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CURRENT MODE CCII OSCILLATORS USING GROUNDED CAPACITORS AND RESISTORS

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SUMMARY

New realizations of grounded C, grounded R current mode oscillators using the current conveyor (CCII) are given. The proposed oscillators are classified into two classes depending on the number of feedback loops. In class I, there is a single current feedback loop, whereas in class II, there are two current feedback loops. Class I includes two types and it employs two CCIIs, three capacitors and three or four resistors. Class II employs two CCIIs having two-outputs each, two capacitors and three resistors and has independent control on the condition of oscillation and on the frequency of oscillation by varying two alternative resistors. PSpice simulations are included. Exact analysis based on the parasitic elements of the CCII is carried out indicating that class I has a third order characteristic equation. Class II has the advantage that the effects of the parasitic elements of the CCIIs can be absorbed in the circuit components. © 1998 John Wiley & Sons, Ltd.

KEY WORDS: CCII oscillators; current mode oscillators

1. INTRODUCTION

A variety of sinusoidal oscillator circuits using the operational amplifier (op amp) as the active element are available in the literature.[1] It is well known that the finite gain–bandwidth product of the op amp affects both the condition and the frequency of oscillation[1]. The first oscillators using the second generation current conveyor (CCII) have been introduced in the literature since over twenty years.[2] One of the oscillators given in[2] is based on using two opposite polarity voltage integrators. Several authors have proposed circuits for sinusoidal oscillators using a single CCII.[3–7] Most of these oscillators employ floating capacitors. The recently reported grounded C, grounded R oscillators with independent control on the frequency and on the condition of oscillation[8,9] employ combinations of the first generation current conveyor (CCI) and CCII.

In this paper, new current mode oscillators using grounded C, grounded R and CCIIs only are given. The reported circuits are classified into two classes based on the number of current feedback loops.

The proposed oscillators are generated from the first CCII oscillator circuit given in[2] based on careful examination and modification of the coefficients of the state equation.

2. THE FIRST CCII OSCILLATOR

Figure 1 displays the first CCII oscillator introduced in the literature[2] which employs two opposite polarity CCIIs with the minimum number of passive elements, namely two resistors and two capacitors. The

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oscillator is described by the state matrix equation:

$$\begin{bmatrix} \dfrac{\mathrm{d}v_1}{\mathrm{d}t} \\ \dfrac{\mathrm{d}v_2}{\mathrm{d}t} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{1}$$

where

$$a_{11} = a_{22} = 0, \qquad a_{12} = -\frac{1}{C_1R_2} \quad \text{and} \quad a_{21} = \frac{1}{C_2R_1} \tag{2}$$

The angular frequency of oscillation is given by

$$\omega_0 = \frac{1}{\sqrt{C_1C_2R_1R_2}} \tag{3}$$

Voltages V_1 and V_2 are 90° out of phase, and they will have equal amplitudes if, $R_1 = R_2$ and $C_1 = C_2$.

Since the commercially available CCIIs are of the CCII + type[10,11] the practical realization of the CCII- is based on using two CCII+s. Figure 2 presents two alternative realizations of the CCII-, the first realization is shown in Figure 2(a) and it employs the second CCII + as a current buffer, whereas the realization of Figure 2(b) employs the second CCII + as a negative impedance converter and has the advantage of a low R_x.[12]

PSpice simulations have been carried out using three AD844 biased with ± 9 V to realize the oscillator of Figure 1 based on the CCII-realization of Figure 2(a), and taking $R_1 = R_2 = 1\ \mathrm{k\Omega}$ and $C_1 = C_2 = 1$ nF. From the simulations the frequency of oscillation was found to be 154·3 kHz, which is slightly lower than its

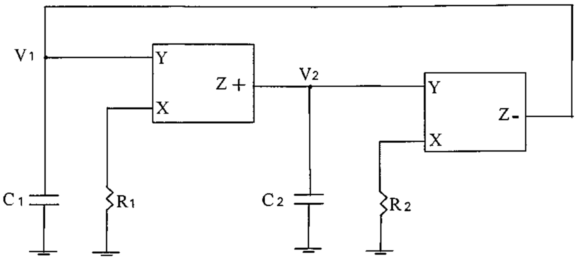


Figure 1. The well-known CCII oscillator based on the two integrator loop

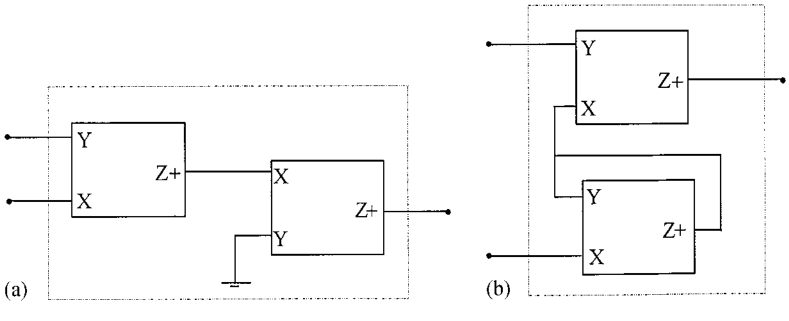


Figure 2. Two alternative realizations of the CCII-

theoretical value of 159·15 kHz, thus the percentage error in f_0 equals -3%. This error in f_0 is due to R_x and C_z of CCII.

Similar simulation results have been carried out using the CCII- of Figure 2(b), in this case $f_0 = 155{\cdot}6$ kHz, thus the percentage error in f_0 equals $-2{\cdot}2\%$. The improvement achieved in this case is due to the low R_x of CCII-.

Of course the error in f_0 can be minimized by taking the effects of R_x and C_z in the design equations of R_1, R_2 and C_1, C_2, respectively.

The main disadvantage of this two integrator loop oscillator is that there is no control on the condition of oscillation, since both a_{11} and $a_{22} = 0$.

The addition of resistor in parallel with C_i $(i = 1, 2)$ will result only in negative a_{ii} coefficients $(i = 1, 2)$. This will prevent the circuit from oscillation, since $a_{11} + a_{22}$ cannot be made equal to zero (similarly with the addition of capacitors in parallel with R_i). This proves that it is not possible to have control on the condition of oscillation of a grounded C, grounded R oscillator realized using two opposite polarity single-output CCIIs.

3. THE CLASS—I OSCILLATORS

In this section, a modification to the oscillator of Figure 1 in order to provide independent control on the condition of oscillation while limiting the number of CCII + s to two only is described. The class of oscillators described in this section includes two types. Class I—type A employs $3C + 4R$ and the condition of oscillation is adjusted by capacitive tuning. On the other hand, class I—type B employs $3C + 3R$ and the condition of oscillation is adjusted by a resistor. In both types, the frequency of oscillation is not affected by the adjustment of the condition of oscillation.

3.1. *Class I—type A oscillator*

Figure 3(a) presents the class I—type A current mode oscillator which employs two CCII + s one of them is a two-output CCII to provide the necessary output current to the load. It is seen that the circuit is a modified

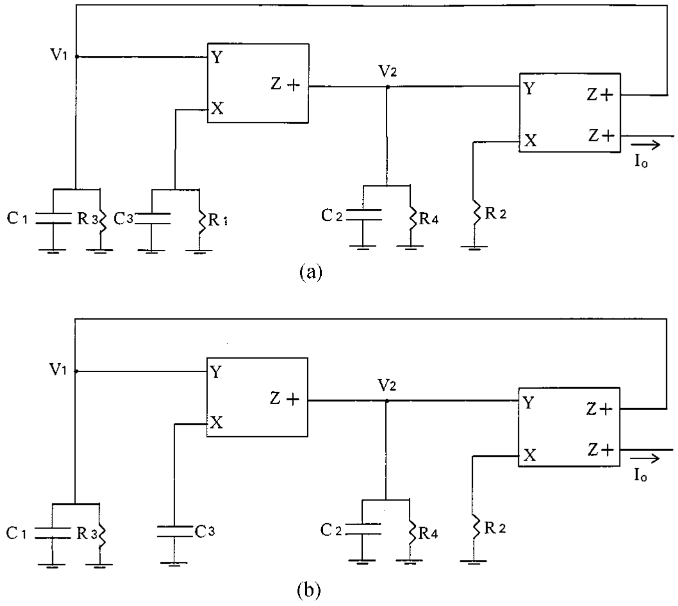


Figure 3. (a) Class I—type A current mode oscillator and (b) class I—type B current mode oscillator

version of that of Figure 1 by adding R_3 in parallel with C_1, R_4 in parallel with C_2 and C_3 in parallel with R_1 and changing the polarity of the second CCII. Assuming ideal CCIIs, the state equation in matrix form is given by

$$\begin{bmatrix} \dfrac{\mathrm{d}v_1}{\mathrm{d}t} \\ \dfrac{\mathrm{d}v_2}{\mathrm{d}t} \end{bmatrix} = \begin{bmatrix} -\dfrac{1}{C_1R_3} & \dfrac{1}{C_1R_2} \\ \dfrac{1}{C_2R_3}\left(\dfrac{R_3}{R_1}-\dfrac{C_3}{C_1}\right) & \dfrac{1}{C_2R_2}\left(\dfrac{C_3}{C_1}-\dfrac{R_2}{R_4}\right) \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{4}$$

Examining equation (4), it is seen that if $C_3 = 0$, both a_{11} and a_{22} will be negative and the circuit will not oscillate. Therefore, it is seen that it is not possible to realize a grounded R, grounded C oscillator using two single-output CCII + s, with the minimum number of capacitors namely two.

From equation (4), the condition of oscillation and the angular frequency of oscillation are given, respectively, by

$$\frac{C_1}{R_4}+\frac{C_2}{R_3}=\frac{C_3}{R_2} \tag{5}$$

$$\omega_0=\sqrt{\frac{1}{C_1C_2}\left(\frac{1}{R_3R_4}-\frac{1}{R_1R_2}\right)} \tag{6}$$

From equation (6), the passive ω_0 sensitivities are obtained as

$$\underset{C_1}{\overset{\omega_0}{S}} = \underset{C_2}{\overset{\omega_0}{S}} = -\frac{1}{2}, \qquad \underset{C_3}{\overset{\omega_0}{S}} = 0 \tag{7a}$$

$$\underset{R_1}{\overset{\omega_0}{S}} = \underset{R_2}{\overset{\omega_0}{S}} = \frac{1}{2\left[\dfrac{R_1R_2}{R_3R_4}-1\right]}, \qquad \underset{R_3}{\overset{\omega_0}{S}} = \underset{R_4}{\overset{\omega_0}{S}} = \frac{-1}{2\left[1-\dfrac{R_3R_4}{R_1R_2}\right]} \tag{7b}$$

It is seen that although the ω_0 sensitivities with respect to C_i ($i = 1, 2, 3$) are very low, the sensitivities with respect to R_i (i = 1, 2, 3, 4) can be high. To limit the magnitude of the ω_0 sensitivities with respect to R_i, it is necessary to take the resistor values such that $R_3R_4/R_1R_2 \leqslant \frac{1}{2}$. Another disadvantage of class I—type A oscillator is that the only way to adjust the condition of oscillation without affecting ω_0 is by tuning the capacitor C_3 which is inconvenient in practice. On the other hand, the frequency of oscillation can be independently controlled by R_1 without affecting the condition of oscillation.

3.2. Class I—type B oscillator

It is worth noting that the minimum number of passive components that can be used in class I is three capacitors and three resistors, which is achieved by setting R_1 as open circuit resulting in the circuit of Figure 3(b). In this case, the condition of oscillation is the same as given by equation (5) and ω_0 simplifies to

$$\omega_0=\frac{1}{\sqrt{C_1C_2R_3R_4}} \tag{8}$$

The passive ω_0 sensitivities are obtained as

$$\underset{C_1}{\overset{\omega_0}{S}} = \underset{C_2}{\overset{\omega_0}{S}} = -\frac{1}{2}, \quad \underset{C_3}{\overset{\omega_0}{S}} = 0 \tag{9a}$$

$$\underset{R_3}{\overset{\omega_0}{S}} = \underset{R_4}{\overset{\omega_0}{S}} = -\frac{1}{2}, \quad \underset{R_2}{\overset{\omega_0}{S}} = 0 \tag{9b}$$

It is seen that the ω_0 sensitivities to all passive circuit components are very low.

The condition of oscillation is controlled by R_2 without affecting the frequency of oscillation. Since it is preferred to control the condition of oscillation by a grounded resistor rather than a capacitor, class I—type B is more practical than class I—type A oscillator.

PSpice simulations were performed for the oscillator of Figure 3(b), with $C_1 = C_2 = C_3 = 0{\cdot}1$ nF, $R_3 = R_4 = 10\,\mathrm{k\Omega}$. The simulations were carried out using a single-output CCII and a two-output CCII based on the modification of the single output CCII given in[15] and biased with ± 9V. To start oscillations, R_2 was decreased from its nominal value of 5 kΩ to 4·5 kΩ. The simulated frequency obtained was found to be 156·03 kHz which is close to its theoretical value of 159·15 kHz.

3.3. Effect of CCII parasitics

In the previous analysis it is assumed that the CCII performs in an ideal manner. In practice the CCII parasitics cannot be ignored in analysing the class I oscillator circuits. There are two main CCII parasitic elements, the non-zero resistance R_x at port X, and the stray capacitance C_z at port Z. For class I, it is seen that the effect of C_z can be added to C_i $(i = 1, 2)$, and the effect of R_x of the second CCII can be added to R_2. The effect of R_x of the first CCII however, results in an increase of the order of the class I oscillator. For brevity, only the class I—type B oscillator is considered here.

Figure 4 represents the equivalent circuit of the oscillator of Figure 3(b) taking into consideration the CCII parasitic elements, where $R_{2a} = R_2 + R_x$ and $C_{ia} = \mathrm{C}_i + \mathrm{C}_z$ $(i = 1, 2)$.

The state equation in matrix form of the circuit of Figure 4 is given by

$$\begin{bmatrix} \dfrac{\mathrm{d}v_1}{\mathrm{d}t} \\ \dfrac{\mathrm{d}v_2}{\mathrm{d}t} \\ \dfrac{\mathrm{d}v_3}{\mathrm{d}t} \end{bmatrix} = \begin{bmatrix} -\dfrac{1}{C_{1a}R_3} & \dfrac{1}{C_{1a}R_{2a}} & 0 \\ \dfrac{1}{C_{2a}R_x} & -\dfrac{1}{C_{2a}R_4} & -\dfrac{1}{C_{2a}R_x} \\ \dfrac{1}{C_3R_x} & 0 & -\dfrac{1}{C_3R_x} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \tag{10}$$

For the design of interest namely, $R_3 = R_4 = R$ and $C_1 = C_2 = C_3 = C$, let $C_{1a} = C_{2a} = C_a$, and define,

$$T = C_aR, \quad K_1 = \frac{R}{R_{2a}}, K_2 = \frac{R}{R_x} \quad \text{and} \quad K_3 = K_2\frac{C_a}{C_3} = K_2\left(1 + \frac{C_z}{C}\right) \tag{11}$$

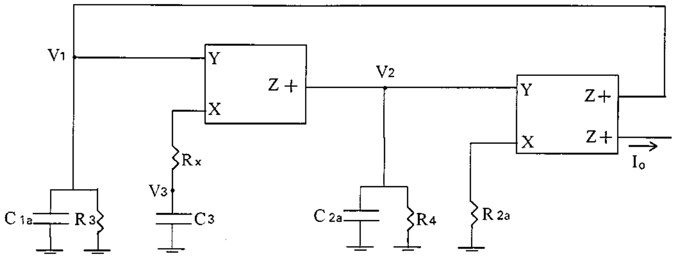


Figure 4. Class I—type B oscillator with the parasitic elements of the CCIIs included

The state matrix equation simplifies to

$$\begin{bmatrix} \dfrac{\mathrm{d}v_1}{\mathrm{d}t} \\ \dfrac{\mathrm{d}v_2}{\mathrm{d}t} \\ \dfrac{\mathrm{d}v_3}{\mathrm{d}t} \end{bmatrix} = \begin{bmatrix} -\dfrac{1}{T} & \dfrac{K_1}{T} & 0 \\ \dfrac{K_2}{T} & -\dfrac{1}{T} & -\dfrac{K_2}{T} \\ \dfrac{K_3}{T} & 0 & -\dfrac{K_3}{T} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \tag{12}$$

The characteristic equation is obtained as

$$s^3T^3 + s^2T^2(K_3 + 2) + sT(1 + 2K_3 - K_1K_2) + K_3 = 0 \tag{13}$$

For $K_3 \gg 1$, the condition of oscillation and the actual angular frequency of oscillation are given respectively by

$$K_1 \approx 2\left[1 + \frac{C_z}{C}\right] \tag{14}$$

$$\omega_{0a} \approx \frac{\omega_0}{1 + \dfrac{C_z}{C} + \dfrac{R_x}{R}} \tag{15}$$

4. THE CLASS—II OSCILLATORS

In this section, two novel oscillator circuits using two-output CCIIs are introduced. The proposed oscillators have the advantage of independent control on the condition of oscillation by varying a grounded resistor without affecting the oscillation frequency. Also the frequency of oscillation is adjusted by varying another grounded resistor without affecting the oscillation condition. Each of the proposed oscillators employs two capacitors and three resistors, which is the minimum number of passive elements required to realize an oscillator with independent control on the condition of oscillation.

The oscillator shown in Figure 5(a) is a modified version from that of Figure 1 by adding the resistor R in parallel with C_1 and replacing the first CCII + by a double output CCII+ (with its second $Z+$ output provides current feedback to its Y port) and the second CCII- by a balanced output CCII. Very recently novel CMOS realizations of the two output CCII have been reported.[13] The state equation in matrix form of the circuit of Figure 5(a) is given by

$$\begin{bmatrix} \dfrac{\mathrm{d}v_1}{\mathrm{d}t} \\ \dfrac{\mathrm{d}v_2}{\mathrm{d}t} \end{bmatrix} = \begin{bmatrix} \dfrac{1}{C_1}\left(\dfrac{1}{R_1} - \dfrac{1}{R}\right) & -\dfrac{1}{C_1R_2} \\ \dfrac{1}{C_2R_1} & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{16}$$

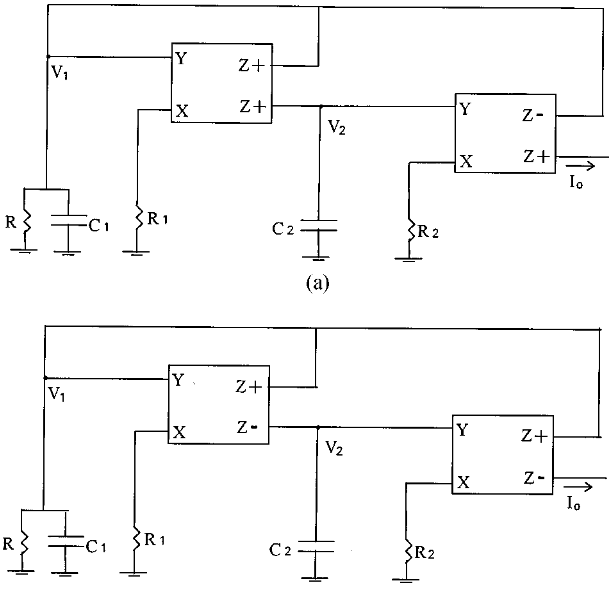
The condition of oscillation is given by

$$R_1 = R \tag{17}$$

The angular frequency of oscillation is the same as given by equation (3).

It is seen that the grounded resistor R which is added to the circuit controls the condition of oscillation without affecting the frequency of oscillation. The oscillator can be tuned electronically by replacing R by a grounded MOS resistor.[14]

Figure 5(b) represents an alternative modified oscillator based on using two balanced output CCIIs. The state equation in matrix form is the same as given by equation (16) except that a_{12} and a_{21} will have opposite



(a)

(b)

Figure 5. Two equivalent realizations of the class II current mode oscillators

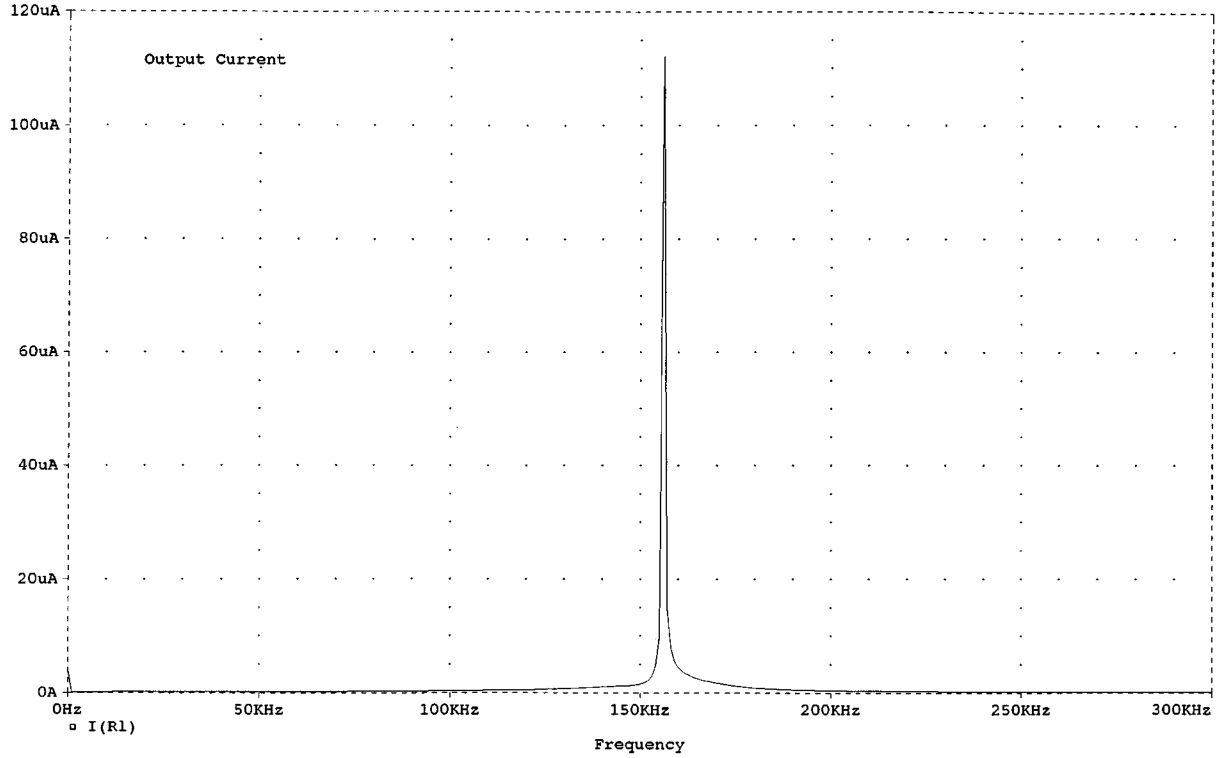


Figure 6. The frequency spectrum of the oscillator of Figure 5(a)

signs. The condition of oscillation is the same as given by equation (17), and of course the angular frequency is the same as given by equation (3).

PSpice simulations for the oscillator circuit of Figure 5(a) have been carried out using two-output CCIIs based on modification of the CCII given in[15], and biased with ± 5 V.

Figure 6 represents the output current frequency spectrum obtained, with a load resistor R_L of 1 kΩ and taking $R_1 = R_2 = 10$ kΩ, $C_1 = C_2 = 0{\cdot}1$ nF. To start oscillations R was adjusted to 10·35 kΩ. The simulated frequency obtained was found to be 156·1 kHz which is close to its theoretical value of 159·15 kHz.

It should be noted that the parasitic elements of the CCIIs can be absorbed in the oscillator circuit components, and the characteristic equation of this class remains as a second order.

5. CONCLUSIONS

New current mode oscillators using grounded C, grounded R and CCIIs are given. The reported circuits are classified into two classes based on the number of current feedback loops. Class I has a single feedback loop and employs two CCII+s, three capacitors and three or four resistors. Class II has two current feedback loops and uses only two capacitors and three resistors. It should be noted that the class I oscillator circuits reported here may also be generated from the oscillator structure given in[16] by interchanging the two CCII polarities and replacing one of the single output CCIIs by a two output CCII. The effect of the CCII parasitics on Class I—type B oscillator has not been considered before and is given here in details in Section 3.3. Class II has the advantage that the frequency of oscillation and the condition of oscillation are independently adjusted by varying two alternative resistors. It should be noted that the parasitic elements of the CCIIs can be absorbed in class II oscillator circuit components, and the characteristic equation of this class remains to be of the second order.

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