Engineering, **2010, 2, 179-183**
doi:10.4236/eng.2010.23025 Published Online March 2010 (http://www.SciRP.org/journal/eng/)

Tunable Bandwidth Third Order Switched-Capacitor with Multiple Feedbacks Filter for Different Center Frequencies

Ganeshchandra N. Shinde[1], Sanjay R. Bhagat[2]
[1]*Indira Gandhi College Nanded, Maharashtra, India*
[2]*Dnyanasadhana College , Thane, Maharashtra, India*
Email: shindegn@yahoo.co.in, sanjaybhagat_14@yahoo.co.in
Received October 6, 2009; *revised November* 8, 2009; *accepted November* 13, 2009

Abstract

This paper proposes third order tunable bandwidth active Switched-Capacitor filter. The circuit consists of only op-amps and switched capacitors. The circuit is designed for circuit merit factor $Q = 10$. The proposed circuit implements three filter functions low pass, band pass and high pass simultaneously in single circuit. The filter circuit can be used for both narrow as well as for wide bandwidth. For various values of cut-off frequencies the behaviour of circuit is studied. The circuit works properly only for higher central frequencies, when $f_0 > 10$ kHz.

Keywords: Third Order Filter, Switched Capacitor, Pass Band Gain, Tunable Bandwidth, Circuit Merit Factor

1. Introduction

Conventional analog circuits use the ratio of resistances to set the transfer function of filter circuits. The values of RC product determine the frequency responses of these circuits [1-4]. It is very difficult to make resistors and capacitors with the values and accuracy that are required in audio and instrumental applications. Resistors are expensive and cannot be easily controlled [5].

The Switched-Capacitor concept can be used to realize a wide variety of universal filter that have the advantage of compactness and tunability [6]. In MOS integrated technology, it is relatively simple to achieve this objective as compared to conventional techniques. It is due to high integration density, high precision and stability and ideal characteristics of MOSFET switches [7].

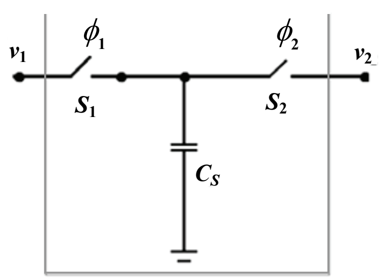
Switched capacitor techniques have been developed so that both digital and analog functions can be integrated on a single silicon chip. Switched capacitor filters are clocked sampled system. The input signal is sampled at a high rate and processed at a discrete time. Using these techniques resistors can be replaced by a capacitor and MOS switches that are rapidly turned on and off. Switched capacitor filters have the advantage of better accuracy in most of the cases [6-9].

Switched-Capacitor filters have the advantage of better accuracy in most cases. Typical center-frequency accuracies are normally on the order of about 0.2% for most Switched-Capacitor ICs, and worst-case numbers range from 0.4% to 1.5% (assuming, of course, that an accurate clock is provided).

2. Basic Switching Operation

The essence of the Switched-Capacitor is the use of Capacitors and analog Switches to perform the same function as resistors. This replacement of resistor, analog with op. amp based integrator, then form an active filter [6]. Furthermore, the use of the Switched-Capacitor will be seen to give frequency tenability to active filters. Filter using Switched-Capacitor technique overcome a major obstacle of filter on a chip fabrication—the implementation of resistors by simulating resistors with high speed Switched-Capacitors using MOSFETs. The switching function of the MOSFET produces a discrete response rather than a continuous response from the filter [6].

The operation of switched capacitor can be explained with the help of following circuit diagram:



The circuit consists of two capacitors and two switches controlled by two non-overlapping clocks, Φ_1 and Φ_2. When Φ_1 is high, S_1 closes while S_2 is open. When Φ_1 goes low, S_1 closes. Then after a short delay Φ_2 goes high, and S_2 closes. This cycle repeats so that S_1 and S_2 close and open alternatively, but they are never closed at the same time.

Each switching cycle transfers a charge q from the input to the output at the switching frequency f. The charge q on a capacitor C is given by

$$q = CV$$

where V is the voltage across the capacitor.

Therefore, when S_1 is closed while S_2 is open, the charge transferred from the source to C_S is:

$$q_1 = CV_1$$

When S_2 is closed while S_1 is open, the charge transferred from C_S to the load is:

$$q_2 = CV_2$$

$$\Delta q = C_1 (V_2 - V_1)$$

If this switching process is repeated N times in time t, then the amount of charge transferred per unit time is given by

$$\frac{\Delta q}{\Delta t} = C_1 \left(V_2 - V_1\right) \frac{N}{\Delta t}$$

L.H.S. is current and number of cycles per unit time is switching frequency.

$$\therefore i = C_1 \left(V_2 - V_1\right) \quad f_{CLK}$$

$$\therefore \frac{\left(V_2 - V_1\right)}{i} = \frac{1}{C_1 f_{CLK}} = R$$

Thus the switched capacitor is equivalent a resistor.

3. Proposed Circuit Configuration

The proposed circuit configuration for Switched-Capacitor filter with multiple feedbacks is shown in **Figure 1**. The circuit consists of three op–amps (μA 741) with wide identical gain bandwidth product (GB) and three Capacitors with MOSFET, which form Switched-Capacitor. Switched-Capacitor can replace resistors, which was proposed earlier [2].

The input sinusoidal voltage is applied to the non-inverting terminal of the first op-amp through switched capacitor (SC). The non-inverting terminal is grounded. SC is used in the feedback circuit. The output of the first op-amp is supplied as non-inverting input of the second op-amp. The inverting terminal is grounded. SC is used as feedback. The output of the second op-amp is supplied as non-inverting input of the third op-amp. The inverting terminal is grounded. SC is used as feedback. Low pass function is observed at the output of the third op-amp. The output of the second op-amp gives Band pass function. The High pass function is seen at the output of the first op-amp.

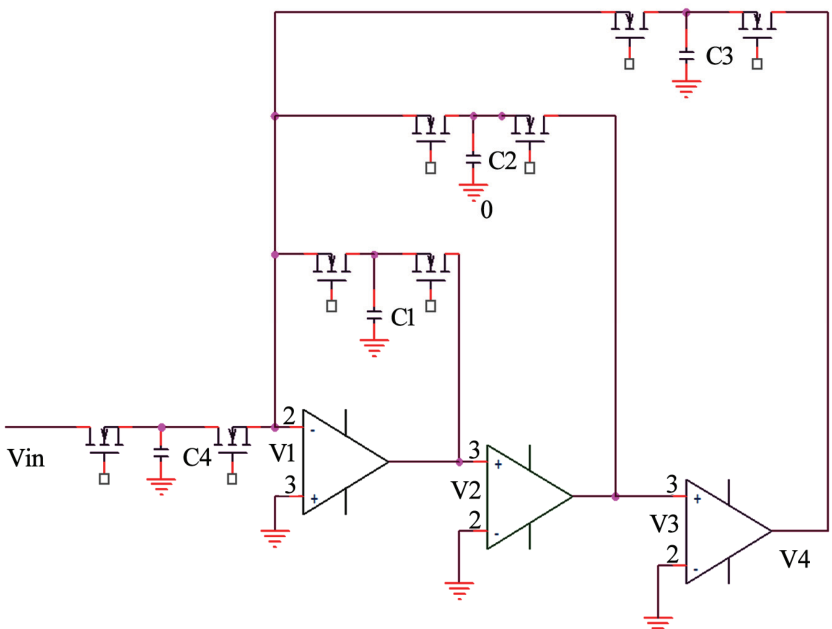


Figure 1. Circuit diagram of universal third order Switched-Capacitor filter.

4. Circuit Analysis and Design Equations

Op-amp μA 741 is an internally compensated op-amp, which represented by "Single pole model",

$$A(S) = \frac{A_0\omega_0}{S+\omega_0} \quad (1)$$

where A_0:- open loop D.C. gain of op-amp
ω_0 : - open loop − 3 dB bandwidth of the op-amp. = $2\pi f_0$
$A_0\,\omega_0$:- GB = gain-bandwidth product of op-amp
for $S >> \omega_0$

$$A(S) = \frac{A_0\omega_0}{S} = \frac{GB}{S} \quad (2)$$

This shows Op-amp as integrator.

Transfer function of the proposed third order Switched-Capacitor filter for low pass $T_{LP}(S)$, for band pass $T_{BP}(S)$ and for high pass $T_{HP}(S)$ are given below.

$$T_{LP}(S) = \frac{-C_4\,GB_1GB_2GB_3}{X_1S^3+X_2S^2+X_3S+X_4} \quad (3)$$

$$T_{BP}(S) = \frac{-C_4\,GB_1GB_2\,S}{X_1S^3+X_2S^2+X_3S+X_4} \quad (4)$$

$$T_{HP}(S) = \frac{-C_4\,GB_1S^2}{X_1S^3+X_2S^2+X_3S+X_4} \quad (5)$$

where

$$X_1 = C_1 + C_2 + C_3 + C_4$$
$$X_2 = GB_1C_1$$
$$X_3 = GB_1GB_2C_2$$
$$X_4 = GB_1GB_2\,GB_3C_3$$

The circuit was designed using coefficient matching technique *i.e.* by comparing these transfer functions with general second order transfer functions [10].

The general second order transfer function is given by

$$T(S) = \frac{a_3\,S^3 + a_2\,S^2 + a_1\,S + a_0}{S^3 + \omega_0\left(1+\frac{1}{Q}\right)S^2 + \omega_0^2\left(1+\frac{1}{Q}\right)S + \omega_0^3} \quad (6)$$

Table 1. Capacitor values for different Q.

f_0 kHz	C_1 μF	C_2	C_3	C_4 μF
1	22	0·33 nF	5·6 nF	100
5	1	8·2 nF	5·6 nF	100
10	2·2	33 nF	5·6 nF	100
20	3·3	0·1 μF	4·7 nF	100
50	10	0·82 μF	68 nF	82
70	10	2·2 μF	0·22 μF	82

Comparing Equations (3), (4) and (5) with Equation (6)

$$\frac{\omega_0^3}{GB^3} = GB_1GB_2\,GB_3C_3$$

$$\omega_0^2\left(1+\frac{1}{Q}\right) = GB_1GB_2C_2$$

$$\omega_0\left(1+\frac{1}{Q}\right) = GB_1C_1$$

$$1 = C_1 + C_2 + C_3 + C_4$$

Using these equations, values of C_1, C_2 and C_3 can be calculated for different values of central frequency f_0.

5. Experimental Set Up

The circuit consists of three op–amps. (μA 741 C) with wide identical gain bandwidth product (GB) and three Capacitors with MOSFET, which form Switched-Capacitor. The circuit performance is studied for different values of Cut-off frequencies with circuit merit factor Q = 10. The general operating range of this filter is 10 Hz to 1·2 MHz. The value of GB (GB1 = GB2) is $2\pi(5\cdot 6) \times 10^5$ rad/sec.

MOSFETs are driven by two non overlapping clocks. The input voltage of 5 mV is applied and the readings are taken at different terminals for different f_0 (1k, 5k, 10k, 20k, 50k).

6. Result and Discussion

Following observations are noticed for low pass, band pass and high pass at corresponding terminals.

A) Low pass response:

The **Figure 2** shows the low pass response for different

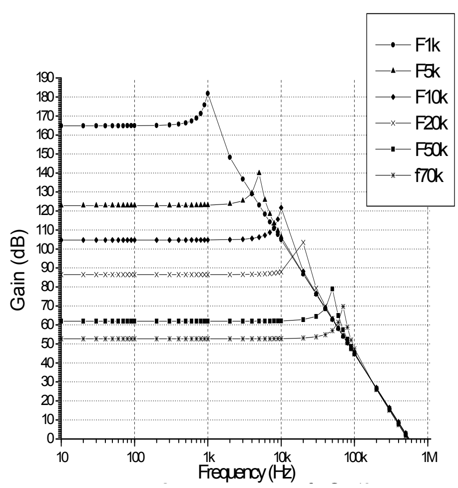


Figure 2. Low pass response for *Q*=10.

Table 2. Data sheet for low pass response.

F_0	Max. Pass band gain (dB)	F_{0L} (kHz)	$F_0 \sim F_{0L}$ (kHz)	Gain Roll-off/octave in stop band	
				dB/octave	Octave starting at (kHz)
1	165	7	6	19	3
5	123	20	15	19	10
10	105	22	12	18	20
20	86	52	32	20	40
50	62	100	50	18	100
70	53	130	60	20	100

values of f_0. Theoretically it is predicted to give high pass band gain 165 dB for f_0 = 1 kHz which is expected to decrease to 105 dB f_0 = 10 kHz. Experimental result shows high pass band gain (86 dB) for 20 kHz and decreases with increase in value of f_0. Gain roll-off values varies between 18 to 20dB/octave, which are close to the ideal value of 18 dB/octave for third order filter. The response shows overshoot of about 17 dB.

B) High pass response:

High pass response of the filter for different values of f_0 is shown in **Figure 3**. Gain roll-off values varies between 13 to 14 dB/octave which is less than the ideal value of 18 dB/octave for third order filter. The value of overshoot decreases from 72 dB to 33 dB with increase in the value of central frequency. The overshoot appears in the leading edge of curve & trailing edge is stabilized after saturation at 0 dB, so it works for high pass response.

C) Band pass response:

The **Figure 4** shows the band pass response for different values of f_0. The expected maximum passband gain is 127 dB for F_0 = 1 kHz and 99 dB for F_0 = 5 kHz. The experimental result shows maximum pass band gain of 87 dB for F_0 = 10 kHz decreases with increase in central frequency. The bandwidth is increases with f_0 but reduces for f_0 = 70 kHz. It is also observed that the pass band distribution of frequency is almost symmetric for both sides. The gain roll-off/octave in leading and trailing part of the response is different.

7. Conclusions

A realization of tunable bandwidth third order active Switched-Capacitor filter has been proposed. The three filter function, low pass, high pass and band pass at different terminals works with satisfied results. The filter circuit can be used for both narrow as well as for wide bandwidth. Low pass function works practically only for higher central frequencies. Stabilization of gain for High pass function cannot be achieved.

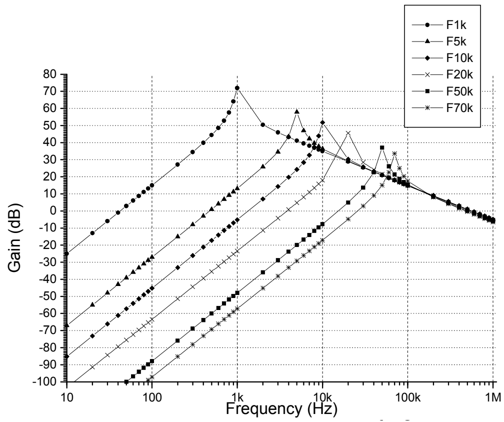


Figure 3. High pass response for Q = 10.

Table 3. Data sheet for high pass response.

F_0 (kHz)	F_{0H} (kHz)	$F_0 \sim F_{0L}$ (kHz)	Gain Roll-off / octave in stop band	
			dB/octave	Octave starting at
1	0·7	0·3	14	600
5	3·6	1·4	13	2 k
10	7	3	13	4 k
20	15	5	13	10k
50	40	10	13	20k
70	60	10	13	40k

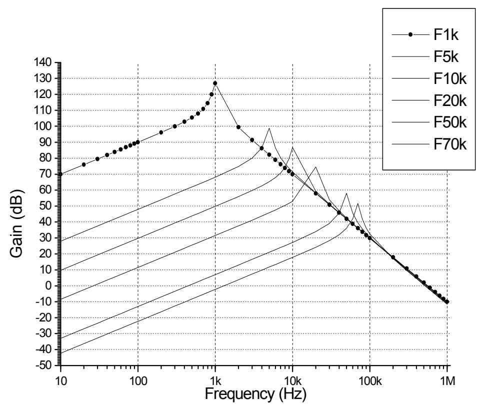


Figure 4. Band pass response for Q=10.

Table 4. Data sheet for band pass response.

F_0 (kHz)	Max. Pass ban gain (dB)	F_{0B} (kHz)	f_1 (kHz)	f_2 (kHz)	BW (kHz)
1	127	1	0.1	3·1	3
5	99	5·5	1·1	10	8·9
10	87	10	3	20	17
20	74	21	10	31	21
50	58	55	30	70	40
70	52	67	60	90	30

The use of the Switched-Capacitor to replace resistor in active filter circuit will suited to overcome a major obstacle to filter on chip fabrication.

8. References

[1] G. N. Shinde and P. B. Patil, "Study of active-R second order filter using feedback of non-inverting terminal," Bulletin of Pure and Applied Sciences, Vol. 21 D, No. 1, pp. 23-30, 2002.

[2] G. N. Shinde and S. R. Bhagat, "Universal second order active switched-capacitor filter for different Q values," Indian Journal of Physics, Vol. 82, No. 10, pp. 1329-1337, 2008.

[3] S. Srinivasan, "Synthesis of transfer functions using the operational amplifier pole," International Journal of Electronics, Vol. 40, No. 1, pp. 5-13, 1976.

[4] M. Ghausi, "Analog active filters," IEEE Transactions on Circuits and Systems, Vol. 31, pp. 13-31, 1984.

[5] G. N. Shinde, P. B. Patil, A. B. Kadam and P. R. Mirkute, "Active-R biquadratic filter using positive feedforward signal," BRI'S JAST, Vol. 5(I and II), pp. 7-15, 2002.

[6] W. R. Grise, "Applications of switched capacitor circuits in active filters and instrumental amplifiers," Vol. 3, No. 3, pp. 1523-1526, 1999.

[7] U. Kumar, "Design and a nalytical study of strays-insensisitive switched capacitor filter," Active and Passive Electronic Components., Vol. 19, pp. 13-24, 1996.

[8] Z. X. Sun, "Active-R filter: A new biquadratic with four terminal," International Journal of Electronics, Vol. 54, No. 4, pp. 523-530, 1993.

[9] A. Kumar and S. K. Saha, "MOS switched capacitor sample data filters," Vol. 55, No. 4, pp. 631-637, 1983.

[10] M. A. Shah, M. R. Rathu and S. Z. Iqbal, "SITO electronically tunable high output impedance current mode universal filter," Analog-Integrated Circuit and Signal Processing, Vol. 47, pp. 335-338, 2006.

[11] G. J. Yu, C. Y. Huang, J. J. Chen and B. D. Liu, "Design of current mode square root domain bandpass filter with reduced voltage," Analog-Integrated Circuit and Signal Processing, Vol. 44, pp. 239-250, 2005.

[12] R. Senani and S. S. Gupta, "Low universal filter using only current followers as active elements," International Journal of Electronics and Communication, Vol. 60, pp. 251-256, 2006.

[13] J. G. Jiang and Y. N. Wang, "Design of a tunable frequency CMOS fully differential fourth order chebyshev filter," Microelectronics Journal, Vol. 37, pp. 84-90, 2006.

