International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 04 Issue 10 October 2021
DOI: 10.47191/ijcsrr/V4-i10-23, Impact Factor: 5.825
IJCSRR @ 2021
www.ijcsrr.org

Frequency Response of Electronically Tunable Current-Mode Third Order High Pass and Low Pass Filter for Q = 10

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ABSTRACT: The circuits using current-mode (CM) building blocks have received considerable attention in many filtering and signal processing applications. Compared to their voltage-mode(VM) counterparts, the current-mode building blocks are attractive because of their wider bandwidth, higher slew rate, and lower power consumptions. In IC technology, it is desirable to operate circuits at low voltages which can be achieved by using CM building blocks. As a large number of op-amp based circuits with elegant realization procedures are already available, it is worthwhile to convert them into the circuits based on current-mode building blocks. In this paper, a realization of a current mode third order high pass and low pass filter is described. The proposed circuit employs operational amplifier as the basic building unit. The filter circuit realizes quadratic work function. It provides electronically tuning capability of the filter characteristics. The proposed circuit works ideal for Center frequency fo= 10 k and Circuit merit factor Q > 1. The gain roll-off this configuration is 18dB/octave. The circuit is suitable for monolithic integration and high frequency operation. The filters developed were successful in obtaining passive sensitivities less than unity in magnitude and active sensitivities are half in magnitude, which is a noteworthy achievement. The circuit is suitable for high frequency operation and monolithic integration.

KEY WORDS: Current Mode Filter, Center Frequency, Circuit Merit Factor, High Pass, Low Pass, Third Order

1. INTRODUCTION

At present, there is a growing interest in designing capacitor-less, resistor-less current mode active only filters using only active elements such as Operational amplifier [OA], Operational trans conductance amplifiers [OTAs]. Current mode filters have many advantages compared with their voltage mode counterparts. Current mode filters have large dynamic range, higher bandwidth, greater linearity, simple circuitry, low power consumption etc. Many circuits for realizing voltage mode filters have been proposed by researchers. The realization of current mode transfer function is topic of considerable interest for researchers. Misami Higashimura proposed a synthesis of current mode high pass transfer function using op-amp pole [Higashimura, 1993]. Extensive work has been done employing active devices such as OAs and OTAs [2, 3]. Due to their many advantages there is growing interest in designing and implementing current mode active filters using second generation current conveyors [CCIIs]. Several implementations of current mode CCII-based filters are available in literature. Current mode active filters are also designed with second generation duel output current conveyors [DO-CCII] [10].

This paper focuses on third order current mode active-R filter with quadratic transfer function.

The proposed circuit is solely designed with op-amps and resistors and hence suitable for highfrequency operation. The filter has low passive sensitivities. The gain roll-off is 40 dB/decade.

2. CIRCUIT CONFIGURATION 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.

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

This model of OA is valid from a few kHz to few hundred kHz.
The transfer function of the circuit for high pass and low pass are

$$T_{HP} = \frac{g_0 S^3}{X_1 S^3 + X_2 S^2 + X_3 S + X_4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$T_{LP} = \frac{g_2\beta_1\beta_2\beta_3 k_1 k_2 k_3}{X_1 S^3 + X_2 S^2 + X_3 S + X_4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Where,

$$X_1 = g_0 + g_1 + g_2 + g_3 + g_{1b} k_1$$
$$X_2 = g_1 \beta_1 k_1$$
$$X_3 = g_2\, \beta_1\, \beta_2\, k_1\, k_2$$
$$X_4 = g_3\, \beta_1\, \beta_2\, \beta_3\, k_1\, k_2\, k_3$$

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

$$T(S) = \frac{\alpha_3 S^3 + \alpha_2 S^2 + \alpha_1 S + \alpha_0}{S^3 + \omega_0(1+\frac{1}{Q})S^2 + \omega_0^2(1+\frac{1}{Q})S + \omega_0^3} \quad \ldots\ldots\ldots (3)$$

Comparing equations (1), (2) with (3), we get,

$$\omega_0^3 = g_3\, \beta_1\, \beta_2\, \beta_3\, k_1\, k_2\, k_3$$

$$\omega_0^2(1+\frac{1}{Q}) = g_2\, \beta_1\, \beta_2\, k_1\, k_2$$

$$\omega_0\left(1+\frac{1}{Q}\right) = g_1 \beta_1 k_1$$

$$g_0 + g_1 + g_2 + g_3 + g_{1b} k_1 = 1$$

But,

$$g_{1b} k_1 << 1$$

Therefore,

$$g_0 + g_1 + g_2 + g_3 = 1$$

Using these equations, the values of g_1, g_2 and g_3 are calculated for different values of merit factor Q and frequency f_0.

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3. PROPOSED CIRCUIT DIAGRAM:

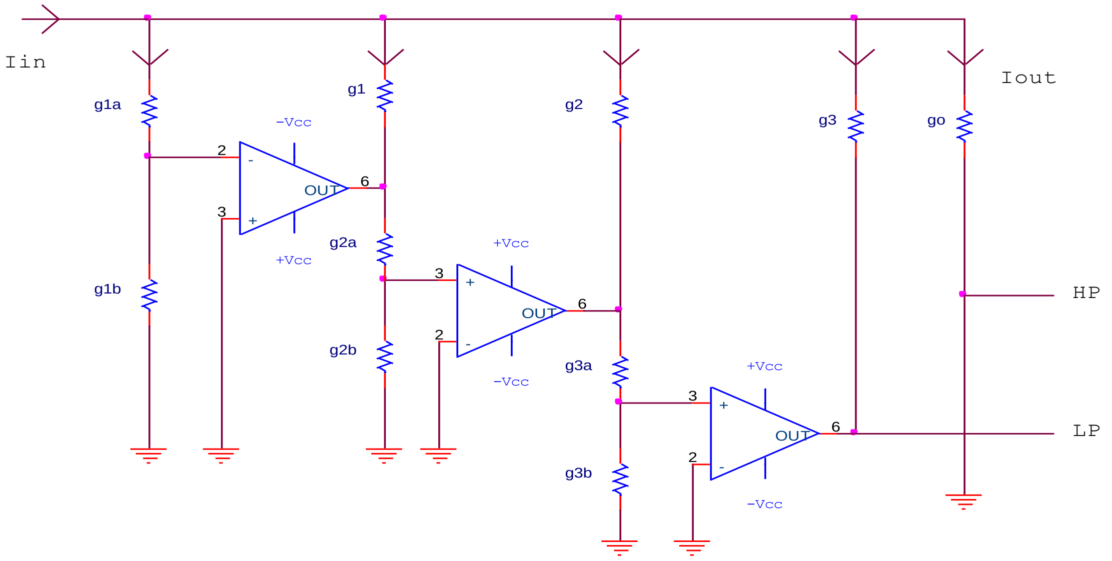

Fig 1. Circuit diagram of third order electronically tunable CM filter

4. LOW PASS RESPONSE

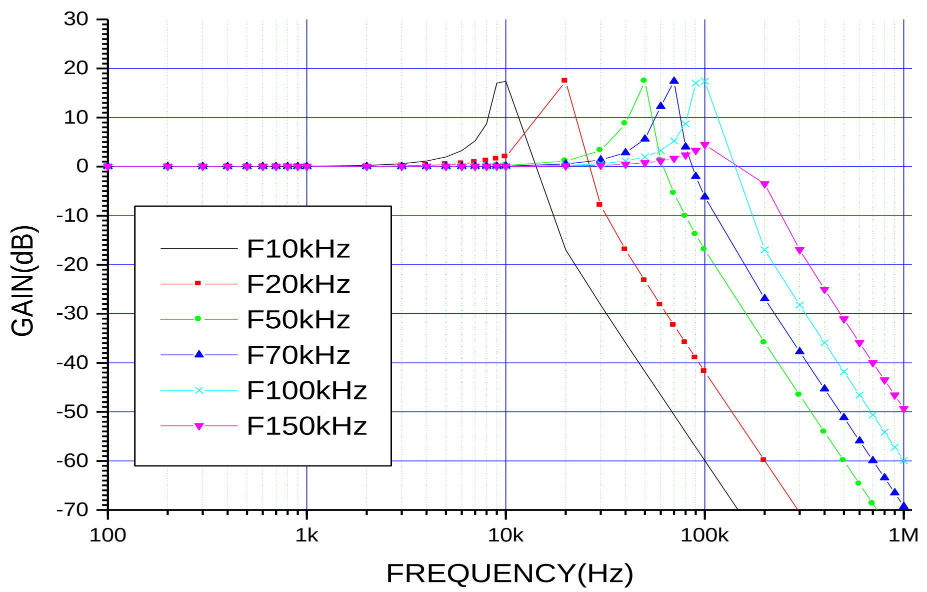

Fig 2.

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Table 1: Analysis of Low pass response

f_0 (kHz)	F_{OL} (kHz)	f_0~ 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 (kHz)		
10	15.1	5.1	18.3	30	0	0.5	17.4	10
20	27.8	7.8	18.7	50	0	0.5	17.3	20
50	66.5	16.5	18.9	100	0	0.5	17.47	50
70	92.6	22.6	20	115	0	0.5	17.3	70
100	151.4	51.4	18.8	200	0	0.5	17	100
150	192	42	18.8	300	0	0.5	4.46	150
F_{OL}: - 3dB Frequency			Fs: Frequency at which gain stabilizes			F_{OSH}: Frequency at which overshoot occurs		

5. HIGH PASS RESPONSE

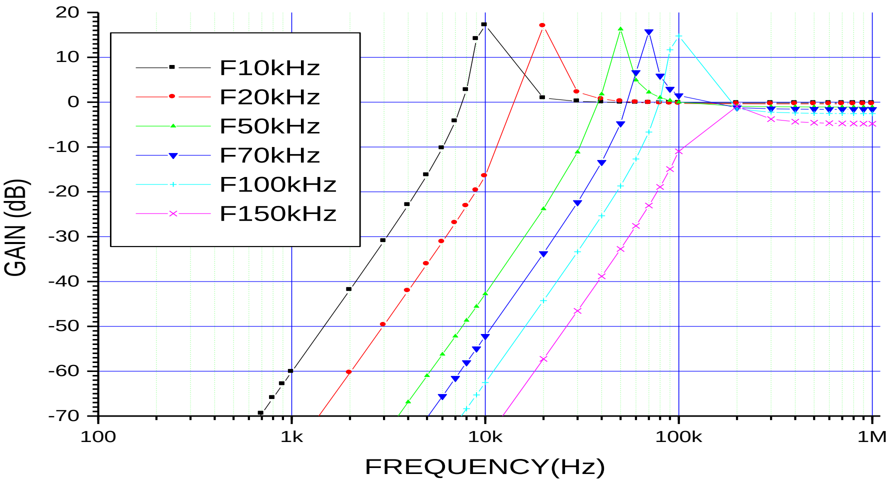

Fig 3.

Table 2: Analysis of High pass response

f_0	F_{OH} (kHz)	f_0~ F_{OH}	Gain Roll-off in stop band		Gain Stabilization		Peak Gain of overshoot dB	F_{OSH} (kHz)
			dB/decade	Decade Starting at (kHz)	dB	F_S (kHz)		
10	7.2	2.8	19.4	5	0	40	17.2	10
20	13.2	6.8	19.9	10	-0.23	80	16.9	20
50	35.9	14.1	18.5	10	-0.88	200	16.2	50
70	51.5	19.5	19.1	30	-1.5	300	15.7	70
100	75.2	24.8	19	40	-2.3	300	14.8	100
150	173.4	23.4	19	40	-4.3	400	-0.48	150
F_{OH}: -3 dB Frequency								

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6. RESULT AND DISCUSSION

The circuit performance is studied for different values of Central frequenciesf_0 (1k, 5k, 10k, 20k, 50k, 70k 100k and 150k.). with circuit merit factor Q= 10.The general operating range of this filter is 10 Hz to 1MHz.The value of β_1 , β_2 and β_3 is 6.392 X 10^6 for LF 356 N

From figure (2) it is observed that gain stabilizes to 0 dB at o.5kHz for all values of central frequencies. The gain roll-off varies between 18.3 to 20 dB/Octave. The average gain roll-off is 18.7 dB/Octave which is close to ideal value of 18 dB/Octave. From figure (3) it is observed that the gain roll-off value varies between 19 to 19.9 dB/Octave close to ideal value. Gain stabilizes beyond 40k.Fig (2) and (3) shows the Overshoot in the responses and it occurs at central frequency.

7. SENSITIVITIES

The sensitivity equations of ω_0 and Q with respect to parameters k_1, k_2, k_3,β_1, β_2 , β_3,g_0, g_1, g_2 and g_3 are as given below.It is found that the proposed circuit has very low sensitivity.

$$S_{K_1}^{\omega_0} = S_{K_2}^{\omega_0} = S_{K_3}^{\omega_0} = \frac{1}{3} \quad , S_{\beta_1}^{\omega_0} = S_{\beta_2}^{\omega_0} = S_{\beta_3}^{\omega_0} = \frac{1}{3}$$

$$S_{K_1}^{Q} = S_{K_1}^{Q} = S_{K_1}^{Q} = S_{K_1}^{Q} = -\frac{(1+Q)}{3}$$

$$S_{g_0}^{\omega_0} = -\frac{1}{3}\left(\frac{g_0}{g_0+g_1+g_2+g_3}\right) \ , S_{g_1}^{\omega_0} = -\frac{1}{3}\left(\frac{g_1}{g_0+g_1+g_2+g_3}\right) ,$$

$$S_{g_2}^{\omega_0} = -\frac{1}{3}\left(\frac{g_2}{g_0+g_1+g_2+g_3}\right) \ , S_{g_3}^{\omega_0} = \left(\frac{1-g_3}{3}\right)$$

$$S_{g_0}^{Q} = S_{g_1}^{Q} = 0 \ , \ S_{g_2}^{Q} = -(1+Q) \ , S_{\beta_1}^{Q} = S_{\beta_2}^{Q} = -\frac{1}{3}(1+Q)$$

$$S_{g_3}^{Q} = S_{\beta_3}^{Q} = S_{k_3}^{Q} = \frac{2}{3}(1+Q)$$

8. CONCLUSION

In this paper, a realization of a current mode third order high pass and low pass filter is described. The proposed circuit employs operational amplifier as the basic building unit. The filter circuit can realize transfer functions and circuit characteristics can be electronically tuned. The circuit has passive sensitivities no more than unity. The proposed circuit works ideal for Q > 1 at central frequency f_0= 10 kHz. The gain roll-off is close to 18dB/octave. The circuit is suitable for high frequency operation and monolithic integration.

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Cite this Article*: Dr. D. D. Mulajkar (2021). Frequency Response of Electronically Tunable Current-Mode Third Order High Pass and Low Pass Filter for Q = 10. International Journal of Current Science Research and Review, 4(10), 1415-1420