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Electronically tunable third-order Feed-Forward CM Band Pass Filter for F_0 = 10KHz

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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 band pass filter is described. The proposed circuit employs an operational amplifier as the basic building unit. The filter circuit realizes quadratic work function. It provides electronically tuning capability of the filter characteristics. 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 circuit is suitable for monolithic integration and high frequency operation. The filter developed have passive sensitivities less than unity in magnitude and active sensitivities one third in magnitude, which is a noteworthy achievement.

Keywords: *Current mode filter, electronically tunable, band pass, circuit merit factor, center frequency.*

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. 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]. 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].

2. PROPOSED CIRCUIT CONFIGURATION

In the designed circuit, three internally compensated Operational Amplifiers (OAs) and resistors are used. 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]. The proposed circuit can realize current transfer function, if voltage dividers have high input impedances and low output impedances. The circuit characteristics can be electronically tuned.

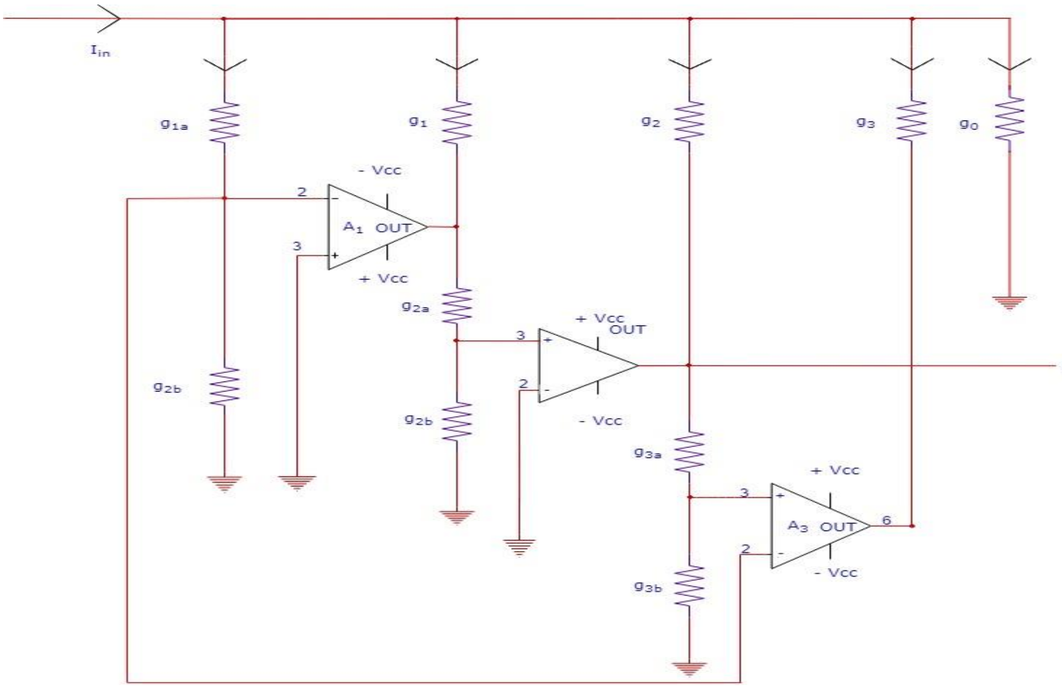


Fig. 1: Circuit diagram of Third Order Current-mode filter

3. CIRCUIT ANALYSIS AND DESIGN EQUATIONS

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

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

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 $S \gg \omega_0$

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

This model of OA is valid from a few kHz to few hundred kHz.

Transfer function of the circuit for band pass T_{BP} is derived and is as follows,

$$T_{BP} = \frac{g_2\beta_1\beta_2k_1k_2S}{(g_0+g_1+g_2+g_3+g_{1b}k_1)S^3+(g_1\beta_1+g_3\beta_3)k_1S^2+g_2\beta_1\beta_2k_1k_2S+g_3\beta_1\beta_2\beta_3k_1k_2k_3}$$

Where,

$$k_1 = \frac{g_{1a}}{g_{1a}+g_{1b}}$$
$$k_2 = \frac{g_{2a}}{g_{2a}+g_{2b}}$$
$$k_3 = \frac{g_{3a}}{g_{3a}+g_{3b}}$$

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

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

Comparing equations for T_{BP} and T(S) 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,

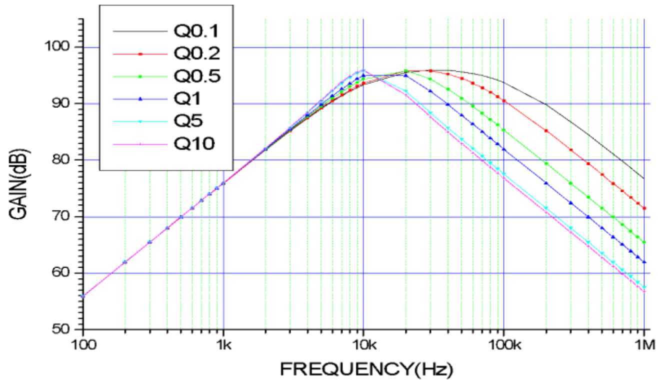
$$g_{1b}k_1 \ll 1$$

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 F_o.

4. BAND PASS RESPONSE



Band-pass response for f_0 = 10kHz

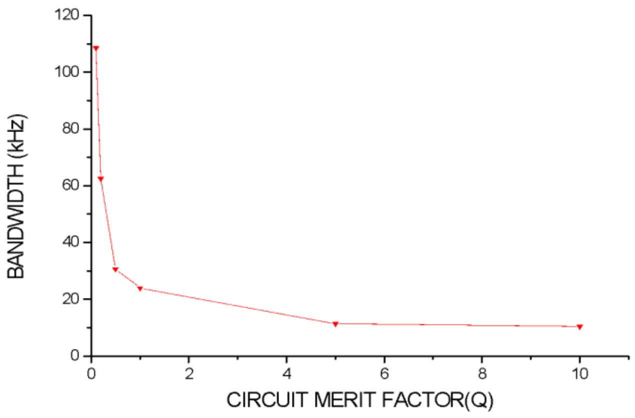
Q	Max. Pass Band Gain (dB)	f_1 (kHz)	f_2 (kHz)	Band-width (kHz)	Gain Roll-off in stop band			
					Leading Part		Trailing Part	
					dB/ Octave	Octave Starting at (kHz)	dB/ Octave	Octave Starting at (kHz)
0.1	95.8	9	117.5	108.5	5	7	4.5	150
					6	2	5.8	400
0.2	95.8	8.5	71	62.5	5.4	6	5.4	100
					6	2	6	400
0.5	95.8	7.9	38.5	30.6	5.6	6	5.5	60
					6	2	6	300
1	95	6.6	30.5	23.9	5.8	5	6	40
					7	1	6	200
5	95.8	6.5	17.9	11.4	6.5	5	6.3	30
					7	1	6	400
10	95.8	6.3	16.7	10.4	6.6	5	6.5	30
					7	1	6	300

5. RESULT AND DISCUSSION

The circuit performance is studied for different values of circuit merit factor Q for Center frequency F_0 = 10 KHz. The general operating range of this filter is 10 Hz to 1MHz.The value of $\beta_1 = \beta_2 = \beta_3 = 2\pi\ (6.392)\ X\ 10^6$ [rad/sec] for LF 356 N.

Table (4.5): Resistor values for f_0 =10 kHz

Q	$R_0(\Omega)$	$R_1(\Omega)$	$R_2(\Omega)$	$R_3(\Omega)$
0.1	1.1	4.6	235	131K
0.5	1	17	862	131K
1.0	1	25	1294	131K
5.0	1	42	2150	131K
10	1	45	2350	131K
20	1	50	2460	131K



Responses show that quality factor Q controls the bandwidth. For higher values of Q, this filter can be used for narrow bandwidth and for lower values; it can be used for wide bandwidth. The maximum passband gain remains the same (95.8) dB for all values of Q. Frequency shift is not observed for Q = 10. But shift is observed all other values of Q. Frequency distribution with respect to f_0 is more symmetric for Q ≥ 1 than other values of Q for which the filter circuit is studied.

The gain roll-off per octave in stop band, in leading and trailing part of response, near the pass band increases with increase in Q. The gain roll-off per octave in stop band in leading/trailing part away from pass band is 6 dB/ kHz for $0.1 \leq Q \leq 0.5$ and 7 dB/ kHz for $1 \leq Q \leq 10$.

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:

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

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

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

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

6. 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$\leq f_0 \leq$ 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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