IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Floating-Gate MOSFET Based Tunable Voltage Differencing Transconductance Amplifier and Its Application to Biquad Filters

Ziad Alsibai

Brno University of Technology, Department of Microelectronics,Technická 10, 616 00 Brno, Czech Republic

xalsib00@stud.feec.vutbr.cz

Abstract

Active circuit element tunable VDTA (Voltage Differencing Transconductance Amplifier) based on floating-gate MOSFETs is proposed in this paper. The mentioned VDTA is brought as the convenient element for current mode signal processing, which might be very suitable for variety of applications such as biquad filters since the circuit has the advantage of being tunable. VDTA is supposed for usage mostly in current mode circuits but it is also good choice in case of voltage mode and/or hybrid (voltage-current) circuits as well. This active circuit element is a type of analog block consists of two multiple-output operational transconductance amplifiers (MO-OTAs) using floating-gate MOSFETs as input stage. Two examples of biquad filters implemented using VDTA are simulated with PSOICE simulations using the 0.18 μm CMOS technology to confirm the good performance of the proposed design in the paper.

Keywords: Biquad filters; floating-gate MOSFET; OTA; VDTA.

Introduction

The behavior of any circuit is always the result of interplay between voltage and current. When individual circuit elements interact by means of voltages the circuit is called Voltage Mode Circuit (VMC), whereas when they interact by means of currents the circuit is called Current Mode Circuit (CMC) [1].

However, CMCs have many advantages over VMCs, the latter suffer from many drawbacks: the output voltage does not change instantly when there is a sudden change in the input voltage, the bandwidth is usually low, the slew rate is also not very high, they are not suitable for use in high frequency applications, and they do not have high voltage swings [2].

For the mentioned reasons, the evolution of modern applications of analog signal processing in the last two decades has followed the trends of current mode. Current-mode techniques have given way to a number of important analog circuits as is evident from a vast amount of literature on current-mode circuits and techniques published in the recent past. An excellent review of the state-of-the-art of current-mode circuits is provided in [3]. Simultaneously with the development of current-mode applications, the mixed-mode circuits are also analyzed because of the necessity of optimizing the interface between the sub-blocks, which are working in different modes [4].

The Voltage Differencing Transconductance Amplifier (VDTA) represents an excellent example of current-mode circuit since that the components of the circuit interact by means of currents.
Section II, follows the introduction, describes the architecture and the operation of the active element. Section III presents two VDTA-filters based on floating-gate MOSFETs.

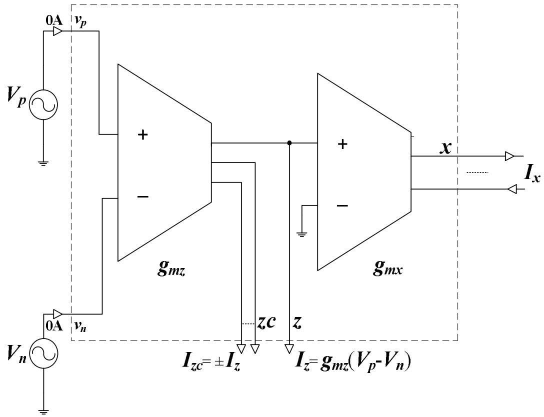
Description of VDTA

The VDTA (Voltage Differencing Transconductance Amplifier) is designed type of analog block that was inspired by operational transconductance amplifier (OTA).

VDTA is designed in the first place as current mode circuit but it is suitable for usage in voltage or hybrid (voltage-current) circuits. The internal structure of the VDTA is shown in Figure 1.
The element consists of two multiple-output OTAs connected in series representing the input and the output of the circuit.

The input behavior is given by properties of the OTA that is described in paragraph II.A. Output current of input stage flows

ISSN: 2277-9655



VDTA element as a connection of two MO-OTAs.

out of the VDTA terminal "z" into an outside load if desired. The voltage across the z-terminal is converted through a transconductance g_{mx} into two or more output currents with opposite polarity.

To increase the universality of the element, it is completed of the I_z copy, this attribute can be implemented by several methods, and the one addressed in [5] is adopted in the paper.

To further increase the versatility of the configuration, it is designed to allow orthogonal tuning capability through transconductance control by the amplifier bias current (I_{abc}) of each OTA, the main component of the proposed circuit.

The VDTA can be remarkably used in filters; it can implement low-pass, bandpass, high-pass filters as introduced in chapter III, as well as band-notch, and all-pass filters.

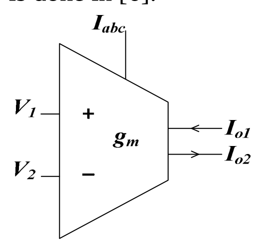
Description of OTA as the Basic Component of VDTA

To understand the functionality of VDTA, properties of OTA must be well described. The well-known OTA can be considered as differential voltage-controlled current source (DVCCS); its transconductance "g_m" represents the ratio of the output current to the differential input voltage, i.e., $I_{out}/\ (V_1\text{-}V_2)$. This transconductance is used as a design parameter and is adjustable by the amplifier bias current (I_{abc}). The benefit of this adjusting possibility is acquiring the ability of electronic orthogonal tunability to circuit parameters. It could be noted that tunability has a main role in integrated circuits, especially to satisfy a variety of design specifications.

OTA is similar to the standard operation amplifier in the sense of infinite input impedances, but its output impedance is much higher. Recently, the multiple-output- OTA (MO-OTA) has been introduced and used, on par with the ordinary operation amplifier, as a basic block in many applications, particularly for realizing universal filters which are able to implement several second-order transfer functions with a minimum of adjustments. The literature provides numerous examples of biquad structures based on OTA element, some of them are introduced in the following chapter.

The symbol of OTA is shown in Figure 2. OTA used in the paper utilizes floating-gate MOSFETs (FG-MOSFETs) as input stage; this kind of transistor has many advantages particularly in the case of low-power and low-voltage applications.

A comprehensive comparison between conventional MOSFET and FG-MOSET highlighting advantages and drawbacks is done in [6].

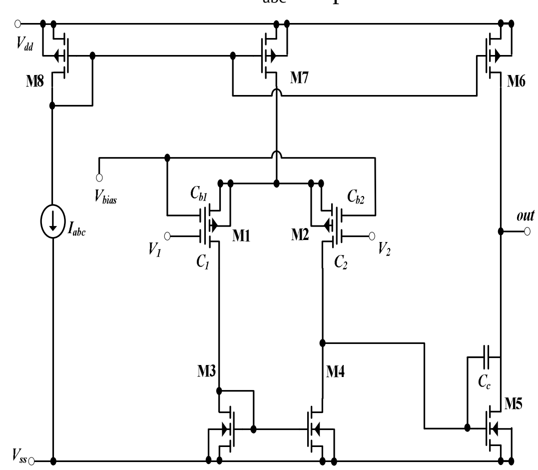


Circuit symbol of OTA.

The structure of FG-OTA configuration is illustrated in Figure 3, Table. I summarizes the performance of OTA in proposed VDTA for I_{abc}=10 mA/V. It is clear from Table. I that the circuit is stable with phase margin of 83◦, whitch is an important factor in determining the efficiency of the circuit.

A point that is worthwhile underlining is that the configuration offers rail-to-rail voltage capability at a low supply voltage of ±0.5 V.

The measurement results of the transconductance of OTA for five values of I_{abc} are presented in Table. II.



The circuit of two-stage OTA using FG-MOSFETs

.

TABLE I. SUMMARY OF THE PERFORMANCE FOR OTA

Characteristics	***Simulated results***
Voltage gain	47 dB
CMRR	61 dB
Offset voltage	291 µV
GBW	1.7 MHz
Phase margin	83◦
Power consumption	76 µW
Slew rate	4.35 MV/s
Settling time	67 0ns
Input range	0.8 V_{pp} = 0.78 V_{DD}
Output impedance	106 kΩ

TABLE II. MEASUREMENT RESULTS OF THE TRANSCONDUCTANCE

	Results of Transconductance g_m for Different Values of Bias Current I_{abc}				
I_{abc} [µA]	5	10	15	20	25
g_m [mA/V]	1.1	2	2.8	3.6	4.2

TABLE III. MEASUREMENT CONDITIONS OF THE CIRCUIT

Parameter	***Value***
C_{b1}, C_{b2}	0.3 pF
C_1, C_2	0.1 pF
C_c	1 pF
V_b	µ0.3 V

TABLE IV. TRANSISTORS DIMENSION

Device	***Type***	***L/W [µm]***	***I_d [µA]***
M1, M2	PMOS	0.2/10	2.3
M3, M4	NOMS	0.8/10	2.3
M5	NOMS	0.6/40	9.7
M6	PMOS	0.8/40	9.5
M7	PMOS	0.8/20	4.6
M8	PMOS	0.8/20	5

Component values are given in Table. III, transistor aspect ratios as well as their biasing currents are given in Table. IV. Results in Table. IV are taken under the condition I_{abc} = 10µA.

Biquads Based on VDTA

Since VDTA consists of two OTAs, a preferable application based on its approach would be operational transconductance amplifiers and capacitors (OTA-C) (also known G_m-C) filters. Several G_m-C structures have been presented in the literature, reference [7] and the references cited therein represent good examples of both voltage- and current-mode multifunction biquadratic filters.

In [8] authors present a new analytical synthesis method for high order current-mode (OTA-C) filters…

According to number of the output terminals of them, filters can be classified into two categories: (I) a multiple-output type (like in [9]), (II) a single-output type (like in [10]), each of which has its advantages and disadvantages. Generally, the multiple-output filters can simultaneously realize three basic filter functions, i.e., low-pass (LP), bandpass (BP), and high-pass (HP), at a time without altering the connection way of the circuits and without input signal matching as shown later. While the single-output filters can realize multifunction outputs by altering the way in which the input signals are connected [11]. The following two paragraphs give examples of single-input multiple-output current-mode filters representing the three basic types of operation; each of them is made up of two OTAs and two grounded capacitors, without requirements for component-matching conditions or cancellation constraints. The transconductance of each OTA is 2 mA/V unless stated otherwise, and the value of each groundrd capacitance is 1 nF.

First Biquad Filter Based on VDTA

A single-input multiple-output OTA-C filter based on VDTA configuration is shown in Figure 4 [7].

Circuit analysis yields the following transfer functions:

Circuit analysis yields the following transfer functions:

$$I_{o1} = sC_2g_{m1}I_{in}/\Delta. \quad (1)$$

$$I_{o2} = g_{m1}g_{m2}I_{in}/\Delta. \quad (2)$$

Where

$$\Delta = s^2C_1C_2 + sC_2g_{m1} + g_{m1}g_{m2}.$$

Thus:

- Bandpass function is obtained from I_{o1}.
- Low-pass function is obtained from I_{o2}.

The resonance angular frequency ω_o and the quality factor Q of proposed network is given by:

$$\omega_o = (g_{m1}g_{m2}/C_1C_2)^{1/2}. \quad (3.a)$$

 ISSN: 2277-9655

$$\omega_o/Q = g_{m1}/C_1. \quad (3.b)$$

But $C_1 = C_2$ and $g_{m1} = g_{m2}$ as mentioned earlier. By substituting in (3) we obtain:

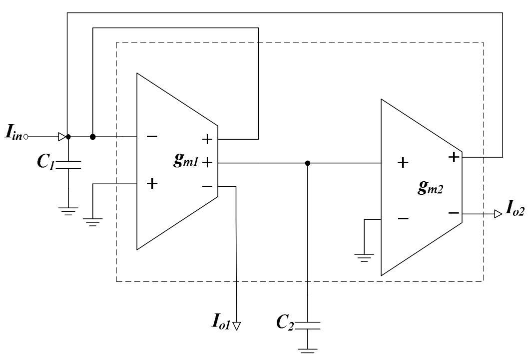
$$\omega_o = g_{mx}/C_x, \quad (4.a)$$

where $x = 1$ or 2.

$$Q = 1. \quad (4.b)$$

It is obvious from (4.b) that quality factor Q has no sensitivity to passive components, and that gives the designer a margin of freedom in designing progress.

Figure 5 shows the simulated low-pass and bandpass results. We observe from Figure 5 some peaking in the low-pass filter response; the reason is the value of Q (Q is 1.225 > 0.707). We can avoid this by reducing Q's value to remain under 0.707 by altering the value of g_{m1} according to (3.b), which is possible thanks to tunability of the circuit.



Single-input multiple-output biquad filter.

It must be mentioned here; that increasing I_{abc1} more than adequate could affect the operation of the MOSFETs in OTA_1 and might push them out of the saturation region. On the other hand, $_o$ is proportional to g_{m1} and g_{m2}. Hence, changing the value of g_{m1} must be done precisely.

The amount of peaking for the low-pass filter vs. Q is indicated in Figure 6.

Moreover, the selectivity of the bandpass filter could be changeable by varying the bias current follows through OTA_1 or OTA_2; Figure 7 shows a variety of curves with different natural (resonance) frequencies when I_{abc2}, thus G_{m2}, is variable.

Values of I_{abc2} and corresponding frequency range and bandwidth for each value are given in Table. V.

We notice from Table. V that bandwidth is increasing with the increase of frequency range, and both of them are proportional to the bias current I_{abc2}.

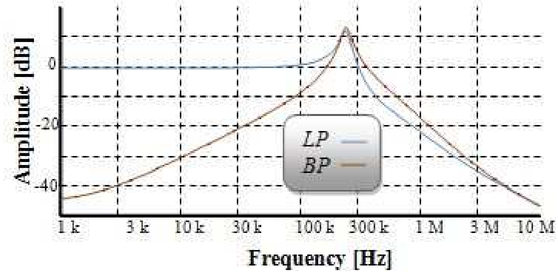


Figure 5. Simulated frequency responses of low-pass and bandpass signals shown in Figure 4.

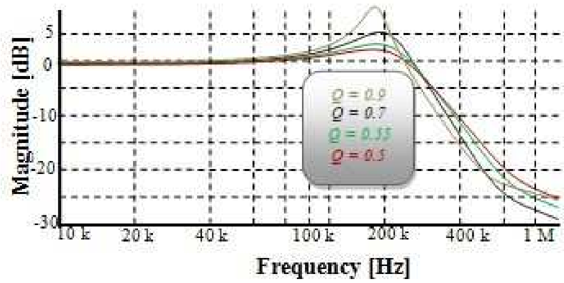


Figure 6. Low-pass filter peaking vs. Q (Gm1 is variable).

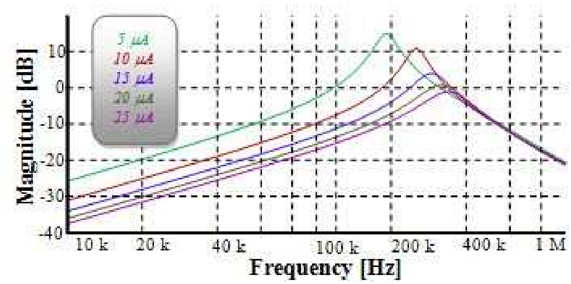


Figure 7. Bandpass filter when Iabc2 is varied (Gm2 is variable).

TABLE V. **FREQUENCY RANGES AND BANDWIDTHS FOR DIFFERENT VALUES OF I_{abc2}**

Bias current I_{abc2} [μA]	*Frequency range [kHz]*	*Bandwidth [kHz]*
5	171-208	37
10	224-278	54
15	247-340	93
20	261-384	123
25	272-417	145

Finally, since the output impedance of the network approaches infinity, the network is cascadable.

Second Biquad Filter Based on VDTA

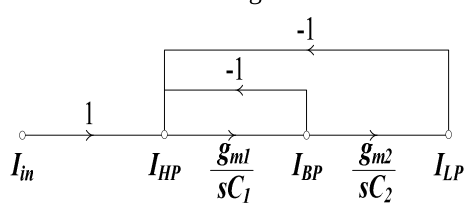
Another application of VDTA is the filter drawn in Figure 9 [4], a universal G_m-C current-mode biquad which is an appropriate implementation of the flow graph depicted in Figure 8, which in turn corresponds to the well-known KHN (Kerwin, Huelsman, Newcomb) filter structure. One can conclude from the circuit that the node, to which the non-inverting input of the VDTA is connected, serves as the summing node for adding up the currents according to the formula:

$$I_{HP} = I_{in} - I_{BP} - I_{LP}. \quad (5)$$

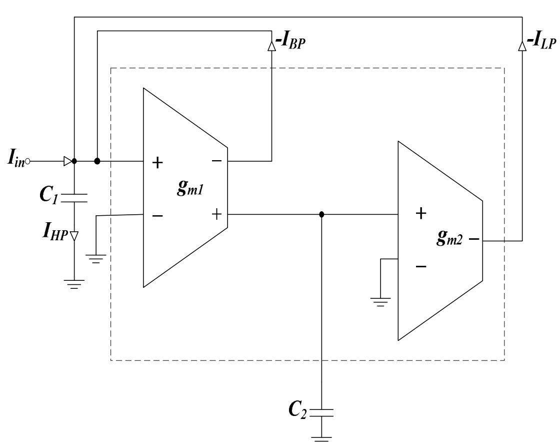
As shown, the configuration offers low-pass, bandpass, and high-pass filter. The frequency characteristic of the high-pass biquad is shown in Figure 10, although it is also possible to implement low-pass and bandpass functions of the multi-output filter shown in Figure 9 thanks of I_z copy attribute of the VDTA, thus the three basic filter types are available in the single-input configuration.

We conclude from Figure 10 (b) that the cutoff frequency is 205 kHz. This value is adjustable by means of tunability of the circuit; we can change the corner frequency, and therefore the passband of the filter, by simply adjusting I_{abc1} so g_{m1} has a new value without altering the passive components.

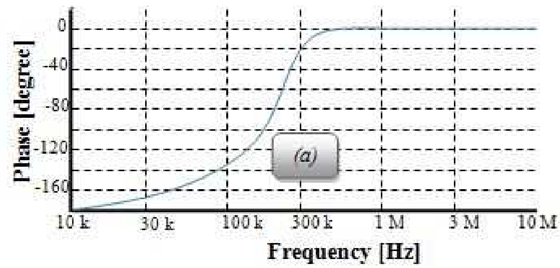
Figure 11 shows several gain curves with different cutoff frequencies for different values of I_{abc1}. The numerical results are given in Table. VI.



Flow graph of KHN structure.



Biquad designed from the graph in Figure 8.



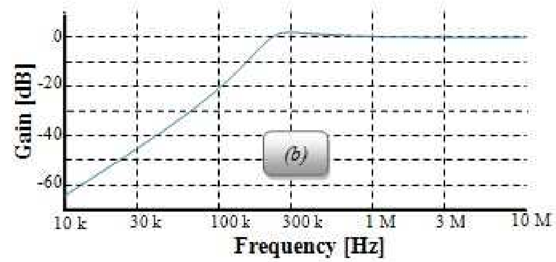
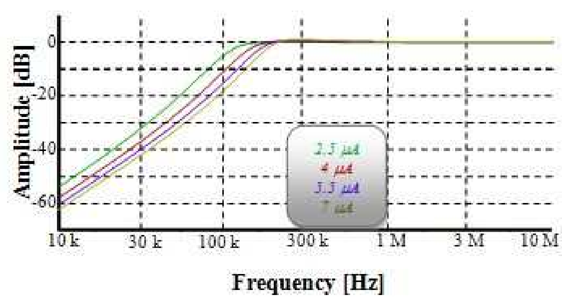


Figure 10. Simulated (a) phase and (b) frequency responses of the HP filter.



High-pass filter cutoff frequency vs. I_{abc1} (G_{m1} is variable).

TABLE VI. **DIFFERENT VALUES OF f_c FOR DIFFERENT VALUES OF I_{abc1}**

Bias current I_{abc2} [μA]	*Cutoff frequency f_c [kHz]*
2.5	112
4	141
5.5	163
7	180

References

[1] R. Prokop, and V. Musil, "New modern circuit block CCTA and some its applications," In Proceeding of 14th International Scientific and Applied Science Conference Electronics (ET'2005), pp. 93–98, 2005.

[2] S. S. Rajput, and S. S. Jamuar, "Low voltage analog circuit design techniques," IEEE Circuits and Systems Magazine, vol. 2, no. 1, pp. 24 – 42, 2002.

[3] B. Wilson, “Recent developments in current conveyors and current mode circuits,” in IEEE Proc. *G*, vol. 132, iss. 2, pp. 63–76, 1990
[4] D. Biolek, R. Senani, V. Biolková, and Z. Kolka, “Active elements for analog signal processing: classification, review, and new proposals,” Radioengineering, vol. 17, no. 4, pp. 15–32, 2008.
[5] G. Ferri, N.C. Errini, Low-Voltage Low-Power CMOS Current Conveyors. Kluwer Academic Publishers,, ch. IV, pp.120, 2003.
[6] Z. Alsibai, “Floating-gate operational transconductance amplifier,” International Journal of Information and Electronics Engineering, vol. 3, no. 4, pp. 361-364, 2013.
[7] C. M. Chang, “New multifunction OTA-C biquads,” IEEE Transactions on Circuits and Systems II, vol. 46, pp. 820–824, June 1999.
[8] C.M. Chang, and B. M. Al-Hashimi, “Analytical synthesis of current-mode high-order OTA-C filters,” IEEE Transactions on Circuit and Systems I: Fundamental Theory and Applications, vol. 50, no. 9, p. 1188–1192, 2003.
[9] M.T. Abuelma'atti, and A.A Bentrcia, “New universal current-mode multiple-input multiple-output OTA-C filter,” IEEE Asia-Pacific Conference on Circuits and Systems, pp. 1037–1040, 2004.
[10] M. Neag, R. Onet, and M. Topa, “A new OTA-C universal biquad resonates out the main parasitic capacitance, ” In Proceeding of European Conference on Circuit Theory and Design (ECCTD), pp. 125–128, 2009
[11] M. Kumngern, and U. Torteanchai, “Voltage-mode MISO OTA-C biquad filter, ” IEEE Symposium on Industrial Electronics and Applications (ISIEA), 2011, pp. 79–82, 2011.