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GENERATION OF CFOA, CCII AND DVCC BASED OSCILLATORS FROM PASSIVE RLC FILTER*

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In a recent paper the link between the Op Amp-based two integrator loop oscillators and current feedback operational amplifier (CFOA)-based oscillators is detected and clearly explained. It was found that one of the grounded capacitor two CFOA two integrator loop oscillators, however, was not related directly to any of the Op Amp oscillators. In this paper the origin of the two CFOA grounded capacitor oscillator is found to be the passive second-order low-pass filter. It is also found that the differential voltage current conveyor (DVCC) grounded passive element oscillator is generated from the same passive second-order low-pass filter. A new family of grounded capacitor oscillators using current conveyors (CCII) and inverting current conveyors (ICCII) which includes sixteen members is introduced. A second new family of grounded passive elements oscillators using CCII and ICCII which includes eight members is also introduced. A discussion and a comparison with some of the previously reported CCII oscillator circuits is also given at the end of the paper.

Keywords: Two integrator loop oscillators; passive RLC filter; current feedback operational amplifier CFOA; DVCC.

1. Introduction

There has been a great interest in realizing sinusoidal oscillator circuits using the CFOA as the basic active element instead of the Op Amp.[1–7] The CFOA is a very versatile building block and is now commercially available from several manufactures.

Most of the CFOA-based oscillators given in the literature were introduced without explaining their link to the original Op Amp-based oscillators. In Ref. 1 it was found that one of the grounded capacitor two integrator loop oscillator[5–7] is not related directly to any of the Op Amp-based oscillators. It is desirable to find out the origin of this grounded capacitor CFOA-based oscillator. One of the objectives of this paper is to show that the origin of this grounded capacitor two integrator loop

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CFOA-based oscillator[5–7] is the passive RLC low-pass filter. A new family of grounded capacitor oscillators which includes sixteen members is introduced. This new family of oscillators has the advantage of absorbing the parasitic elements into circuit parameters. A second new family of grounded passive elements oscillator using two CCII (one of them is a double output CCII) is also introduced. The effects of parasitic elements in this family are discussed in details.

2. Generation of CFOA Oscillator from Passive Filter

Consider the second-order passive RLC low-pass filter shown in Fig. 1(a), its transfer function is given by:

$$\frac{V_{\mathrm{LP}}}{V_i} = \frac{1}{s^2LC + sCR + 1}\,. \tag{1}$$

This transfer function is represented by the block diagram shown in Fig. 1(b) which is equivalent to the two integrator loop shown in Fig. 1(c)[8] where;

$$T_1 = \frac{L}{R} \quad \text{and} \quad T = CR\,. \tag{2}$$

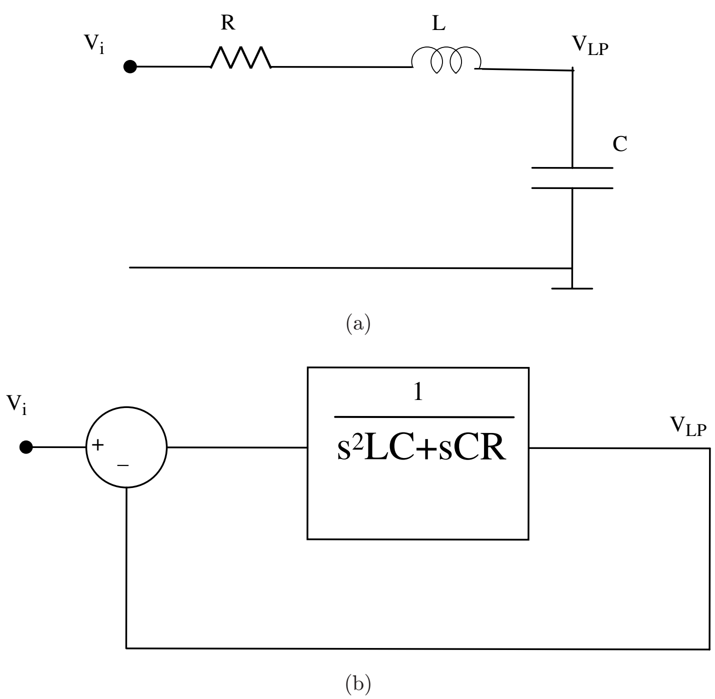
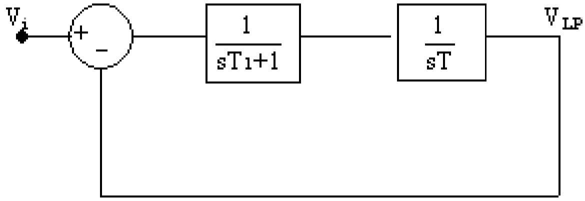
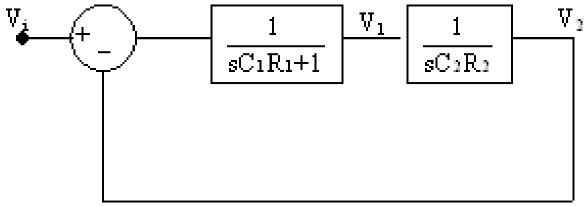


Fig. 1. Passive RLC low-pass filter and equivalent block diagram.



(c)



(d)

Fig. 1. (*Continued*)

The block diagram of Fig. 1(d) is obtained from that of Fig. 1(c) after setting;

$$L = C_1 R_1 R\,, \quad CR = C_2 R_2 \quad \text{and} \quad V_{\text{LP}} = V_2\,. \tag{3}$$

The first realization of the block diagram shown in Fig. 1(d) using two CFOA is given in Fig. 2(a). The CFOA is a four terminal active building block defined by the following matrix equation[9]:

$$\begin{bmatrix} V_X \\ I_Y \\ I_Z \\ V_O \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} I_X \\ V_Y \\ V_Z \\ I_O \end{bmatrix}. \tag{4}$$

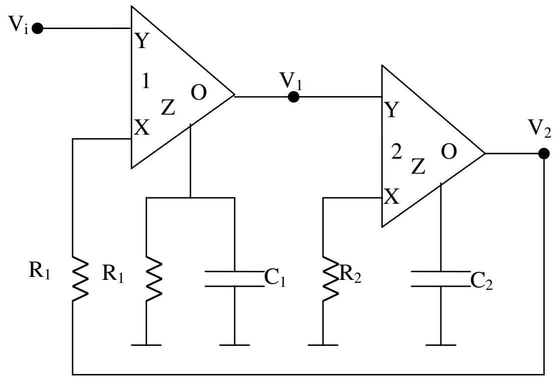
From Eq. (3) in Eq. (1) the low-pass transfer function is given by:

$$\frac{V_2}{V_i} = \frac{1}{s^2 C_1 R_1 C_2 R_2 + s C_2 R_2 + 1}\,. \tag{5}$$

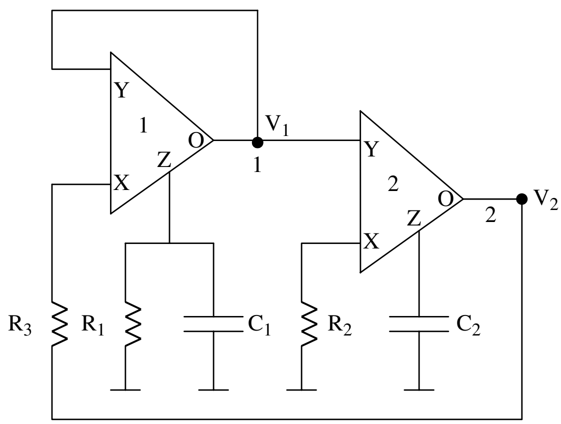
The circuit of Fig. 2(a) realizes also a band-pass transfer function at the output node 1 and the transfer function is given by:

$$\frac{V_1}{V_i} = \frac{s C_2 R_2}{s^2 C_1 R_1 C_2 R_2 + s C_2 R_2 + 1}\,. \tag{6}$$

This equation realizes a second-order band-pass transfer function having a unity gain at the center frequency. This circuit uses only one feedback path which is voltage sampling series mixing. Setting the above transfer function to unity which is physically achieved by connecting the input node to the band-pass output node 1: results in the well-known oscillator circuit shown in Fig. 2(b).[5–7] The feedback floating resistor



(a)



(b)

Fig. 2. (a) Realization of Fig. 1(d) using two CFOA. (b) Two CFOA oscillator generated from Fig. 2(a).

connected between terminal X of the first CFOA and terminal O of the second CFOA will be defined as R_3 instead of R_1, so that there will be independent control on the condition of oscillation by tuning R_1. The state matrix equation for this oscillator circuit is given by:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} G_3 - G_1 & -G_3 \\ G_2 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} . \tag{7}$$

From the above equation the condition of oscillation and the radian frequency of oscillation are obtained as:

$$G_3 = G_1 \, , \tag{8}$$

$$\omega_0 = \sqrt{\frac{G_2 G_3}{C_1 C_2}} \, . \tag{9}$$

The condition of oscillation is controlled by G_1 without affecting the frequency of oscillation which is independently controlled by G_2 without affecting the condition of oscillation.

2.1. *Effect of parasitic elements of the CFOA*

The three most effective parasitic elements of the CFOA are the resistance of terminal X defined as R_X, the capacitance at node Z defined as C_Z and the output resistance at node O defined as R_O.

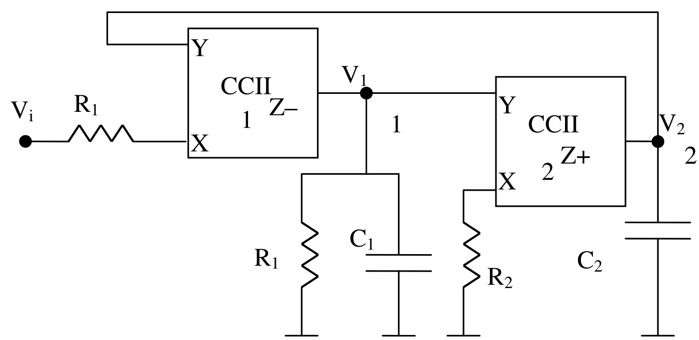
The oscillator circuit of Fig. 2(b) has the advantage that it can absorb the parasitic elements into the circuit parameters as next explained. The compensated design is achieved by taking the value of R_2 equals to its design value minus R_{X2}, taking the value of R_3 equals to its design value minus $(R_{X1} + R_{O2})$, taking the value of C_1 equals to its design value minus C_{Z1} and taking the value of C_2 equals to its design value minus C_{Z2}.

3. Generation of CCII Oscillator Family

The second realization of the block diagram shown in Fig. 1(d) using two current conveyors (CCII)[10] is shown in Fig. 3(a). The CCII is a three-terminal active building block defined by the following matrix equation:

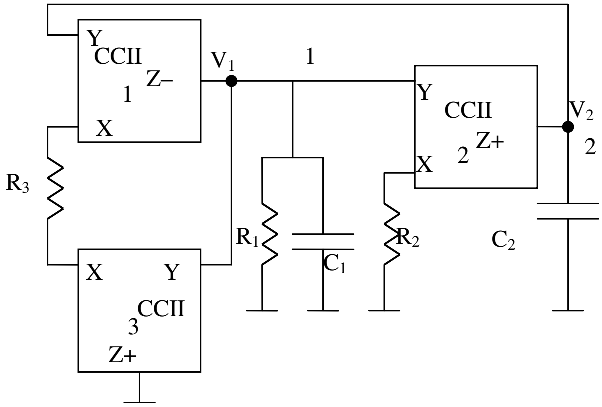
$$\begin{bmatrix} V_X \\ I_Y \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ \pm 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_X \\ V_Y \\ V_Z \end{bmatrix}. \tag{10}$$

The sign in the third row determines the CCII type, a positive sign indicates a CCII+ and a negative sign indicates a CCII−.



(a)

Fig. 3. (a) Realization of Fig. 1(d) using two CCII. (b) Three CCII oscillator generated from Fig. 3(a).



(b)

Fig. 3. (*Continued*)

The two opposite polarity CCII circuit shown in Fig. 3(a) realizes the same low-pass and band-pass transfer functions given by Eqs. (5) and (6), respectively. In fact this circuit is excited at port X of the first CCII and is equivalent to the CFOA circuit of Fig. 2(a) which is excited at port Y of the first CFOA.[11] This circuit also uses one feedback path which is voltage sampling series mixing.

Setting the band-pass transfer function to unity which is physically achieved by connecting the input node to the band-pass output node 1 after adding a voltage buffer between the two nodes to avoid the change in the KCL at node 1. The feedback floating resistor connected between terminal X of the first CCII and terminal X of the third CCII acting as a buffer, will be defined as R_3 instead of R_1 so that there will be independent control on the condition of oscillation by tuning R_1. Figure 3(b) represents the new three CCII oscillator circuit. The state matrix equation for this oscillator circuit is the same as given by Eq. (7). Equations (8) and (9) apply also to this new oscillator circuit.

3.1. *Effect of parasitic elements of the CCII*

The two most effective parasitic elements of the CCII are the resistance of terminal X defined as R_X and the capacitance at node Z defined as C_Z.

The oscillator circuit of Fig. 3(b) has the advantage that it can absorb the parasitic elements into the circuit parameters as next explained. The compensated design is achieved by taking the value of R_2 equals to its design value minus R_{X2}, taking the value of R_3 equals to its design value minus $(R_{X1} + R_{X3})$, taking the value of C_1 equals to its design value minus C_{Z1} and taking the value of C_2 equals to its design value minus C_{Z2}.

3.2. *Generalized three CCII oscillator*

The oscillator circuit of Fig. 3(b) which uses three CCII is a special case from a family of sixteen oscillator circuits using CCII or ICCII,[12] as will be demonstrated by considering the generalized configuration shown in Fig. 4 which includes three generalized conveyors (GC).

The ICCII is a three-terminal active building block defined by the following matrix equation[12]:

$$\begin{bmatrix} V_X \\ I_Y \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 \\ 0 & 0 & 0 \\ \pm 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_X \\ V_Y \\ V_Z \end{bmatrix} . \tag{11}$$

The sign in the third row determines the ICCII type, a positive sign indicates an ICCII+ and a negative sign indicates an ICCII−.

The characteristic equation of the oscillator circuit in Fig. 4 is obtained as:

$$s^2 C_1 C_2 + s C_2 [G_1 + K_1 a_3 G_3] - a_1 K_1 a_2 K_2 G_2 G_3 = 0 . \tag{12}$$

From the above equation it is seen that necessary conditions of oscillation are given by:

$$K_1 a_3 = -1 , \quad a_1 K_1 a_2 K_2 = -1 . \tag{13}$$

There are sixteen circuits that satisfy the conditions in Eq. (13) and the coefficient signs and the types of the three GC are given in Table 1.

These oscillator circuits provide an output current in addition to the two quadrature voltage outputs. From Table 1 it is seen that the two oscillators number 10 and 11 have a floating property.

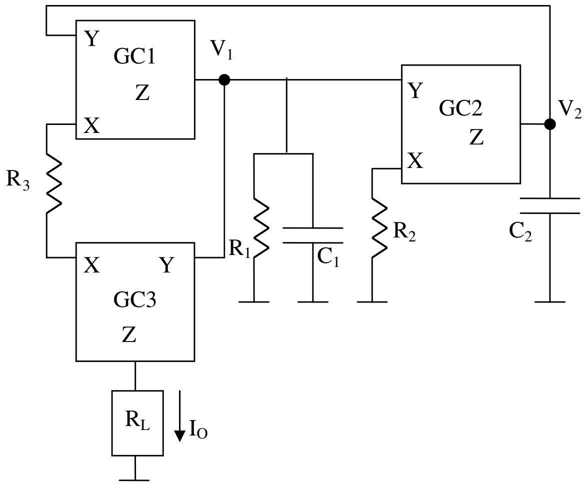


Fig. 4. A generalized oscillator circuit to Fig. 3(b).

Table 1. Sixteen equivalent realizations to the oscillator circuit of Fig. 4.

Circuit	a_1	K_1	a_2	K_2	a_3	K_3	GC1	GC2	GC3	Floating
1	+	−	+	+	+	+	CCII−	CCII+	CCII+	No
2	+	−	−	−	+	+	CCII−	ICCII−	CCII+	No
3	−	−	+	−	+	+	ICCII−	CCII−	CCII+	No
4	−	−	−	+	+	+	ICCII−	ICCII+	CCII+	No
5	−	+	+	+	−	+	ICCII+	CCII+	ICCII+	No
6	+	+	−	+	−	+	CCII+	ICCII+	ICCII+	No
7	+	+	+	−	−	+	CCII+	CCII−	ICCII+	No
8	−	+	−	−	−	+	ICCII+	ICCII−	ICCII+	No
9	+	−	+	+	+	−	CCII−	CCII+	CCII−	No
10	+	−	−	−	+	−	CCII−	ICCII−	CCII−	Yes
11	−	−	+	−	+	−	ICCII−	CCII−	CCII−	Yes
12	−	−	−	+	+	−	ICCII−	ICCII+	CCII−	No
13	−	+	+	+	−	−	ICCII+	CCII+	ICCII−	No
14	+	+	−	+	−	−	CCII+	ICCII+	ICCII−	No
15	+	+	+	−	−	−	CCII+	CCII−	ICCII−	No
16	−	+	−	−	−	−	ICCII+	ICCII−	ICCII−	No

4. Generation of DVCC Oscillators

In this section it will be shown that the origin of the grounded passive element DVCC oscillators[13−15] is the passive RLC filter also.

The DVCC is a four-terminal active building block defined by the following matrix equation[16,17]:

$$\begin{bmatrix} V_X \\ I_{Y1} \\ I_{Y2} \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \pm 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_X \\ V_{Y1} \\ V_{Y2} \\ V_Z \end{bmatrix}. \tag{14}$$

The sign in the fourth row determines the DVCC type, a positive sign indicates a DVCC+ and a negative sign indicates a DVCC−.

The floating resistor R_3 in Fig. 3(b) can be avoided and realized as a grounded resistor by combining the two CCII numbers 1 and 3 to realize a DVCC as shown in Fig. 5(a).

The state matrix equation for this oscillator circuit is the same as given by Eq. (7). Equations (8) and (9) apply also to this oscillator circuit.

To this author's knowledge this oscillator circuit has no direct link to Op Amp oscillator circuits. This circuit can be generated from a CCII-based oscillator using nodal admittance matrix expansion (NAM) as demonstrated in Ref. 14. There are a total of four oscillator circuits belonging to this circuit and using the DVCC defined by Eq. (14) and the circuit of Fig. 5(a) is the same as the circuit A-3 as given in Ref. 15. Figure 5(b) represents another oscillator from this family which is a floating oscillator circuit and is the same as the circuit A-4 in Ref. 15.

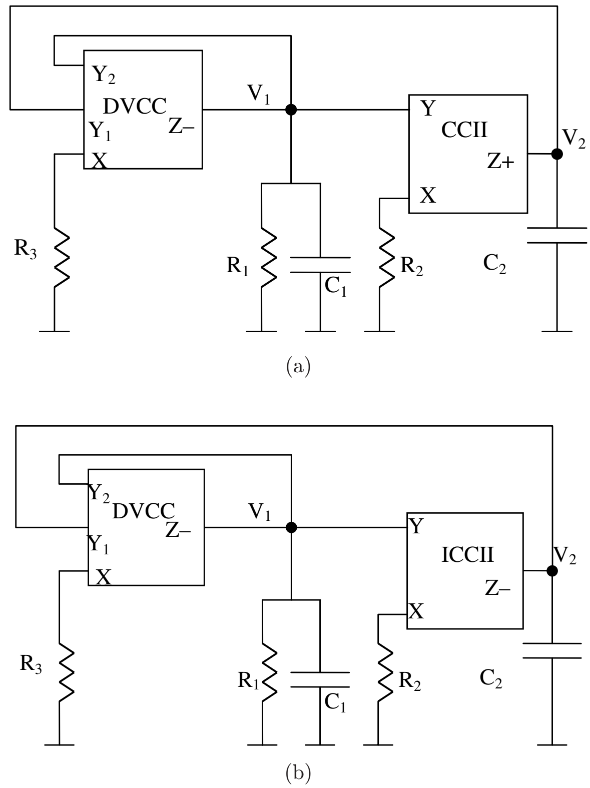


Fig. 5. (a) A grounded passive element oscillator using DVCC− and CCII+. (b) A floating oscillator circuit using DVCC− and ICCII−.

4.1. *Effect of parasitic elements of the DVCC and the CCII*

The oscillator circuits given in Fig. 5 have the advantage that they can absorb the parasitic elements into the circuit parameters as next explained. The compensated design is achieved by taking the value of R_2 equals to its design value minus R_{X2}, taking the value of R_3 equals to its design value minus R_{X1}, taking the value of C_1 equals to its design value minus C_{Z1} and taking the value of C_2 equals to its design value minus C_{Z2}.

5. Grounded Passive Element CCII Oscillator Family

The current mode band-pass filter shown in Fig. 6(a) is obtained from the voltage mode circuit of Fig. 3(a) by transforming the voltage source in series with the resistance R_1 connected to port X to a current source in parallel to the same resistor and rename it as R_3 in order to have independent control on the center frequency. The current flowing in R_2 represents a band-pass response thus adding a second

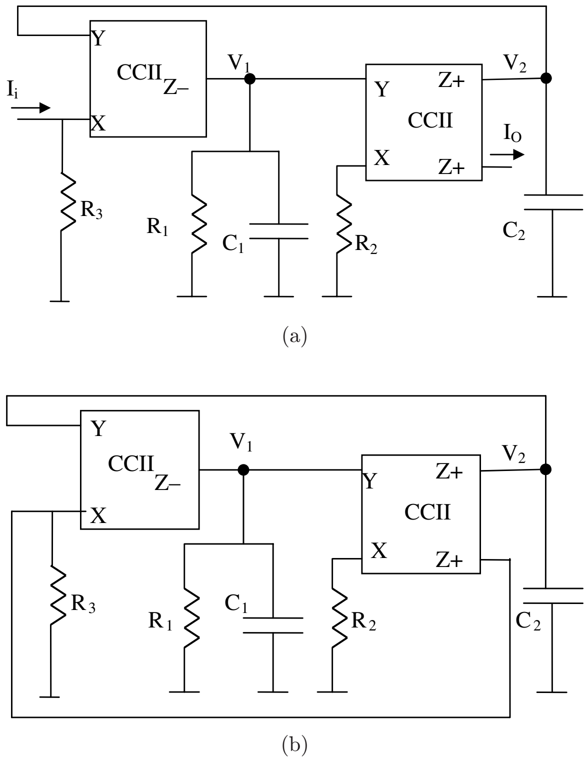


Fig. 6. (a) A grounded passive element current mode band-pass filter. (b) Grounded passive element oscillator generated from Fig. 6(a).

$Z+$ output to CCII number 2 to deliver a non-inverting band-pass output current I_O. The current transfer function is given by:

$$\frac{I_O}{I_i} = \frac{sC_2G_2}{s^2C_1C_2 + sC_2G_1 + G_2G_3} \,. \tag{15}$$

Since a center frequency unity gain is realizable from this circuit by taking G_2 equal to G_1, therefore an oscillator circuit can be obtained from this circuit by setting I_O equal to I_i which is physically achieved by connecting the input X node to the $Z+$ output node as shown in Fig. 6(b).

The state matrix equation for this oscillator circuit is given by:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} G_2 - G_1 & -G_3 \\ G_2 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} . \tag{16}$$

The condition of oscillation is given by:

$$G_2 = G_1 \,. \tag{17}$$

The radian frequency of oscillation is the same as given by Eq. (9).

The condition of oscillation is controlled by G_1 without affecting the frequency of oscillation which is independently controlled by G_3 without affecting the condition of oscillation.

5.1. *Generalized two CCII oscillator*

The grounded passive element oscillator circuit of Fig. 6(b) which uses two CCII is a special case from a family of eight oscillator circuits using CCII or ICCII as will be demonstrated by considering the generalized configuration shown in Fig. 7 which includes two GC. The circuit characteristic equation is obtained as:

$$s^2C_1C_2 + sC_2[G_1 + a_2K_1K_3G_2] - a_1K_1a_2K_2G_2G_3 = 0\,. \tag{18}$$

From the above equation it is seen that necessary conditions of oscillation are given by:

$$a_2K_1K_3 = -1\,, \quad a_1K_1a_2K_2 = -1\,. \tag{19}$$

The coefficient signs of the eight circuits that satisfy the conditions in Eq. (19) and the types of the two GC are given in Table 2.

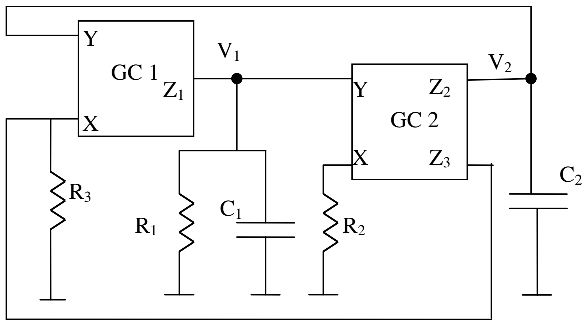


Fig. 7. Grounded passive element generalized conveyor oscillator.

Table 2. Eight equivalent realizations to the oscillator circuit of Fig. 7.

Circuit	a_1	K_1	a_2	K_2	K_3	GC1	GC2
1	−	+	+	+	−	ICCII+	CCII+−
2	+	−	+	+	+	CCII−	CCII++
3	+	+	−	+	+	CCII+	ICCII++
4	+	+	+	−	−	CCII+	CCII−−
5	+	−	−	−	−	CCII−	ICCII−−
6	−	+	−	−	+	ICCII+	ICCII−+
7	−	−	+	−	+	ICCII−	CCII−+
8	−	−	−	+	−	ICCII−	ICCII+−

6. Comparison with Known Oscillator Circuits

In this section some of the previously published circuits that have some similarity to the new reported circuits introduced in this paper are reviewed and compared with the new circuits generated from the passive RLC filter given in this paper.

6.1. *Three CCII oscillator circuits*

The new oscillator circuit reported in Fig. 3(b) belongs to the generalized configuration shown in Fig. 8(a) and defined in Ref. 18 as the class I five node oscillator. The NAM expansion generation method used in Ref. 18 resulted in the family of oscillators which includes the three CCII+ oscillator circuit shown in Fig. 8(b), originally introduced in Ref. 19 as one of its members. It is clear that the new oscillator circuit shown in Fig. 3(b) which uses two CCII+ and one CCII− has a different circuit topology from the oscillator circuit of Fig. 8(b) which uses three CCII+.

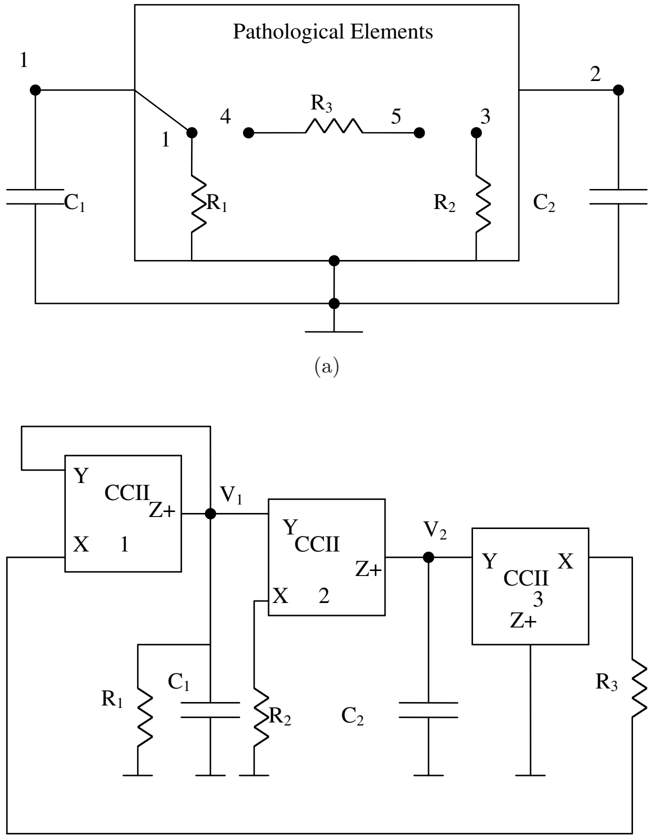


Fig. 8. (a) Class-I five node oscillator.[18] (b) Three CCII+ based oscillator circuit.[19]

It is of interest to show here how the new oscillator circuit of Fig. 3(b) can be generated using the NAM expansion method.[20,21] Consider the NAM of the class-I type A oscillators defined in Ref. 18 by:

$$Y = \begin{bmatrix} G_1 - G_3 & G_3 \\ -G_2 & 0 \end{bmatrix}. \tag{20}$$

Adding a third blank row and column to the above Y matrix and using a nullator between nodes 1 and 3 and a pathological current mirror (CM)[22,23] between nodes 2 and 3 to move $-G_2$ to be G_2 at the diagonal position 3, 3 as follows:

$$Y = \begin{bmatrix} G_1 - G_3 & G_3 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & G_2 \end{bmatrix}. \tag{21}$$

Adding a fourth blank row and column to the above Y matrix and using a nullator between nodes 2 and 4 to move G_3 to the position 1, 4 as follows:

$$Y = \begin{bmatrix} G_1 - G_3 & 0 & 0 & G_3 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}. \tag{22}$$

Adding a fifth blank row and column to the above Y matrix and using a nullator between nodes 1 and 5 to move $-G_3$ to at the position 1, 5 as follows:

$$Y = \begin{bmatrix} G_1 & 0 & 0 & G_3 & -G_3 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \tag{23}$$

Next using a norator between nodes 1 and 4 to move G_3 and $-G_3$ from the first row to the fourth row to the positions 4, 4 and 4, 5 respectively as follows:

$$Y = \begin{bmatrix} G_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 & 0 \\ 0 & 0 & 0 & G_3 & -G_3 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \tag{24}$$

Finally, a CM is used to link the fifth row to ground to retrieve the missing $\pm G_3$ terms in the fifth row so that the floating conductance G_3 is realizable between nodes 4 and 5 as follows:

$$Y = \begin{bmatrix} G_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_2 & 0 & 0 \\ 0 & 0 & 0 & G_3 & -G_3 \\ 0 & 0 & 0 & -G_3 & G_3 \end{bmatrix}. \quad (25)$$

Inserting the two capacitors at nodes 1 and 2, the pathological realization of the above equation is given in Fig. 9, which results in the new circuit of Fig. 3(b). It should be noted that both the circuit of Fig. 3(b) and the circuit of Fig. 8(b) can absorb all R_X and C_Z parasitic element effects.

6.2. *Two CCII oscillator circuits*

The new oscillator circuit introduced in Fig. 6(b) uses the same circuit components as the circuit shown in Fig. 10(a) which was introduced earlier in Fig. 5(a) of Ref. 24. Each of the two circuits employs one CCII− and one double output CCII++, plus the three grounded resistors and the two grounded capacitors. The state matrix equation of the oscillator circuit shown in Fig. 10(a) is given by:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} G_3 - G_1 & -G_2 \\ G_3 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}. \quad (26)$$

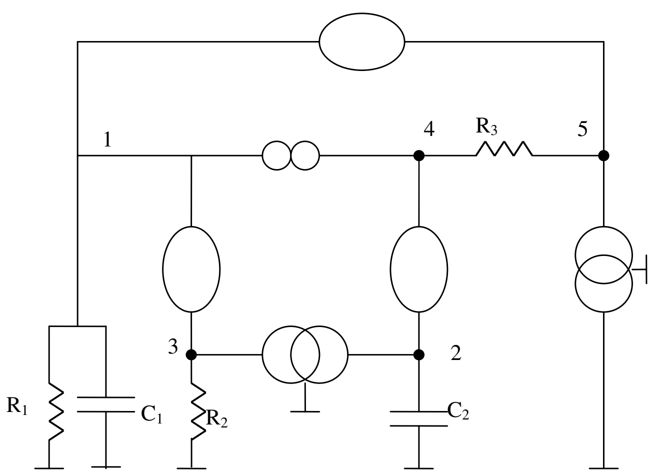


Fig. 9. Pathological realization of Eq. (25) after inserting the capacitors.

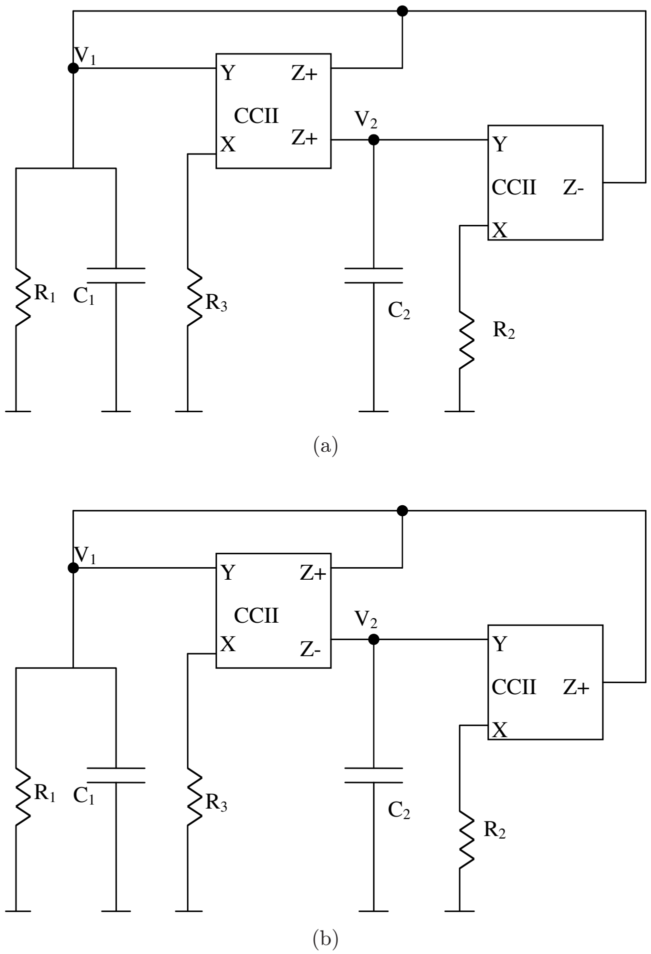


Fig. 10. (a) and (b) Grounded passive element two CCII; oscillator circuit.[24]

The circuit shown in Fig. 10(b) was introduced in Fig. 5(b) of Ref. 24, it employs one balanced output CCII and one CCII. The state matrix equation is given by:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} G_3 - G_1 & G_2 \\ -G_3 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}. \tag{27}$$

The above equations are different from Eq. (16) representing the new oscillator circuit of Fig. 6(b). The condition of the oscillation and radian frequency of oscillation for the oscillators of Fig. 10 are the same as given by Eqs. (8) and (9). The oscillator circuits of Fig. 10 have the advantage that the parasitic elements R_X and C_Z can be absorbed in circuit parameters. On the other hand the oscillator circuit of Fig. 6(b) is affected by R_{X1} and C_{Z3}, as explained next.

6.3. *Effect of parasitic elements of the oscillator of Fig.* 6(b)

The parasitic resistance R_{X2} can be compensated by subtracting its value from R_2. Similarly the parasitic capacitances C_{Z1} and C_{Z2} can be compensated by subtracting their values from C_1 and C_2, respectively. On the other hand the parasitic resistance R_{X1} and the parasitic capacitance C_{Z3} are affecting the circuit, as explained next.

Taking R_{X1} into consideration the state matrix equation is modified to be:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} -G_1 + \dfrac{G_2}{1+\dfrac{R_{X1}}{R_3}} & -\dfrac{G_3}{1+\dfrac{R_{X1}}{R_3}} \\ G_2 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}. \quad (28)$$

From the above equation the condition of oscillation and the radian frequency of oscillation are modified to be:

$$G_2 = G_1\left[1 + \frac{R_{X1}}{R_3}\right], \quad (29)$$

$$\omega_{oa} = \omega_0\left[1 - \frac{R_{X1}}{2R_3}\right]. \quad (30)$$

Taking C_{Z3} into consideration the state matrix equation is modified to be:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} -G_1 + G_2\left(1 - \dfrac{C_{Z3}}{C_2}\right) & -G_3 \\ G_2 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}. \quad (31)$$

From the above equation the condition of oscillation is modified to be:

$$G_2 = G_1\left[1 + \frac{C_{Z3}}{C_2}\right]. \quad (32)$$

The radian frequency of oscillation is not affected by C_{Z3} as given by:

$$\omega_{oa} = \omega_0\,. \quad (33)$$

6.4. *Two single output CCII+ oscillator circuit*

The Wien bridge circuit shown in Fig. 11[25] is different also from the circuit of Fig. 6(b) and it uses two single output CCII+ with one feedback path only. It uses, however, one more resistor and has one resistor floating. The state matrix equation is given by:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} -G_1 + \dfrac{G_2G_3}{G_4} & -\dfrac{G_2G_3}{G_4} \\ G_2 & -G_2 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}. \quad (34)$$

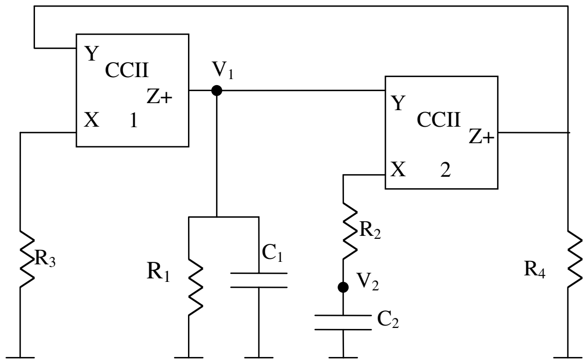


Fig. 11. Grounded capacitor two CCII Wien oscillator circuit.[25]

It is seen that the element in the 2×2 position is not zero as is the case in all oscillator circuits in this paper.

From the above equation the condition of oscillation and the radian frequency of oscillation are obtained as:

$$\frac{G_3}{G_4} = \frac{G_1}{G_2} + \frac{C_1}{C_2}\,, \tag{35}$$

$$\omega_0 = \sqrt{\frac{G_1 G_2}{C_1 C_2}}\,. \tag{36}$$

It is seen that G_3 or G_4 controls the condition of oscillation without affecting the radian frequency. On the other hand there is no independent control on the radian frequency of oscillation.

7. Conclusions

The origin of the two CFOA grounded capacitor oscillator shown in Fig. 2(b) is found to be the passive second-order low-pass filter. It is also found that the differential voltage current conveyor (DVCC) grounded passive element oscillator shown in Fig. 5(a) is generated from the same passive second-order low-pass filter. The grounded passive element oscillator shown in Fig. 6(b) is generated from the current mode band-pass filter given in Fig. 6(a). In Sec. 6 the oscillator circuit of Fig. 6(b) is generated using NAM expansion from the general admittance matrix of the class I-type-A five node oscillators.[18] A new family of grounded capacitor oscillators using current conveyors (CCII) and inverting current conveyors (ICCII), which includes sixteen members, is introduced. A second new family of grounded passive elements oscillators using CCII and ICCII, which includes eight members, is also introduced.

A discussion and a comparison with some of the previously reported CCII oscillator circuits are also included.

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