IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 8 Issue 9, October 2021
ISSN (Online) 2348 – 7968 | Impact Factor (2020) – 6.72
www.ijiset.com

Dual Current Output OTA Based Current Mode Third Order Low Pass Filter for circuit merit factor Q = 10

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Abstract – Presently, there is a growing interest in synthesizing current-mode circuits because of their potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry and lower power consumption. In communication, we require new configurations to realize third-order low pass (LP), high pass (HP), band pass (BP),all pass(AP) and band reject (BR) filters .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 various 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. The proposed circuit facilitates integrability, programmability and ease of implementation.

Key Words: Universal Current Mode, Electronic tunable, active filter, OTAs, OA, Circuit merit factor Q.

Introduction:

For the Active filter design the first step is to select the active component. For the filter. DDA, OTA and op-amps are the few options. OTA has been chosen as the active device for this design [1, 2].

The conventional operational amplifier (op amp) is used as the active device in the vast majority of the active filters. It has also become apparent that operational amplifier limitations preclude the use of these filters at high frequencies, attempts to integrate these filters have been unsuccessful (with the exception of a few non-demanding applications), and convenient voltage or current control schemes for externally adjusting the filter characteristics do not exist [16].

But OTAs offer improvements in design simplicity and programmability when compared to op- amp based structures as well as reduced component count [3,8].Among its advantages are that it is easy to implement in monolithic form, has significantly higher bandwidth compared to OA , can be electronically tuned, and leads to very simple filter configurations [13].

The latest research trends are to design circuits using OTAs, both in single output and multiple output configurations. Multiple output OTAs are used in current mode applications. OTAs have electronic tunability which makes them superior to OAs. OTA based circuits requires no resistors; hence they are suitable for monolithic integration.

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. The circuit characteristics such as natural frequency (ω_0), bandwidth ($\frac{\omega_0}{Q}$), quality factor Q and transconductance gain gm are electronically tunable. can be electronically tuned by the transconductance gains of OTAs.

CIRCUIT ANALYSIS AND ANALYTICAL TREATMENT:

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

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

Where $A_{0:}$: Open loop D.C.gain of op-amp.

ω_0: Open loop – 3dB bandwidth of the op-amp= $2\pi f_0$

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

For $S \gg \omega_0$

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

This model of OA is valid from few kHz to few hundred kHz. In this frequency range, OTA works as an ideal active 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

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

From (1), it can be seen that the low pass transfer function can be realized with

$$g_{mb0} = 0 \quad g_{mb1}\beta_1 = g_{mb2}\beta_2 \ \text{ and } g_{mb2}\beta_1\beta_2 = g_{mb3}\beta_2\beta_3$$

The low pass transfer functions obtained are as follows,

$$T_{LP} = \frac{\propto_0}{g_{ma0}S^3 + (g_{ma1}\beta_1 - g_{ma2}\beta_2)S^2 + (g_{ma2}\beta_1\beta_2 + g_{ma3}\beta_2\beta_3)S + g_{ma3}\beta_1\beta_2\beta_3}$$

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

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

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

$$\left.\begin{aligned}
\omega_0^3 &= \frac{g_{ma3}\beta_1\beta_2\beta_3}{g_{mao}} \\
\omega_0^2(1+\frac{1}{Q}) &= \frac{(g_{ma1}\beta_1-g_{ma2}\beta_2)}{g_{mao}} \\
\omega_0\left(1+\frac{1}{Q}\right) &= \frac{(g_{ma2}\beta_1\beta_2+g_{ma3}\beta_2\beta_3)}{g_{mao}} \\
\alpha_3 = \frac{g_{mbo}}{g_{mao}} \quad &\text{and } \alpha_0 = -\frac{g_{mb3}\beta_1\beta_2\beta_3}{g_{mao}}
\end{aligned}\right\} \quad (3)$$

From (3) we get,

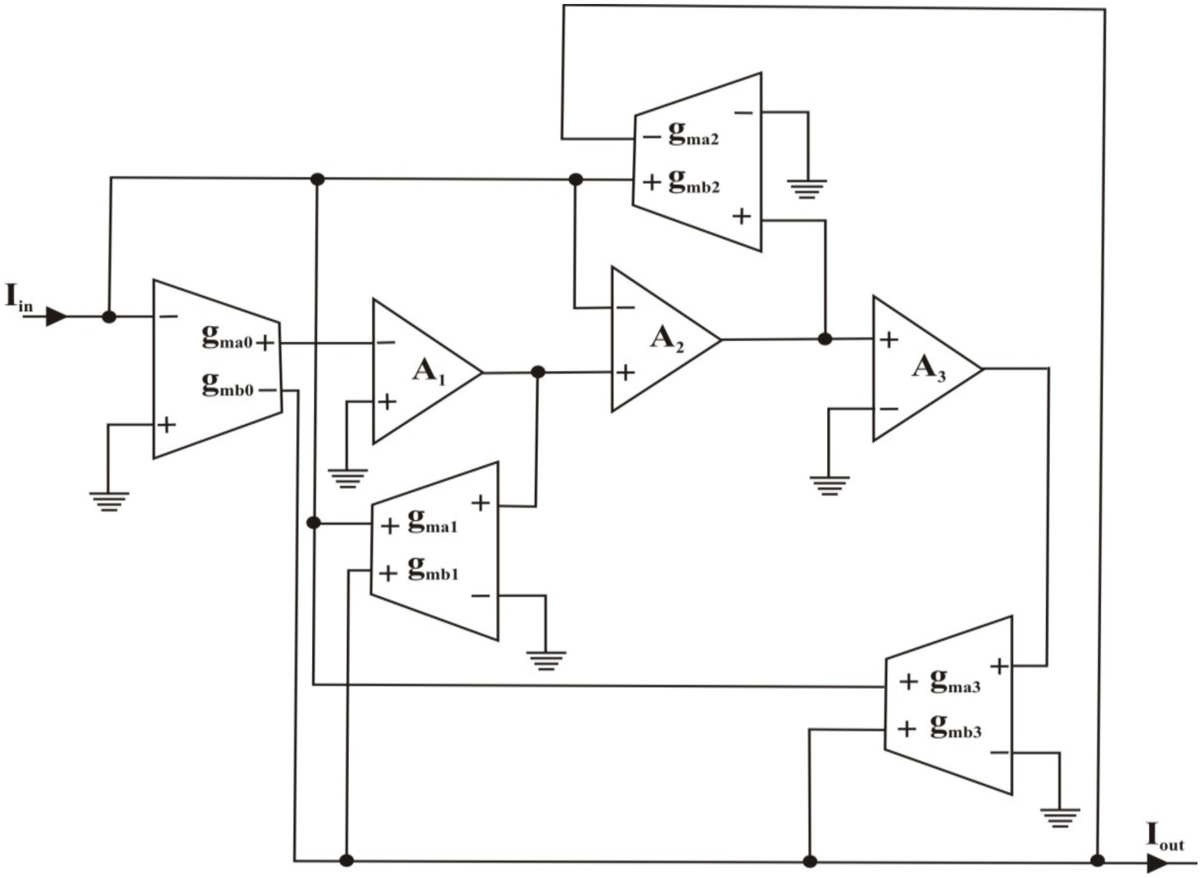
$$g_{ma3} = \frac{\omega_0^3\beta_1\beta_2\beta_3}{g_{ma0}}$$

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

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

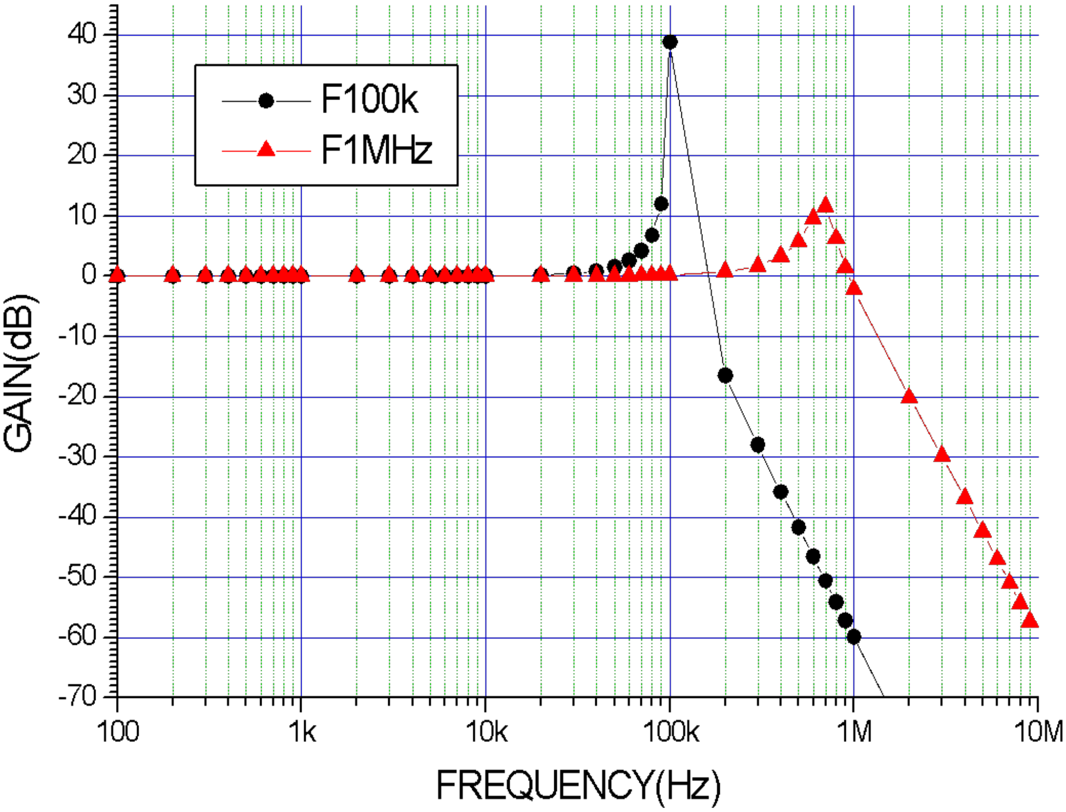
The parameter ω_0 can be set by g_{ma2}. The parameters Q and α_3 can be set by $g_{ma1}$and g_{mb0} respectively. It seems that the values of Q and α_3 are also limited by the dynamic ranges of the OA and OTA.

3 Proposed Circuit diagram:



The proposed circuit is built with four dual current output OTAs and three OAs. The V^+ terminal of the first OTA and V^- terminal of all other OTAs are grounded. Output terminal of the first OTA carrying positive polarity current is fed to the inverting terminal of the first OA. Its output is fed to the non-inverting terminal of the second OA and V^+ terminal of the second OTA. Inverting terminal of the second OA is grounded. Output of the second OA is fed to V^+ terminal of the third OTA and non-inverting of the third OA. The inverting terminal of third OA is connected to V^- terminal of first OTA and inverting terminal of first OA.The 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 add to give output current of the circuit. The circuit can realize various third order filter functions by suitably choosing the current output branches.

Low-pass response:



Low-pass response for Q = 10								
f_0 (kHz)	F_{OL} (kHz)	$f_0 \sim F_{OL}$ (kHz)	Gain Roll-off in stop band		Gain Stabilization		Peak Gain of overshoot dB	F_{OSH} (kHz)
			dB/Octave	Octave starting at (kHz)	dB	F_S (Hz)		
100	170	70	18.9	300	0	200	38.6	100
1M	1.03M	3	16.7	2M	0	200	11.5	700

Table 2: Analysis of Frequency Response of Low Pass function for Q = 10

6. Result and Discussion:

The circuit performance is studied for Central frequencies f_0 = 100 kHz and 1 MHz with circuit merit factor Q= 10. The value of $\beta_1 = \beta_2 = \beta_3 = 6.392 \times 10^6$ 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 $\frac{g_{mb0}}{g_{ma0}} = 1$

Response is studied for Q= 10 for low-pass function. The gain roll-off is 18.9dB/octave for f_0 = 100 kHz and 16.7 dB/octave for f_0 = 1 MHz which is close to the ideal value of 18dB/octave for third order filter. The gain stabilizes to 0dB for frequencies less than 100Hz for both central frequencies. Overshoot of 38.6 dB at 100 kHz is seen for f_0=100 kHz and of 11.5 dB for f_0 = 1MHz

The values of transconductance gains for f_0 =100 kHz and 1 MHz obtained are given in table3 and 4 respectively

g_{ma}	Value in mS
g_{ma0}	2
g_{ma1}	0.196
g_{ma2}	0.0193
g_{ma3}	0.0019
g_{mb0}	2
g_{mb3}	0.0019

Table 3

g_{ma}	Value in mS
g_{ma0}	2
g_{ma1}	1.936
g_{ma2}	0.225
g_{ma3}	1.9
g_{mb0}	2
g_{mb3}	1.9

Table 4

7. **Concluding remarks**:

A versatile current-mode active-only filter using OAs and OTAs has been proposed. The proposed circuit can 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. The gain roll-off is close to ideal value18dB/octave. The proposed circuit facilitates integrability, programmability and ease of implementation.

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