Available online at www.sciencedirect.com
SCIENCE DIRECT®
Int. J. Electron. Commun. (AEÜ) 60 (2006) 443 – 446
International Journal of Electronics and Communications AEÜ
www.elsevier.de/aeue

# Current-mode KHN filter employing current differencing transconductance amplifiers

Ali Ümit Keskin[a,*], Dalibor Biolek[b], Erhan Hancioglu[c], Viera Biolková[d]

[a]Department of Biomedical Engineering, Yeditepe University, Istanbul, Turkey
[b]Department of Microelectronics, Brno University of Technology, Brno, Czech Republic
[c]Department of Electrical Engineering, Yeditepe University, Istanbul, Turkey
[d]Department of Radioelectronics, Brno University of Technology, Brno, Czech Republic

Received 2 March 2005

**Abstract**

This study proposes a current mode (CM) Kerwin–Huelsman–Newcomb (KHN) filter employing only two current differencing transconductance amplifiers (CDTA) and two grounded capacitors. It is concluded that the circuit described here offers a simpler and more economical alternative to other CM KHN filters reported previously in literature.


***Keywords:*** CDTA; KHN filters; Active filters

## 1. Introduction

The Kerwin–Huelsman–Newcomb (KHN) biquad filter [1,2] belongs to popular filter structures of the type of "two lossless integrators in the feedback loop". An important feature of this structure is the generation of all three basic filter transfer functions, i.e., low-pass (LP), band-pass (BP), and high-pass (BP) simultaneously. In addition, filter tuning can be done without modifying the quality factor of the circuit. For identical values of passive components, the DC gain of LP, high-frequency gain of HP, and maximum gain of BP filters remain constant (unity-values) while tuning, and thus the upper bound of the filter dynamic range remains unchanged. KHN-type biquad filter offers low passive and active sensitivities, low component spread and good stability. However, relatively high number of resistors can be a disadvantage of the OpAmp-based voltage-mode operating classical KHN structure, besides its frequency bandwidth limitation. In order to overcome the limited frequency-bandwidth properties of the operational amplifiers, many KHN biquads based on different current mode (CM) active components are reported in literature [3–10]. But, some of these circuits require more active elements than the others. For example, transforming the classical voltage mode KHN structure into the popular "$g_m - C$" filter requires 6 OTAs and two capacitors [9,10].

In this paper, we report a CM KHN structure employing current differencing transconductance amplifiers (CDTAs) as active elements [11], whose input and output signals are currents. It should also be noted here that, the CDTA offers wider frequency bandwidth advantages as compared to its close relative, the current differencing buffered amplifier (CDBA) [12]. The proposed filter consists of only two CDTAs and two capacitors, and thus it can be classified as CDTA-C filter, an analogy with the well-known $g_m - C$ filters. The results of circuit simulations are given and non-ideal behavior of CDTA elements that have to be taken into account in the design of this filter structure are discussed.

* Corresponding author.
*E-mail addresses:* auk@yeditepe.edu.tr (A.Ü. Keskin), dalibor.biolek@unob.cz (D. Biolek).

1434-8411/$ - see front matter 
doi:10.1016/j.aeue.2005.09.003

## 2. CDTA-based KHN filter

The CDTA element [11] with its schematic symbol in Fig. 1 has a pair of low-impedance current inputs $p$ and $n$, and an auxiliary terminal $z$, whose outgoing current is the difference of input currents. Here, output terminal currents are equal in magnitude, but flow in opposite directions, and the product of transconductance ($g_m$) and the voltage at the $z$ terminal gives their magnitudes. Therefore, this active element can be characterized with the following equations:

$$V_p = V_n = 0, \quad I_z = I_p - I_n,$$
$$I_{x+} = g_m V_z, \quad I_{x-} = -g_m V_z, \tag{1}$$

where $V_z = I_z.Z_z$ and $Z_z$ is the external impedance connected to $z$ terminal of the CDTA. CDTA can be thought as a combination of a current differencing unit [13] followed by a dual-output operational transconductance amplifier, DO-OTA. Ideally, the OTA is assumed as an ideal voltage-controlled current source and can be described by $I_x = g_m(V_+ - V_-)$, where $I_x$ is output current, $V_+$ and $V_-$ denote non-inverting and inverting input voltage of the OTA, respectively. Note that $g_m$ is a function of the bias current. When this element is used in CDTA, one of its input terminals is grounded (e.g., $V_- = 0\,\mathrm{V}$). With dual output availability, $I_{x+} = -I_{x-}$ condition is assumed.

A possible CMOS-based CDTA circuit realization suitable for the monolithic IC fabrication is displayed in Fig. 2.

The proposed CDTA-based CM KHN biquad is given in Fig. 3. Note that, in contrast to conventional OpAmp, the CDTA enables an easy implementation of the non-inverting integrator.

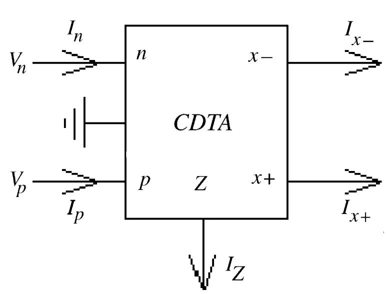


**Fig. 1.** Symbol for the CDTA.

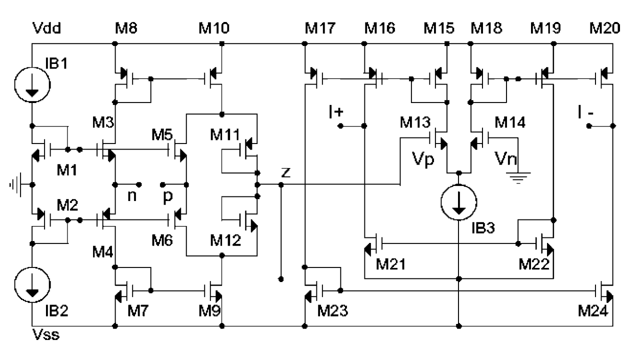


**Fig. 2.** CMOS-based CDTA : IB1 = IB2 = 85 μA, IB3 = 200 μA, bandwidth = 400 MHz.

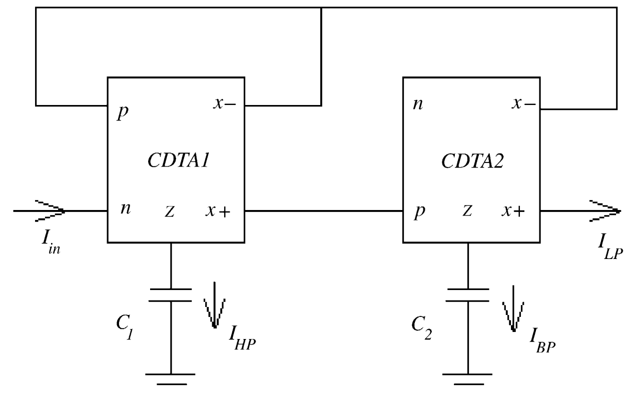


**Fig. 3.** CDTA-based CM KHN circuit.

Routine calculations for the proposed circuit in Fig. 3 yield the following current transfer functions:

$$\frac{I_{\mathrm{HP}}}{I_{\mathrm{in}}} = -\frac{s^2}{D(s)}, \quad \frac{I_{\mathrm{BP}}}{I_{\mathrm{in}}} = -\frac{(g_{m1}/C_1)s}{D(s)},$$
$$\frac{I_{\mathrm{LP}}}{I_{\mathrm{in}}} = -\frac{(g_{m1}g_{m2}/C_1C_2)}{D(s)}, \tag{2a–c}$$

where

$$D(s) = s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}. \tag{3}$$

The natural angular frequency and the quality factor can be given as

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}}, \quad Q = \sqrt{\frac{g_{m2}C_1}{g_{m1}C_2}}. \tag{4}$$

Here, passive $\omega_0$ and $Q$ sensitivities are all calculated as 1/2 in magnitude. It is obvious that this circuit provides all the LP, HP, and BP transfer functions, with the low-impedance input and high-impedance outputs.

## 3. Non-ideal case

In non-ideal case, the CDTA can be characterized by

$$V_p = V_n = 0, \quad I_z = \alpha_p I_p - \alpha_n I_n,$$
$$I_{x+} = g_m V_z, \quad I_{x-} = -g_m V_z, \tag{5}$$

where $\alpha_p$, $\alpha_n$ are parasitic current gains between $p$–$z$, $n$–$z$ terminals of the CDTA, respectively, which are generally deflected from their ideal unit values by current tracking errors, those absolute values being much less than one.

In non-ideal case, natural angular frequency and $Q$-factor of the proposed CM KHN biquad become

$$\omega_0 = \sqrt{\alpha_{p1}\alpha_{p2}\frac{g_{m1}g_{m2}}{C_1C_2}}, \quad Q = \sqrt{\frac{\alpha_{p2}}{\alpha_{p1}}\frac{g_{m2}C_1}{g_{m1}C_2}}. \tag{6}$$