Electronically Tunable Voltage-Mode Universal Filter with Single-Input Multiple-Output base on simple OTAs

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Preface

Welcome to 2011 IEEE International Conference on Computer Science and Automation Engineering (CSAE 2011)! Welcome to Shanghai, China! We believe that the solid conference program and the amazing city of Shanghai will offer you irresistible attraction.

This year's CSAE 2011 is co-sponsored by IEEE Beijing Section, Pudong New Area Association for Computer, Pudong New Area Science and Technology Development Fund, Tongji University, Xiamen University, University of Bradford, Iwate Prefectural University. Much work went into preparing a program of high quality.

At this very moment, we would like to thank the program committees and the organizing staffs for their hard work. We would like to especially thank Pudong New Area Association for Computer for hosting this conference. We would like to deliver our appreciation to the keynote speakers for their great contribution to this conference.

The scope of this conference is to gather researchers from different areas and disciplines to present results and participate in discussions under the common theme of computer science and automation engineering. These interactions will facilitate a better understanding of the diversity of the different approaches as well as of their similarities. In addition it will open the way for applying approaches that have been successful in one area to problem solving in different areas and applications.

We wish each of you successful deliberations, stimulating discussions, new friendships and all enjoyment that Shanghai can offer. While this is a truly remarkable Conference, there is more yet to come. We look forward to seeing all of you in Shanghai.

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Electronically Tunable Voltage-Mode Universal Filter Using Simple OTAs

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***Abstract*—This paper presents a new voltage-mode universal filter with single-input multiple-output employing seven simple CMOS operational transconductance amplifiers, two grounded capacitors and one resistor. The proposed filter can realize lowpass, bandpass, highpass, bandstop and allpass voltage responses from the same topology. The natural frequency (ω_o) and the quality factor (Q) can be controlled orthogonally and electronically by adjusting the bias currents of OTAs. The performances of the proposed circuit are simulated with PSPICE to confirm the presented theory.**

Keywords–universal filter, voltage-mode circuit, operational transconductance amplifier (OTA)

I. INTRODUCTION

An operational transconductance amplifier (OTA) has exhibited some advantages in the"circuit design. The OTA provides an electronic tunability, a wide tunable range and powerful ability to generate various circuits. Moreover, OTA-based circuits require no resistors and, therefore, are suitable for integrated circuit (IC) implementation [1]. These features are very attractive to filter dsign.

A biquad filter is very useful block to realize high-order filters which is importance in communication and electronic systems. Several voltage-mode biquadratic filters based on OTAs have been reported, e.g. [2]–[12]. In [2], a two integrator loop universal biquad filter using eight OTAs and two grounded capacitors is proposed. In [3], universal filter structure based on the signal flow graph and requires at most six OTAs and two grounded capacitors for general biquadratic transfer functions is proposed. In [4], a voltage-mode universal biquad filter using six OTAs and two capacitors is proposed. However, all of these reported can provide only one filtering output simultaneously. In [5]–[7], voltage-mode universal biquadratic filters with multiple-input single-output have been reported. However, these filters can not benefit from orthogonal control of the natural frequency (ω_o) and quality factor (Q). Recently, simple CMOS OTA-based voltage-mode universal biquad filters have been developed with either a single-input multiple-output or a multiple-input single-output [8]–[12]. However, these filters still can not benefit from orthogonal control of the parameters ω_o and Q.

In this paper, a new voltage-mode universal biquadratic filter with single input and multiple outputs using seven simple CMOS OTAs, two grounded capacitors and one external resistor is presented. The proposed filter can realize all standard filter responses, that is, LP, BP, HP, BS and AP voltage responses from the same configuration. The circuit is suitable for integrated circuit by using grounded capacitors. It can be implemented in both bipolar and CMOS technologies. The parameters ω_o and Q can also be controlled orthogonally and electronically by adjusting the bias currents of OTAs. There is no need to impose component choice for realizing the LP, BP, HP, BS, AP voltage responses. The performances of the circuit are also confirmed by PSPICE.

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II. CIRCUIT DESCRIPTION

The circuit symbol of the operational transconductance amplifier (OTA) is shown in Fig. 1. It is assumed a voltage-controlled current source. The characteristic of ideal OTA can be described by following equation,

$$I_o = g_m(V_1 - V_2) \tag{1}$$

where I_o is the output current, g_m is the transconductance gain, and V_1 and V_2 denote non-inverting and inverting input voltage, respectively, of the OTA. Fig. 2 shows the CMOS implementation for simple OTA. This circuit uses only four MOS transistors and one current source. Assume that MOS transistors, M_1 to M_4, are operated in saturation regions, the transconductance gain (g_m) can be expressed by

$$g_m = \sqrt{\mu_o C_{ox}(W/L)I_{abc}} \tag{2}$$

where I_{abc} is the bias current, μ_o is the carrier mobility, C_{ox} is the gate oxide capacitance per unit area, W and L are the channel width and length of MOS transistor. It can see from equation (2), the transconductance gain can be electronically controlled by adjusting the bias current I_{abc} which is very suitable for electronically adjustable function of the filter.

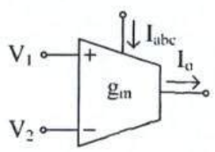

Figure 1. Circuit symbol of OTA.

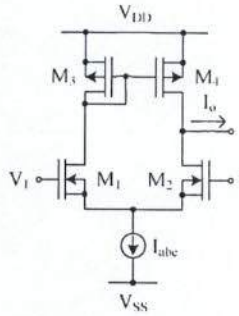

Figure 2. CMOS implementation for simple OTA.

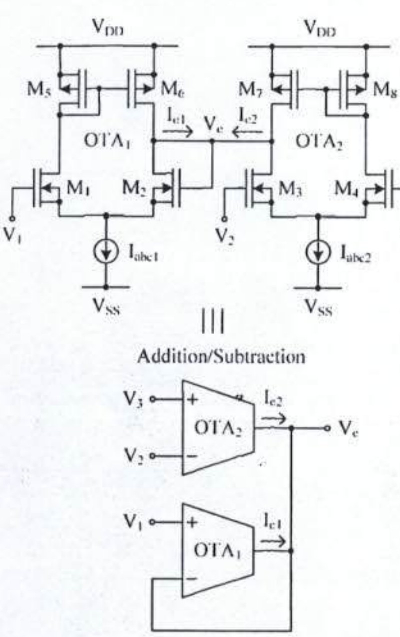

Figure 3. Simple CMOS OTA-based addition/subtraction circuit.

By using the simple CMOS OTA as shown in Fig. 2, the addition/subtraction circuit can be shown in Fig. 3. Referring to [13], [14], this circuit may be called the "pool circuit". Assume all the NMOS devices (M_1-M_4) in Fig. 3 are biased in the saturation region with individual wells connected to their sources to eliminate the body effect, let the transconductance parameter and the threshold voltage of M_1 through M_4 be equal to K and V_{TH}, respectively, $I_{abc1}=I_{abc}$ and $I_{abc2}=I_{abc}$ are two current sources, the currents I_{o1} and I_{o2} can be given as [10], [11]

$$I_{o1} = K(V_1 - V_o)\sqrt{\frac{2I_{abc}}{K} - (V_1 - V_o)^2} \quad (3)$$

$$I_{o2} = K(V_3 - V_2)\sqrt{\frac{2I_{abc}}{K} - (V_3 - V_2)^2}\,. \quad (4)$$

Therefore, at the equilibrium state

$$V_o = V_1 - V_2 + V_3\,. \quad (5)$$

This circuit operates as a pool [10] in the sense that the currents flowing in and flowing out are in equilibrium at the output node V_o. Therefore, the addition/subtraction voltages can be achieved by using the circuit in Fig. 3.

Using the OTA in Fig. 2 and the addition/subtraction circuit in Fig. 3, the proposed filter can be shown in Fig. 4. It employs seven simple CMOS OTAs, two grounded capacitors and one floating resistor. The voltage transfer functions of the proposed circuit can be expressed as

$$\frac{V_{o1}}{V_{in}} = \frac{-g_{m1}g_{m2}}{s^2C_1C_2 + sC_1R_1g_{m2}g_{m3} + g_{m1}g_{m2}} \quad (6)$$

$$\frac{V_{o2}}{V_{in}} = \frac{sC_1g_{m2}}{s^2C_1C_2 + sC_1R_1g_{m2}g_{m3} + g_{m1}g_{m2}} \quad (7)$$

$$\frac{V_{o3}}{V_{in}} = \frac{-s^2C_1C_2 - g_{m1}g_{m2}}{s^2C_1C_2 + sC_1R_1g_{m2}g_{m3} + g_{m1}g_{m2}} \quad (8)$$

$$\frac{V_{o4}}{V_{in}} = \frac{s^2C_1C_2}{s^2C_1C_2 + sC_1R_1g_{m2}g_{m3} + g_{m1}g_{m2}} \quad (9)$$

$$\frac{V_{o5}}{V_{in}} = \frac{s^2C_1C_2 - sC_1C_2 + g_{m1}g_{m2}}{s^2C_1C_2 + sC_1R_1g_{m2}g_{m3} + g_{m1}g_{m2}}\,. \quad (10)$$

Thus, the circuit realizes a LP signal at V_{o1}, a BP signal at V_{o2}, a BS signal at V_{o3}, a HP signal at V_{o4} and an AP signal at V_{o5}. It should be noted that there is no need to impose component choice except realizing the all-pass voltage response. The filter configuration is very suitable for implementation in CMOS technology. The use of grounded capacitor makes the circuit ideal for integrated circuit implementation.

The natural frequency (ω_o) and the quality factor (Q) can be given by

$$\omega_o = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (11)$$

$$Q = \frac{1}{R_1g_{m3}}\sqrt{\frac{C_2g_{m2}}{C_1g_{m1}}}\,. \quad (12)$$

Suppose $g_{m1}=g_{m2}=g_m$ and $C_1=C_2=C$, the parameters ω_o and Q can be simplified as

$$\omega_o = \frac{g_m}{C} \quad (13)$$

$$Q = \frac{1}{R_1g_{m3}}\,. \quad (14)$$

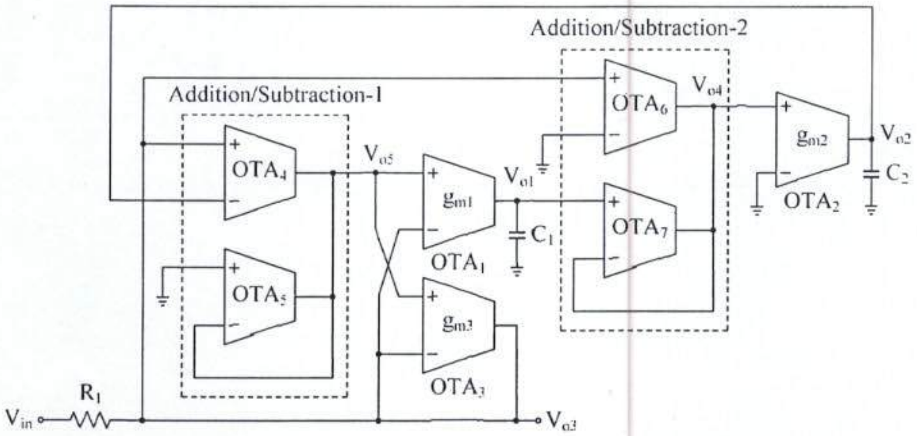

Figure 4. Proposed voltage-mode single-input five-output universal filter.

TABLE I. SENSITIVITIES OF CIRCUIT COMPONENTS.

X	$S_x^{\omega_o}$	S_x^Q
g_{m1}	0.5	-0.5
g_{m2}	0.5	-0.5
C_1	-0.5	0.5
C_2	-0.5	0.5
R_1	0.0	-1.0

It can see from (13) and (14) that the parameter ω_o can be electronically controlled by g_m (i.e. $g_m=g_{m1}=g_{m2}$), whereas the parameter Q can be electronically controlled by g_{m3} without disturbing parameter ω_o. This means that the proposed circuit can be orthogonally controlled. The incremental sensitivities of the parameters ω_o and Q are calculated as Table I. It can see that the active and passive sensitivities are low.

III. SIMULATION RESULTS

The proposed circuit in Fig. 4 was simulated using PSPICE program. The simple OTA was realized by the CMOS implementation using 0.5μm CMOS technology process parameters from MOSIS [10]. The power supplies are selected as ±3V. The bias currents for OTA_4 to OTA_7 are chosen as 25μA. For example design, the aspect ratios of the MOS transistors are W/L=2μm/2μm for all NMOS and W/L=40μm/2μm for all PMOS [10]. $C_1=C_2=100$pF, $R_1=10$kΩ and $I_{abc1}=I_{abc2}=I_{abc3}=50$μA ($g_m=77.52$μS) are given. This setting has been designed to obtain the LP, BP, HP, BS and AP filter responses with f_o=123.376kHz and Q=1.29. The simulated response of the LP, BP, HP and BS of the proposed filter are shown in Fig. 5. In this figure, the pole frequency of 123.12kHz is obtained. This error would be caused by voltage tracking errors of addition/subtraction circuits.

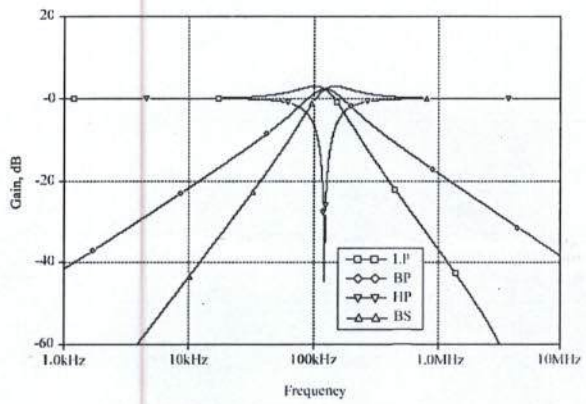

Figure 5. Simulated LP, BP, HP and BS voltage responses of proposed universal filter.

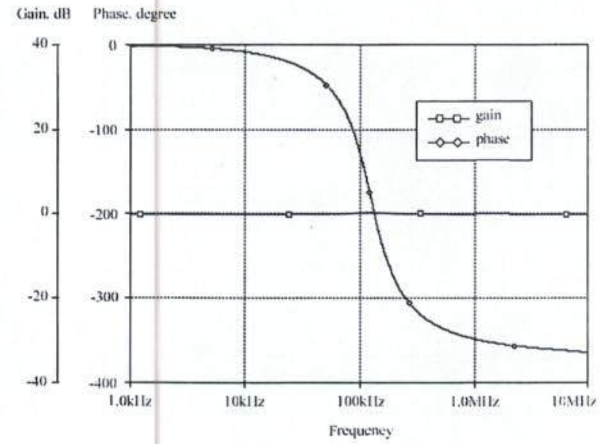

Figure 6. Simulated frequency and phase responses of the AP filter.

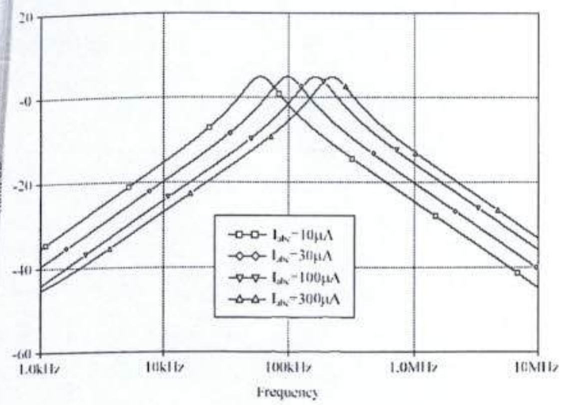

Figure 7. Simulated frequency responses of the BP filter when I_{abc} is varied.

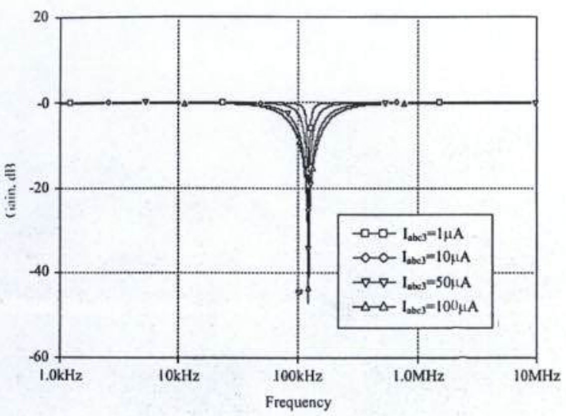

Figure 8. Simulated frequency responses of the BS filter when I_{abc3} is varied.

Fig. 6 shows the simulated frequency responses of the gain and phase characteristics of the AP filter. It is evident from Figs. 5 and 6 that the proposed filter performs five-standard biquadratic filtering functions well. For LP, BP, HP, BS voltage responses, no critical matching conditions are imposed. The corresponding current characteristics of the BP filter when I_{abc} (i.e. $I_{abc}=I_{abc1}=I_{abc2}$) is varied are shown in Fig. 7. This result is confirmed by (13). Fig. 8 shows the simulated BS filter response when the bias current I_{abc3} was adjusted for the values 1μA, 10μA, 50μA and 100μA, respectively, while keeping capacitors $C_1=C_2=100$pF and bias currents $I_{abc1}=I_{abc2}=50\mu A$. This result is confirmed by (14). It can conclude from Figs. 7 and 8 that the parameters ω_o and Q can be electronically and orthogonally controlled.

IV. Conclusions

In this paper, a new single input and five outputs electronically tunable voltage-mode universal biquadratic filter employing seven simple CMOS OTAs, two grounded capacitors and one resistor is presented. The proposed circuit possesses the following properties: (i) use simple CMOS OTA, (ii) ability of realizing the LP, BP, HP, BS and AP filter responses into a single circuit, (iii) orthogonal control of parameters ω_o and Q and (iv) electronic-controlled of the parameters ω_o and Q Simulation results are also given to demonstrate the effectiveness of our schemes.

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