

A Comparative Analysis of Universal Filters using Current Conveyors

G. Appala Naidu* and B. T. Krishna

Department of Electronics and Communication Engineering, University College of Engineering Vizianagaram, JNTUK, Vizianagaram – 535003, Andhra Pradesh, India; ganaidu401@gmail.com

Abstract

Objectives: Current mode of operation is drawing the attention of many researchers due to their potential advantages such as wider Bandwidth, greater gain, higher slew-rate, etc., So, the design of Universal filters in current mode is essential keeping in view of power, Bandwidth. **Methods:** This paper concentrates on the analysis of some of the Universal filter Topologies which are realized using second generation current conveyor. For each Topology, the detailed mathematical analysis is carried out using circuit analysis techniques. The transfer function expressions is derived. The effects of floating and grounded point passive elements is briefly discussed with respect to hardware complexity, Quality factor and resonant angular frequency. **Findings:** The main objective of the paper is to analyze and compare various universal filter topologies. The objective of the paper also focus on the selection of the current conveyor by studying various generations in it. The Universal filters are used to act like low pass, High pass Band pass and Band reject filters. The merits and demerits of each Topology is compared. It has been observed that Topology I uses as minimum number of components as possible. There is no independent control of Q-factor in all topologies. All current conveyors and different Topologies are simulated in MULTISIM 13.0. **Application:** The proposed circuits finds applications in many areas such as communication, controls, Signal processing, Instrumentation. The work can be extended to design universal filter circuits with lesser passive components, better Q and Bandwidth values.

Keywords: Active Component, Circuit Analysis, Current Mode, Filter, Quality Factor Second Generation Current Conveyor, Topology, Universal Filter

1. Introduction

The design and analysis of Universal filters using Current mode operation is an important topic of research now days.¹ Current mode filters circuits are preferred compared to voltage mode filter circuits due to wide Bandwidth and greater linearity. The active element in the current mode filters is current conveyor.^{2,4} Out of various types of Current Conveyors the Second Generation Current Conveyor is widely used.

The Current-mode filters can be

1. Many input and single output type.
2. One input and many output type.

The first is used in situations only when one output is desired. The second category is preferred when multiple

output are needed. The category circuits contain floating as well as grounded Resistors and Capacitors. The universal filter can be used to realize Low pass, High pass, Band pass, Band reject and All pass filters without having to change the filter configurations. The huge values of overall output impedance enables them to be cascade easily.⁵⁻¹⁴

The CCII is a current controlled current source. The CCII based filter is very suitable for high frequency operation. These features are very attractive to filter topologies. Most of the circuits realize simultaneously three filter functions. For most circuits floating passive elements are required.

The discussion of the paper is as follows. Basics of Current mode are presented in section:

1. Mathematical analysis of current conveyor is presented in Section.

*Author for correspondence

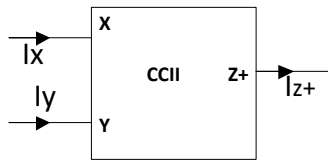
2. Different topologies of universal current mode filters are analyzed in Section.
3. Discussion on simulation results is presented in Section.
4. Finally conclusions are drawn in Section 5.

2. Second Generation Current Conveyor

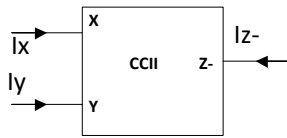
The block diagram of CCII is shown in Figure 1(a), (b), (c), (d) and (e) respectively. The current flowing through terminal Y is equal to zero. The representation of CCII is²,

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_x \\ I_x \\ V_z \end{bmatrix} \quad (1)$$

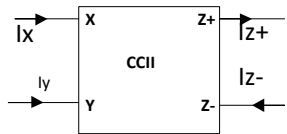
Dual output current conveyor shown in Figure (c) has two outputs Z+, Z- and both output currents in opposite directions.



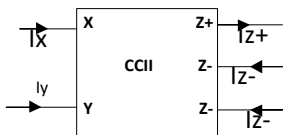
(a) Block diagram of CCII+



(b) Block diagram of CCII-



(c) Block diagram of Dual output CCII (DOCCII)



(d) Block diagram of three outputs CCII (TOCCII)

Figure 1. Different block of CCII (a) CCII+ (b) CCII- (c) CCII+ (DOCCII) (d) CCII+--(TOCCII).

$$\begin{bmatrix} I_y \\ V_x \\ I_{z+} \\ I_{z-} \\ I_{z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_x \\ I_x \\ V_{z+} \\ V_{z-} \end{bmatrix} \quad (2)$$

Figure (d) shows three outputs with one Z+ output and two Z- outputs, which block is defined matrix equation (2) all above configurations are used in different universal filter circuit topologies described in this paper

The internal diagram of CCII using the complementary metal oxide semiconductor (CMOS) is shown in Figures 2, 3, and 4 respectively. The $\frac{W}{L}$ ratio of the corresponding circuits is tabulated in Tables 1.¹¹⁻¹²

Table 1. $\frac{W}{L}$ Ratio comparison of various Transistors used in different CCII Topologies

Name of the Circuit	Transistor	$\frac{W}{L}$ ratios (μm)
CCII	M1, M2, M8,M9	100/0.5
	M4-M7, M10-M13	3.33/0.5
DOCCII	M1, M2, M13,M14	100/0.5
	M3-M8, M17-M22	3.33/0.5
	M9-M12	6/0.5
	M15,M16, M23, M24	4/0.5
TOCCII	M1, M2, M15,M16	100/0.5
	M3-M8, M17-M22	3.33/0.5
	M9-M14	6/0.5
	M23-M27	4/0.5

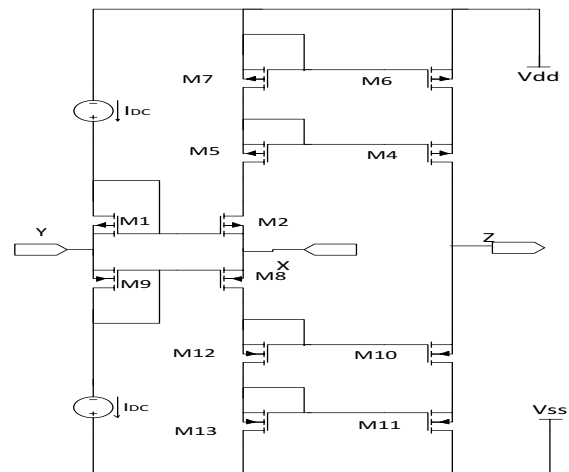


Figure 2. Circuit diagram of Second Generation Current Conveyor (CCII) using CMOS.

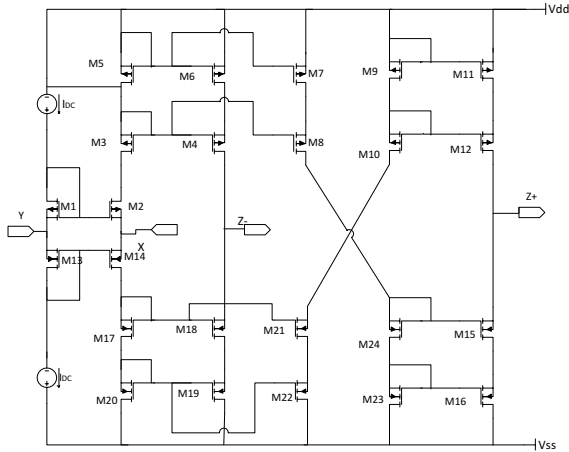


Figure 3. Circuit diagram of Dual Output Second Generation Current Conveyor (DOCCII) using CMOS.

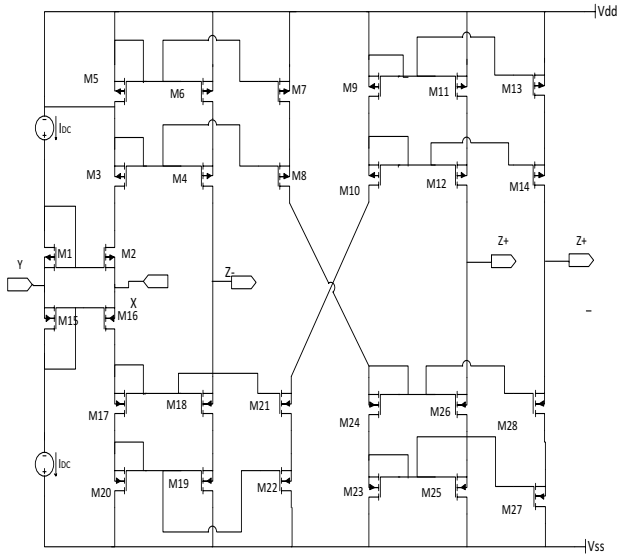


Figure 4. Circuit diagram of Three Output Second Generation Current Conveyor (TOCCII) using CMOS.

3. Universal Current Mode Filters

Current Mode operation is also used to perform various filtering operations which are possible in voltage mode.⁴ These make use of passive elements and active elements. Five Topologies that exist in literature are considered for analysis. The Mathematical analysis for various Topologies is as follows:

3.1 Topology 1

This topology employs 4 Dual Output Second Generation Current Conveyors (DOCCII) and 4 passive elements.⁵

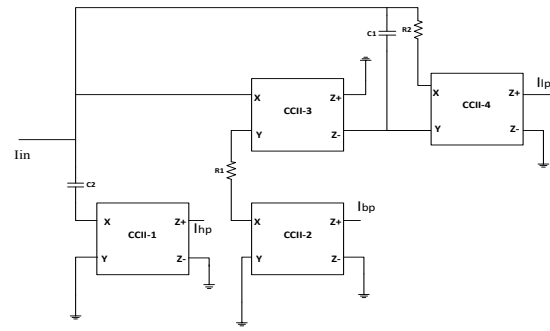


Figure 5(a). Universal Filter Topology given in.⁵

From the CCII, it is known that $I_{z+} = I_x$ and $I_{z-} = -I_x$. Let the applied input voltage is V_i . Apply KCL at input node,

$$I_{in} = I_{hp} + I_{lp} + I_{bp} \tag{1}$$

I_{x1} , Current through C_2 is,

$$sC_1V_i = I_{x1} = I_{hp} \tag{2}$$

I_{lp} , Current through R_2 is,

$$I_{lp} = \frac{V_i - V_{x4}}{R_2} \tag{3}$$

Apply KVL in the loop formed between ground of CCII-2, R_1 , C_2 and ground of CCII-1,

$$-\frac{V_i}{R_1} = I_{bp} = I_{lp}sC_2R_2 \tag{4}$$

By substituting equation (2) in (4), it is evident that,

$$I_{bp} = I_{lp}sC_2R_2 = -\frac{I_{hp}}{sC_1R_1} \tag{5}$$

Substituting equation (5) in equation (1) and simplifying,

$$\frac{I_{hp}}{I_{in}} = \frac{-s^2}{s^2 + \frac{s}{C_1R_1} + \frac{1}{C_1C_2R_1R_2}} \tag{6}$$

$$\frac{I_{bp}}{I_{in}} = \frac{-s/C_1R_1}{s^2 + \frac{s}{C_1R_1} + \frac{1}{C_1C_2R_1R_2}} \tag{7}$$

$$\frac{I_{lp}}{I_{in}} = \frac{-1/C_1C_2R_1R_2}{s^2 + \frac{s}{C_1R_1} + \frac{1}{C_1C_2R_1R_2}} \tag{8}$$

3.2 Topology 2

This topology consists of 4 active elements.⁶ This can be either CCII- or CCII+ and 4 passive elements. Applying KCL at input node

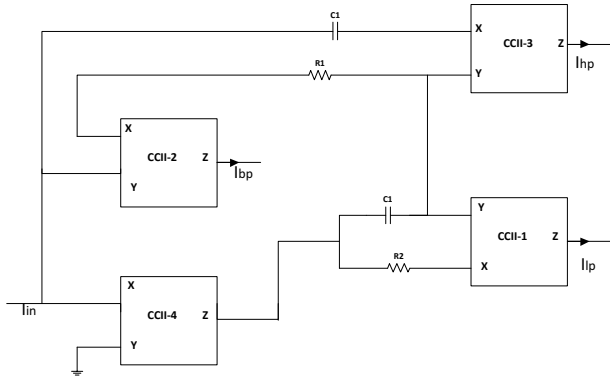


Figure 5(b). Universal Filter Topology given in.⁶

$$I_{in} = I_{x4} + I_{hp} \tag{9}$$

Using the properties of CCII,

$$I_{hp} = V_{x3} SC_1 = V_{y4} SC_1 \tag{10}$$

Writing KCL at the Node Joining \$R_2\$ and \$C_1\$

$$I_{x4} = I_{lp} + I_{bp} \tag{11}$$

From circuit, it can be written that,

$$V_z - V_{x1} = R_2 I_{lp} \tag{12}$$

$$(V_z - V_{y3}) SC_2 = I_{bp} \tag{13}$$

$$\text{And } V_{x1} = V_{y3} \tag{14}$$

Making use of equation (14) in (12), (13) and simplifying,

$$I_{bp} = sC_2 R_2 I_{lp} \tag{15}$$

It can also be shown that,

$$I_{hp} = SC_1 R_1 I_{bp} = s^2 C_1 C_2 R_1 R_2 I_{lp} \tag{16}$$

From equation (9)

$$\begin{aligned} I_{in} &= I_{x4} + I_{hp} \\ \Rightarrow I_{in} &= I_{bp} + I_{lp} + I_{hp} \end{aligned} \tag{17}$$

equations (16) & (17), it can be shown that,

$$\frac{I_{lp}}{I_{in}} = \frac{1/C_1 C_2 R_1 R_2}{S^2 + \frac{S}{C_1 R_1} + \frac{1}{C_1 C_2 R_1 R_2}} \tag{18}$$

$$\frac{I_{bp}}{I_{in}} = \frac{S/C_1 R_1}{S^2 + \frac{S}{C_1 R_1} + \frac{1}{C_1 C_2 R_1 R_2}} \tag{19}$$

$$\frac{I_{hp}}{I_{in}} = \frac{-S^2}{S^2 + \frac{S}{R_1} + \frac{1}{C_1 C_2 R_1 R_2}} \tag{20}$$

3.3 Topology 3

This topology employs 4 active elements all are of DOCCII type. It has 4 passive elements (2 resistors and 2 capacitors).⁷ High pass, Band pass, Low pass filter responses are observed at CCII-2, CCII-3, and CCII-4 respectively. Band rejects filter response also possible by adding responses of CCII-2, CCII-4. From above figure:

$$(I_{z+} - I_{hp})R_3 = -I_{bp}R_1 = -I_{hp} \frac{1}{SC_1} \tag{21}$$

(since for CCII \$I_{z+} = -I_{z-}\$ and \$V_x = V_y\$)

$$I_{bp} \frac{1}{SC_2} = I_{lp} R_2 \tag{22}$$

By writing KCL at input node,

$$I_{in} = I_z + I_{lp} \tag{23}$$

$$I_{z-} = -I_{bp} \frac{R_1}{R_3} + I_{hp} = -I_{hp} \frac{1}{SC_1 R_3} + I_{hp} \tag{24}$$

$$I_{bp} = I_{lp} SC_2 R_2 \tag{26}$$

$$I_{hp} = I_{bp} SC_1 R_1 \tag{27}$$

$$I_{hp} = I_{lp} S^2 C_1 C_2 R_1 R_2 \tag{28}$$

$$\text{From equation (23) } I_{z+} + I_{lp} = I_{in} \tag{29}$$

By substituting \$I_{z+}\$ value in above equation we get

$$-I_{bp} \frac{R_1}{R_3} + I_{hp} + I_{lp} = I_{in} \tag{30}$$

$$I_{lp} \frac{SC_2 R_1 R_2}{R_3} + I_{lp} S^2 C_1 C_2 R_1 R_2 + I_{lp} = I_{in} \tag{31}$$

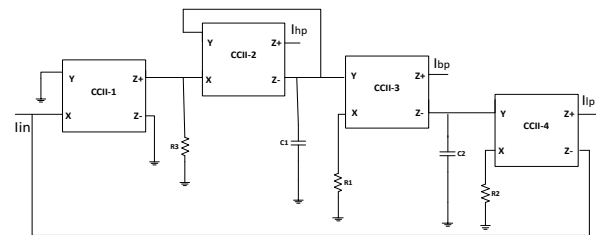


Figure 5(c). Universal Filter Topology given in.⁷

$$\frac{I_{lp}}{I_{in}} = \frac{\frac{1}{C_1 C_2 R_1 R_2}}{S^2 + \frac{S}{C_1 R_2} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (32)$$

From equation (23) $I_{z+} + I_{lp} = I_{in}$ (33)

$$-I_{bp} \frac{R_1}{R_2} + I_{hp} + I_{lp} = I_{in} \quad (34)$$

$$-I_{bp} \frac{R_1}{R_2} + I_{bp} S C_1 R_1 + \frac{I_{bp}}{S C_2 R_2} = I_{in} \quad (35)$$

$$\frac{I_{bp}}{I_{in}} = \frac{-\frac{S}{C_1 R_1}}{S^2 + \frac{S}{C_1 R_2} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (36)$$

Similarly

$$\frac{I_{hp}}{I_{in}} = \frac{S^2}{S^2 + \frac{S}{C_1 R_2} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (37)$$

3.4 Topology 4

In this topology three CCII's and 4 passive elements (2 resistors and 2 capacitors) are employed.⁹ Two active elements are DOCCII type and another one is TOCCII type. Band pass, high pass, Low pass filter responses are observed simultaneously at CCII-1, CCII-2, and CCII-3 respectively. Band rejects filter response also possible by adding two response of CCII-2, CCII-3. from below figure apply KCL at input node

$$I_{bp} + I_{hp} + I_{lp} = I_{in} \quad (38)$$

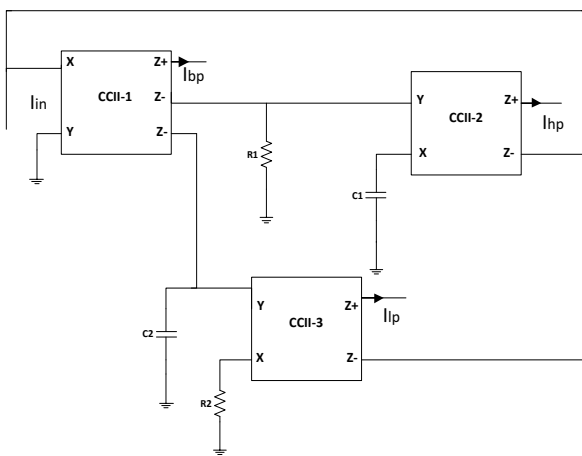


Figure 5 (d). Universal Filter Topology given in.⁹

$$I_{hp} = -\frac{V_{x2}}{1/SC_1} \quad (39)$$

(By KCL at CCII-2 X)

From above figure $I_{bp} = -\frac{V_{y2}}{R_1}$ (40)

From the characteristics of CCII $V_{x2} = V_{y2}$

Therefore $I_{bp} = \frac{I_{hp}}{S C_1 R_1}$ (41)

$$I_{lp} = -\frac{V_{x2}}{R_2} \quad (42)$$

$$I_{bp} = -\frac{V_{y2}}{1/SC_2} \quad (43)$$

From the characteristics of CCII $V_{x2} = V_{y2}$

$$I_{bp} = I_{lp} S C_2 R_2 \quad (44)$$

From equation (38)

$$I_{bp} + I_{hp} + I_{lp} = I_{in} \quad (45)$$

By substituting I_{lp} and I_{bp} values in above equation we get

$$\frac{I_{hp}}{S C_1 R_1} + I_{hp} + \frac{I_{hp}}{S^2 C_1 C_2 R_1 R_2} = I_{in} \quad (46)$$

$$\frac{I_{hp}}{I_{in}} = \frac{S^2}{S^2 + \frac{S}{C_1 R_1} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (47)$$

Similarly we can prove

$$\frac{I_{lp}}{I_{in}} = \frac{\frac{1}{C_1 C_2 R_1 R_2}}{S^2 + \frac{S}{C_1 R_1} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (48)$$

and

$$\frac{I_{bp}}{I_{in}} = \frac{-\frac{S}{C_1 R_1}}{S^2 + \frac{S}{C_1 R_1} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (49)$$

The values of ω_n and Q are shown to be

Natural frequency $\omega_n = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}$ (50)

$$\text{Quality factor } Q = \sqrt{\frac{C_2 R_2}{C_1 R_1}} \quad (51)$$

3.5 Topology 5

This topology employs 4 active elements which are of DOCCII type and 5 passive elements.¹² Low pass, band pass, high pass filter responses are observed simultaneously at CCII-1, CCII-3, CCII-4 respectively. Band reject filter response is possible by adding two response of CCII-1, CCII-4. Applying KCL at input node,

$$I_{lp} - I_{x2} = I_{in} \quad (52)$$

$$\frac{V_{x1} - V_{y2}}{R_2} = I_{lp} \quad (53)$$

$$\text{Where } V_{y1} = V_{x1} = 0 \quad (54)$$

$$\text{Therefore } V_{y2} = I_{lp} R_2 \quad (55)$$

$$I_{bp} = -\frac{V_{y2}}{1/SC_2} \quad (56)$$

$$\Rightarrow I_{bp} = I_{lp} SC_2 R_2 \text{ or } I_{lp} = \frac{I_{bp}}{SC_2 R_2} \quad (57)$$

$$V_{x2} = -I_{bp} R_1 = V_{y2} \quad (58)$$

$$-I_{x2} + \frac{V_{y2}}{R_3} + I_{hp} = 0 \quad (59)$$

$$I_{x2} = -\frac{I_{bp} R_1}{R_3} + I_{hp} \quad (60)$$

$$\frac{V_{y2}}{1/SC_1} = I_{hp} \Rightarrow V_{y2} = \frac{I_{hp}}{SC_1} = V_{x2} \quad (61)$$

$$\Rightarrow I_{hp} = -I_{bp} SC_1 R_1 \quad (62)$$

From equation (52)

$$I_{lp} - I_{x2} = I_{in} \quad (63)$$

$$-I_{lp} + I_{hp} - I_{bp} \frac{R_1}{R_3} = I_{in} \quad (64)$$

$$-\frac{I_{bp}}{SC_2 R_2} - I_{bp} SC_1 R_1 - I_{bp} \frac{R_1}{R_3} = I_{in} \quad (65)$$

Simplifying the above equations,

$$\frac{I_{bp}}{I_{in}} = \frac{-\frac{S}{C_1 R_1}}{S^2 + \frac{S}{C_1 R_3} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (66)$$

$$\frac{I_{hp}}{I_{in}} = \frac{S^2}{S^2 + \frac{S}{C_1 R_3} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (67)$$

$$\frac{I_{lp}}{I_{in}} = \frac{-\frac{C_2 R_2}{C_1 R_1}}{S^2 + \frac{S}{C_1 R_3} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (68)$$

The values of ω_n and Q are shown to be

$$\omega_n = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}} \quad (69)$$

$$Q = R_3 \sqrt{\frac{C_1}{C_2 R_1 R_2}} \quad (70)$$

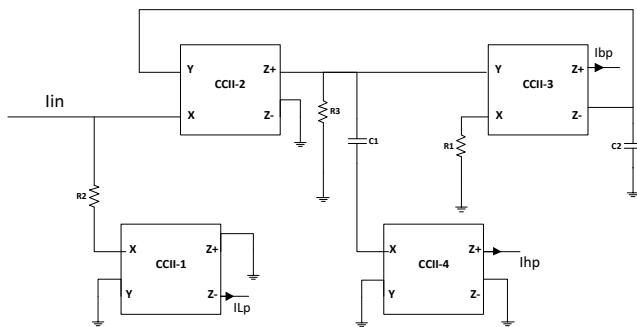


Figure 5(e). Universal Filter Topology given in.¹²

4. Simulation Results

In this paper, Multisim software is used for the simulation purpose. The CMOS considered is of 0.5 μ m with input source current of 1 mA. The output of Topology under consideration is as shown in Figure 6-10.

4.1 Topology 1

In this Universal current mode filter, the chosen values are $R_1=1M\Omega$, $R_2=2.25K\Omega$, $C_1=10pF$, $C_2=100pF$, the response of different filters is shown in Figure 6.

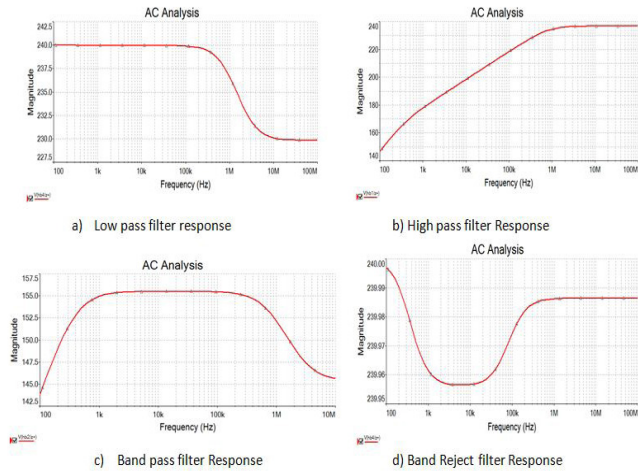


Figure 6. Magnitude Responses of HP, LP, BP, BR filters corresponding to Figure 5(a).

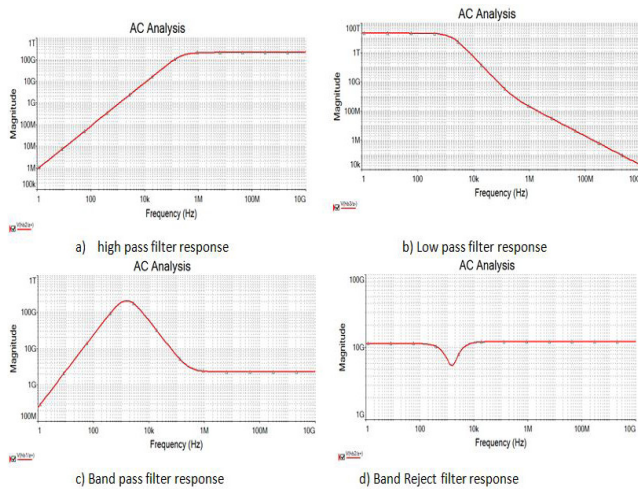


Figure 7. Magnitude Responses of HP, LP, BP, BR filters corresponding to Figure 5(b).

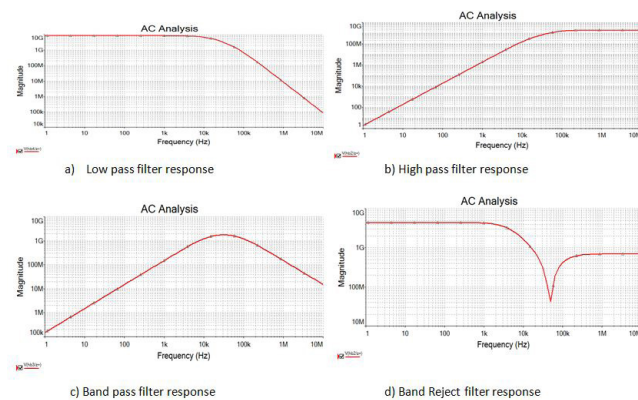


Figure 8. Magnitude Responses of LP, HP, BP, BR filters corresponding to Figure 5(c).

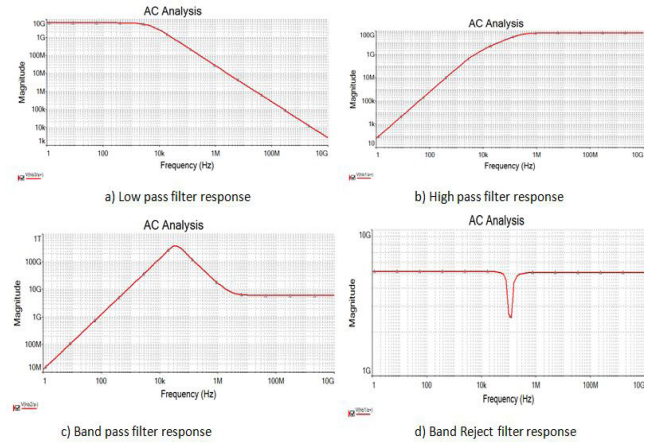


Figure 9. Magnitude Responses of HP, LP, BP, BR filters corresponding to Figure 5(d).

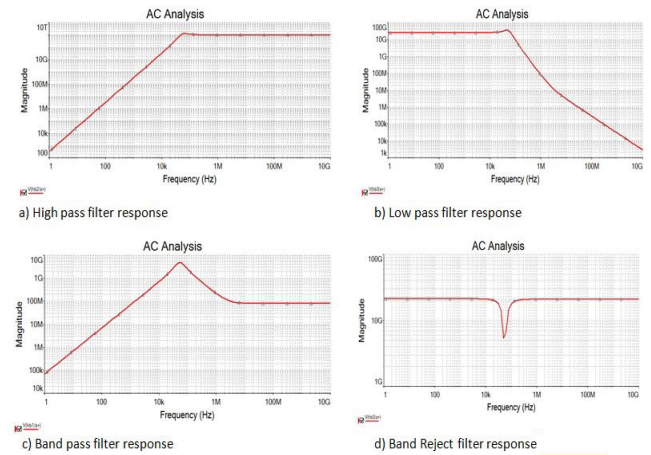


Figure 10. Magnitude Responses of LP, HP, BP, BR filters corresponding to Figure 5(e).

4.2 Topology 2

In this Universal current mode filter, the chosen values are $R_1 = R_2 = 1M\Omega$, $C_1 = C_2 = 10pF$, the magnitude response of different filters is as in Figure 7.

4.3 Topology 3

By selecting $R_1 = R_2 = 15.9K\Omega$, $C_1 = C_2 = 100pF$, $R_3 = 1.124K\Omega$ the magnitude responses obtained are as shown in Figure 8.

4.4 Topology 4

By choosing $R_1 = 1M\Omega$, $R_2 = 2.25K\Omega$, $C_1 = 10pF$, $C_2 = 100pF$, the magnitude response of different filters corresponding to Figure 9.

4.5 Topology 5

By selecting $R_1 = R_2 = 22.5\text{K}\Omega$, $C_1 = C_2 = 100\text{pF}$, $R_3 = 15.9\text{K}\Omega$ the magnitude response of different filters corresponding to Figure 10.

5. Conclusion

Five of the topologies are considered for the comparative analysis. The following are the observations:

1. Topology 1 has minimum number of passive elements and reduced number of active elements. CCII-1 and CCII-2 has high output impedance.
2. The disadvantage of Topology I is that all Passive elements are floating in nature and Q-factor cannot be controlled.
3. In Topology 2, CCII-1, CCII-2 and CCII-3 have high output impedance. All are floating point passive element. There is no independent control of filter quality factor Q.
4. In Topology 3 R_3 controls the filter Q factor and independently without affecting any other filter parameter. In this topology all pass filter is also possible at $R_3 = R_1$, but which results in losing independent control of Q.
5. Topology 4 uses two balanced output CCII's and three outputs CCII. The circuit has very low input impedance. It consists of two resistors and two capacitors. It cannot have independent control of filter Q factor. The disadvantages of circuit is capacitor C1 connected to port of X of second CCII.
6. In Topology 5 R_3 controls the filter Q factor, which is independent of all other parameter. For all pass filter at $R_3 = R_1$, which results in losing independent control of filter Q. It has only one floating element.

6. Acknowledgments

Authors thank the Vice-Chancellor and registrar of Jawaharlal Nehru Technological University Kakinada for their support.

7. References

1. Mohan PVA. Current Mode VLSI Analog Filters. Birkhauser Boston; 2003 Jun. p. 453.
2. Smith KC, Sedra AS. The current conveyor-a new circuit building block. IEEE Proceeding on Circuits and Systems. 1968 Aug; 56(8):1368-9.
3. Sedra AS, Smith KC. A second generation current conveyor and its application. IEEE Transaction on Circuit Theory. 1970 Jan; 17(1):132-4. Crossref
4. Soliman AM. Current mode universal filter. Electronics Letters. 1995 Aug; 31(17):1420-1. Crossref
5. Sagbas M, Fidanboyu K, Bayram MC. A new current-mode multifunction filter with high impedance outputs using minimum number of passive elements. International Journal of Signal Processing. 2004 Jan; 1(4):352-6.
6. Ozoguz S, Toker A, Cicekoglu O. New current-mode universal filters using only four (CCII+)s. Microelectronics Journal. 1999 Mar; 30(3):255-8. Crossref
7. Wang HY, Lee CT. Versatile insensitive current mode universal biquad implementation using current conveyors. IEEE Transactions on Circuits and Systems II. 2001 Apr; 48(4):409-13. Crossref
8. Horng JW. Current conveyors based current-mode universal biquadratic filter. Journal of the Chinese Institute of Electrical Engineering. 2002 May; 9(2):147-50.
9. Soliman AM. New current mode universal filters using single output current conveyors. Alta Frequenza. 1996 Nov; 8(6):42-4.
10. Senani R, Singh AK, Singh VK, Bhaskar DR. Tunable current-mode universal biquads employing only three MOCCs and all grounded passive elements. Journal of Telecommunications. 2005 Oct, 59(9):220-4.
11. Singh VK, Singh AK, Senani R. Dual function capability of recently proposed four-current conveyor-based VM biquad. Journal of Circuits, Systems and Computers. 2005 Feb; 14(1):51-6. Crossref
12. Soliman AM. Current-Mode Universal Filters Using Current Conveyors. Classification and Review. Journal of Circuits, Systems & Signal Process. 2008 Jun; 27(3):405-27.
13. Khan AA, Bimal S, Dey KK, Roy SS. A simple methodology for sinusoidal oscillator design based on simulation of differential equation using AD844 configured as second-generation current conveyor. Indian Journal of Science and Technology. 2010 June; 3(6):684-86.
14. Arora TS, Sharma RK. Adjoint-KHN Equivalent Realization of Current Mode Universal Biquad Employing Third Generation Current Conveyor. Indian Journal of Science and Technology. 2016 Apr; 9(13):1-8. Crossref