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

Electronically Tunable Third Order Feed Forward CM Band Pass Filter for Q = 10

Dr. D. D. Mulajkar
Department of Physics, Satish Pradhan Dnyanasadhana College, Thane

ABSTRACT: A new electronically tunable current-mode third order filter is proposed in this paper. OP-AMP is used as an active building block. With current input the filter can realize band pass responses in current mode. The filter circuit realizes calculated transfer function. The other attractive features of the filter are a) Employment of minimum active and passive elements b) Responses are electronically tunable c) Low active and passive sensitivities d) Suitable for high frequency operation e) Ideal for integrated circuit implementation.

KEYWORDS: Band Pass, Circuit Merit Factor, Center Frequency, Current Mode Filter, Electronically Tunable

1. INTRODUCTION

The applications and advantages of various active filter transfer functions that use different active elements have been studied extensively. The filters are classified as current-mode (CM) , voltage-mode (VM), transadmittance-mode(TAM) and transimpedance-mode(TIM) depending upon the nature of input and output signals. TAM and TIM structures can function as bridges for transferring VM to CM and vice versa. In CM structure both input and output signals are currents while in VM structure both input and output signals are voltages. Compared to their voltage-mode (VM) counterparts, the current-mode building blocks have received considerable attention in many filtering and signal processing applications. The circuits using current-mode (CM) building blocks are attractive because of their wider bandwidth, higher slew rate, and lower power consumptions. These circuits operate at low voltages so are desirable for IC technology. 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 transconductance 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 a 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 dual output current conveyors [DO-CCII] [10].

This paper focuses on a 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 high frequency operation. The filter has low passive sensitivities.

2. PROPOSED CIRCUIT CONFIGURATION:

The electronically tunable feed forward universal third order current-mode filter with internally compensated Operational Amplifiers (OAs) and resistors only is presented. The proposed circuit can realize three different current transfer functions, if voltage dividers have high input impedances and low output impedances. The circuit characteristics can be electronically tuned.

In the designed circuit, three op-amps are used. The op-amps are coupled such that output of first op-amp is connected to non-inverting input of second op-amp through second voltage divider arrangement (formed by $g_{2a}$and g_{2b}) and output of second op-amp is connected to non-inverting input of third op-amp through third voltage divider arrangement (formed by $g_{3a}$and g_{3b}).In this circuit sinusoidal low current is applied at inverting terminal of first op-amp through first voltage divider (formed by g_{1a} and g_{1b}).

Non-inverting terminal of first op-amp and Inverting terminal of second are grounded. The input signal is fed forward by connecting the inverting terminal of first op-amp to inverting terminal of third op-amp. The negative feedback is incorporated by resistors g_1, g_2 and g_3. The output of second op-amp gives band pass function[13].

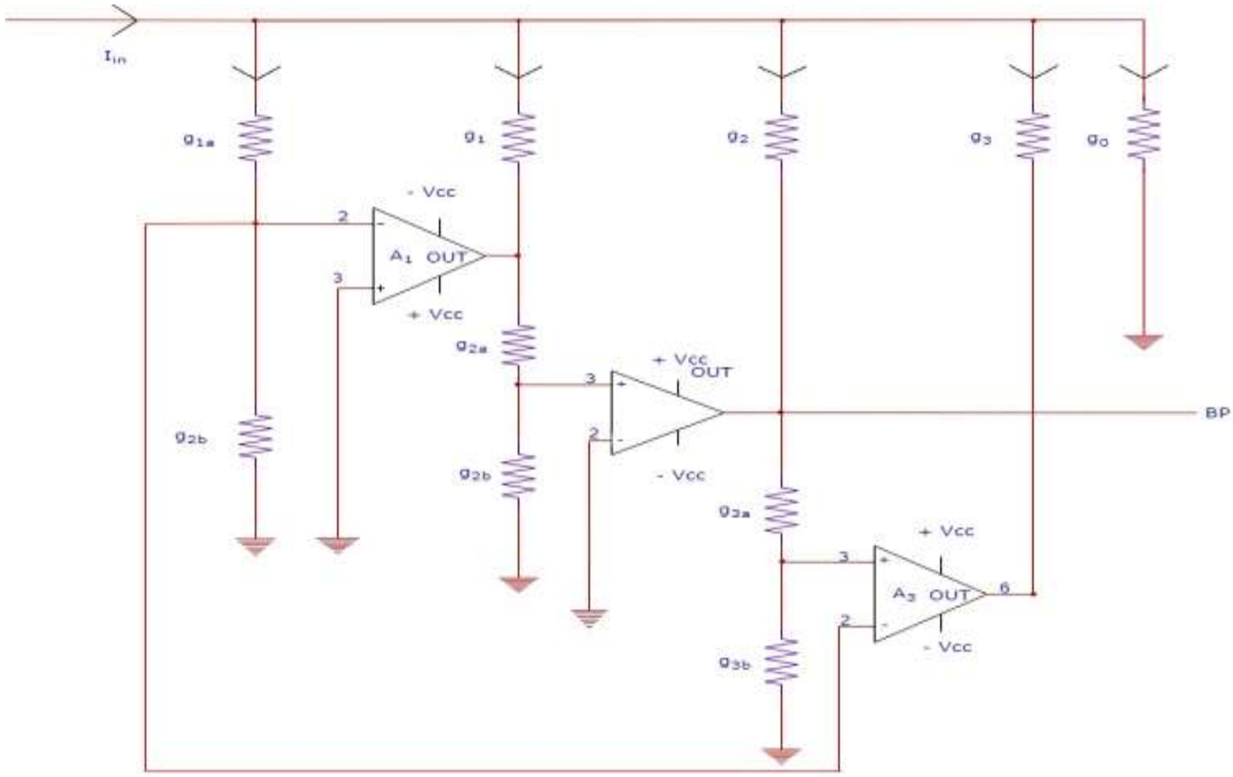

Fig 1 Circuit diagram of Third Order Current-mode filter

3. CIRCUIT ANALYSIS AND DESIGN EQUATIONS:

Ideal op-amp is assumed to have infinite gain, which actually has frequency dependent gain. To account for this frequency dependence of the op-amp, we represent the op-amp by single pole model i.e. gain dependence on frequency is taken into consideration.

So here, Op-amp is represented by "Single 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 $S >> \omega_0$

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

This shows Op-amp as integrator.

Transfer function of the circuit for band pass T_{BP} are calculated as,

$$T_{BP} = \frac{g_2\beta_1\beta_2k_1k_2S}{X_1S^3+X_2S^2+X_3S+X_4}$$

Where,

$$X_1 = (g_0 + g_1 + g_2 + g_3 + g_{1b}k_1)$$
$$X_2 = (g_1\beta_1 + g_3\beta_3)k_1$$

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$$X_3 = g_2\beta_1\beta_2k_1k_2$$
$$X_4 = g_3\beta_1\beta_2\beta_3k_1k_2k_3$$
$$k_1 = \frac{g_{1a}}{g_{1a}+g_{1b}}$$
$$k_2 = \frac{g_{2a}}{g_{2a}+g_{2b}}$$
$$k_3 = \frac{g_{3a}}{g_{3a}+g_{3b}}$$

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

$$T(S) = \frac{\alpha_3S^3+\alpha_2S^2+\alpha_1S+\alpha_0}{S^3+\omega_0(1+\frac{1}{Q})S^2+\omega_0^2(1+\frac{1}{Q})S+\omega_0^3} \quad 5.4$$

Comparing equations (5.1), (5.2), (5.3) with (5.4), we get,

$$\omega_0^3 = g_3\beta_1\beta_2\beta_3k_1k_2k_3$$
$$\omega_0^2\left(1+\frac{1}{Q}\right) = g_2\beta_1\beta_2k_1k_2$$

$$\omega_0\left(1+\frac{1}{Q}\right) = (g_1\beta_1 + g_3\beta_3)k_1$$
$$g_0 + g_1 + g_2 + g_3 + g_{1b}k_1 = 1$$

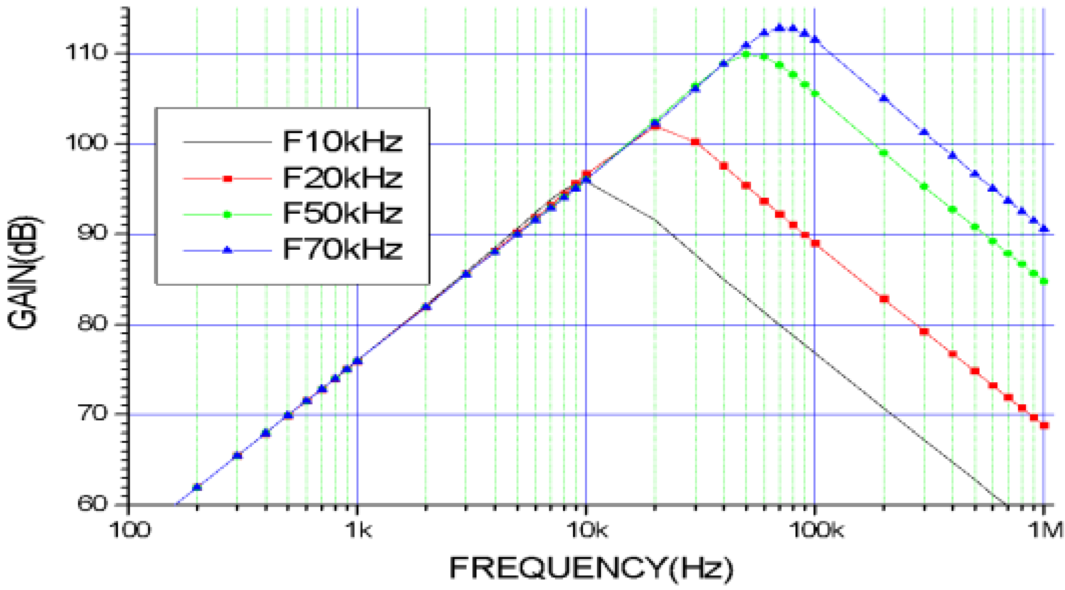
But,

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

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

Using these equations, the values of g_0, g_1 , $g_2$and g_3 are calculated for different values of merit factor Q and frequency Fo.

Band pass response for Q=10:



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Band-pass response for Q = 10								
F (kHz)	Max. Pass Band Gain (dB)	f_1 (kHz)	f_2 (kHz)	Band-width (kHz)	Gain Roll-off in stop band			
					Leading Part		Trailing Part	
					dB/Octave	Octave Starting at (kHz)	dB/Octave	Octave Starting at (kHz)
10	95.9	6.4	16	9.6	6.5	5	6.3	30
							6.1	100
20	101.8	13.8	31.9	18.1	6.5	10	6.5	50
					5.9	1.0	6.2	300
50	109.8	31.72	87.45	55.7	6.4	20	6.2	200
					6.0	2.0		
70	113	44.3	121.4	77.1	7.0	30	2.0	200
					6.1	6.0	-	-

4. RESULT AND DISCUSSION

The circuit performance is studied for different values of Central frequencies with circuit merit factor Q= 10.The general operating range of this filter is 10 Hz to 1MHz.The value of $\beta_1 = \beta_2 = 2\pi$ (6.392) X 10^6 [rad/sec] for LF 356 N.

Table 2: Resistor values for Q=10

f_0(kHz)	$R_0(\Omega)$	$R_1(\Omega)$	$R_2(\Omega)$	$R_3(\Omega)$
1	1	423	215K	1M
5	1	84	8.6K	1.05M
10	1	42	2.2K	131K
20	1	21	550	16K
50	1	8	85	1052
70	1	6	44	383

It is observed that - 3 dB bandwidth of the circuit is 9.6 kHz for f_0= 10 kHz and is 77.1 kHz for f_0= 70 kHz. The bandwidth increases with increase in value of f_0. The variation of bandwidth with central frequency is as shown in figure 5.3.1. For lower values of f_0, this filter can be used for narrow bandwidth and for higher values of f_0, it can be used for wide bandwidth.

The symmetry of the curve i.e. frequency distribution in the response with respect to centre frequency is better for f_0= 10 kHz compared to other curves. The gain roll-off per octave in the leading and trailing part of response is the same (about 6.1) for 10 kHz and 20 kHz near the pass band. For f_0= 70 kHz, gain roll-off per octave has value 7.0 in the leading part for octave starting at 30 kHz whereas it is 2.0 in trailing part for octave starting at 200 kHz.

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The circuit gives better band pass response for 10 kHz≤ f_0≤ 70 kHz with better pass band gain, no shift in centre frequency, better symmetry of curves and optimum bandwidth while it has low gain roll-off. The filter circuit is better for wider bandwidth.

Sensitivity:

Equations of the ω_0 and Q Sensitivities of the transfer function with respect to the parameters k_1, k_2, k_3, β_1, β_2, β_3, g_0, g_1, g_2 and g_3 are as follows.

ω_0 Sensitivities:

$$S_{g_0}^{\omega_0} = -\frac{1}{3}\left[\frac{g_0}{g_0 + g_1 + g_2 + g_3}\right]$$

$$S_{g_1}^{\omega_0} = -\frac{1}{3}\left[\frac{g_1}{g_0 + g_1 + g_2 + g_3}\right]$$

$$S_{g_2}^{\omega_0} = \frac{1}{3}\left[\frac{g_2}{g_0 + g_1 + g_2 + g_3}\right]$$

$$S_{g_3}^{\omega_0} = \left(\frac{1 - g_3}{3}\right)$$

$$S_{k_1}^{\omega_0} = S_{k_2}^{\omega_0} = S_{k_3}^{\omega_0} = \frac{1}{3}$$

Q Sensitivities

$$S_{K_1}^{Q} = -\left[\frac{1 + Q}{3}\right]$$

$$S_{K_2}^{Q} = -\left[\frac{1 + Q}{3}\right]$$

$$S_{K_2}^{Q} = \left[\frac{2(1 + Q)}{3}\right]$$

$$S_{g_1}^{Q} = 0$$

$$S_{g_2}^{Q} = -(1 + Q)$$

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

β Sensitivities:

$$S_{\beta_1}^{Q} = -\left[\frac{1 + Q}{3}\right]$$

$$S_{\beta_2}^{Q} = -\left[\frac{1 + Q}{3}\right]$$

$$S_{\beta_3}^{Q} = \left[\frac{2(1 + Q)}{3}\right]$$

$$S_{\beta_1}^{\omega_0} = S_{\beta_2}^{\omega_0} = S_{\beta_3}^{\omega_0} = \frac{1}{3}$$

5. CONCLUSION

In this paper a realization of an electronically tunable feed forward current-mode third order band pass filter is described. The proposed circuit employs OP-AMP as an active building block. With current input the filter can realize band pass responses in current mode. The filter circuit realizes calculated transfer function. The symmetry of the curve i.e. frequency distribution in the response with respect to center frequency is better for f_0= 10 kHz compared to other curves. The circuit gives better band pass response for 10 kHz≤ f_0≤ 70 kHz with better pass band gain, no shift in centre frequency, better symmetry of curves and optimum bandwidth while it has low gain roll-off. The filter circuit is better for wider bandwidth. The proposed circuit has minimum active and passive elements, low active and passive sensitivities, suitable for high frequency operation and monolithic implementation.

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Cite this Article: Dr. D. D. Mulajkar (2021). Electronically Tunable Third Order Feed Forward CM Band Pass Filter for Q = 10. International Journal of Current Science Research and Review, 4(10), 1214-1219