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A Comparative Analysis of Universal Filters using Current Conveyors

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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 fucntion expressions is derived. The effects of floating and grounded point passive elements is brieffy discussed with respect to hardware complexity, Quality factor and resonat 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 componenets 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 componets, 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 Band width 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.

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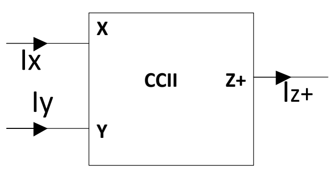
2. Different topologies of universal current mode filters are analyzed in Section.
3. Discussion on simulation results is presented in Section.
4. Finally conclusions are drawn in Section 5.

2. Second Generation Current Conveyor

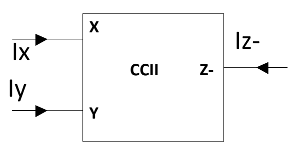
The block diagram of CCII is shown in Figure 1(a), (b), (c), (d) and (e) respectively. The current flowing through terminal Y is equal to zero. The representation of CCII is[2],

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

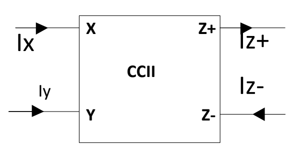
Dual output current conveyor shown in Figure (c) has two outputs Z+, Z– and both output currents in opposite directions.



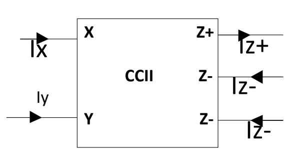
(a) Block diagram of CCII+



(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).

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

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

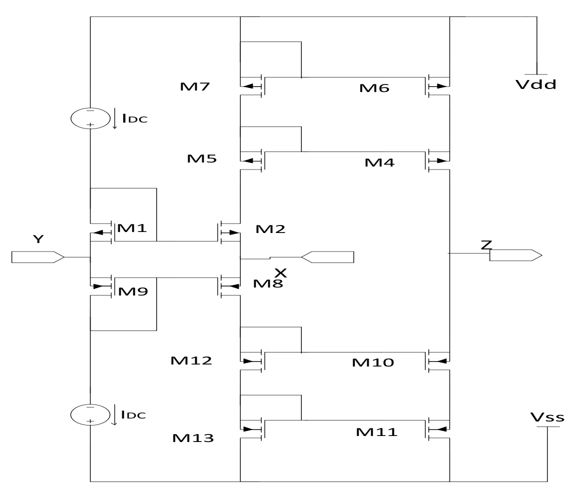


Figure 2. Circuit diagram of Second Generation Current Conveyor (CCII) using CMOS.

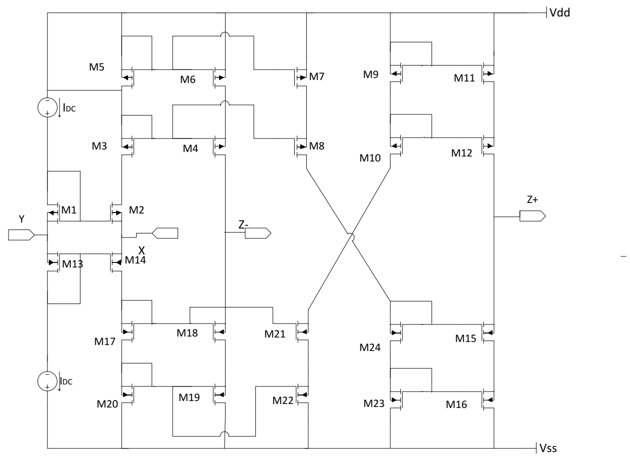


Figure 3. Circuit diagram of Dual Output Second Generation Current Conveyor (DOCCII) using CMOS.

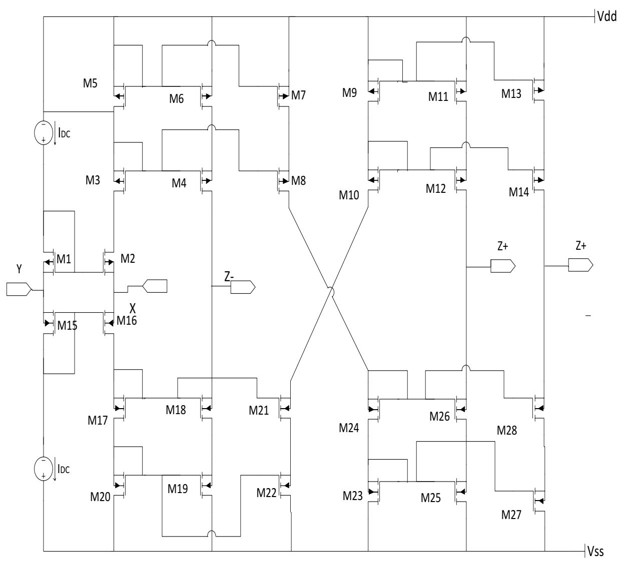


Figure 4. Circuit diagram of Three Output Second Generation Current Conveyor (TOCCII) using CMOS.

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]

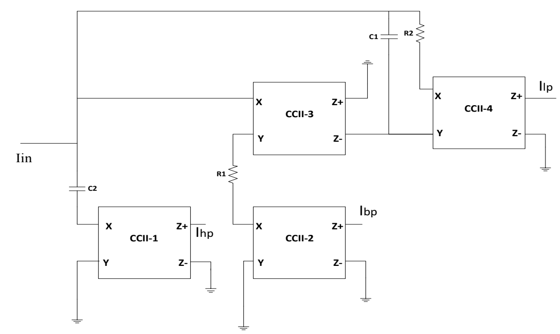


Figure 5(a). Universal Filter Topology given in.[5]

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,

$$I_{in} = I_{hp} + I_{lp} + I_{bp} \quad (1)$$

I_{x1}, Current through C_2 is,

$$sC_1V_i = I_{x1} = I_{hp} \quad (2)$$

I_{lp}, Current through R_2 is,

$$I_{lp} = \frac{V_i - V_{x4}}{R_2} \quad (3)$$

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

$$-\frac{V_i}{R_1} = I_{bp} = I_{lp}sC_2R_2 \quad (4)$$

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

$$I_{bp} = I_{lp}sC_2R_2 = -\frac{I_{hp}}{sC_1R_1} \quad (5)$$

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

$$\frac{I_{hp}}{I_{in}} = \frac{-S^2}{S^2 + \frac{S}{C_1R1} + \frac{1}{C_1C_2R_1R_2}} \quad (6)$$

$$\frac{I_{bp}}{I_{in}} = \frac{-{}^{S}/_{C_1R_1}}{S^2 + \frac{S}{C_1R_1} + \frac{1}{C_1C_2R_1R_2}} \quad (7)$$

$$\frac{I_{lp}}{I_{in}} = \frac{-{}^{1}/_{C_1C_2R_1R_2}}{S^2 + \frac{S}{C_1R_1} + \frac{1}{C_1C_2R_1R_2}} \quad (8)$$

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

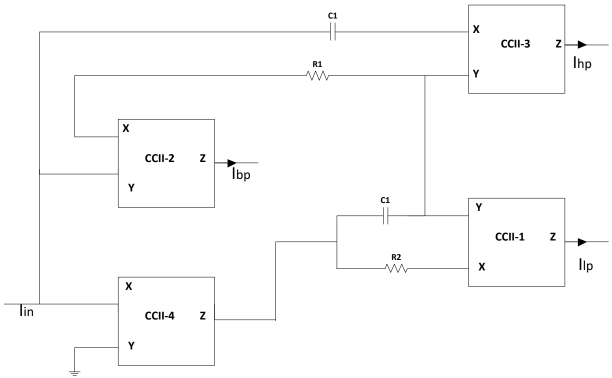


Figure 5(b). Universal Filter Topology given in.[6]

$$I_{in} = I_{x4} + I_{hp} \quad (9)$$

Using the properties of CCII,

$$\mathbf{I_{hp} = V_{x3}\ SC_1 = V_{y4} SC_1} \quad (10)$$

Writing KCL at the Node Joining R_2 and C_1

$$I_{x4} = I_{lp} + I_{bp} \quad (11)$$

From circuit, it can be written that,

$$V_z - V_{x1} = R_2 I_{lp} \quad (12)$$

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

$$\text{And } V_{x1} = V_{y3} \quad (14)$$

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

$$I_{bp} = sC_2 R_2 I_{lp} \quad (15)$$

It can also be shown that,

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

From equation (9)

$$I_{in} = I_{x4} + I_{hp}$$

$$=> I_{in} = I_{bp} + I_{lp} + I_{hp} \quad (17)$$

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

$$\frac{I_{lp}}{I_{in}} = \frac{1/C_1C_2R_1R_2}{S^2 + \frac{S}{C_1R_1} + \frac{1}{C_1C_2R_1R_2}} \quad (18)$$

$$\frac{I_{bp}}{I_{in}} = \frac{S/C_1R_1}{S^2 + \frac{S}{C_1R_1} + \frac{1}{C_1C_2R_1R_2}} \quad (19)$$

$$\frac{I_{hp}}{I_{in}} = \frac{-S^2}{S^2 + \frac{S}{R_1} + \frac{1}{C_1C_2R_1R_2}} \quad (20)$$

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:

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

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

$$I_{bp}\frac{1}{Sc2} = I_{lp}R_2 \quad (22)$$

By writing KCL at input node,

$$I_{in} = I_z + I_{lp} \quad (23)$$

$$I_{z-} = -I_{bp}\frac{R1}{R_3} + I_{hp} \quad = -I_{hp}\frac{1}{SC_1R_3} + I_{hp} \quad (24)$$

$$I_{bp} = I_{lp}SC_2R_2 \quad (26)$$

$$I_{hp} = I_{bp}SC_1R1 \quad (27)$$

$$I_{hp} = I_{lp}S^2C_1C_2R_1R_2 \quad (28)$$

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

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

$$-I_{bp}\frac{R_1}{R_3} + \mathrm{I}_{hp} + I_{lp} = I_{in} \quad (30)$$

$$I_{lp}\frac{SC_2R_1R_2}{R_3} + I_{lp}S^2C_1C_2R_1R_2 + I_{lp} = I_{in} \quad (31)$$

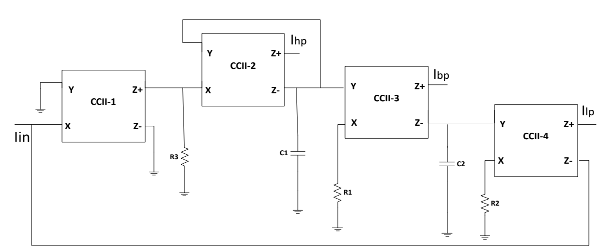


Figure 5(c). Universal Filter Topology given in.[7]

$$\frac{I_{lp}}{I_{in}} = \frac{\frac{1}{C_1 C_2 R_1 R_2}}{S^2 + \frac{S}{C_1 R_3} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (32)$$

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

$$-I_{bp}\frac{R_1}{R_3} + I_{hp} + I_{lp} = I_{in} \quad (34)$$

$$-I_{bp}\frac{R_1}{R_3} + I_{bp} S C_1 R_1 + \frac{I_{bp}}{S C_2 R_2} = I_{in} \quad (35)$$

$$\frac{I_{bp}}{I_{in}} = \frac{-\frac{S}{C_1 R_1}}{S^2 + \frac{S}{C_1 R_3} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (36)$$

Similarly

$$\frac{I_{hp}}{I_{in}} = \frac{S^2}{S^2 + \frac{S}{C_1 R_3} + \frac{1}{C_1 C_2 R_1 R_2}} \quad (37)$$

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

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

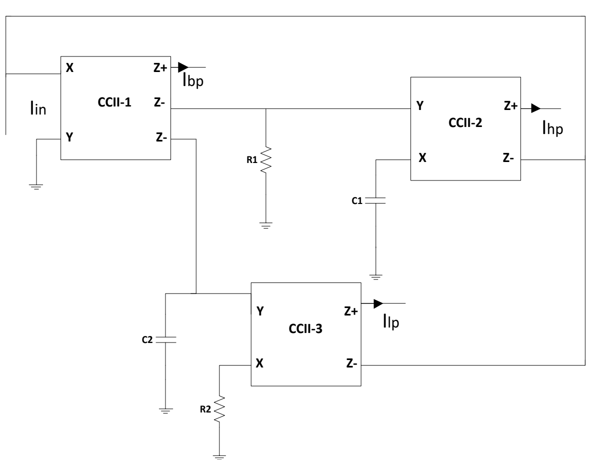


Figure 5 (d). Universal Filter Topology given in.[9]

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

(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)

$$I_{lp} = -\frac{V_{x3}}{R_2} \quad (42)$$

$$I_{bp} = -\frac{V_{y3}}{1/SC_2} \quad (43)$$

From the characteristics of CCII $V_{x3} = V_{y3}$

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

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

$$\frac{I_{lp}}{I_{in}} = \frac{\frac{1}{C_1 C_2 R_1 R_2}}{S^2 + \frac{S}{C_1 R_1} + \frac{1}{c1 C_2 R_1 R_2}} \quad (48)$$

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)

Quality factor $$Q = \sqrt{\frac{C_2R_2}{C_1R_1}} \quad (51)$$

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,

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

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

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

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

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

$$=> I_{bp} = I_{lp}SC_2R_2 \quad or \; I_{lp} = \frac{I_{bp}}{SC_2R_2} \quad (57)$$

$$V_{x3} = -I_{bp}R_1 = V_{y3} \quad (58)$$

$$-I_{x2} + \frac{V_{y3}}{R_3} + I_{hp} = 0 \quad (59)$$

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

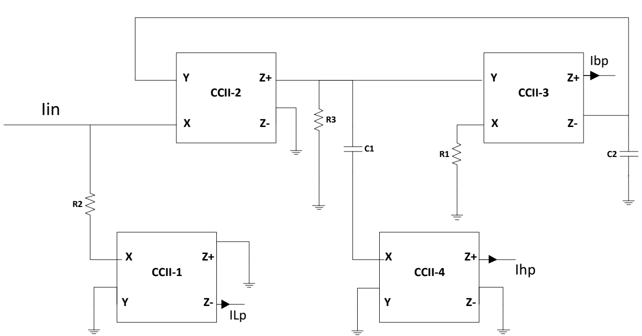


Figure 5(e). Universal Filter Topology given in.[12]

$$\frac{V_{y3}}{1/SC_1} = I_{hp} => V_{y3} = \frac{I_{hp}}{SC_1} = V_{x3} \quad (61)$$

$$=> I_{hp} = -I_{bp}SC_1R_1 \quad (62)$$

From equation (52)

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

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

$$-\frac{I_{bp}}{SC_2R_2} - I_{bp}SC_1R_1 - I_{bp}\frac{R1}{R_3} = I_{in} \quad (65)$$

Simplifying the above equations,

$$\frac{I_{bp}}{I_{in}} = \frac{-\frac{S}{C_1R_1}}{S^2 + \frac{S}{C_1R_3} + \frac{1}{C_1C_2R_1R_2}} \quad (66)$$

$$\frac{I_{hp}}{I_{in}} = \frac{S^2}{S^2 + \frac{S}{C_1R_3} + \frac{1}{C_1C_2R_1R_2}} \quad (67)$$

$$\frac{I_{lp}}{I_{in}} = \frac{-\frac{C_2R_2}{C_1R_1}}{S^2 + \frac{S}{C_1R_3} + \frac{1}{C_1C_2R_1R_2}} \quad (68)$$

The values of ω_n and Q are shown to be

$$\omega_n = \frac{1}{\sqrt{C_1C_2R_1R_2}} \quad (69)$$

$$Q = R_3\sqrt{\frac{C_1}{C_2R_1R_2}} \quad (70)$$

4. Simulation Results

In this paper, Multisim software is used for the simulation purpose. The CMOS considered is of 0.5μm 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=1MΩ, R_2=2.25KΩ, C_1=10pF, C_2=100pF, the response of different filters is shown in Figure 6.

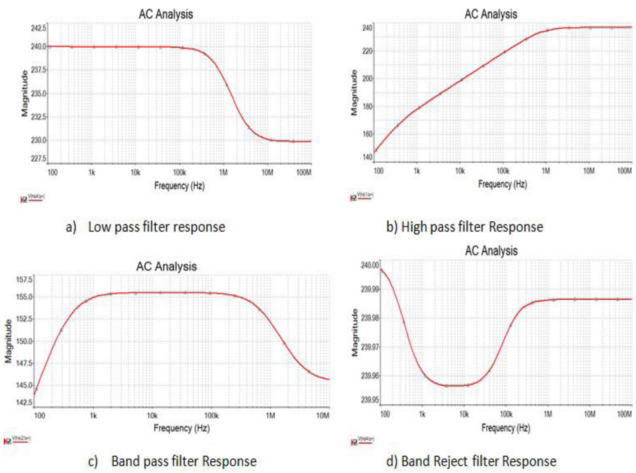


Figure 6. Magnitude Responses of HP, LP, BP, BR filters corresponding to Figure 5(a).

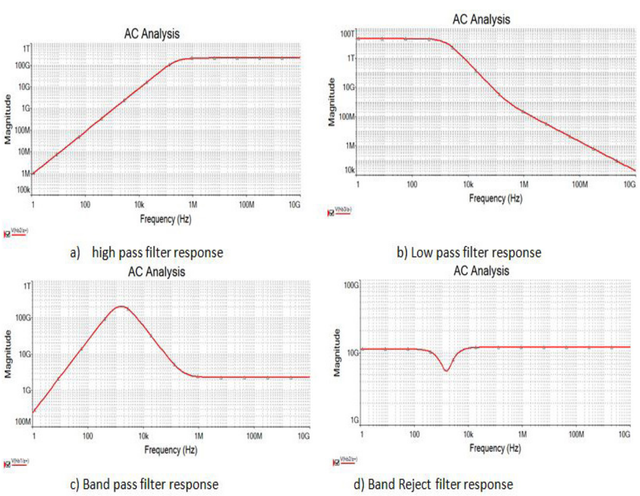


Figure 7. Magnitude Responses of HP, LP, BP, BR filters corresponding to Figure 5(b).

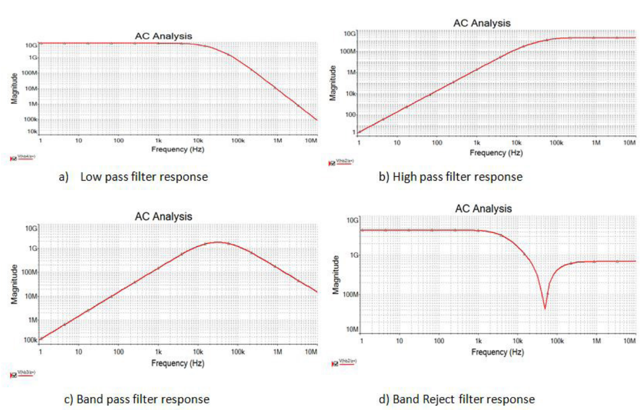


Figure 8. Magnitude Responses of LP, HP, BP, BR filters corresponding to Figure 5(c).

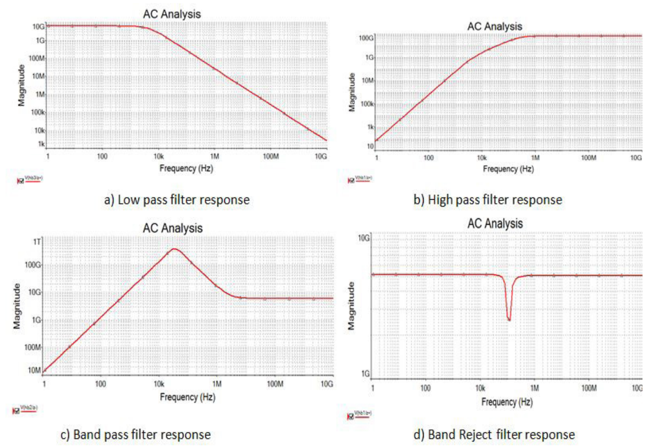


Figure 9. Magnitude Responses of HP, LP, BP, BR filters corresponding to Figure 5(d).

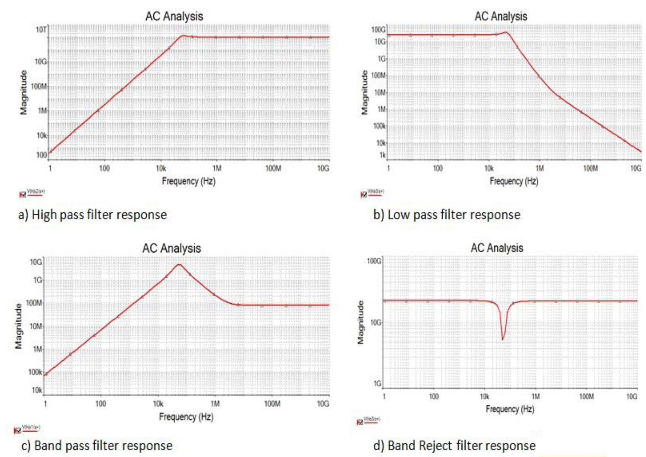


Figure 10. Magnitude Responses of LP, HP, BP, BR filters corresponding to Figure 5(e).

4.2 Topology 2

In this Universal current mode filter, the chosen values are $R_1 = R_2 = 1M\Omega$, C1= C_2= 10pF, the magnitude response of different filters is as in Figure 7.

4.3 Topology 3

By selecting R1= R_2=15.9KΩ, $C_1 = C_2$= 100pF, R_3=1.124KΩ the magnitude responses obtained are as shown in Figure 8.

4.4 Topology 4

By choosing R_1=1MΩ, R_2=2.25KΩ, C_1=10pF, C_2=100pF, the magnitude response of different filters corresponding to Figure 9.

4.5 Topology 5

By selecting $R_1 = R_2 = 22.5K\Omega$, $C_1 = C_2 = 100pF$, $R_3 = 15.9K\Omega$ 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 3R_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 CCIIs 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 5R_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

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7. References

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