Voltage and Current Mode Filter Realizations using Active Devices

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Abstract -- **Two circuits employing one current conveyor (either CCII+ or CCII-) for realizing various second and first order filters are proposed. It is shown that minimum four (three) *RC* elements are required to realize second order (first order) filters.**

Keywords: All-pass filters, Current conveyors, Voltage mode filters, Current mode filters

I. INTRODUCTION

THERE are many circuits reported by the researchers [1]-[28] [30]-[33]in the past for realizing all-pass (AP) filters. Some of them are passive and active, some are first and second order, some are voltage mode and current mode, some are the special cases of more general circuit. They had selected the particular circuit and chosen the values. In this paper, *some of these filters are derived logically from two general circuits using a single current conveyor.* Second order filters are derived using 1 capacitor and 2 resistors or 2 capacitors and 1 resistor, while first order filters are derived using 1 capacitor and 2 resistors or 2 capacitors and 1 resistor.

II. FILTER REALIZATIONS

2.1 Second order filters

Circuit A: Consider the circuit A shown in Fig. 1 where CC II+ is a current conveyor with the following terminal characteristic [1].

$$V_X = V_Y, I_Y = 0, I_Z = I_X \quad (1)$$

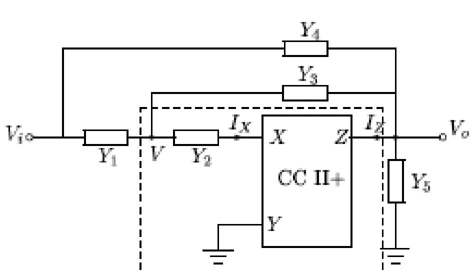


Figure 1. Circuit A.

Its voltage transfer function is given by

$$T(s) = \frac{Y_1Y_4 + Y_2Y_4 + Y_3Y_4 - Y_1Y_2 + Y_1Y_3}{Y_1Y_4 + Y_2Y_4 + Y_3Y_4 + Y_1Y_5 + Y_2Y_5 + Y_3Y_5 + Y_1Y_3 + 2Y_2Y_3}. \quad (2)$$

From Fig. 1, it is obvious that Y_5 cannot be ∞, otherwise the output will be grounded. Assuming that each admittance consists of a single component, *it can be either a resistor or a capacitor*. Note that when $Y_3 = 0$ ($Y_1 = \infty$), Y_1 and Y_2 (Y_3 and Y_4) come in series (parallel). they can be replaced by the equivalent admittance $Y_a = Y_1Y_2/(Y_1 + Y_2)$, $Y_b = Y_3 + Y_4$. Thus,Y_a (Y_b) can have one resistor and one capacitor in series (parallel). Therefore, the interchange of the resistor and the capacitor in Y_a and/or Y_b does not give a new circuit. Since all the terms in the numerator and the denominator are product of two admittances, we can have the highest power of *s* as 2. Therefore, *it is not possible to realize filters with order greater than 2*. We are looking for filters which require minimum number of capacitors N_C and minimum number of total passive components *N*. For second order filters, $N_C = 2$. Therefore, we can choose *two admittances as capacitors and the remaining may be resistors*. Only Y_5 can have a capacitor grounded. However, Y_5 does not appear in the numerator, we cannot generator s^2 terms with Y_5 as a capacitor. Therefore, *this configuration cannot realize any capacitor grounded.* Now Y_5 can only be a resistor. To generate a s^2 (s^o) terms in both the numerator and the denominator, we must have the product of two capacitances (resistances) and these product terms must be present both in the numerator and the denominator. To reduce *N*, there are many choices: Any one product of admittances out of 5 can be capacitors and the remaining can be resistors. An *s* term is generated by product of a capacitance and a resistance. The negative term Y_1Y_2 in the numerator must be present for realizing all filters other than a band-pass filter. Therefore, Y_1 and/or Y_2 cannot be zero for these filters. Now we proceed further to realize specific second order filters and then the first order filters, followed by current mode filters.

2.1 Second order filters

2.11 Circuit A1: Let

$$Y_1 = G, Y_2 = sC, Y_3 = \frac{G}{m},$$
$$Y_4 = nsC, Y_5 = 0, \quad m, n > 0$$

Then, from Eq (2),

$$T_1(s) = \frac{ns^2 + s\left(n + \frac{n}{m} - 1\right)\frac{G}{C} + \frac{G^2}{mC^2}}{ns^2 + s\left(n + \frac{n}{m} + \frac{2}{m}\right)\frac{G}{C} + \frac{G^2}{mC^2}}. \quad (3)$$

For BP, the condition is

$$n + \frac{n}{m} = 1.$$

$$\rightarrow m = \frac{n}{1-n}, \quad n < 1. \tag{4}$$

Suitable value of *n* may be chosen to keep the spread of capacitors in practical limits, and then *m* may be evaluated from Eq. (3).

For AP, the condition is

$$n + \frac{n}{m} - 1 = -\left(n + \frac{n}{m} + 2\frac{n}{m}\right)$$
$$\rightarrow m = \frac{4}{1-2n}, \quad n < \frac{1}{2}. \tag{5}$$

BR and AP filters are shown in Fig. 2. LP, BP, HP filters cannot be obtained because s^2 and s^0 terms cannot be made 0.

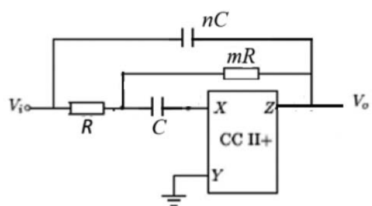


Figure 2. Circuit A1 for BR and AP filters.

Filter type	*m*
BR	$\frac{n}{1-n}, \quad n < 1$
AP	$\frac{4}{1-2n}, \quad n < \frac{1}{2}$

Circuit A2: Let

$$Y_1 = sC,\ Y_2 = G,\ Y_3 = nsC,\ Y_4 = G/m,\ Y_5 = 0. \tag{6}$$

Then Eq. (2) gives

$$T_2(s) = \frac{ns^2 + s\left(\frac{n}{m} + \frac{1}{m} - 1\right)\frac{G}{C} + \frac{G^2}{mC^2}}{ns^2 + s\left(\frac{n}{m} + \frac{1}{m} + 2n\right)\frac{G}{C} + \frac{G^2}{mC^2}}.$$

Following the similar procedure as above, the results are given in Fig. 3.

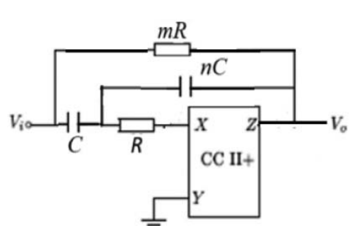


Figure 3. Circuit A2 for BR and AP filters.

Filter type	*m*
BR	$m = n + 1$
AP	$\frac{2(n+1)}{1-2n}, \quad n < \frac{1}{2}$

Circuit A3: Let

$$Y_1 = G,\ Y_2 = sC,\ Y_3 = 0,\ Y_4 = snC + G/m,$$
$$\text{or } \left\{Y_1 = \infty, Y_2 = \frac{sC}{1+sCR},\ Y_3 = \frac{G}{m}, Y_4 = snC,\ Y_5 = 0.\right\} \tag{7}$$

Then

$$T_3(s) = \frac{ns^2 + s\left(\frac{1}{m} + n - 1\right)\frac{G}{C} + \frac{G^2}{mC^2}}{ns^2 + s\left(\frac{1}{m} + n + 2n\right)\frac{G}{C} + \frac{G^2}{mC^2}}.$$

Following the similar procedure as above, the results are given in Fig. 4.

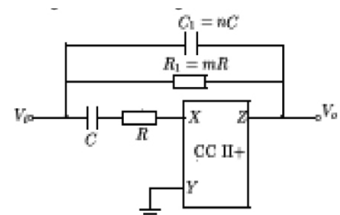


Figure 4. Circuit A3 for BR and AP filters.

Filter type	*m*
Band pass	$m = \frac{1}{n-1}, \quad n < 1$
	$\frac{2}{1-4n}, \quad n < \frac{1}{4}$

Circuit A4:

$$Y_1 = sC,\ Y_2 = G,\ Y_3 = G/m,\ Y_4 = nsC,\ Y_5 = 0.$$
$$m, n > 0.$$

$$T_4(s) = \frac{ns^2 + s\left\{n + \frac{n}{m} + \frac{1}{m} - 1\right\}\frac{G}{C} + \frac{G^2}{mC^2}}{ns^2 + s\left\{n + \frac{n}{m} + \frac{1}{m}\right\}\frac{G}{C} + \frac{2G^2}{mC^2}}. \tag{8}$$

This circuit will not have the geometric symmetry around the null frequency for BR filter, and will not give any other standard filter. The results are given in Fig. 5.

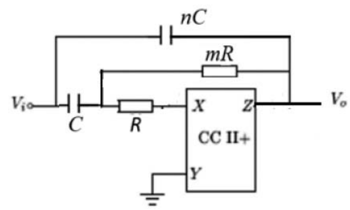


Figure 5. Circuit A4 for BR and AP filters.

Filter type	*m*
BR	$\frac{1+n}{1-n}, \quad n<1$

Circuit A5: Let

$$Y_1 = G,\ Y_2 = sC,\ Y_3 = 0,\ Y_4 = nsC,\ Y_5 = G/m \tag{9}$$

$$T_5(s) = -\frac{ns^2 + s(n-1)\frac{G}{C}}{ns^2 + s\left(n + \frac{1}{m}\right)\frac{G}{C} + \frac{G^2}{mC^2}}. \tag{10}$$

This is an HP filter function when $n = 1$. The circuit is shown in Fig. 6 where m is chosen as 1 to have equal valued resistors.

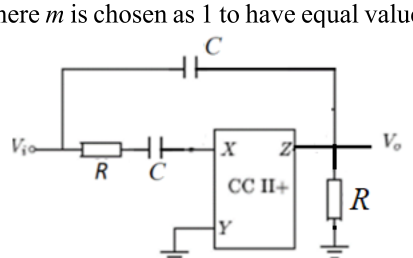


Figure 6. Circuit A5 for high-pass filter.

Circuit A6: Let

$$Y_1 = G,\ Y_2 = 0,\ Y_3 = sC,\ Y_4 = nsC,\ Y_5 = G/m.$$

$$T_6(s) = -\frac{ns^2 + s(n-1)\frac{G}{C}}{\left\{ns^2 + s\left(n + 1 + \frac{1}{m}\right)\frac{G}{C} + \frac{G^2}{mC^2}\right\}}. \tag{11}$$

This function represents an HP function when $n = 1$. The circuit is shown in Fig. 7 where m is chosen as 1 to have equal valued resistors.

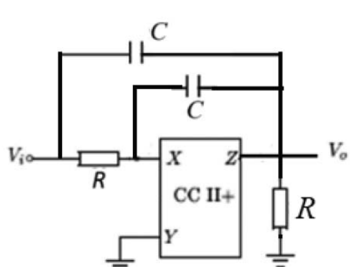


Figure 7. Circuit A6 for high-pass filter.

Circuit A7: Let

$$Y_1 = \frac{sGC}{sC+G},\ Y_2 = \infty,\ Y_3 = (nsC + G/m),\ Y_4 = 0,\ Y_5 = 0. \tag{12}$$

$$T_7(s) = -\frac{sG/C}{2n\left\{s^2 + s\left(1 + \frac{1}{nm}\right)\frac{G}{C} + \frac{G^2}{mnC^2}\right\}}.$$

This is a band-pass function. The circuit is shown in Fig. 8. For unity gain at the resonance frequency, the condition is

$$\left(1 + \frac{1}{nm}\right) = 1$$
$$m = \frac{2}{1-2n}, \quad n < \frac{1}{2}. \tag{13}$$

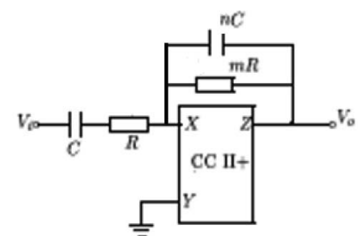


Figure 8. Circuit A7 for band-pass filter.

Circuit B:

Consider the circuit B shown in Fig. 9 where CC II- has the terminal characteristic [2].

$$V_X = V_Y,\ I_Y = 0,\ I_Z = -I_X. \tag{14}$$

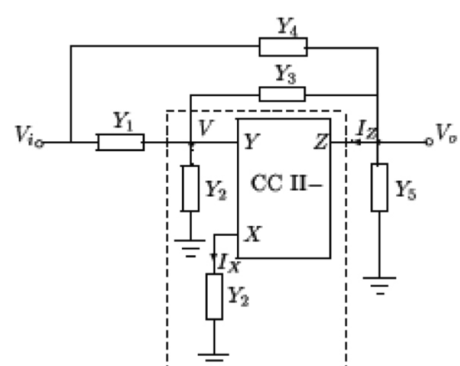


Figure 9. Circuit B.

From Fig. 9, we note the following.

1. It has 6 admittances, two of them are Y_2, and three of them are grounded. Thus, there is a possibility of having grounded capacitor(s).
2. It has the same transfer function as given by Eq. (2). Hence the same treatment is possible as given above for circuit 1. However, due to two Y_2, it will require a greater number of elements. In case $Y_1 = \infty$, Y_2 connected at Y gets

directly connected to the voltage source, therefore, it can be eliminated. In such cases, the number of elements will be the same as in Circuit 1.To conserve space, we are not showing explicitly these circuits.

More filter circuits

(a) By RC:CR transformation: Since each of the above circuits obtained has two capacitors and two resistors, RC:CR transformation will convert them into different circuits but the same number of resistors and capacitors.

(b) Since all the realizations of *T*(*s*) obtained from circuit A have virtual ground, a new function can be obtained by interchanging the input and ground terminals [2] given by

$$1 - T(s) = \frac{Y_1Y_5 + Y_2Y_5 + Y_3Y_5 + Y_1Y_2}{Y_1Y_4 + Y_2Y_4 + Y_3Y_4 + Y_1Y_5 + Y_2Y_5 + Y_3Y_5 + 2Y_2Y_3 + Y_1Y_3}. \quad (15)$$

Since there is no negative term present in the numerator, only band-pass filters can be realized. For example, the realization shown in Fig. 4 reduces, after interchanging the input and ground terminals, to band-pass filter shown in Fig. 10.

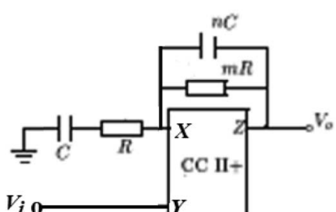


Figure 10. Band-pass filter.

Filter type	*m*
Band pass	$m = \frac{1}{n-1}, \quad n < 1$
	$\frac{2}{1-4n}, \quad n < \frac{1}{4}$

First order circuits

It will be shown in the next section that the minimum number of elements required for a first order filter is 3: (2*R* + 1*C*) or (1*R* + 2*C*). Therefore, one has to either remove one capacitor or 1 resistor from the second order filters.

Circuit B1:

Remove the capacitor *nC, i.e.,nC* = 0 from Circuit 11. Thus, we get

$$Y_1 = G,\ Y_2 = sC,\ Y_3 = G/m,\ Y_4 = Y_5 = 0 \quad (16)$$

Then from Eq. (2)

$$T_8(s) = -\left[\frac{s - \frac{G}{mC}}{\frac{2}{m}s + \frac{G}{mC}}\right].$$

For all-pass filter, the condition is *m* = 2. The circuit is shown in Fig. 11(b)(i).

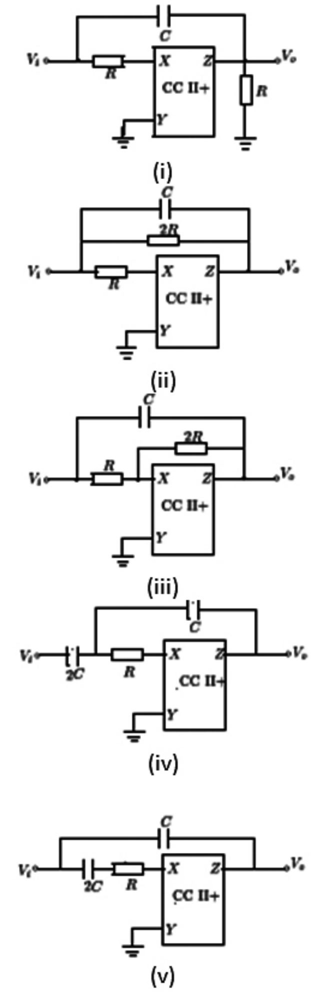
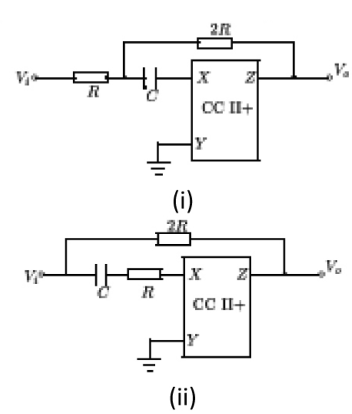
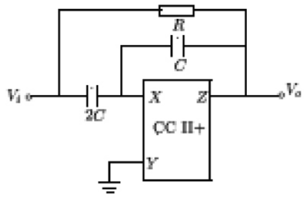
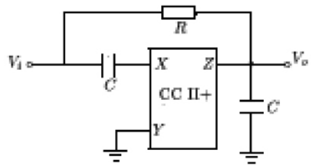


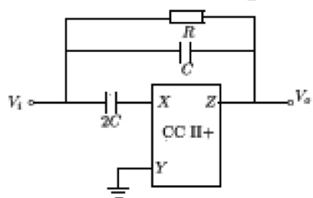
Figure 11 (a). First order AP filters with positive gain.





(iii)





(iv)

Figure 11 (b). First order AP Filters with negative gain

Circuit B2: Let

$Y_1 = G,\ Y_2 = \infty,\ Y_3 = G/m,\ Y_4 = sC.$

From Eq. (2), we get

$$T_9(s) = \left[\frac{s - \frac{G}{C}}{s + \frac{2G}{mC}}\right] \quad (17)$$

For all-pass filter, the condition is $m = 2$. The circuit is shown in Fig. 9(a)(iii).

Circuit B3:

Let

$Y_1 = G, Y_2 = sC,\ Y_3 = 0,\ Y_4 = G/m.$

Then, from Eq (2),

$$T_{10}(s) = \frac{(1/m - 1)s - G/Cm}{(1/m)s + G/Cm}.$$

LP filter: Condition is

$$m = 1$$

Circuit B4: Let

$Y_1 = sC,\ \ Y_2 = G,\ Y_3 = 0,\ Y_4 = nC,\ Y_5 = 0$

$$T_{11}(s) = \frac{ns - (1 - n)G/C}{ns + nG/C}$$

(i) HP filter: Condition is

$$n = 1$$

(ii) AP filter: Condition is

$$n = 1/2.$$

Circuit B5: Let

$Y_1 = sC,\ Y_2 = G,\ Y_3 = G/m,\ G_4 = 0,\ Y_5 = 0.$ Then

$$T_{12}(s) = \frac{s(1 - m)}{s + \frac{2G}{Cm}}.$$

It is a high-pas filter, when m < 1.

Similarly, various first order filters are obtained from the second order AP filters from circuit A. Only first order all-pass filters are shown in Fig. 11 and the conditions of realizations are summarized in Table 1.

Similarly, additional 8 filters are obtained from circuit B and are shown in Fig. 12.

Note the following.

1. The circuits shown in Fig. 11(a) have positive gain and those shown in Fig. 11(b) have negative gain.

2. Positive gain filters of *N*th order, when *N* is odd, can be converted into negative gain filters by RC:CR transformation [5]. However, for *N* even, the sign of $T(s)$ remains unchanged. Thus 1*C*+2*R* filters are converted into 2*C*+1*R* filters.

3. All the first order filters of Figs 11 and 12 require 3 passive elements except that shown in Fig. 11(a)(iii) and 11(b)(i) which require 4 elements because *R* and *C* in these figures are not connected directly across an ideal voltage source. Only CC II– filters of Figs.12(b)(i, ii, iii) have all the capacitor(s) grounded. This situation is especially suitable for integrated circuit technology.

4. All those voltage realizations, which have a virtual ground, can be converted into current mode realizations by changing Y and Z terminals of the current conveyors [29]. Current mode realizations using other devices (FTFN, CFA, OA, can be seen in [29].

Table 1: Elements for first order all-pass filters given in Fig. 11

Figure No	Y_1	Y_2	Y_3	Y_4	Y_5
Positive Gain					
11a(i)	∞	G	sC	0	G
11a(ii)	∞	G	$G/2$	sC	0
11a(iii)	G	∞	$G/2$	sC	0
11a(iv)	sC	G	$sC/2$	0	0
11a(v)	sC	G	0	$sC/2$	0
Negative Gain					
11b(i)	G	sC	G/2	0	0
11b(ii)	sC	G	0	$G/2$	0
11b(iii)	sC	∞	$sC/2$	G	0
11b(iv)	sC	∞	0	G	sC
11b(v)	∞	sC	$sC/2$	G	0

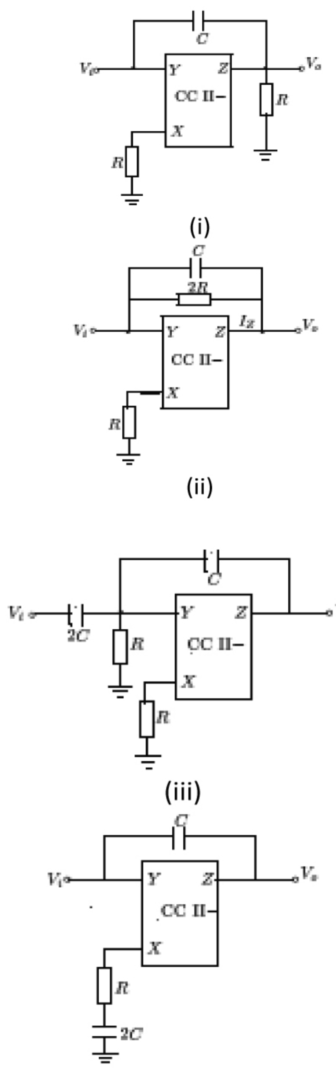


Figure 12 (a): First order all-pass filters with positive gain.

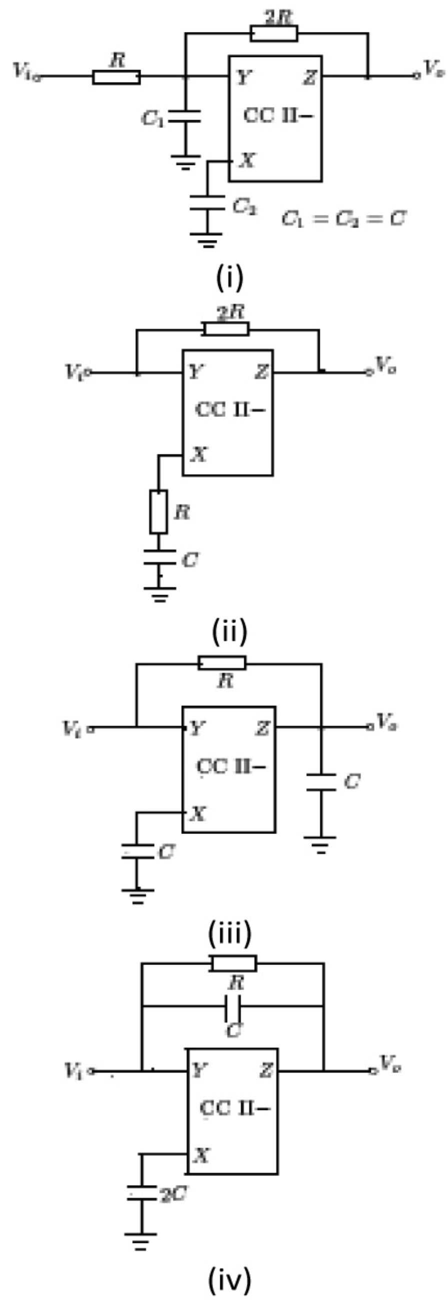


Figure 12 (b). First order all-pass filters with negative gain.

3. Minimal all-pass realizations

First order all-pass filter can be considered as a special case of $T(s) = (s - \tau_1)/ (s + \tau_2)$ when $\tau_1 = \tau_2$. Since T' has a positive real zero, it cannot be realized with only passive elements. Thus, at least one active element is required. Further, since T' is of first order, at least one capacitor is required. Finally, since $\tau_{1,2}$ have the dimensions of time, they must represent two different RC products, and therefore, at least one capacitor (resistor) and two resistors (capacitors) are required to give $\tau_{1,2} = CR_{1,2}$ $(C_{1,2}R)$. Thus, (1C, 2R) (2C, 1R) and one active element constitute the minimal realization of T'. Since, τ_1=τ_2 in (8) does not reduce the number of internal critical frequencies of *T'*, the same number of passive and active elements also constitute the minimal realization of *T*. Therefore, all the first order all-pass filters shown in Figs 3 and 5, except that shown in Figs 5(a)(iii) and 5(b)(i), are minimal.

IV. CONCLUSION

Two circuits using a single current conveyor (CCII+ or CII-) as active devices are introduced for realizing several second and first order filters. It has been shown that *C*, 2*R* or 2*C* 1*R*, and 1 active element constitute minimal 1st order realizations. Other realizations using different active devices, such as FTFN, CFA, OA etc., by input and ground interchange, by RC:CR transformation, and voltage mode to current mode transformation are possible. We have not attempted to provide experimental results as they have been tested by several authors.

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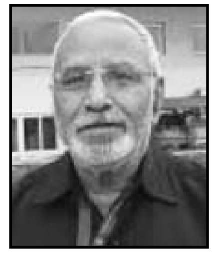

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