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Third Order Current Mode Universal Filter Using Only Op.amp. and OTAs

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Abstract

A novel current mode active-only universal filter using four dual current output Operational Transconductance Amplifiers (OTAs) and three Operational Amplifiers (OAs) is presented. The circuit can realize low pass and high pass filter characteristics by choosing the suitable current output branches. The filter performance factors natural frequency (ω_0), bandwidth $(\frac{\omega_0}{Q})$, quality factor Q and transconductance gain gm are electronically tunable. The proposed circuit has very low sensitivities with respect to circuit active elements. From sensitivity analysis, it has been clearly shown that the proposed circuit has very low sensitivities with respect to the circuit active elements. The gain roll-off of high pass and low pass configuration is 18 dB/octave. The proposed circuit facilitates integrability, programmability and ease of implementation.

Keywords: Current Mode Filter, OTA, Bandwidth, Center Frequency, Circuit Merit Factor Q

1. Introduction

In recent years, current mode analogue signal processing circuit techniques have received wide attention due to the high accuracy, the wide signal bandwidth and the simplicity of implementing signal operations [1]. The design of current mode circuits employing active devices such as OAs, OTAs, and current conveyors (CCs) have been reported in the literature [2-6]. An OTA provides a high linear electronic tunability and wide tunable range of its transconductance gain.OTA based circuits requires no resistors; hence they are suitable for monolithic integration.

Recently, the multiple current output OTAs have been used for realizing current mode filters [7-12]. In 1996, Tsukutani *et al*. proposed good versatile current mode biquad filter using multiple current output OTAs and two grounded capacitors.

This paper focuses on realization of the current-mode third order active-only filter. The proposed circuit is constructed with OAs and dual current output OTAs. It is shown that the circuit can realize the biquadratic transfer function, and that the circuit characteristics can be electronically tuned by the transconductance gains of OTAs. The proposed circuit enjoys the features of:

- saving in components,
- realization of various filtering responses,
- devoid of resistors and capacitors which suits IC design techniques,
- high impedance outputs,
- electronic adjustment of ω_0 and $\frac{\omega_0}{Q}$ through bias currents of the active elements
- independent electronic adjustment of passband gains,
- low sensitivity figures.

2. Circuit Analysis and Analytical Treatment

The open loop gain of an OA is represented by the well known first order pole model [13-15]

$$A(S) = \frac{A_0\omega_0}{S+\omega_0}$$

where A_0: Open loop D.C. gain of op-amp.

ω_0 : Open loop – 3dB bandwidth of the op-amp = 2 πf$_0$

$A_0\,\omega_0$: β_i = gain-bandwidth product of op-amp.

For $S >> \omega_0$

$$A(S) = \frac{A_0\omega_0}{S} = \frac{\beta_i}{S} \qquad (i = 1,2,3,)$$

This model of OA is valid from a few kHz to few hundred kHz. In this frequency range, OTA works as an ideal device. The OTA is characterized by the port-relation

$$I_O = g_m (V_+ - V_-)$$

where, g_m is transconductance of OTA. In the dual current output OTA, the plus current output has a positive polarity, and the minus current output has a negative polarity.

The analysis gives the current transfer function $T = [I\ out / I\ in]$ as follows:

$$T(S) = \frac{g_{mb0}S^3 - (g_{mb1}\beta_1 - g_{mb2}\beta_2)S^2 + (g_{mb2}\beta_1\beta_2 - g_{mb3}\beta_2\beta_3)S - g_{mb3}\beta_1\beta_2\beta_3}{g_{ma0}S^3 + (g_{ma1}\beta_1 - g_{ma2}\beta_2)S^2 + (g_{ma2}\beta_1\beta_2 + g_{ma3}\beta_2\beta_3)S + g_{ma3}\beta_1\beta_2\beta_3} \qquad (1)$$

The circuit was designed using coefficient matching technique. *i.e.*, by comparing these transfer functions with general third order transfer functions is given by,

$$T(S) = \frac{\alpha_3S^3 + \alpha_2S^2 + \alpha_1S + \alpha_0}{S^3 + \omega_0(1+\frac{1}{Q})S^2 + \omega_0^2(1+\frac{1}{Q})S + \omega_0^2} \qquad (2)$$

Comparing Equations (1) with (2) we get,

$$\omega_0^3 = \frac{g_{ma3}\beta_1\beta_2\beta_3}{g_{ma0}} \qquad \omega_0^2(1+\frac{1}{Q}) = \frac{g_{ma1}\beta_1 + g_{ma2}\beta_2}{g_{ma0}} \qquad (3)$$

$$\omega_0(1+\frac{1}{Q}) = \frac{g_{mb2}\beta_1\beta_2 + g_{mb3}\beta_2\beta_3}{g_{ma0}}$$

$$\alpha_3 = \frac{g_{mb0}}{g_{ma0}} \quad \text{And} \quad \alpha_0 = \frac{g_{mb3}}{g_{ma0}}$$

It is found from above equations that circuit parameters ω_0, Q; α_0 can independently set and electronically tuned adjusting the transconductance gains of the OTAs. If g_{ma0}, β_1, β_2 and β_3 are given, the parameter ω_0 can be set by g_{ma2}. The parameters Q and α_3 can be set by g_{ma1} and g_{mb0} respectively. It seems that the values of Q and α_3 are also limited by the dynamic ranges of the OA and OTA.

From (1), it can be seen that:

1) The low pass transfer function can be realized with $g_{mb0} = 0$

$$g_{mb1}\beta_1 = g_{mb2}\beta_2 \quad \text{and} \quad g_{mb2}\beta_1\beta_2 = g_{mb3}\beta_2\beta_3$$

2) The high pass transfer function can be realized with $g_{mb3} = 0$ $\;g_{mb1}\beta_1 = g_{mb2}\beta_2$ and $g_{mb2}\beta_1\beta_2 = g_{mb3}\beta_2\beta_3$

3) The band pass transfer function can be realized with $g_{mb3} = g_{mb0} = 0$ $\;g_{mb1}\beta_1 = g_{mb2}\beta_2$

The high pass and low pass transfer functions obtained are as follows,

$$T_{HP} = \frac{\alpha_0S^3}{g_{ma0}S^3 + (g_{ma1}\beta_1 + g_{ma2}\beta_2)S^2 + \left(g_{ma2}\beta_1\beta_2 + g_{ma3}\beta_2\beta_3\right)S + g_{ma3}\beta_1\beta_2\beta_3}$$

$$T_{LP} = \frac{\alpha_3}{g_{ma0}S^3 + (g_{ma1}\beta_1 + g_{ma2}\beta_2)S^2 + \left(g_{ma2}\beta_1\beta_2 + g_{ma3}\beta_2\beta_3\right)S + g_{ma3}\beta_1\beta_2\beta_3}$$

The realization of the other transfer functions invariably requires matching the conditions in terms of the transconductance gains of the OTAs and the gain-bandwidth products of the OAs.

The transconductance gains of the OTAs to realize the desired characteristics are obtained from (3) as

$$g_{ma3} = \frac{\omega_0^3\beta_1\beta_2\beta_3}{g_{ma0}}$$

$$g_{ma2} = \frac{\omega_0^2}{\beta_1\beta_2}\left\{\left(1+\frac{1}{Q}\right) - \frac{g_{ma0}\omega_0}{\beta_1\beta_2\beta_3}\right\}$$

$$g_{ma1} = \frac{g_{ma0}\omega_0}{\beta_1}\left(1+\frac{1}{Q}\right) - \frac{g_{ma2}\beta_2}{\beta_1}$$

where ω_0, Q, β_1, β_2, β_3 and g_{ma0} should be given in advance.

Methods of implementing a dual current output OTA have been discussed previously (Ramirez-Angulo *et al.* 1992, Wu 1994).

3. Circuit Diagram

The diagram was shown in **Figure 1**.

4. Circuit Description

The proposed circuit is built with four dual current output OTAs and three OAs is as shown in **Figure (1)**. The V+ terminal of first OTA and V-terminal of all other OTAs are grounded. Output terminal of first OTA carrying positive polarity current is fed to inverting terminal of first OA. Its output is fed to inverting terminal of

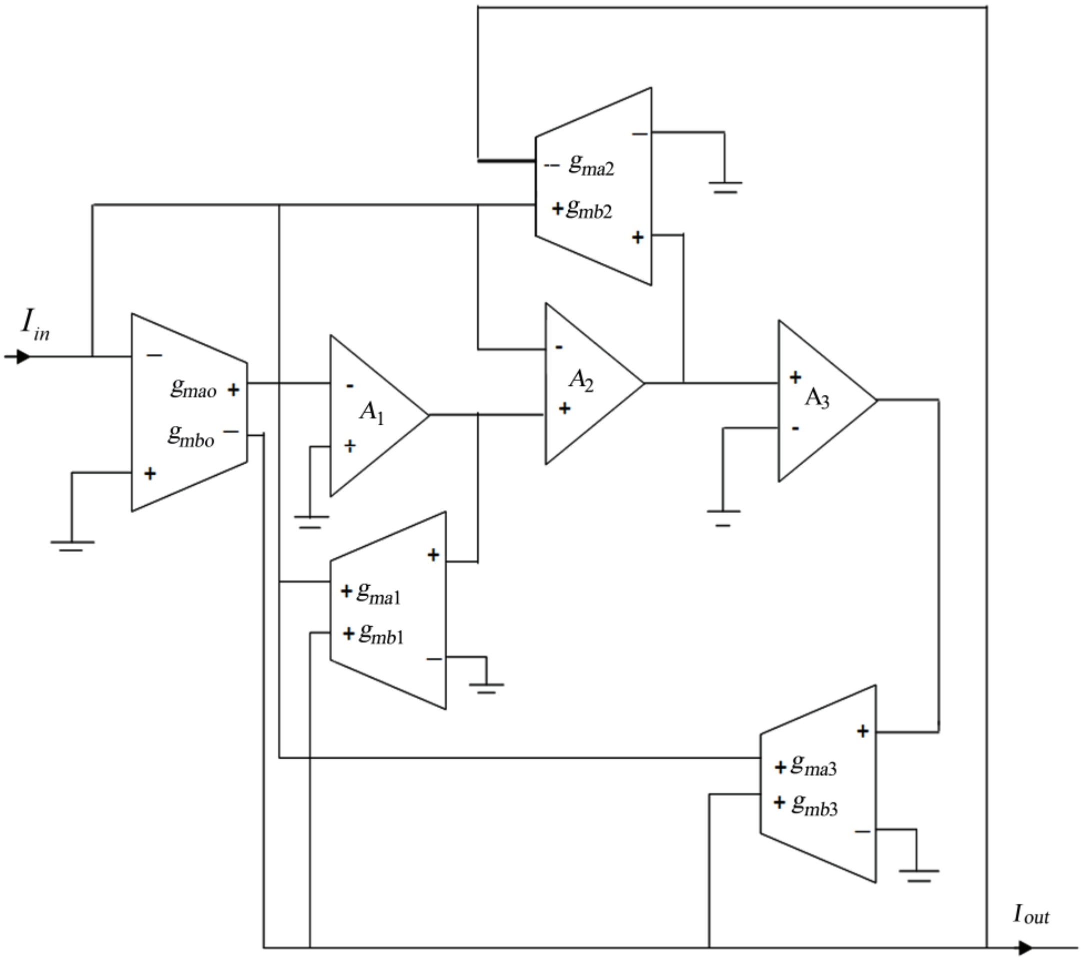

Figure 1. Circuit diagram of electronically tunable third order current-mode universal filter.

non-inverting of third OA output of third OA is then fed to v+ terminal fourth OTA. Output terminals of all OTAs carrying positive current are fed to inverting of first OA whereas remaining current output terminals of all OTAs adds to give output current of the circuit. The circuit can realize various third order filter functions by suitably choosing the current output branches.

5. Result and Discussion

The circuit performance is studied for Central frequencies f_0 = 100 kHz and 1 MHz with circuit merit factor Q = 1. The general operating range of this filter is 10 Hz to 1 MHz. The value of $\beta_1 = \beta_2 = \beta_3$ = 6.392 × 10^6 for LF 356 N. The proposed circuit gives response only for very high frequencies since the values of transconductance of OTAs takes very low values at frequencies less than 100 kHz. The values of g_{ma1}, g_{ma2} and g_{ma3} are calculated by taking g_{ma0} = 2 and $\frac{g_{ma3}}{g_{ma0}} = 1$ Response is studied for Q = 1 for high pass and low pass function. **Figures 2** and **3** shows high pass and low pass response of the proposed filter circuit respectively. Data obtained after analysis high pass and low pass response is given in **Tables 2** and **3**. From **Figures 2** and **3**, it is seen that the gain roll-off is 18 dB/octave for both the functions and the gain stabilizes to 0 dB at frequency 200Hz. There is no overshoot in the response. Observed - 3 dB frequency *i.e.* cutoff frequency matches with designed value f_0. Thus the filter circuit works ideal for high pass as well as low pass function. The values of transconductance gains for f_0 = 100 kHz and 1 MHz obtained are given in **Tables 1(a)** and **(b)** respectively.

6. Sensitivities

The practical solution is to design a network that has low sensitivity to element changes [14,15]. Thus sensitivity must be less than limit *i.e.* unity. The lower the sensitivity of the circuit, the less will its performance deviate because of element changes. The sensitivities $S_x^{\omega_0}$ and

$S_x^{\alpha_3}$ with respect to the circuit active elements are shown in **Table 4**. These values are within the range $0 \le S_x^y \le 1$ It is found that the proposed circuit has very low sensitivity with respective to active elements.

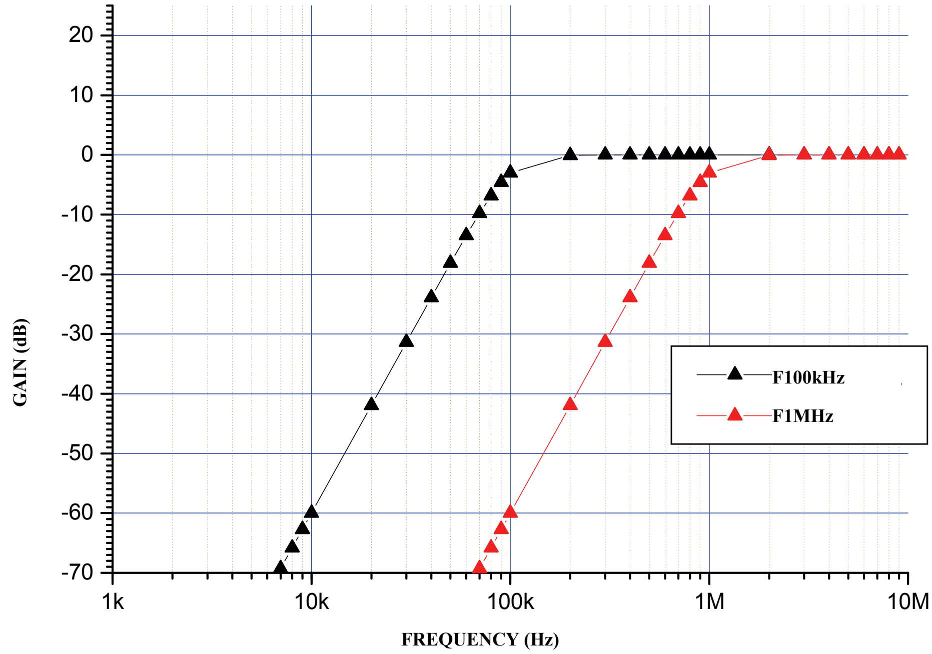

Figure 2. High pass response of proposed current-mode filter.

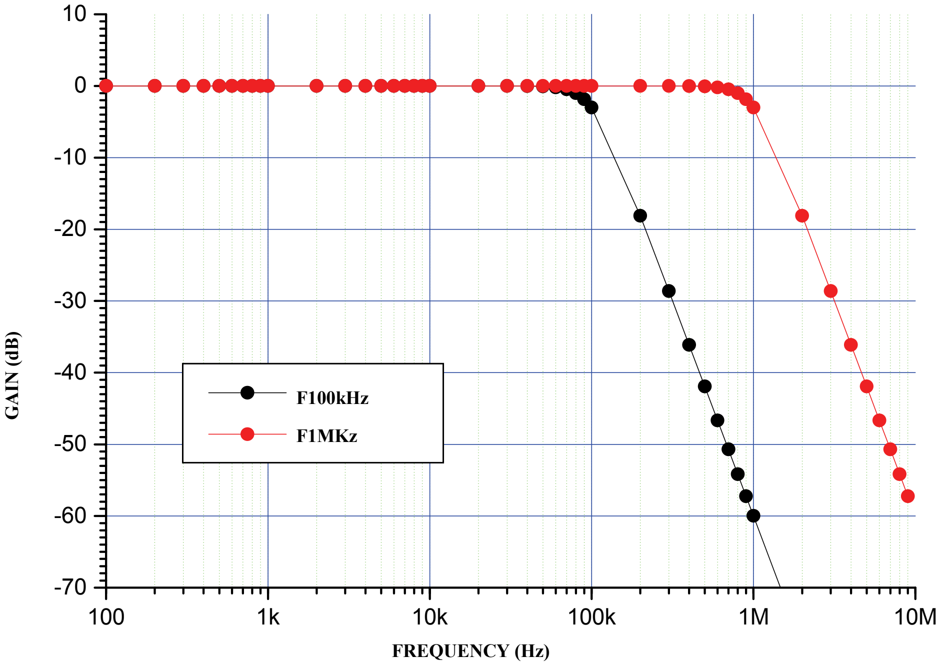

Figure 3. Low pass response of proposed current-mode filter.

7. Concluding Remarks

A versatile current-mode active-only filter using OAs and OTAs has been proposed. The proposed circuit can

Table 1. The values of transconductance gains.

g_{ma}	Value in mS for f_0 = 100 kHz
g_{ma0}	2
g_{ma1}	0.356
g_{ma2}	0.0367
g_{ma3}	0.0019
g_{mb0}	2
g_{mb3}	0.0019

(a) for f_0 = 100 kHz

g_{ma}	Value in mS for f_0 = MHz
g_{ma0}	2
g_{ma1}	1.966
g_{ma2}	1.965
g_{ma3}	1.9
g_{mb0}	2
g_{mb3}	1.9

(b) for f_0 = 1 MHz

Table 2. Analysis of frequency response of high pass function for Q = 1.

f_0 (kHz)	F_{OH} (kHz)	$f_0 \sim F_{OH}$ (kHz)	Gain Roll-off in stop band		Gain Stabilization	
			dB/Octave	Octave starting at (kHz)	dB	F_S (kHz)
100	100	0	18	500	0	
1 M	1 M	0	18	500	0	2 M

F_{OH}: –3 dB Frequency F_S: Frequency at which gain stabilizes

Table 3. Analysis of frequency response of low pass function for Q = 1.

f_0 (kHz)	F_{OL} (kHz)	$f_0 \sim F_{OL}$ (kHz)	Gain Roll-off in stopband		Gain Stabilization	
			dB/Octave	Octave starting at (kHz)	dB	F_S (Hz)
100	100	0	18	400	0	100
1M	1M	0	18.3	2 M	0	100

F_{OL}: –3 dB Frequency

realize the biquadratic transfer function and the circuit characteristics can be electronically tuned by the transconductance gains. From sensitivity analysis, it has been clearly shown that the proposed circuit has very low sensitivities with respect to the circuit active elements.

Table 4. Sensitivities $S_x^{\omega_0}$ and $S_x^{\alpha_3}$.

x	$S_x^{\omega_0}$	$S_x^{\alpha_3}$
g_{ma0}	–0.33	–1.0
g_{ma1}	0	0
g_{ma2}	0	0
g_{ma3}	0.33	0
g_{mb0}	0.33	1.0
β_1	0.33	0
β_2	0.33	0
β_3	0.33	0

The gain roll-off of high pass and low pass configuration is 18dB/octave.

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