New Fully-Uncoupled Current-Controlled Sinusoidal Oscillator Employing Grounded Capacitors

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Abstract A new electronically-controllable fully-uncoupled sinusoidal oscillator, employing four second generation current-controlled conveyors (CCCIIs) and two grounded capacitors, is presented. The oscillation frequency and condition of oscillation are totally uncoupled and electronically adjustable. The circuit has low sensitivities and a high frequency stability factor. SPICE simulation results confirm the validity of the proposed oscillators.

Keywords: sinusoidal oscillator, current mode circuits, current controlled conveyors


1. Introduction

Fabre, Saaid, Wiest, and Boucheron introduced [1], [2] the second generation current controlled conveyor (CCCI) as an attractive building block for realizing electronically controllable analog signal processing circuits. Since a CCCI is based upon a four transistor based mixed translinear cell (MTC), the intrinsic X-port resistance ($R_x$) is electronically controllable through an external bias current ($I_B$) with $R_x$ being inversely proportional to $I_B$. It is this characteristic which makes CCCII a suitable building block for electronically controllable functional circuits. Even in a CMOS realization using CMOS MTC, the tunability of $R_x$ is available although $R_x$ is now inversely proportional to $\sqrt{I_B}$. For a comprehensive account of numerous applications of CCCII such as in the realization of grounded and floating current controlled positive or negative resistances, current controlled voltage-mode/current-mode (VM/CM) amplifiers, active only summing/difference amplifiers, instrumentation amplifiers, electronically-controllable grounded/floating inductors/transformers, electronically controllable multifunction VM/CM biquads, PID controller, Precision rectifiers, CM multiplier/divider, squaring/square rooting circuits, ASK/FSK/PSK/QAM wave generator circuits, see [1-10] and the references cited therein. References [11,12] have also elaborated upon the various current controllable sinusoidal oscillators using two to three CCCIIs.

From a survey of the existing literature on CCCIIs [1-10], it has been found that any topology for realizing fully-uncoupled oscillator capable of providing independent control of condition of oscillation (CO) and independent linear control of frequency of oscillation (FO) has not been proposed in the open literature so far. The purpose of this paper is, therefore, to present a new CCCI-based oscillator configuration which fills this void.

2. New Fully-uncoupled Current-controlled Sinusoidal Oscillator

The symbolic notation of second generation current controlled conveyor (CCCI) is shown in Fig.1. The port relationships of CCCI± can be described by the following matrix equation:

$$\begin{bmatrix} i_x \\ v_x \\ i_z \\ v_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & R_x & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_y \\ v_y \\ i_{z+} \\ v_{z-} \end{bmatrix}$$

Figure 1. Symbolic notation of CCCI

In the above equation (1), $R_x$ is the intrinsic (parasitic) resistance of CCCI which is controllable through the bias current. The positive and negative signs of the z-port current $i_z$ denote the positive (CCCI+) and negative CCCI-respectively. The proposed oscillator configuration is shown in Figure 2.
Assuming that the CCCII± are described by the equation (1), the characteristic equation (CE) for the oscillators as shown in Figure 2 is given by:

\[ s^2 C_1 C_2 R_x R_y + s C_2 R_x R_y \left( \frac{1}{R_x} - \frac{1}{R_y} \right) + 1 = 0 \] (2)

From equation (2), the condition of oscillation (CO) and frequency of oscillation (FO) can be expressed as:

**CO:**

\[ R_x - R_y \leq 0 \]

and **FO:**

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{1}{C_1 C_2 R_x R_y}} \] (3)

Thus, from equation (3), it is clear that the resistors which are in CO, do not appear in FO, hence both CO and FO are fully uncoupled. Since \( R_x \) is tunable by bias current \( \frac{V_T}{2I_B} \), both CO and FO are independently electronically controllable. Independent controllability of FO is useful in realization of current controlled oscillators while control of CO independently is advantageous to incorporate amplitude stabilization.

The sensitivities of \( s_{00} \) with respect to passive elements can be obtained as:

\[ S_{C_1}^{s_{00}} = S_{C_2}^{s_{00}} = S_{R_x}^{s_{00}} = S_{R_y}^{s_{00}} = -\frac{1}{2} \] and

\[ S_{R_x}^{s_{00}} = S_{R_y}^{s_{00}} = 0 \] (4)

From equation (4) it is seen that the proposed oscillator circuits enjoy low sensitivities.

**3. Frequency Stability Analysis**

Frequency stability is an important figure of merit on the basis of which different sinusoidal oscillators can be compared. We use the definition of frequency stability factor to be:

\[ S^F = \frac{d\varphi(u)}{du} \bigg|_{u=1} \]

\[ \varphi(u) = \frac{s}{C_1 R_x} \]

Thus, from equation (5), the phase of the \( T(s) \) with the selection of \( C_1 = C_2 = C, R_x = R_y = R_x = R_y \) is represented by the following equation:

\[ \varphi(u) = -\tan^{-1}\left(\frac{u\sqrt{n}}{1-u^2n}\right) \] (6)

Now differentiating equation (6) with respect to \( u \), we obtain:

\[ \frac{d\varphi(u)}{du} = \frac{\sqrt{n}(1+u^2)}{n(1-u^2)^2 + u^2} \]

for both the oscillators is obtained to be \( 2\sqrt{n} \). Thus, the new current controlled oscillators offer very good frequency stability factor for larger values of \( n \). Similarly, if we vary both the resistors \( R_x \) and \( R_y \) simultaneously i.e., \( R_x = R_y = R/n, S^F \) will become \( 2n \). Therefore, excellent frequency stability can be obtained by selecting larger values of \( n \).

**4. Simulation Results**

To evaluate the workability of the proposed new current controlled oscillator circuits, SPICE simulations have been performed using the bipolar transistor parameters of PR100N (PNP) and NR100N (NPN) [13]. The capacitor values used were \( C_1 = C_2 = 100nF \), the condition of oscillation was established through the variation of \( R_x \) as a function of the D.C. bias current \( I_{B2} \) while keeping \( R_x \) fixed. The CCCIIIs were biased with ± 2.5V D.C. power supplies. The value of \( R_x \) was fixed through \( I_{B3} \) and the control of frequency was done through the variation of \( I_{B4} \).
The SPICE generated transient and steady state responses of the oscillator output voltage are shown in Figure 3(a) and Figure 3(b) respectively. Figure 3(c) shows the frequency spectrum which clearly shows the THD as 2.4% only which is reflective of good spectral purity of the generated signal. To check the influence of random variations in the parameter and element values on the startup of the oscillations, a Monte Carlo simulation was carried out whose results are shown in Figure 3(d). The results in Figure 3(d) demonstrate that component/parameter tolerances do not have much effect on the build-up of the oscillations of the proposed oscillator.

The simulation results of Figure 3(a)-(d), thus, confirm the workability of the proposed oscillator configuration.

5. Concluding Remarks

Although a number of current-controlled sinusoidal oscillators employing the controlled current conveyors as an active element [1-12] have been proposed in the earlier literature, from a review of the earlier works it was found that any sinusoidal structure providing fully uncoupled tuning laws for oscillation condition as well as frequency
of oscillation had not been reported earlier. This paper introduced a circuit of this kind using four CCCIIs and two grounded capacitors. The proposed circuit has excellent frequency stability. The workability of proposed circuit was demonstrated by PSpice simulations.

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References


