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On the generation of CCII and ICCII oscillators from three Op Amps oscillator

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ABSTRACT

A new quadrature oscillator using two current conveyors (CCII) and two inverting current conveyors (ICCII) is generated from a three Op Amp two integrator loop oscillator. The proposed oscillator is generalized and it is found that it is a member of a family of 64 oscillator circuits using combination of CCII and ICCII. Four of the reported oscillators are floating. The three Op Amps oscillator is also found to be the reference oscillator circuit in the generation of two basic CCII two integrator loop grounded passive element oscillators. The nodal admittance matrix (NAM) expansion is used to show the basic steps in the generation of the two alternatives CCII grounded passive element oscillators. Each of the two CCII oscillators is a member of a family of sixteen oscillator circuits using combination of CCII and ICCII. Two of the reported oscillators are floating and their adjoint oscillator circuits are not floating. Simulation results are included.

1. Introduction

Several Op Amp RC sinusoidal oscillator circuits are available in the literature. The two integrator loop oscillator using three Op Amps has received attention since long time and is modified in [1] to have independent control on the frequency of oscillation. Due to the frequency dependent nature of the Op Amp gain [2], the actual performance of the Op Amp RC oscillators differs from the ideal performance. A two integrator loop oscillator using grounded capacitors and bipolar transistors was introduced in [3]. A grounded passive element two integrator loop oscillator using current conveyors (CCII) [4] as the active element was introduced in [5]. Most recently a detailed study of the two integrator loop oscillators was given in [6].

2. The three Op Amps oscillator

A new modified oscillator circuit with independent control on the condition of oscillation and on the radian frequency of oscillation is introduced recently in [7] and is shown in Fig. 1.

The analysis in this section is based on assuming matched Op Amps are used and using the single pole model of the Op Amp which is represented by the following Eq. [2]:

$$A=\frac{\omega t}{s} \tag{1}$$

The NAM equation based on using the single pole model of the Op Amp and neglecting second order terms is obtained as

$$Y=\begin{bmatrix} sC_1+G_1-G_3+\dfrac{G_1+3G_3+G_4}{\omega t}s & G_4 \\ -G_2+\dfrac{2G_2}{\omega t}s & sC_2+\dfrac{G_2}{\omega t}s \end{bmatrix} \tag{2}$$

The partially self compensated oscillator shown in Fig. 2 uses the feed-forward technique introduced in [8] to cancel the excess phase lag introduced by the inverter stage as will be explained next.

For the circuit of Fig. 1 the transfer function of the inverter stage is given by

$$\frac{V_O}{V_1}=\frac{-1}{1+(2/A_2)} \tag{3}$$

Using the single pole model given by Eq. (1) it is seen that the inverter stage provides excess phase lag given by $-2\omega/\omega_{t2}$.

For the circuit of Fig. 2 the transfer function of the self compensated inverter stage is given by

$$\frac{V_O}{V_1}=-\frac{1+(2/A_1)}{1+(2/A_2)} \tag{4}$$

For matched Op Amps $A_1=A_2$ and the inverter stage behaves as ideal inverter.

For the circuit of Fig. 2 the NAM equation is given by

$$Y=\begin{bmatrix} sC_1+G_1-G_3+\dfrac{G_1+G_3+G_4}{\omega t}s & G_4 \\ -G_2 & sC_2+\dfrac{G_2}{\omega t}s \end{bmatrix} \tag{5}$$

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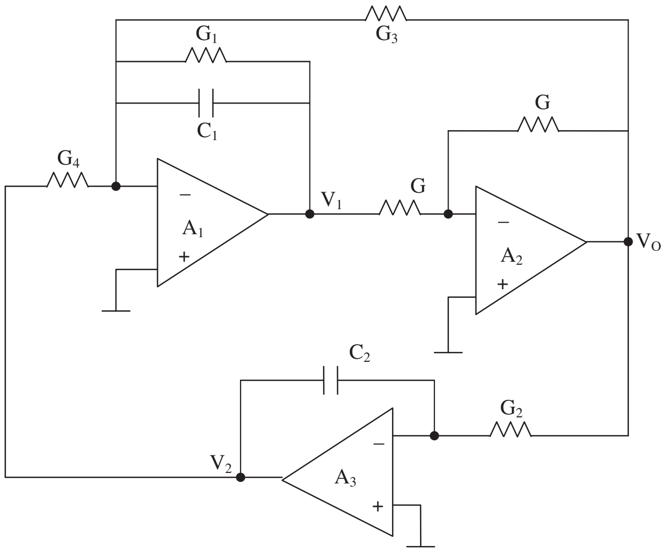


Fig. 1. Three Op Amp two integrator loop oscillator.

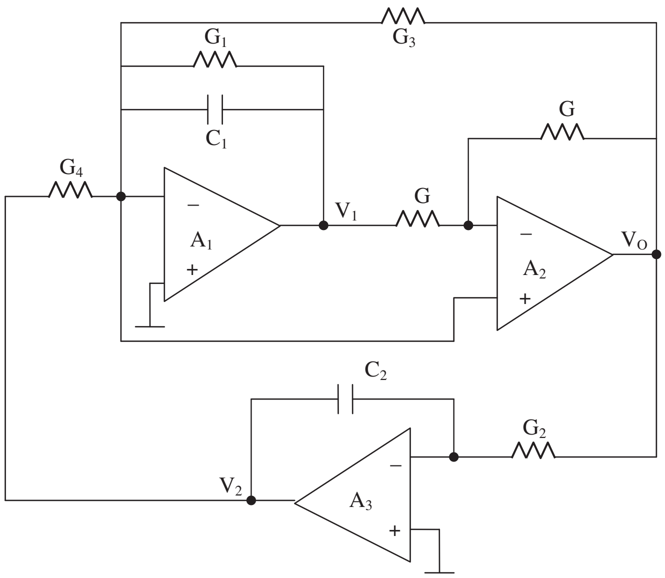


Fig. 2. Feed-forward partial compensation applied to circuit of Fig. 1.

Neglecting second order terms the characteristic equation is given by

$$s^2C_1C_2+s\left(C_2+\frac{G_2}{\omega t}\right)(G_1-G_3)+G_2G_4=0 \tag{6}$$

The condition of oscillation is given by

$$G_3=G_1 \tag{7}$$

Assuming ideal Op Amps the NAM equation is simplified to

$$Y=\begin{bmatrix} sC_1+G_1-G_3 & G_4 \\ -G_2 & sC_2 \end{bmatrix} \tag{8}$$

The characteristic equation in this case is given by

$$s^2C_1C_2+sC_2(G_1-G_3)+G_2G_4=0 \tag{9}$$

The condition of oscillation is the same as given by Eq. (7) and is controlled by G_3 or G_1 without affecting the radian frequency of oscillation which is given by

$$\omega_o=\sqrt{\frac{G_2G_4}{C_1C_2}} \tag{10}$$

The frequency of oscillation is independently controlled by G_2 or G_4 without affecting the condition of oscillation.

It should be noted that real world oscillators are nonlinear circuits. The above analysis is based on assuming linear oscillators and is used as a starting point for oscillator design. The steady state oscillations however are achieved by varying G_3 or G_1 controlling the s term.

3. The four conveyors oscillator

A grounded capacitor equivalent circuit to Fig. 2 is shown in Fig. 3(a). In addition to the two grounded capacitors the circuit uses two CCII, two ICCII+, two grounded resistors and two floating resistors. It has the same characteristic equation given by Eq. (9). This is a new oscillator circuit and can provide two quadrature output currents as well as four output voltages.

3.1. *Generation of the family of four conveyor oscillators*

This circuit belongs to a family of oscillators that can be obtained by generalizing the circuit of Fig. 3(a) using generalized conveyors (GC) defined by

$$I_Y=0,\quad V_X=aV_Y \text{ and } I_Z=KI_X \tag{11}$$

where $a=1$ for CCII and $a=-1$ for ICCII.

$K=1$ for CCII+ and ICCII+ and $K=-1$ for CCII– and ICCII–. A summary of definitions of pathological elements and realizations of Op Amp and different types of current conveyors are included in Tables 1 and 2. Fig. 3(b) represents the realization of the GC using voltage controlled voltage source (VCVS) of gain a, and current controlled current source (CSCS) of gain K.

The generalized circuit topology is shown in Fig. 3(c).The oscillator family members can be obtained from the following generalized characteristic equation:

$$s^2C_1C_2+sC_2[G_1+K_1a_2G_3]+K_1K_3a_2a_3a_4G_2G_4=0 \tag{12}$$

The necessary conditions of oscillation are given by

$$K_1a_2=-1 \quad K_1K_3a_2a_3a_4=1 \tag{13}$$

$$G_1=G_3 \tag{14}$$

The radian frequency of oscillation is given by Eq. (10).The condition of oscillation is controlled by the grounded conductance G_1 without affecting the radian frequency of oscillation which is controlled by the grounded conductance G_2 without affecting the condition of oscillation.

The generation technique from a known topology was introduced and used in [9–11]. There are sixty four circuits satisfy the coefficient conditions given by Eq. (13), thirty two of them are specified in Table 3. Taking K_2 to be positive and keeping all other parameters unchanged for circuits from circuit 1 to circuit 16 results in the additional circuits from circuit 17 to circuit 32 as shown in Table 3. Next taking K_4 to be positive and keeping all other parameters unchanged results in the remaining additional thirty two circuits not shown to limit table length. Four of the sixty four oscillator circuits are floating as shown in Table 3, the floatation of the circuit is determined with the two currents at the Z terminals of conveyors 2 and 4 taken into account. It should be noted that the only floating circuit which uses four identical building blocks is circuit number 1 which uses four CCII −. Circuit number 4 uses two CCII– and two ICCII–, circuit number 9 uses three CCII– and one ICCII– and finally circuit number 12 uses one CCII– and three ICCII–.

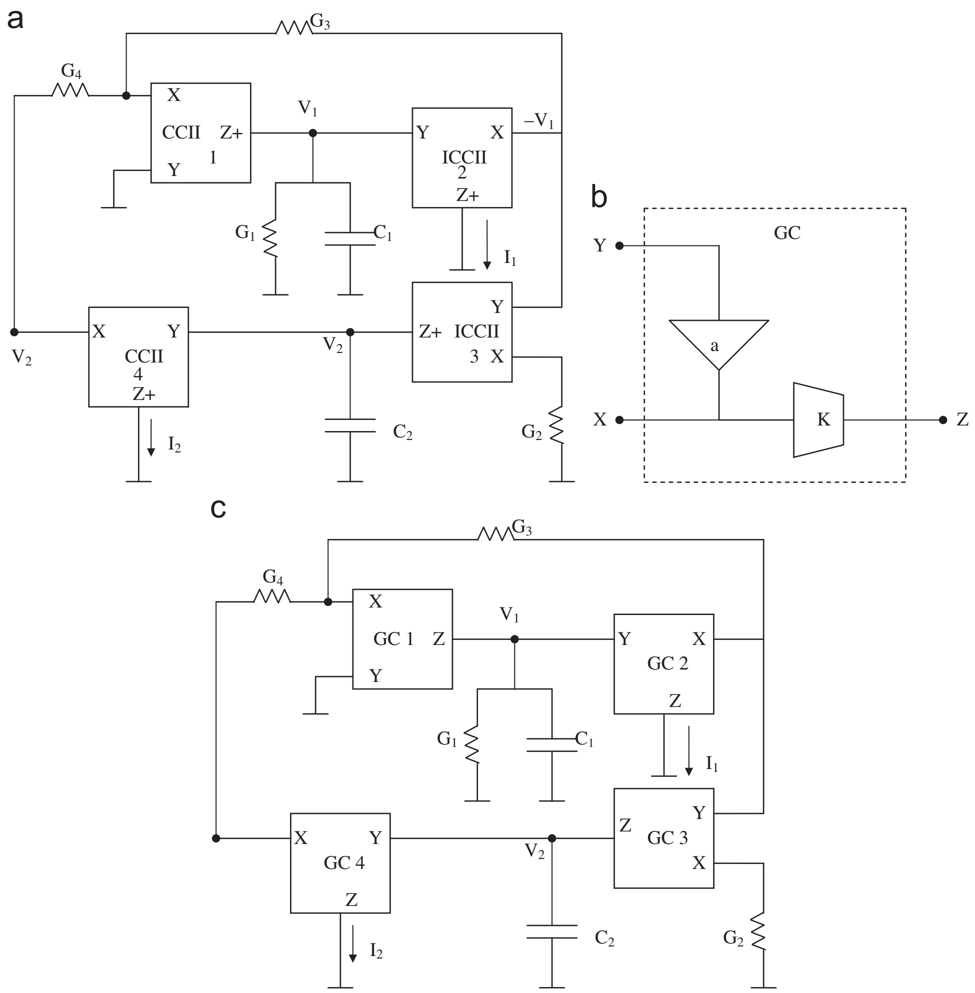


Fig. 3. (a) Two CCII+, two ICCII+ grounded capacitor quadrature oscillator. (b) Realization of GC using VCVS and CCCS. (c) Generalized grounded capacitor quadrature oscillator

4. Generation of grounded passive element oscillators

The two grounded passive element oscillator circuits considered in this section were first introduced in [12] and were generated from the two integrator loop oscillator using CCII introduced in [5] to have independent control on condition of oscillation. It is shown here that the CCII circuits are related to the three Op Amp oscillator circuit shown in Fig. 1.The NAM expansion method introduced in [13–15] and generalized in [16–19] is used next to show the generation steps for the two CCII oscillators.

4.1. The first oscillator circuit

Consider Eq. (8) representing the Y matrix of the three Op Amp oscillator. And adding a blank third row and column, and using a nullator between nodes 1 and 3 and a CM [20,21] between nodes 2 and 3 to move $-G_2$ to the diagonal position 3, 3 therefore

$$Y=\begin{bmatrix} sC_1+G_1-G_3 & G_4 & 0 \\ 0 & sC_2 & 0 \\ 0 & 0 & G_2 \end{bmatrix} \qquad (15)$$

Adding a blank fourth row and column, and using a nullator between nodes 2 and 4 and a norator between nodes 1 and 4 to move G_4 to the diagonal position 4, 4 therefore

$$Y=\begin{bmatrix} sC_1+G_1-G_3 & 0 & 0 & 0 \\ 0 & sC_2 & 0 & 0 \\ 0 & 0 & G_2 & 0 \\ 0 & 0 & 0 & G_4 \end{bmatrix} \qquad (16)$$

Adding a blank fifth row and column, and using a nullator between nodes 1 and 5 and a CM between nodes 1 and 5 to move $-G_3$ to the diagonal position 5, 5 therefore

$$Y=\begin{bmatrix} sC_1+G_1 & 0 & 0 & 0 & 0 \\ 0 & sC_2 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 & 0 \\ 0 & 0 & 0 & G_4 & 0 \\ 0 & 0 & 0 & 0 & G_3 \end{bmatrix} \qquad (17)$$

Table 1
Summary of the definitions and symbols of the pathological elements.

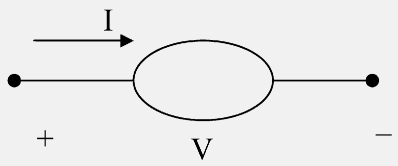
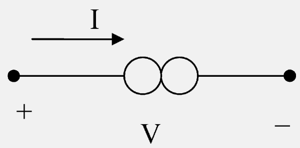
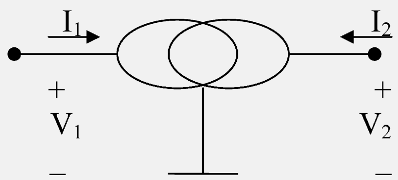
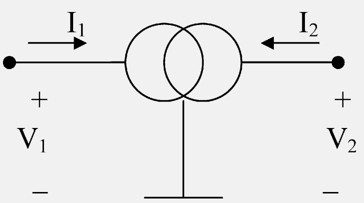
Pathological element	Definition	Symbol
Nullator	$V=I=0$	
Norator	V and I are arbitrary	
Voltage mirror	$V_1=-V_2$ $I_1=I_2=0$	
Current mirror	V_1 and V_2 are arbitrary $I_1=I_2$, and they are also arbitrary	

Table 2
Summary of the definitions and pathological realization of Op Amp, CCII and ICCII.

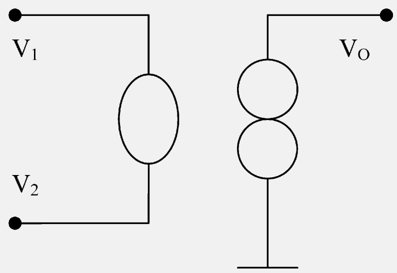
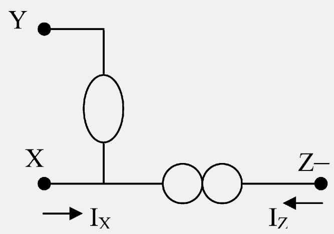
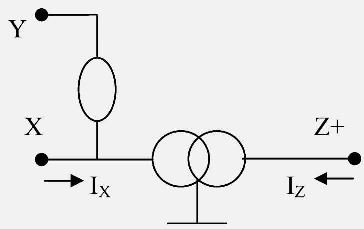
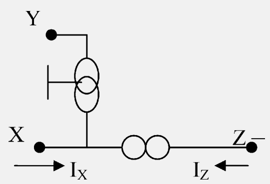
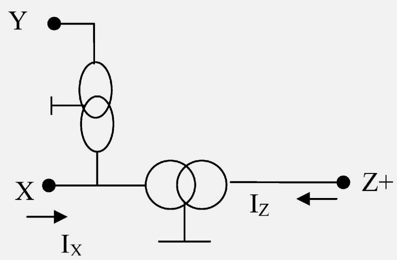
Active element	Definition	Pathological realization
Op Amp	$V_O=A(V_1-V_2)$ Ideally: $A=$Infinity Actually: $A=\omega t/s$	
CCII –	$V_X=V_Y$ $I_Z=-I_X$	
CCII+	$V_X=V_Y$ $I_Z=I_X$	
ICCII –	$V_X=-V_Y$ $I_Z=-I_X$	
ICCII+	$V_X=-V_Y$ $I_Z=I_X$	

Fig. 4 represents the pathological element realization of the above equation which includes three nullators, two CM and one norator.

Fig. 5(a) represents the oscillator circuit originally introduced in [12] and using a CCII – and two CCII+ and generated here using NAM expansion [22].

4.1.1. Generation of the family of self adjoint oscillators

Fig. 5(b) represents the generalized oscillator circuit obtained from Fig. 5(a) by replacing the three CCII by generalized conveyors (GC) defined by Eq. (11). The oscillator family members can be obtained from the following generalized characteristic equation:

$$s^2C_1C_2+sC_2[G_1-a_3K_3G_3]-a_1K_1a_2K_2G_2G_4=0 \tag{18}$$

The necessary conditions for oscillation are given by

$$a_3K_3=1, \quad a_1K_1a_2K_2=-1 \tag{19}$$

$$G_1=G_3 \tag{20}$$

The radian frequency of oscillation is given by Eq. (10). The condition of oscillation is controlled by any of the grounded resistors G_3 or G_1 without affecting the radian frequency of oscillation which is controlled by G_2 or G_4 without affecting the condition of oscillation.

There are sixteen circuits satisfy the coefficient conditions given by Eq. (19) as given in Table 4. The two oscillator circuit numbers 14 and 16 are floating, each of them employ one CCII– and two ICCII–.

Although the adjoint circuit theorem is originally used to transfer voltage mode circuits to current mode circuits [23] it can also be useful in generating oscillator circuits.

The pathological circuit shown in Fig. 6(a) is the adjoint [23,24] to that of Fig. 4 and is obtained by replacing nullators by norators

Table 3
32 equivalent oscillator circuits from a total of 64 circuits belong to Fig. 3(c).

Circuit	GC 1	GC 2	GC 3	GC 4	Floating
1	CCII –	CCII –	CCII –	CCII –	Yes
2	CCII –	CCII –	ICCII+	CCII –	No
3	CCII –	CCII –	CCII+	ICCII –	No
4	CCII –	CCII –	ICCII –	ICCII –	Yes
5	CCII+	ICCII –	CCII –	CCII –	No
6	CCII+	ICCII –	ICCII+	CCII –	No
7	CCII+	ICCII –	CCII+	ICCII –	No
8	CCII+	ICCII –	ICCII –	ICCII –	No
9	ICCII –	CCII –	CCII –	CCII –	Yes
10	ICCII –	CCII –	ICCII+	CCII –	No
11	ICCII –	CCII –	CCII+	ICCII –	No

Table 3 (*continued*)

Circuit	GC 1	GC 2	GC 3	GC 4	Floating
12	ICCII –	CCII –	ICCII –	ICCII –	Yes
13	ICCII+	ICCII –	CCII –	CCII –	No
14	ICCII+	ICCII –	ICCII+	CCII –	No
15	ICCII+	ICCII –	CCII+	ICCII –	No
16	ICCII+	ICCII –	ICCII –	ICCII –	No
17	CCII –	CCII+	CCII –	CCII –	No
18	CCII –	CCII+	ICCII+	CCII –	No
19	CCII –	CCII+	CCII+	ICCII –	No
20	CCII –	CCII+	ICCII –	ICCII –	No
21	CCII+	ICCII+	CCII –	CCII –	No
22	CCII+	ICCII+	ICCII+	CCII –	No
23	CCII+	ICCII+	CCII+	ICCII –	No
24	CCII+	ICCII+	ICCII –	ICCII –	No
25	ICCII –	CCII+	CCII –	CCII –	No
26	ICCII –	CCII+	ICCII+	CCII –	No
27	ICCII –	CCII+	CCII+	ICCII –	No
28	ICCII –	CCII+	ICCII –	ICCII –	No
29	ICCII+	ICCII+	CCII –	CCII –	No
30	ICCII+	ICCII+	ICCII+	CCII –	No
31	ICCII+	ICCII+	CCII+	ICCII –	No
32	ICCII+	ICCII+	ICCII –	ICCII –	No

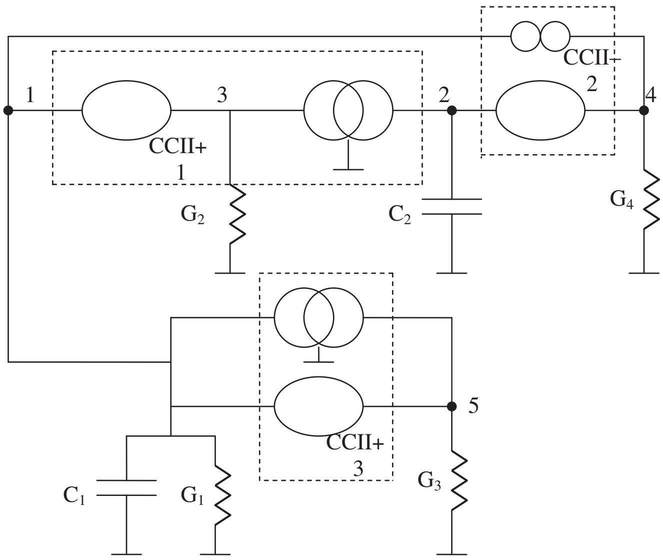


Fig. 4. Pathological realization of Eq. (17).

and vice versa [25] and CM by voltage mirror (VM) as described in [20]. Fig. 6(b) represents the CCII– and two ICCII– realization of the pathological circuit of Fig. 6(b). The GC oscillator circuit to Fig. 6(b) is shown in Fig. 6(c) which is similar to Fig. 5(b) except G_2 and G_4 are interchanged, that is the circuit of Fig. 5(b) is self adjoint. Table 4 includes a right column showing the adjoint oscillator circuit number to the one in the specified row. Also it is shown that the adjoint of circuits 14 and 16 are non-floating oscillator circuits. It is important to note that a circuit and its adjoint do not have to assume the same floating status [24].

4.2. *The second oscillator circuit*

Starting from Eq. (15) and adding a blank fourth row and column, and using a nullator between nodes 2 and 4 to move G_4 to the position 1, 4 therefore

$$Y=\begin{bmatrix} sC_1+G_1-G_3 & 0 & 0 & G_4 \\ 0 & sC_2 & 0 & 0 \\ 0 & 0 & G_2 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{21}$$

Table 4
Sixteen equivalent realizations to the oscillator circuit of Fig. 5(b).

Circuit	GC 1	GC 2	GC 3	Floating	Adjoint to
1	CCII+	CCII –	CCII+	No	14
2	CCII+	ICCII+	CCII+	No	13
3	CCII –	CCII+	CCII+	No	16
4	ICCII+	CCII+	CCII+	No	15
5	ICCII –	ICCII+	CCII+	No	10
6	ICCII –	CCII –	CCII+	No	9
7	ICCII+	ICCII –	CCII+	No	12
8	CCII –	ICCII –	CCII+	No	11
9	CCII+	CCII –	ICCII –	No	6
10	CCII+	ICCII+	ICCII –	No	5
11	CCII –	CCII+	ICCII –	No	8
12	ICCII+	CCII+	ICCII –	No	7
13	ICCII –	ICCII+	ICCII –	No	2
14	ICCII –	CCII –	ICCII –	Yes	1
15	ICCII+	ICCII –	ICCII –	No	4
16	CCII –	ICCII –	ICCII –	Yes	3

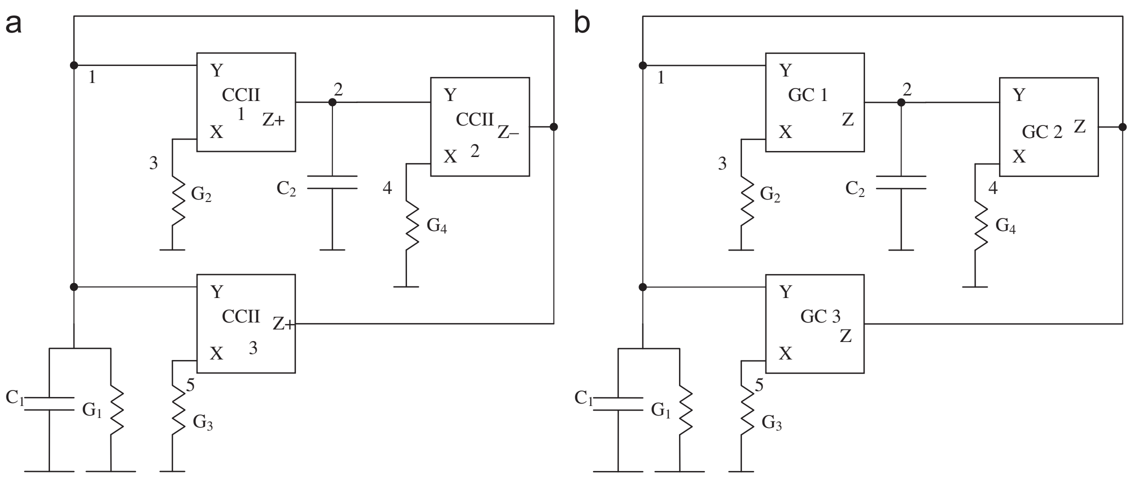


Fig. 5. (a) CCII realization of Fig. 4. (b) Generalized conveyor realization of Fig. 5(a).

Adding a blank fifth row and column, and using a nullator between nodes 1 and 5 to move $-G_3$ to the position 1, 5 therefore:

$$Y=\begin{bmatrix} sC_1+G_1 & 0 & 0 & G_4 & -G_3 \\ 0 & sC_2 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (22)$$

Next a CM between nodes 1 and 5 is added to move $-G_3$ to the diagonal position 5, 5 and becomes G_3 and also to move G_4 to the position 5, 4 and becomes $-G_4$ therefore

$$Y=\begin{bmatrix} sC_1+G_1 & 0 & 0 & 0 & 0 \\ 0 & sC_2 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -G_4 & G_3 \end{bmatrix} \quad (23)$$

Finally a CM is used between nodes 4, 5 to move $-G_4$ to become G_4 at the diagonal position 4, 4 as follows:

$$Y=\begin{bmatrix} sC_1+G_1 & 0 & 0 & 0 & 0 \\ 0 & sC_2 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 & 0 \\ 0 & 0 & 0 & G_4 & 0 \\ 0 & 0 & 0 & 0 & G_3 \end{bmatrix} \quad (24)$$

Fig. 7(a) represents the pathological element realization of the above equation which includes three nullators and three CM.

Fig. 7(b) represents the oscillator circuit originally introduced in [12] and using three CCII+ and generated here using NAM expansion.

5. Simulation results

Simulation results for the circuit of Fig. 2 using three μA741 Op Amps biased with ±12 V and using equal resistors of 10 kΩ each and two equal capacitors of 1 nF each. Fig. 8(a) shows the simulation results, the simulated frequency is slightly less than its

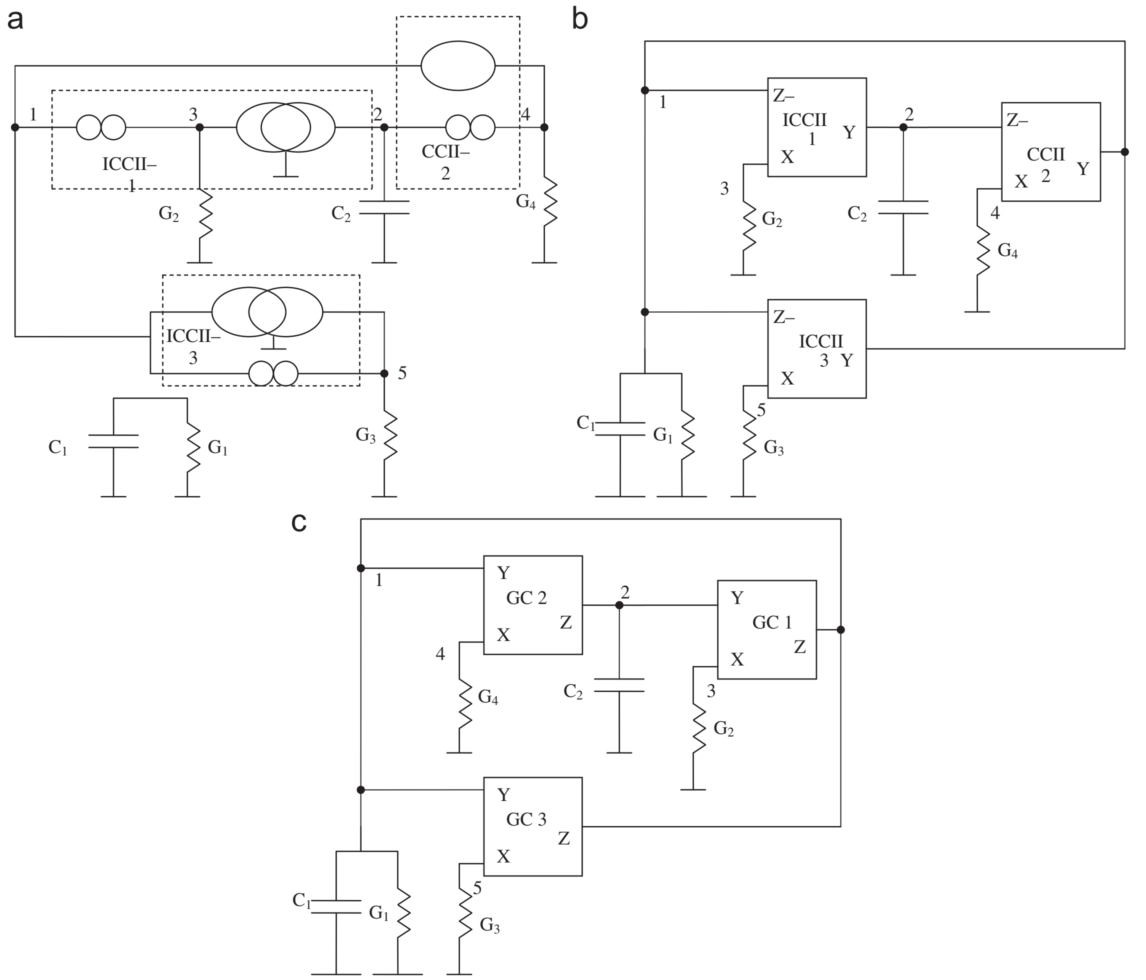


Fig. 6. (a) Adjoint pathological realization to Fig. 4. (b) A CCII− and two ICCII− realization of Fig. 6(a). (c) Generalized conveyor realization of Fig. 6(b)

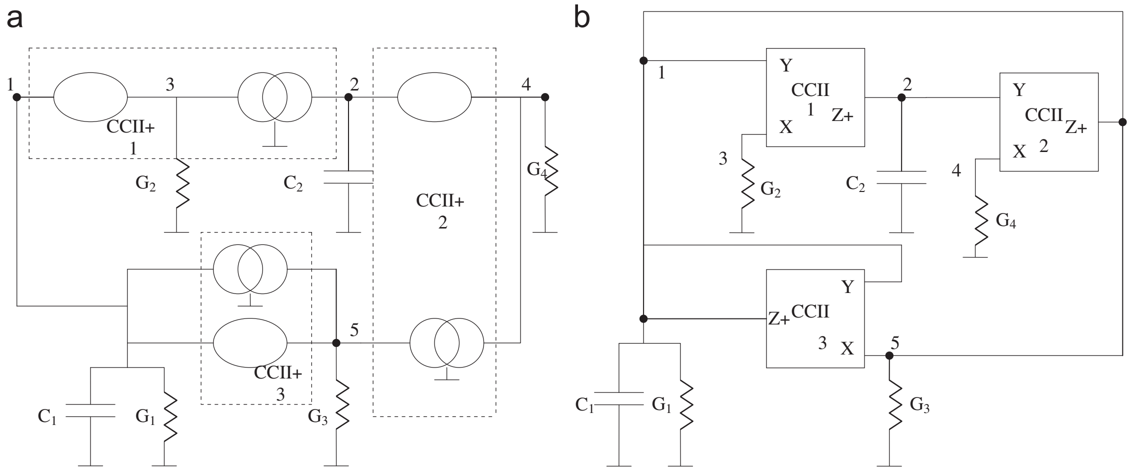


Fig. 7. (a) Pathological realization of Eq. (24). (b) Three CCII+ realization of Fig. 7(a).

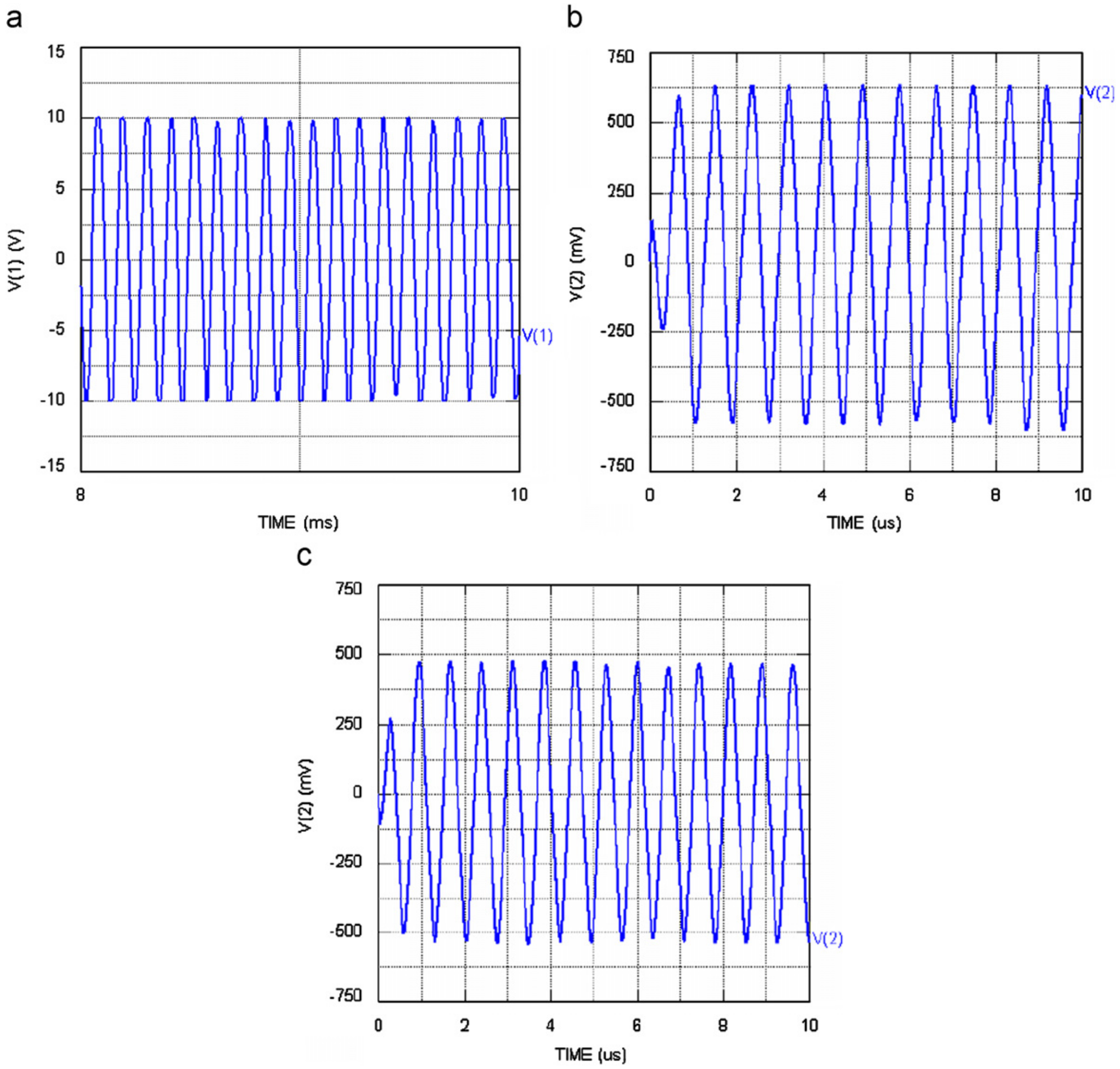


Fig. 8. (a) Simulation results of the three Op Amp oscillator circuit of Fig. 2. (b) Simulation results of the oscillator circuit 1 in Table 3. (c) Simulation results of the oscillator circuit 3 in Table 3.

ideal value of 15.9 kHz due to the finite gain-bandwidth of the Op Amp. The total power dissipation is given by 95.7940 mW.

Simulation results for the generalized conveyor circuit shown in Fig. 3(c) with conveyors specified in Table 3 for circuits 1 and 3 are obtained using the differential voltage current conveyor (DVCC) [26,27] which realizes each of CCII+, CCII–, ICCII+ and ICCII– as special cases.

The DVCCS is biased with ± 1.5 V.

Fig. 8(b) represents the output voltage waveform of the oscillator circuit 1 of Fig. 3(c) designed for oscillation frequency equal to 1.59 MHz by taking $C_1=C_2=10$ pF, $R_1=R_2=R_3=R_4=10$ kΩ.

Fig. 8(c) represents the output voltage waveform of the oscillator circuit 3 of Fig. 3(c) using the same design values as above.

The total power dissipation for each of circuits 1 and 3 in Table 3 is given by 3.91453 mW.

6. Conclusions

Three families of CCII and ICCII oscillators are generated from a three Op Amp oscillator circuit. The first family uses four conveyors and it includes 64 circuits whereas the second uses three conveyors and it includes 16 oscillator circuits. The second two families are generated from the Op Amp oscillator using NAM expansion

It should be noted the family of CCII and ICCII shown in generalized form in Fig. 5(b) is self adjoint and two of the family members are floating. The generated three CCII+ oscillator circuit shown in Fig. 7(b) introduced originally in [12] was generalized in [28] to obtain the complete 16 family members and it is not self adjoint.

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References

[1] B.D.O. Anderson, Oscillator design problem, IEEE Journal of Solid State Circuits 6 (1971) 89–91.
[2] A. Budak, D. Petrala, Frequency limitations of active filters using operational amplifiers, IEEE Transactions on Circuit Theory 19 (1972) 322–328.
[3] F. Doorenbosch, An integrated wide-tunable sine oscillator, IEEE Journal of Solid-State Circuits 11 (1976) 401–403.
[4] A.S. Sedra, K.C. Smith, A second generation current conveyor and its applications, IEEE Transactions Circuit Theory CT-17 (1) (1970) 132–134.
[5] A.M. Soliman, Simple sinusoidal active RC oscillators, International Journal of Electronics 39 (4) (1975) 455–458.
[6] E. Lindberg, K. Murali, A. Tamasevicius, L. Wangenheim, An Eigen value study of a double integrator oscillator, in: Proceedings of the 20th European Conference on Circuit Theory and Design (ECCCD 09), 2009, pp. 217–220.
[7] A.M. Soliman, Transformation of oscillators using Op Amps, unity gain cells and CFOA, Analog Integrated Circuits and Signal Processing. doi:10.1007/s10470-010-9458-8 Online February 2010.
[8] P.O. Brackett, A.S. Sedra, Active compensation for high frequency effects in op amp circuits with applications to active filters, IEEE Transaction on Circuits and Systems 23 (1976) 68–72.
[9] A.M. Soliman, Current conveyors steer universal filter, IEEE Circuits and Devices Magazine 11 (1995) 45–46.
[10] A.M. Soliman, New inverting—noninverting bandpass and lowpass biquad circuit using current conveyors, International Journal of Electronics 81 (1996) 577–583.
[11] A.M. Soliman, Current conveyor filters: classification and review, Microelectronics Journal 29 (1998) 133–149.
[12] A.M. Soliman, Synthesis of grounded capacitor and grounded resistor oscillators, Journal of Franklin Institute 336 (4) (1999) 735–746.
[13] D.G. Haigh, T.J.W. Clarke, P.M. Radmore, Symbolic framework for linear active circuits based on port equivalence using limit variables, IEEE Transactions on Circuits and Systems I 53 (9) (2006) 2011–2024.
[14] D.G. Haigh, A method of transformation from symbolic transfer function to active-RC circuit by admittance matrix expansion, IEEE Transactions on Circuits and Systems I 53 (12) (2006) 2715–2728.
[15] D.G. Haigh, F.Q. Tan, C. Papavassiliou, Systematic synthesis of active-RC circuit building-blocks, Analog Integrated Circuits and Signal Processing 43 (3) (2005) 297–315.
[16] R.A. Saad, A.M. Soliman, Generation, modeling, and analysis of CCII-based gyrators using the generalized symbolic framework for linear active circuits, International Journal of Circuit Theory and Applications 36 (3) (2008) 289–309.
[17] R.A. Saad, A.M. Soliman, Use of mirror elements in the active device synthesis by admittance matrix expansion, IEEE Transactions on Circuits and Systems I 55 (9) (2008) 2726–2735.
[18] R.A. Saad, A.M. Soliman, A new approach for using the pathological mirror elements in the ideal representation of active devices, International Journal of Circuit Theory and Applications 38 (2) (2010) 148–178.
[19] R.A. Saad, A.M. Soliman, On the systematic synthesis of CCII-based floating simulators. International Journal of Circuit Theory and Applications, (2009). doi:10.1002/cta.604.
[20] I.A. Awad, A.M. Soliman, Inverting second generation current conveyors: the missing building blocks, CMOS realizations and applications., International Journal of Electronics 86 (1999) 413–432.
[21] I.A. Awad, A.M. Soliman, On the voltage mirrors and the current mirrors, Analog Integrated Circuits and Signal Processing 32 (2002) 79–81.
[22] A.M. Soliman, Generation of current conveyor based oscillators using nodal admittance matrix, Analog Integrated Circuits and Signal Processing. doi:10.1007/s10470-009-9432-5 Online December 2009.
[23] B.B. Bhattacharyya, M.N.S. Swamy, Network transposition and its application in synthesis, IEEE Transaction on Circuit Theory 18 (1971) 394–397.
[24] A.M. Soliman, Adjoint network theorem and floating elements in the NAM, Journal of Circuits, Systems and Computers 18 (2009) 597–616.
[25] A. Carlosena, G. Moschytz, Nullators and norators in voltage to current mode transformations, International Journal of Circuit Theory and Applications 21 (1993) 421–424.
[26] H.O. Elwan, A.M. Soliman, Novel CMOS differential voltage current conveyor and its applications, IEE Proceedings—Circuits, Devices and Systems 144 (3) (1997) 195–200.
[27] W. Chiu, S.I. Liu, H.W. Tsao, J.J. Chen, CMOS differential difference current conveyors and their applications, IEE Proceedings—Circuits, Devices and Systems 143 (2) (1996) 91–96.
[28] A.M. Soliman, Generation of three oscillator families using CCII and ICCII, International Journal of Electronics and Communication (AEU). doi:10.1016/j.aeue.2009.07.001.