DESIGN OF NEW UNIVERSAL FILTERS WITH SECOND GENERATION CURRENT CONVEYOR

By

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ABSTRACT

In this paper, new type of single input and three output universal filters with current conveyor as an active element is proposed. Current conveyor works similar to operational amplifier but the input and output signals are current rather than voltage. There are several types of current conveyors exist. Out of the existing, Second order current conveyor (CCII) is chosen as an active element. The proposed circuits are designed using the similar type of active element and grounded passive components. The detailed mathematical analysis is carried out. The necessary expressions for quality factor and sensitivity are also derived. The responses of High pass filter, Low pass filter and Band pass filter are measured simultaneously. The notch and all pass filters can also be realized by adding the appropriate components. All simulation work is carried out with MULTISIM 13.0. The comparative analysis is carried out with the existing techniques and is tabulated. It has been observed that the proposed circuits works good in comparison with the existing topologies.

Keywords: Current Mode, Universal Filter, Dual Output, Second Generation Current Conveyor, Bandwidth, Sensitivity.

INTRODUCTION

In analog circuit design either voltage mode or current mode of operation can be used (Mohan, 2003). When compared to voltage mode, current mode is preferable with respect to higher band width, large dynamic range, greater linearity and power consumption (Ozoguz, Toker, & Cicekoglu, 1998; Toker & Özuğuz, 2001). Today filters play vital role in Mobile Communication, Signal Processing, Automatic control and instrumentation. So, the design of current mode universal filter is an important problem of research.

In (Ozoguz et al., 1998; Toker, Özoğuz, & Çiçekoğlu, 1999) came up with another new current mode multifunction filters with single input and three outputs. Which employs three dual output current conveyors and four passive elements. In proposed topologies, the number of active and passive elements is minimum and High Pass (HP), Band Pass (BP) and Low Pass (LP) responses at high impedance outputs which enables easy cascading. All passive and active sensitivities of these Current-Mode Single Input and Three Output (CM SITO) filters are low. Minaei, Kuntman, Cicekoglu, Turkoz, and Tarim (2000) proposed dual output current conveyor based Universal filter, which simultaneously realize low pass, band pass and high pass functions. This filter permits orthogonal adjustment of Quality factor and reasonant angular frequency and no element matching conditions are imposed. Toker and Ozoguz (2000) presented a new CM SITO type universal filter, which has only three Dual output Second Generation Current Conveyor (DOCCII)s and five ground passive components. Notch and all pass filter responses can be obtained by interchanging the corresponding outputs. The natural angular frequency and the quality factor of the circuit can be orthogonally controlled. Authors also investigated the effect of the non-idealities of Current Conveyors on the filter performance and give proper design criteria.

Toker and Özuğuz (2001) extended to design CM active filter for low frequency. The authors also achieve low sensitivity, easily integrable CM filters, and new lossless and lossy integrators. These circuits accommodate all parasitic capacitance and are therefore very suitable for the high performance filter realizations. In addition, they can be implemented with integrable passive component values for frequencies as low as a few tenth hertz. Çiçekoğlu (2001) proposed a new single input multiple output current mode multifunction filters which can simultaneously realize LP, HP, BP and Band Refect (BR) filter functions at all high impedance outputs, thus permits easy cascadadility. This circuit employs a minimum number of active elements, only four dual output current conveyors and five passive components, all grounded. Çiçekoğlu, Tarim, and Kuntman (2002) presented five new universal filters. These filters employ only ground passive components, which is advantageous for integration. No element matching conditions are imposed, which permits orthogonal adjustment of ω0 and Q.

Shah and Malik (2005) introduced a new single input and four outputs (SIFO), which gives simultaneous outputs of LP, HP, BP and Notch filters. This circuit has features like low input impedance, high output impedance, low passive sensitivity figures, independent tuning of the parameters ω0 and ω0/Q and orthogonal tuning of the parameters ω0 and Q. Keskin and Cam (2007) introduced a new DOCCII based Current Mode (CM) single-input and three-output (SITO) type biquad circuit. This filter employs minimum number of active and passive elements. Notch and all pass filter response can be obtained by interchanging corresponding outputs. All passive components are free from passive parameter matching conditions and grounded or virtually grounded.

Horng, Hou, Chang, Shie, and Chang (2007) presented two new current mode multifunction filters with high impedance outputs using minimum number of passive elements. These topologies have following advantages like use of minimum number of passive elements, realize all pass filter response, very low active and passive filter sensitivities, high output impedance which enables easy cascadadility without need of any supplementary buffer circuits. Soliman (2008) reviewed nineteen current mode filters. These filters are classified in two categories. In one category, floating passive elements and in remaining category, resistors and capacitors are grounded. Author also subcategorize each topology based on the filter capability to have independent control on the filter quality factor or not and most of topologies responses demonstrated. Yuce and Minaei (2008) focused on limitations of Current Conveyor (CC) based second order filters due to the gain constant and quality factor of the filter. Authors also concentrate on signal limitation problems due to the applied input current and give solutions to reduce the signal limitation problems of the filter. Time and frequency domain results of the proposed topology are also demonstrated. Chen (2013) proposed a new low input and high output impedance tunable CM universal biquadratic filter either single input and three outputs or three inputs and two outputs. This topology, realizes all the standard filter responses by choosing appropriate input and output terminals. Author also concentrates on non-ideal effects and parasitic element influence.

Ramezani and Ahmadpoor (2013) introduced another universal current mode filter, which was implemented by two CCII and five passive elements. The proposed topology illustrates high performance in features of low power, high frequency and low complexity. The cut-off frequency and quality factor changed by varying resistor values and same feature can provide digitally programmable implement capability by switches and logic pins. This topology especially useful in CM interface and RF application. Hamad (2016) employs only two Differential Voltage Current Conveyor (DVCC) and five passive elements, in which all are grounded and their corresponding sensitivities also low. Author illustrates non-ideality analysis, verified circuit operation in current mode and along with there are no conditions to impose for selecting components.

Naidu and Krishna (2017) surveyed different type Universal Current Conveyors with quality factor, resonance frequency and number of active and passive components with floating and grounded elements. Supavarasuwat, Kumngern, Sangyaem, Jaiklaand and Khateb (2018) introduced active block Voltage Differencing Differential Difference Amplifier (VDDDA) as controllable voltage-mode universal filter. The authors used three VDDDAs along with two grounded capacitors and a single grounded resistor. The proposed circuit has high input impedance for all input voltage nodes and low output impedance for output voltage node. Psychalinos, Kasimis, and Khateb (2018) proposed Multiple Input Single-Output Operational Transconductance Amplifier-Capacitor (MISO OTA-C), it offers all the attractive benefits of universal biquads, with minimum active and passive component count in comparison. The frequency response, linearity, and sensitivity are verified with simulation and experimentation. Tonk and Afzal (2019) realized a second order LP/BP filter and reconfigurable integrator and differentiator have been realized using CMOS based FDCCII. The filter is independent of gain, ωo and Q. The integrator's and differentiator's response are digitally controlled.

As per literature survey, Current Mode (CM) filter topologies can be classified into three types. Namely, (i) Multi Input and Multi Output (MIMO) type (ii) Multi Input and Single Output (MISO) type (iii) Single Input and Three Output (SITO) type. In this paper, SITO type is considered to realize Universal filer.

1. Objective of the Work

The main objective of the work is to design universal filters using novel topologies. The single circuit can be used for many filter circuit applications. The new proposed topologies are analyzed, and then tested.

2. Second Generation Current Conveyor

The block diagram of CCII is shown in Figure 1. It has an outputs Z+, which is in same phase as the input current. The matrix representation for the second generation current conveyor is (Smith & Sedra, 1968; Sedra & Smith, 1970; Surakampontorn, Riewruja, Kumwachara, & Dejhan, 1991).

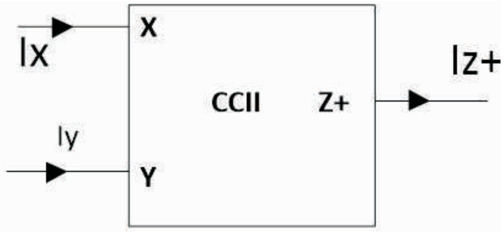

Figure 1. Block Diagram of CCII

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

The block diagram of CCII is implemented using CMOS technology is shown in Figure 2. The aspect ratio of MOS transistors used in implementation of CCII are shown in Table 1.

3. Proposed Circuits

One of the proposed Current Mode Universal filters realized with three second generation current conveyors (CCII) and 4 passive elements(two resistors and two capacitors) is as shown in Figure 3. High pass, Band pass and Low pass filter responses are observed at CCII-1, CCII-2, and CCII-3 respectively. From the CCII, it is known that $I_{z+} = I_x$, $V_x = V_y$. Let the input variables be V_{in} and I_{in}. Applying KCL at input node,

$$I_{in} = I_{lp} + I_{hp} \quad (2)$$

Applying KVL at the input,

$$V_{in} = I_{lp}R_1 = I_{bp}(R_2 + \frac{1}{sC_2}) = I_{hp}\frac{1}{sC_1} \quad (3)$$

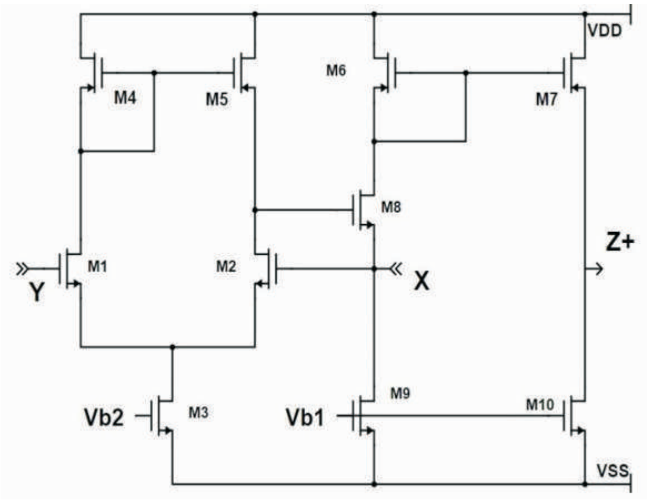

Figure 2. Internal Circuit diagram of CCII using CMOS (Sedra & Smith, 1970)

Transistor	W/LL Ratios (μm)
M1, M2, M3	14/0.7
M4, M5	16.8/0.7
M6, M7, M9, M10	5.6/0.7
M8	56/0.7

Table 1. W/L Ratio of Various Transistors used in CCII

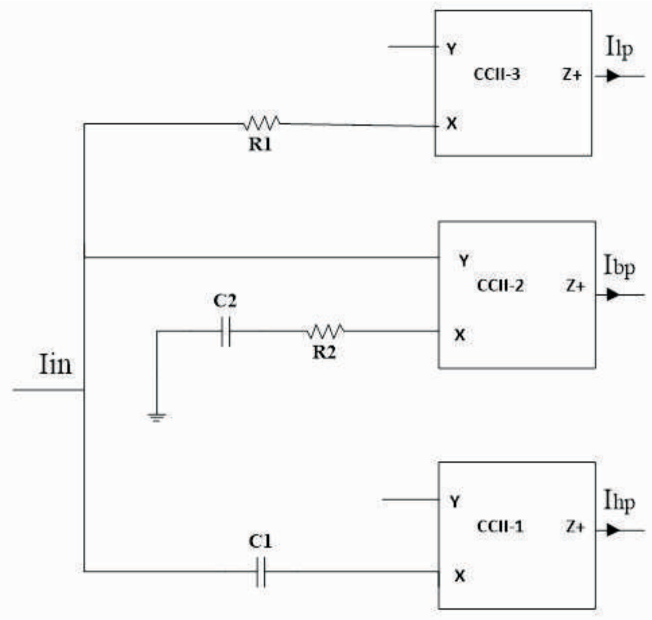

Figure 3. Proposed Current Mode Universal Filter

Therefore

$$I_{in} = \frac{V_{in}}{R_1} + \frac{V_{in}}{1/SC_1}$$

$$I_{in} = V_{in}(\frac{1}{R_1} + SC_1) \tag{4}$$

On substituting equation (3) in (4)

$$I_{in} = I_{bp}(R_2 + \frac{1}{SC_1})\,(\frac{1}{R_1} + SC_1)$$

$$I_{in} = I_{bp}\left(\frac{R_2}{R_1} + \frac{1}{SC_2R_1} + SC_1R_2 + \frac{C_1}{C_2}\right)$$

$$\frac{I_{bp}}{I_{in}} = \frac{SC_2R_1}{S^2C_1C_2R_1R_2 + S(C_1R_1 + C_2R_2) + 1} \tag{5}$$

The relation between lowpass and Bandpass currents is,

$$I_{lp}R_1 = I_{bp}(R_2 + \frac{1}{SC_2}) \tag{6}$$

By substituting I_{bp} value,

$$I_{lp}R_1 = I_{in}\left[\frac{SC_2R_1}{S^2C_1C_2R_1R_2 + S(C_1R_1 + C_2R_2) + 1}\right](R_2 + \frac{1}{SC_2})$$

$$\frac{I_{lp}}{I_{in}} = \frac{SC_2R_1\left[\frac{R_2}{R_1} + \frac{1}{SC_2R_1}\right]}{S^2C_1C_2R_1R_2 + S(C_1R_1 + C_2R_2) + 1}$$

$$\frac{I_{lp}}{I_{in}} = \frac{1 + SC_2R_2}{S^2C_1C_2R_1R_2 + S(C_1R_1 + C_2R_2) + 1} \tag{7}$$

Similarly using the relation between Bandpass and HighPass filters,

$$I_{bp}(R_2 + \frac{1}{SC_2}) = I_{hp}\frac{1}{SC_1} \tag{8}$$

By substituting I_{bp} value in above equation,

$$I_{hp}\frac{1}{SC_1} = I_{in}\left[\frac{SC_2R_1}{S^2C_1C_2R_1R_2 + S(C_1R_1 + C_2R_2) + 1}\right](R_2 + \frac{1}{SC_2})$$

$$\frac{I_{hp}}{I_{in}} = \frac{SC_2R_1\left(SC_1R_2 + \frac{C_1}{C_2}\right)}{S^2C_1C_2R_1R_2 + S(C_1R_1 + C_2R_2) + 1}$$

$$\frac{I_{hp}}{I_{in}} = \frac{S^2C_1C_2R_1R_2 + SC_1R_1}{S^2C_1C_2R_1R_2 + S(C_1R_1 + C_2R_2) + 1} \tag{9}$$

The values of ω_n and Q are shown in equations (10) and (11)

Natural frequency $\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}}$ (10)

Quality factor $Q = \frac{R_1C_1 + R_2C_2}{\sqrt{R_1R_2C_1C_2}}$ (11)

Sensitivity analysis:

$$S_{R_1}^{\omega_n} = S_{R_2}^{\omega_n} = S_{C_1}^{\omega_n} = S_{C_2}^{\omega_n} = -\frac{1}{2} \tag{12}$$

$$S_{R_1}^{Q} = S_{C_1}^{Q} = -S_{R_2}^{Q} = -S_{C_2}^{Q} = \frac{R_1C_1 - R_2C_2}{R_1C_1 + R_2C_2} \tag{13}$$

The Figure 4 shows another proposed current mode

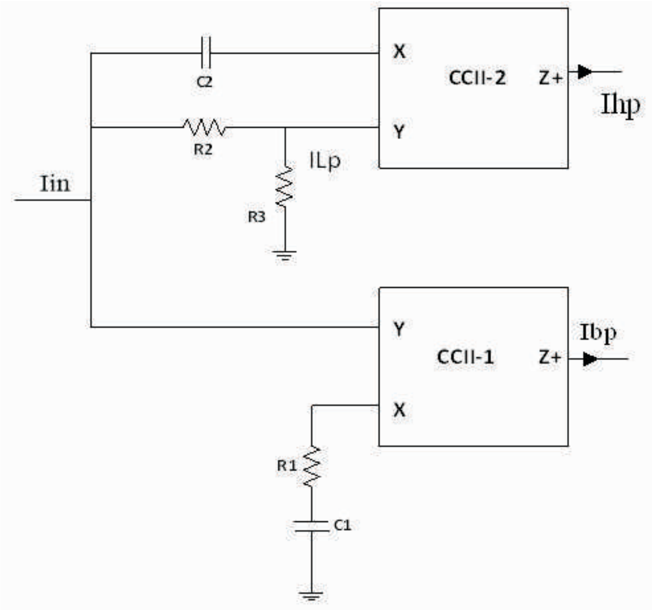

Figure 4. Proposed Current Mode Universal Filter Responses with High Impedance Outputs

Universal filters. This employs with two CCII and 5 passive elements (three resistors and two capacitors). Band pass and High pass filter responses are observed simultaneously at output terminals of CCII-1, CCII-2. Finally, Low pass filter response observed at R3. From the CCII, it is known that $I_{z+} = I_x$, $V_x = V_y$. Let the applied input voltage is V_{in} and current is I_{in}. Applying KCL at input node,

$$I_{hp} = \frac{V_{in}-V_{x2}}{1/SC_2}$$

$$I_{hp} = (V_{in} - V_{x2})SC_2$$

$$I_{hp} = \left[I_{lp}(R_2 + R_3) - I_{lp}R_3\right]SC_2 \qquad (14)$$

Where $V_{x2} = V_{y2} = R_3I_{lp}$ and $V_{in} = I_{lp}(R_2+R_3)$

Therefore $I_{hp} = I_{lp}R_2SC_2$ (15)

$$I_{lp} = \frac{V_{in}}{R_2+R_3} \text{ and } I_{bp} = \frac{V_{in}}{R_1+\frac{1}{SC_1}}$$

$V_{in} = I_{lp}(R_2 + R_3)$

$$-I_{bp} = \frac{I_{lp}(R_2+R_3)}{R_1+\frac{1}{SC_1}}$$

$$\text{Therefore } I_{bp} = -I_{lp}\frac{SC_1(R_2+R_3)}{SC_1R_1+1} \qquad (16)$$

$$\frac{I_{hp}}{I_{bp}} = -\frac{R_2C_2(1+SC_1R_1)}{C_1(R_2+R_3)} \qquad (17)$$

From the circuit

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

$$I_{in} = \frac{I_{hp}}{SR_2C_2} + I_{hp} \qquad \text{(From Equation (15))}$$

$$\frac{I_{hp}}{I_{in}} = \frac{SR_2C_2}{1+SR_2C_2} \qquad (18)$$

Since input current can be expressed as a sum of Low pass and HighPass currents,

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

$I_{in} = I_{lp} + I_{lp}SR_2C_2$

$$\frac{I_{lp}}{I_{in}} = \frac{1}{1+SR_2C_2} \qquad (19)$$

The simplified expression for the Bandpass Filter response will be,

$$\frac{I_{bp}}{I_{in}} = -\frac{SC_1(R_2+R_3)}{S^2C_1C_2R_1R_2+S(C_1R_1+C_2R_2)+1} \qquad (20)$$

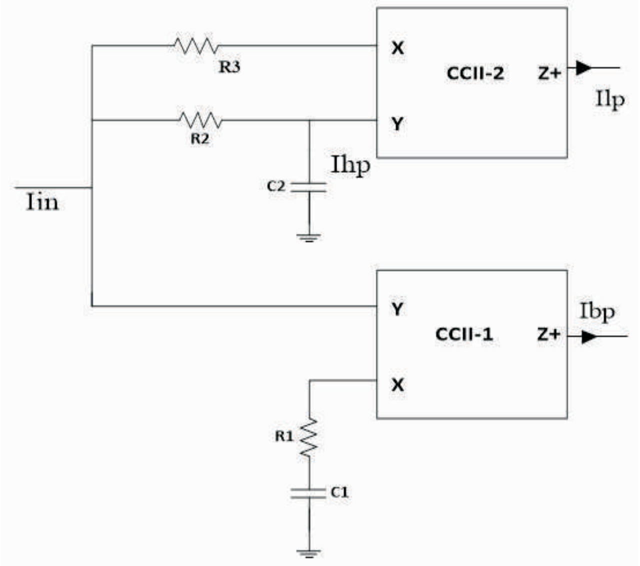

Figure 5. Proposed Current Mode Universal Filter Responses with high impedance outputs

The Third proposed Current mode Universal filters is shown in Figure 5. It has two CCII and 5 passive elements (three resistors and two capacitors). Band pass and Low pass filter responses are observed at output terminals of CCII-1, CCII-2 respectively. Finally, High pass filter response is observed at C_2. Applying KCL at input node,

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

$$I_{lp} = \frac{V_{in}-V_{x2}}{R_2}$$

$$I_{lp} = \frac{I_{hp}\left(\frac{1}{SC_2}+R_3\right)-I_{hp}R_3}{R_2} \qquad (21)$$

where,

$$V_{in} = I_{hp}\left(\frac{1}{SC_2} + R_3\right)$$

Therefore

$$I_{lp} = I_{hp}\frac{1}{SC_2R_2}$$

$$I_{hp} = \frac{V_{in}-V_{y2}}{1/SC_2} \qquad (22)$$

$$I_{hp} = \frac{-I_{bp}\left(R_1+\frac{1}{SC_1}\right)-I_{hp}R_3}{1/SC_2}$$

$$I_{hp}\left(\frac{1}{SC_2} + R_3\right) = -I_{bp}\left(R_1 + \frac{1}{SC_1}\right)$$

$$\frac{I_{hp}}{I_{bp}} = -\frac{(1+SC_1R_1)C_2}{(1+SC_2R_3)C_1} \tag{23}$$

We know,

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

$I_{in} = I_{lp}(1+SC_2R_2)$

Therefore,

$$\frac{I_{lp}}{I_{in}} = \frac{1}{1+SC_2R_2} \tag{24}$$

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

$$I_{in} = I_{hp}\frac{1}{SC_2R_2} + I_{hp}$$

$$\frac{I_{hp}}{I_{in}} = \frac{SC_2R_2}{1+SC_2R_2} \tag{25}$$

The expression for Bandpass filter response is,

$$\frac{I_{bp}}{I_{in}} = -\frac{(1+SC_2R_3)SC_2R_2}{(1+SC_1R_1)(1+SC_2R_2)}\frac{C_1}{C_2}$$

$$\frac{I_{bp}}{I_{in}} = -\frac{S^2C_1C_2R_2R_3+SC_1R_2}{S^2C_1C_2R_1R_2+S(C_1R_1+C_2R_2)+1} \tag{26}$$

4. Results

In this paper, three proposed Current Mode Universal Filters are simulated using Multisim software. First topology have three CCII blocks, remaining two topologies consists two CCII blocks. TheCCII block was realized by the CMOS implementation. For the purpose of simulation 0.7μm, level 1 MOSFETs are used. The supply voltages are

V_{DD} = -V_{SS} = -1.65V

V_{b1} = -1V

V_{b2} = -0.76V

The input source current of 2 μA with 1 kHz frequency is common for three models. Figure 6 represents frequency responses of Low pass, High Pass and Band Pass filters corresponding to the Figure 3. The chosen passive components values are R_1=100KΩ, R_2=50 KΩ, C_1=50 pF, C_2=100 pF. For, the Figure 4 and the Figure 5, the chosen values are R_1= 2R_2=350KΩ, R_3=1.5 KΩ C_1=0.2 nF C_2= 100 pF. The response of simulation results for the Figures 4 and 5 are showed in Figures 7 and 8 respectively. The Figures 9, 10, and 11 represents the relationship between

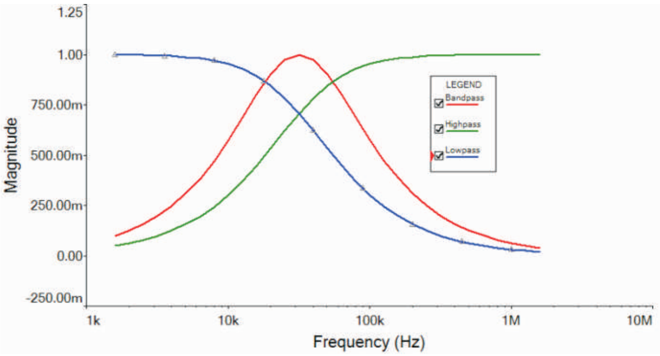

Figure 6. Normalized Magnitude Responses of LP, HP, BP, filters corresponding to Figure 3

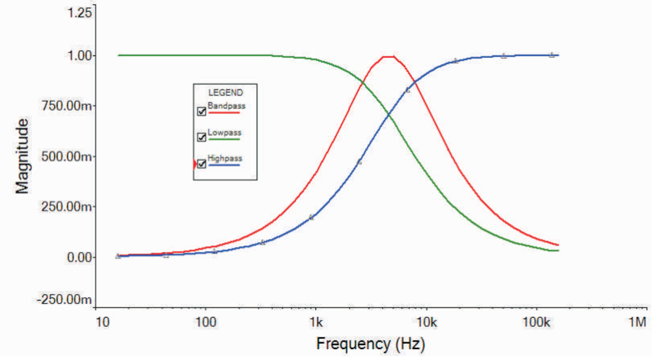

Figure 7. Normalize Magnitude Responses of LP, HP, BP, Filters Corresponding to Figure 4

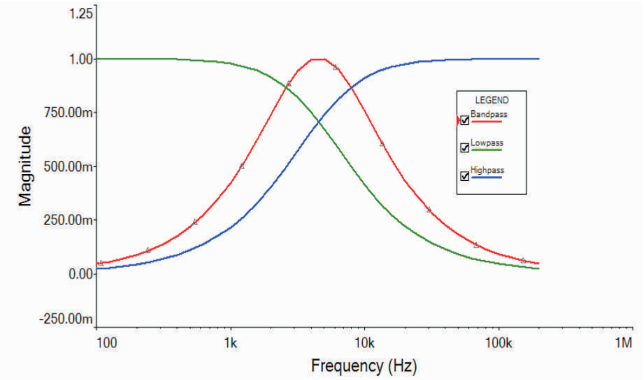

Figure 8. Normalize Magnitude Responses of LP, HP, BP, Filters Corresponding to Figure 5

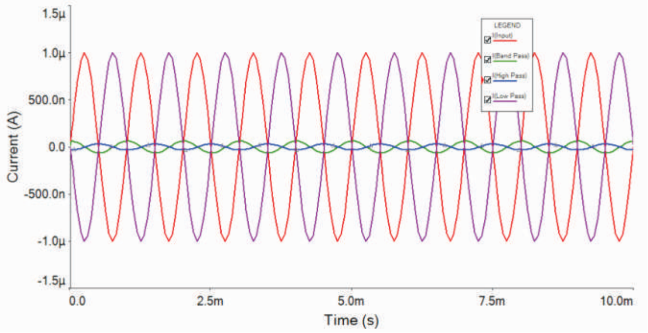

Figure 9. The Relationship between Input Current and Output Currents of Low Pass, High Pass and Band Pass Filters Corresponding to Figure 3

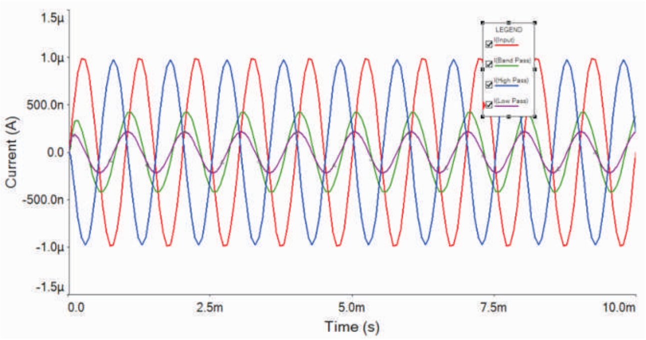

Figure 10. The Relationship between Input Current and Output Currents of Low Pass, High Pass and Band Pass Filters Corresponding to Figure 4

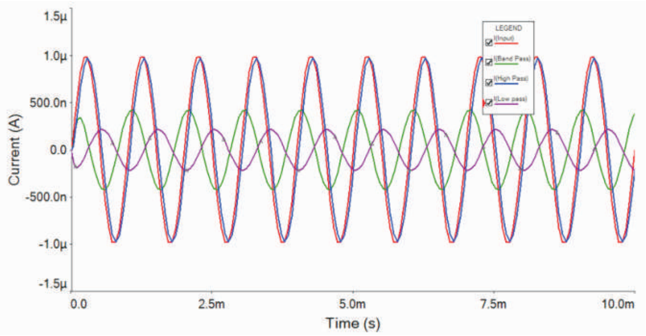

Figure 11. The Relationship between Input Current and Output Currents of Low Pass, High Pass and Band Pass Filters Corresponding to Figure 5

		No. of CCII					
Ref	Figure No. related to corresponding references	Single output (CCII-/CCII+)	Two Output (DOCCII)	No. of Passive components (R+C)	No. of Floating components	Q	Input impendence
Ozoguz et al. (1998)	Figure 2	3	0	3+2	2	Dependent	Frequency dependent
Toker et al. (1999)	Figure 1	0	3	2+2	3	Dependent	Frequency dependent
	Figure 2	0	3	2+2	4	Dependent	
	Figure 3	0	3	2+2	3	Dependent	
Çiçekoğlu et al. (2002)	Figure 2a	0	4	4+3	0	Dependent	Frequency dependent
	Figure 2b	1	3	4+2	0	Dependent	Low
	Figure 2c	0	4	3+3	0	Dependent	Low
	Figure 2d	1	3	3+3	0	Independent	Frequency dependent
	Figure 2e	0	4	3+3	0	Independent	Frequency dependent
Minaei et al. (2000)	Figure 2	0	4	3+3	0	Independent	Frequency dependent
Toker and Özuğuz (2001)	Figure 3	0	4	4+2	0	Dependent	Low
Çiçekoğlu (2001)	Figure 2	0	4	3+2	0	Independent	Frequency dependent
Toker and Ozoguz (2000)	Figure 3	0	3	3+2	0	Independent	Low
Shah and Malik (2005)	Figure 1	0	6	4+2	4	Independent	Frequency dependent
Keskin and Cam (2007)	Figure 2	0	3	2+2	1	Dependent	Low
Horng et al. (2007)	Figure 3	0	3	4+2	1	Dependent	Low
Sagbas, Fidanboylu, and Bayram (2004)	Figure 3	0	4	2+2	3	Dependent	Frequency dependent
	Figure 4	0	4	2+2	4	Independent	Frequency dependent
Ozoguz and Acar (1997)	Figure 1	4	0	2+2	0	Independent	Low
Soliman (2008)	Figure 16	1	3	3+2			
Yuce and Minaei (2008)	Figure 1	5	0	3+3	2	Dependent	Low
Chen (2013)	Figure 3	0	3	3+2	0	Independent	Low
Proposed Work	Figure 3	3	0	2+2	3	Dependent	Frequency dependent
Temizyurek and Myderrizi (2003)	Figure 3	0	2	3+2	0	Independent	Frequency dependent
Ramezani and Ahmadpoor (2013)	Figure 6	0	2	2+2	0	Dependent	Frequency dependent
Hamad (2016)	Figure 3b	0	2	3+2	0	Independent	Frequency dependent
Proposed Work	Figure 4	2	0	3+2	3	Independent	Frequency dependent
	Figure 5	2	0	3+2	3	Independent	Frequency dependent

Table 2. Comparison of the Proposed and Existing Circuits

input current and output current of low pass, High pass and Band pass filters corresponding to Figures 3, 4, and 5 respectively. The merits of the proposed filters over the existing filters are tabulated in Table 2.

Conclusion

In this paper, three new Current Mode Universal Filters has been proposed. One universal filter employs with three CCII and four passive components. Remaining two topologies implemented with only two CCII and five passive components. Plus type second order current conveyor (CCII+) is used in all configurations. Detailed mathematical analysis for three topologies are carried out. LP, HP, BP and BR filter response simultaneously realize all functions at high impedance outputs, thus can be used in cascadability. The Q-factor is independent in all these proposed circuits.

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