thus, a careful examination of the structure of Fig 1 shows that each nullor therein can be readily realized by an FTFN. Furthermore, with each three terminal nullor represented as a CCII- gives the circuit of Fig. 2(a) (change of CCII- to CCII+ gives another alternative); with R_1 removed and x-port parasitics of the two CCs accounted for, leads to the circuit of Fig. 2(b) which employs two controlled-current-conveyors (CCCII) and finally, with R_1 together with both the three terminal nullors represented as a dual output OTA leads to the circuit of Fig. 2(c). It is interesting to note that in all cases, the internal hardware of the employed building blocks can be easily modified to facilitate multiple (complementary) outputs which would be useful in interconnecting two or more such configurations as well as to provide feedback paths and summations as needed for biquad realizations or higher order filter design. Alternatively, a differential summer can be realized by the nullor-based structure of Fig. 3.

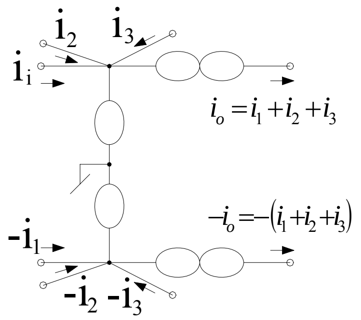

Fig 3. Summer with complementary CM outputs

Using the summer of Fig 3 in conjunction with FD integrators realized with the structure of Fig 2(a) (with multiple outputs of CCIIs employed), an exemplary fully differential CM universal filter can be formulated as shown in Fig. 5.

A straight forward analysis of the structure of the Fig. 4, using equation 1, those given in Fig 3, and assuming a multiple output CCII (MOCCII) to be characterized by $i_y=0$, $v_x=v_y$, $i_z^+=-i_z^-=i_x$, the following transfer functions are obtained

$$\frac{I_{BP}}{I_{in}} = H_o \frac{-\left(\frac{\omega_0}{Q_0}\right)s}{\Delta}; \quad \frac{I_{LP}}{I_{in}} = H_o \frac{\omega_o^2}{\Delta}; \quad \frac{I_{HP}}{I_{in}} = H_o \frac{s^2}{\Delta}; \qquad (2)$$

$$where\ \Delta = s^2 + \frac{s}{C_1 R_1} + \frac{1}{C_1 C_2 R_1 R_2} \qquad (3)$$

$$H_o = 1,\ \omega_0^2 = \frac{1}{C_1 C_2 R_1 R_2},\ \frac{\omega_0}{Q_0} = \frac{1}{C_1 R_1} \qquad (4)$$

which shows that the structure realizes LP, BP and HP responses.

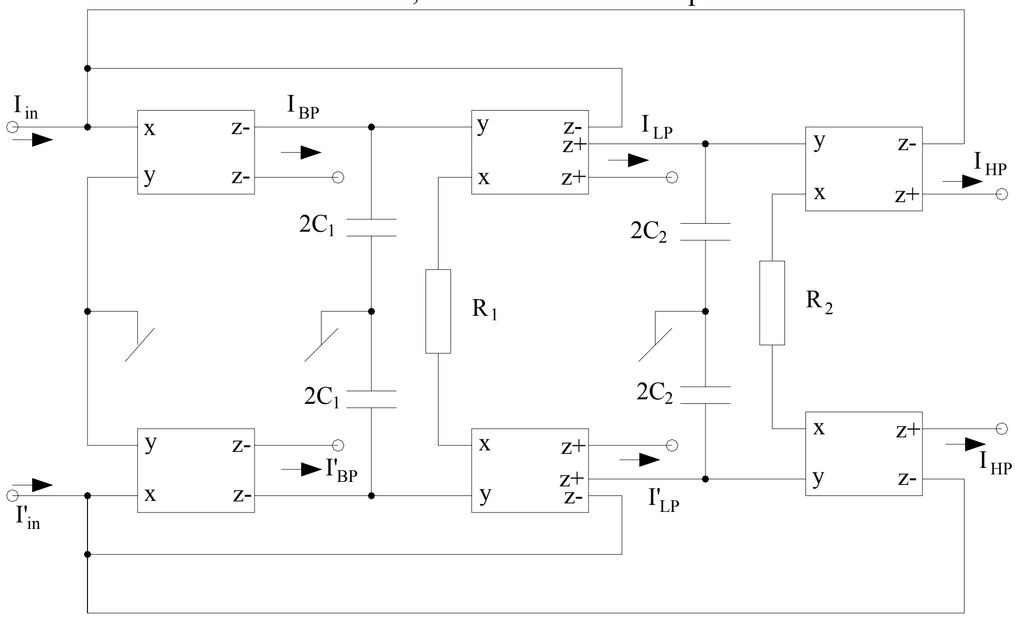

Fig 5. Fully differential CM universal filter

The high pass and low pass outputs can be combined to get the band elimination response and the high pass, band pass and low pass responses can be combined to get the all pass response, without requiring any component-matching conditions other than equality of capacitors (which is inherent in all earlier FD structures as well).

It may be noted that w_0/Q_0 and w_0 can be orthogonally tuned by R_1 and R_2, in that order; however, the gain is fixed at one in all the cases.

3. Simulation results

An exemplary implementation of the circuit of Fig. 4 was simulated with MOCC hardware of [17]. The components used were $R_1 = R_2 = 7078\Omega$, $C_1 = 0.4\text{nF}$, $C_2 = 0.2\text{nF}$ for BP and BE filters and $C_1 = 0.2\text{nF}$, $C_2 = 0.4\text{nF}$ for LP, HP and AP filters.

Fig 5 gives the various responses obtained from SPICE simulations of the circuit which establish the workability of the ideas presented in the paper.

4. Discussions and Concluding remarks

Although, we have shown the workability of the proposed methodology using MOCCs and through an exemplary fully differential CM universal biquad, the following other options are worth mentioning.

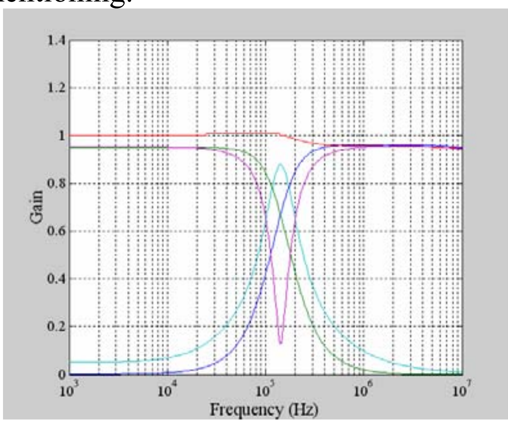

Fig. 5: Sample simulation results: Amplitude response for the LP, HP, AP filters with Q_0=0.707 and BP, BE filters with Q_0=2 (f_o =159kHz).

- *Electronically controllable FDCM filters* can be obtained by implementing the block of Fig. 1 by multiple output CCCIIs. Alternatively, electronically tunable multiple output OTA-based implementations would emerge by exercising the option of Fig. 2(c).
- *Higher order fully differential CM filters:* A variety of fully differential higher order CM filter may be evolved using any of the above approaches in conjunction with leap-frog or signal flow graph based approaches by appropriate extension of the methodology used in deriving the biquad structure of Fig. 4. An

interesting higher order filter design using the block of Fig 2(c) has appeared recently in [7], however the unified methodology presented here has not explicitly appeared in the literature earlier.

In conclusion, using the concept of nullors, a unified methodology of synthesizing fully differential CM filters has been formulated whose workability was demonstrated using an exemplary implementation of MOCCs. It is highlighted how the proposed methodology provides a unifying link to derive a number of other structures of practical interest using a variety of other active devices. However, the proposed extensions together with their CMOS implementations require further work.

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