SYNTHESIS OF CURRENT-MODE FILTERS USING A UNIVERSAL ACTIVE DEVICE

Tlelo-Cuautle E., Torres-Muñoz D., Díaz-Méndez A.

INAOE
Luis Enrique Erro No. 1. P.O.Box 51 and 216. 72840 México.
e.tlelo@ieee.org, ajdiaz@inaoep.mx

ABSTRACT

A method focused on the synthesis of current-mode filters by transforming the already known OTA-C filters working in voltage-mode using a universal active device, e.g. the CCII-, is presented. First, the ideal behavior of the OTA is modeled using nullors. Second, voltage-mode filters are transformed into its current-mode adjoint network. Third, nullator-norator pairs of the current-mode nullor circuit are synthesized with the CCII-, which has been designed using a CMOS technology of 0.35μm of AMS, and biased at 1.5V. Finally, the simulation of the frequency response using HSPICE demonstrates the suitability of the proposed method to be used in education.

1. INTRODUCTION

Analog systems can be described at various levels of abstraction where the more detailed the structure, the less abstract the description [1]. On the one hand, the *nullor* can be used to model the behavior of many analog circuits at the most abstract level of detail [2]-[5]. On the other hand, a detailed description of an active device using nullors can be done by adding parasitic elements to approximate its real behavior [6].

Filter design can be done at the most abstract level where the required building-blocks can be represented using nullors and the minimal impedance elements to convert voltages and currents. That way, any OTA-based circuit [7, 8], can be represented as a nullor circuit, from which the transformation technique to convert circuits working in voltage- to current-mode, and vice-versa can be easily done [5]. The transformed nullor circuit can furtherly be synthesized using a basic building-block, the CCII-, by joining nullator-norator pairs.

The adjoint transformation process using nullors is described in section 2. The design of the CCII- is given in section 3 along with several simulation results of practical implementations using HSPICE. The synthesis of a first order low-pass filter using the CCII-, working in current mode, is presented in section 4. Finally, the conclusions are listed in section 5.

2. ADJOINT TRANSFORMATIONS

Among all active devices [2], three of them are shown in Fig. 1. The CCII- is considered a universal active device (UAD) [3, 4], which is quite useful for synthesis purposes [5]. Besides, the accurate quantitative modeling and characterization of active devices is an essential prerequisite for the successful design and optimization of high performance analog systems.

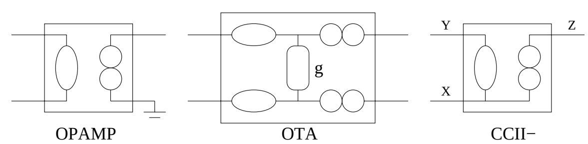

Figure 1: Basic nullor-based analog building blocks.

The ideal opamp has the properties: At its input-port: v=i=0, and at its output port: v=i=undefined. The ideal OTA has the properties: The differential input-voltage is bypassed directly to the conductance **g**, where the output current becomes i_o=$g_m(v_i{}^+ - v_i{}^-)$. For the ideal CCII- has the properties: across the nullator v_x=v_y and i_y=0, and through the norator i_z=i_x. As one sees, an OTA can be approximated by coupling two CCII-s between a conductance, this will help us to synthesize OTA-C filters using the CCII-.

The adjoint transformation process of a nullor-based OTA-C circuit from voltage- to current-mode is done as follows:
(1) Set nullator-norator interconnection-references.
(2) For each nullor, interchange the nullator/norator by the norator/nullator, but keeping intact the external circuitry.
(3) The independent voltage/current source is short/open circuited. Now it becomes the output port where the current/voltage is measured.
(4) If the output port-variable is voltage/current, connect an independent current/voltage source. Now this port becomes the input-port where the current/voltage is supplied.

Lets consider the OTA-C filter circuit shown in Fig. 2 [8], which works in voltage mode. The adjoint transformation process is sketched in Fig. 3. In Fig. 3a, it is shown the nullor circuit-equivalent of the OTA-C filter. In Fig. 3b, it is shown the adjoint circuit working in current mode.

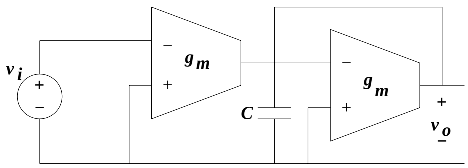

Figure 2: OTA-C filter working in voltage mode.

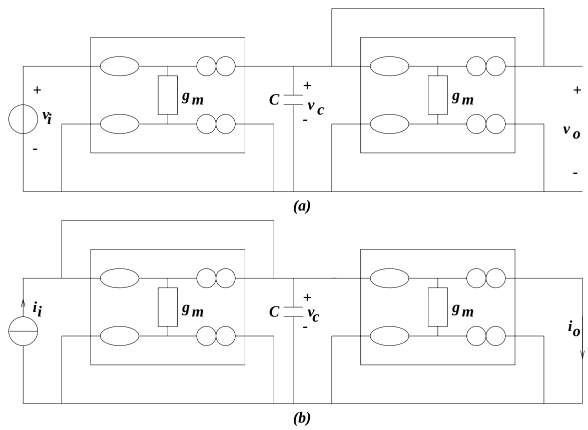

Figure 3: Nullor-based OTA-C filter working in (a) voltage and (b) current mode.

The computation of the symbolic transfer functions of the circuits shown in Fig. 3, have the following relationship:

$$\frac{V_o}{V_i} = \frac{I_o}{I_i} = \frac{1}{1 + \frac{sC}{G_m}} \tag{1}$$

By synthesizing each pair of nullors-arrangement from Fig. 3b with the OTA, the resulting OTA-C filter working in current mode, is shown in Fig. 4. However, using the CCII- an OTA can be approximated by coupling two CCII-s as shown in Fig. 5.

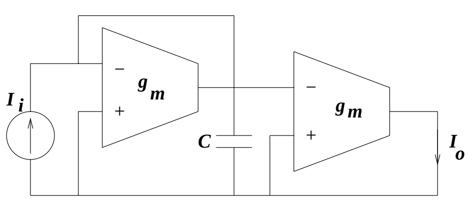

Figure 4: $OTA - C$ filter working in current mode.

3. DESIGN OF THE CCII-

Besides, there are many current conveyors proposed in the literature, the one considered as a UAD is the CCII- [2, 3],

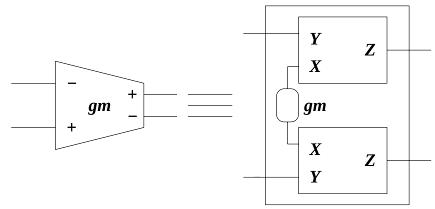

Figure 5: OTA implemented with two CCII-s

whose ideal behavior can be represented by a single nullor. That way, the design of the CCII- presented herein is based on the topology given in [3, 4]. It has been designed using CMOS technology of 0.35μm of AMS with the BSIM3v3 MOSFET model. The proposed CMOS design of the CCII- is shown in Fig. 6 [9].

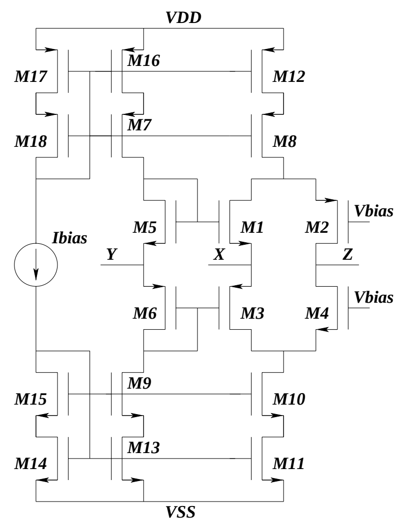

Figure 6: CCII- designed with CMOS technology

The designed CCII- is biased at V_{DD}=1.5V and V_{SS}=-1.5V. The W/L relationships are shown in Table 1.

Table 1: MOSFET dimentions

MOSFET	W/L relation
M1,M4,M5,M8,M12	180
M2,M3,M6	440
M7,M16,M17,M18	90
M9,M13,M14,M15	38
M10,M11	76

HSPICE simulations of the CCII- shows that the parasitic impedance at node X, as shown in Fig. 7, has several hundreds of ohms in magnitude, equal to R_X=480 ohms, as shown in Fig. 8. Using R_X, the simulation of an inductor by coupling two OTAs [3, 7, 8, 9], which are implemented by the CCII- as shown in Fig. 5, and by changing only the value of the capacitor, agree with practical realizations as shown in Fig. 9.

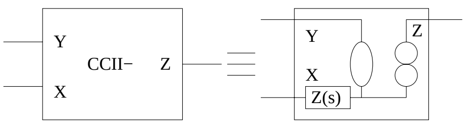

Figure 7: CCII- including its parasitic impedance.

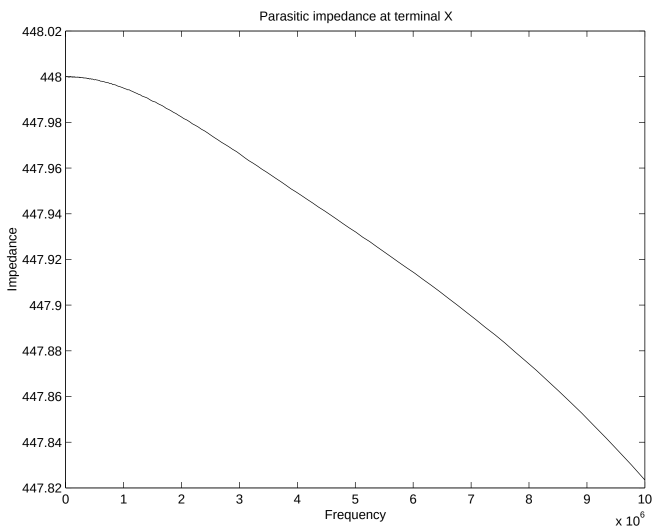

Figure 8: Parasitic impedance of the CCII- at node X.

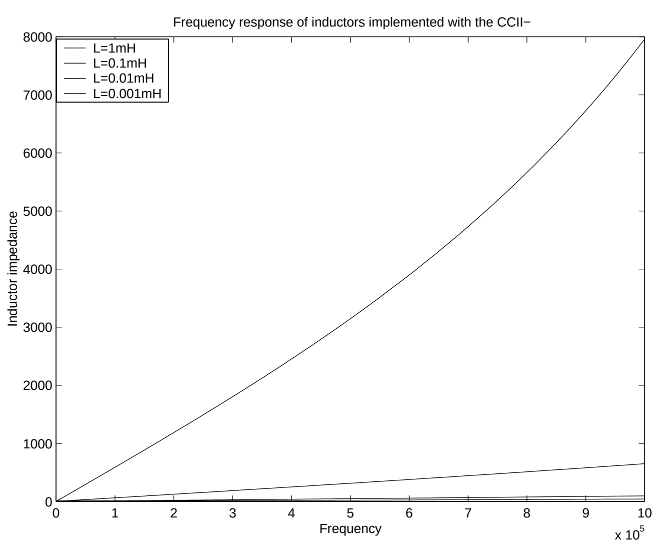

Figure 9: Implementing an inductor

4. SYNTHESIS OF NULLOR CIRCUITS USING A UAD: THE CCII-

The parasitic impedance R_X of the CCII- has been used to implement the conductance associated to an OTA, as shown in Fig. 5. In this manner, the resulting OTA implemented by two CCII-s has a transconductance equal to $g = \frac{1}{2R_X}$. Using this implementation and by setting C=1.62nF, the low-pass filters approximated by equation (1) have a dominant-pole at 100kHz (-3dB), as shown in Fig. 10. As one sees, both transfer functions in voltage- and current-mode present the same frequency behavior leading us to conclude about the suitability of the proposed adjoint-transformation technique.

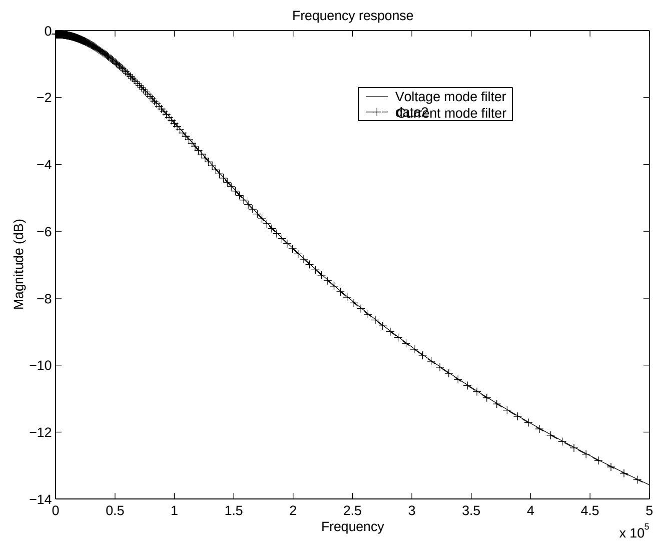

Figure 10: HSPICE simulations of the adjoint lowpass filters with a cut-off frequency of 100kHz.

By changing the capacitor value to have a dominant-pole at 1MHz (-3dB), the simulation results are shown in Fig. 10. As one sees, both transfer functions in voltage- and current-mode nearly-present the same frequency behavior, the error occurs due that the designed CCII- has a bandwidh of around 30MHz, at which the gain is 0.7 instead of 1. However, simulation results lead us again to conclude about the suitability of the proposed adjoint-transformation technique to be used within a synthesis methodology.

5. CONCLUSIONS

A method focused on the synthesis of current-mode filters by transforming the already known OTA-C filters working in voltage-mode using a universal active device, has been presented. It has been shown that using nullors, the ideal behavior of many active devices can easily be done. That

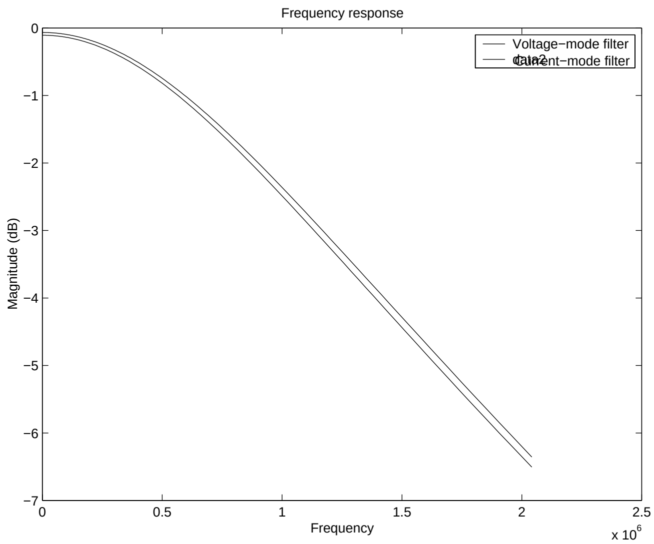

Figure 11: HSPICE simulations of the adjoint lowpass filters with a cut-off frequency of 1MHz.

way, the OTA has been modeled using two nullors which can be replaced by a CCII-.

It has been shown that any OTA-C circuit can be transformed into its adjoint network by manipulating nullator-norator pairs. The nullator-norator pairs in the current-mode nullor circuit are synthesized with the CCII-, which has been designed using a CMOS technology of 0.35μm of AMS, and biased at 1.5V. Finally, simulation results of several implementations using the CCII-, demonstrates the suitability of the proposed method to be used within synthesis methodologies focused on analog design automation.

6. REFERENCES

[1] Jean-Michel Bergé, Oz Levia and Jacques Rouillard, *Modeling in analog design*, Kluwer Academic Publishers, 1995.

[2] Hanspeter Schmid, *Approximating the universal active element*, IEEE TCAS-II: Analog and digital signal processing, vol. 47, no. 11, pp. 1160-1169, November 2000.

[3] R. Cabeza Laguna, *Diseño y aplicaciones de un elemento activo universal*, Ph.D. Thesis UPNA, España, 1996.

[4] Tlelo-Cuautle E., Sarmiento-Reyes L., *Synthesis of the CCII- using the nullor concept*, IEEE ICCDCS'2000, Cancún, México, pp. C-84, March, 2000.

[5] Tlelo-Cuautle E., Sarmiento-Reyes A., *Transforming OTA-C filters from voltage to current-mode*, IEEE ICCDCS, pp. C022-1-4, ISBN: 0-7803-7381-2, Aruba, April 2002.

[6] Tlelo-Cuautle E., Cid-Monjaráz Jaime, *Computing symbolic transfer functions from SPICE files using nullors*, Advances in Systems Theory, Mathematical Methods and Applications, A series of reference books, pp. 74-79, ISBN: 960-8052-61-0, WSEAS PRESS, 2002.

[7] J. Silva-Martínez, M. Steyaert, W. Sansen, *High-Performance CMOS Continuous-Time Filters*, Kluwer Academic Publishers, 1993.

[8] Randall L. Geiger and Edgar Sánchez-Sinencio, *Active Filter Design Using Operational Transconductance Ampli£ers: A Tutorial*, IEEE Circuits and Devices Magazine, pp. 20-32, March 1985.

[9] Torres-Muñoz Delia, *Diseño de un current conveyor negativo de segunda generación*, Bachelor Thesis, INAOE, MEXICO, 2002.