Universal Current-Mode Gm-C Biquad

Dalibor BIOLEK[1,2], *Viera BIOLKOVÁ*[3], *Zdeněk KOLKA*[3]

[1] Dept. of EE, University of Defence, Kounicova 65, 612 00 Brno, Czech Republic
[2] Dept. of Microelectronics, University of Technology, Údolní 53, 602 00 Brno, Czech Republic
[3] Dept. of Radio Electronics, University of Technology, Purkyňova 118, 612 00 Brno, Czech Republic

dalibor.biolek@unob.cz, biolkova@feec.vut.cz, kolka@feec.vut.cz

Abstract. *A universal current-mode biquad is described which is designed on the basis of well-known KHN (Kerwin, Huelsman, Newcomb) voltage-mode filter. In its most general form, the circuit consists of five operational transconductance amplifiers (OTAs) and of two grounded capacitors. The filter provides simultaneously three current outputs of HP, BP, and LP types into independent loads. The quality factor can be adjusted electronically independently on the natural frequency. Less rigorous rules of controlling the filter parameters can imply a reduction of number of OTAs to three or even two. The principle is verified by Spice simulation on the level of a CMOS structure of OTAs.*

Keywords

Biquad, Current Mode, Gm-C filter.

1. Introduction

The Gm-C circuits represent a popular technique of integrated realization of frequency filters. The biquads for cascade synthesis are mostly based on the principle of two integrators in a feedback loop [1]. These blocks, mostly synthetized using the operational transconductance amplifiers (OTAs), can be designed for voltage or current mode of operation. The voltage-mode version of these circuits usually leads to a relatively large number of active components [2]. The current mode with the utilization of multiple-output (MO) OTAs features more economical topologies [3], [4], [5]. These biquads have more current inputs. The superposition of input currents and output currents of multiple-output OTAs yields all basic transfer functions.

A fundamental drawback of these topologies consists in the fact that the transfer functions, coming from such superpositions, are greatly sensitive to the matching errors of currents whose copies are combined together. As shown in [6], the matching errors, generated by the current CMOS technologies, can lead to undue deformations of frequency responses.

An economical current-mode biquad, described by Chang in [4], consists only of two OTAs and two grounded capacitors. However, some of the transfer functions are implemented as a sensitive superposition of several current inputs and outputs. Moreover, controlling the quality factor independently of the natural frequency must be accomplished under the awkward condition of constant product of the transconductances of both OTAs.

A universal biquad is described below, whose synthesis starts from the flow graphs of conventional KHN (Kerwin, Huelsman, Newcomb) filter. The resulting structure of "two integrators in a feedback loop" is similar to those in [4]. However, in contrast to [4] and [5], the various types of transfer functions are not achieved by sensitive combination of more input currents. Three independent current outputs of "HP", "BP", and "LP" types are available in the basic configuration. The quality factor and the bandwidth can be modified via the transconductance of one or two OTAs without disturbing the natural frequency.

2. Synthesis of novel Gm-C biquad

The flow graph, which corresponds to the classical structure of the KHN filter, is shown in Fig. 1. The facts that the circuit variables are not voltages but currents as well as that the Gm-C integrators will be used are also reflected in the graph.

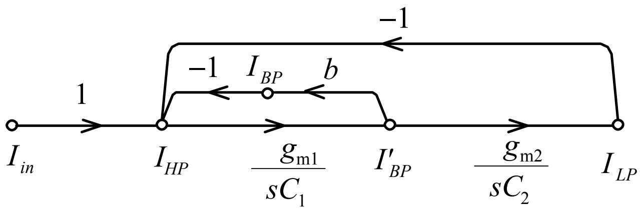

Fig. 1. Flow graph of current-mode KHN filter; b>0 is a real number.

The following transfer functions result from this graph:

$$\frac{I_{HP}}{I_{in}}=\frac{s^2}{\Delta},\ \frac{I_{BP}}{I_{in}}=\frac{sB}{\Delta},\ \frac{I'_{BP}}{I_{in}}=\frac{sB/b}{\Delta},\ \frac{I_{LP}}{I_{in}}=\frac{\omega_0^2}{\Delta},\quad (1)$$

where

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$$\Delta = s^2 + sB + \omega_0^2\,, \tag{2}$$

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}}\,, Q = \frac{1}{b}\sqrt{\frac{C_1}{C_2}\frac{g_{m2}}{g_{m1}}}\,,\; B = \frac{\omega_0}{Q} = \frac{g_{m1}}{C}b\,. \tag{3}$$

The symbols ω_0, Q, and B denote the natural frequency, the quality factor, and the filter bandwidth.

As results from the above formulas, the flow graph in Fig. 1 represents a biquad with three outputs of HP, BP, and LP types, with the possibility of Q and B tuning via b parameter, without disturbing the pre-set natural frequency. The high-frequency HP gain, the low-frequency LP gain, and the maximum frequency of BP gain are fixed to one.

The filter, designed from the above flow graph, is shown in Fig. 2.

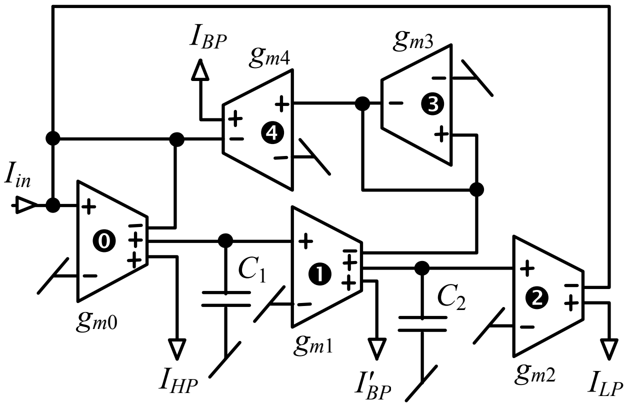

Fig. 2. Biquad, designed from the flow graph in Fig. 1.

The capacitors C_1 and C_2 together with OTAs No. 1 and 2 form a cascade of two current integrators. OTA No. 0 serves as a current summator. Two amplifiers No. 3 and 4 are connected as a current amplifier with the gain of

$$b = \frac{g_{m4}}{g_{m3}}\,. \tag{4}$$

It should be noted from (3) and (4) that the quality factor is proportional to the transconductance g_{m3} whereas the bandwidth is proportional to the transconductance g_{m4}.

3. SPICE simulation

The filter functionality was verified via Spice simulation of its model. The OTA amplifiers were modeled as the CMOS structure in Fig. 3 [7] with 0.5µm MIETEC transistor parameters. The W/L ratios are in Table 1. The transconductance g_m is varied within the range of 199µA/V to 635µA/V while changing the current I_{bias} from 20µA to 700µA. The supply voltage is ±2.5V.

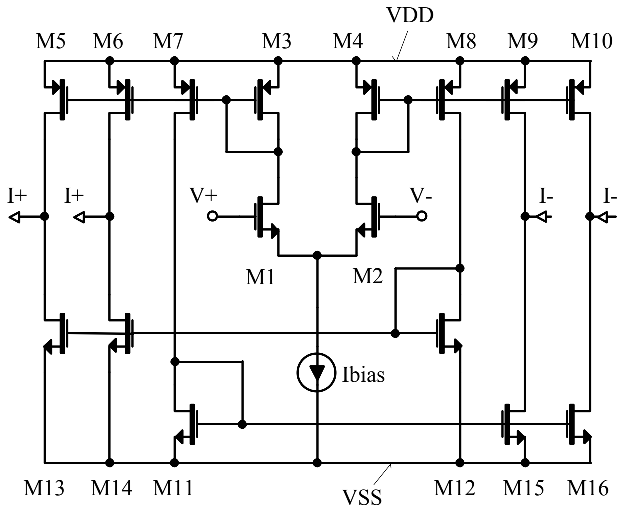

Fig. 3. CMOS structure of OTA. Adopted from [7].

Transistor	W [µm] /L [µm]
M1 – M2	16 /1
M3 - M10	6 / 1
M11 - M16	4 / 1

Tab. 1. W/L transistor ratios.

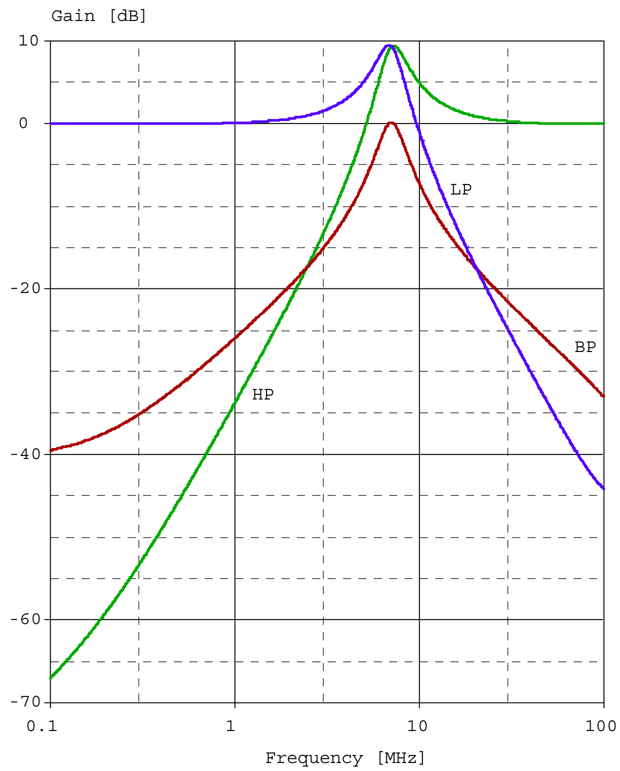

Fig. 4. Amplitude frequency responses of filter in Fig. 2 (Spice simulation).

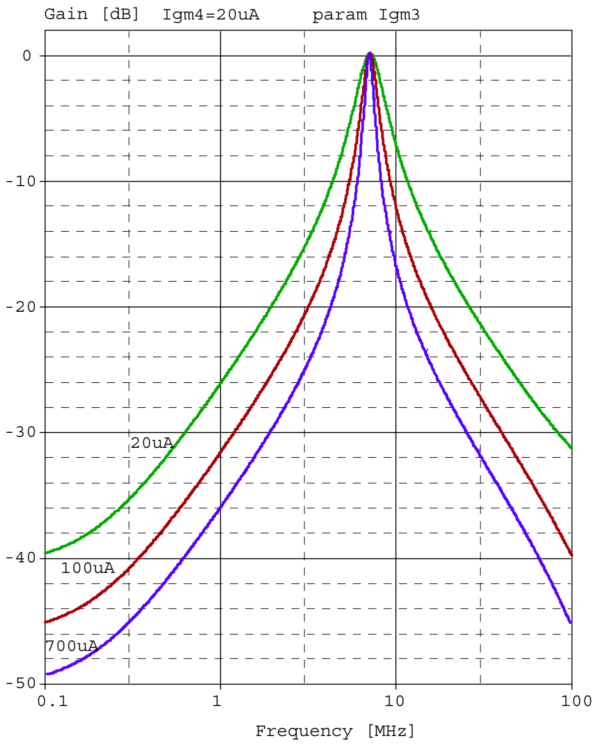

Fig. 5. Q-modification via transkonductance g_{m3} which is controlled by the bias current I_{gm3}.

The magnitude frequency responses in Fig. 4 were obtained for the following circuit parameters: I_{bias}=700µA, C_1=40pF, C_2=5pF. The theoretical values of the characteristic frequency and of the quality factor are f_0 = 7.146MHz, Q=2.828. The values, extracted from the simulation results, are in a good agreement: f_0 = 7.06MHz, Q=2.95. Fig. 5 shows the modification of the quality factor via the transconductance g_{m3}.

4. Conclusions

The proposed universal current-mode biquad holds the following features: Both working capacitors are grounded which is advantageous for prospective on-chip implementation. The filter provides all basic transfer functions of HP, BP, and LP types, and the output currents flow out of the OTAs into the independent loads. The change of the polarities of output currents is easy on principle. The transfer functions of BR (Band-Reject) and AP (All-Pass) types can be implemented by a proper joining the existing output outlets. The high-impedance outputs enable direct cascade connection of such biquads, providing high-order filters. Equations (3) indicate low sensitivities of ω_0, Q, and B to variations of working capacitances and transconductances. The gains of the individual HP, BP and LP sections are fixed during the electronic control of filter parameters. The simultaneous modification of g_{m1}=g_{m2} provides the ω_0 tuning without affecting the Q. The Q (or B) parameter is directly proportional to transconductance g_{m3} (or g_{m4}) without affecting the natural frequency.

The auxiliary circuit, consisting of OTAs No. 3 and 4, forms a current amplifier with the gain of b=g_{m4}/g_{m3}, connected between the output of OTA No. 1 and the input of OTA No. 0. It is possible to omit it and to replace it by short connection. The parameters of the resulting simpler 3-OTA biquad will be again described by Eqs. (3), but with the condition of b = 1. Note that the B and Q setting independently on ω_0 would be more problematic, namely via g_{m1} and g_{m2}, fixing their product to a constant value. Skipping further OTA No. 0 yields the economical 2-OTA biquad, published in [4]. However, it does not provide the HP output to the independent load.

The Spice simulations show a good conformity of circuit features with the theoretical parameters.

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