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

D. R. Bhaskar[1], D. Prasad[1], R. Senani[2,*], M. K. Jain[3], V. K. Singh[3], D. K. Srivastava[3]

[1]Department of Electronics and Communication Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi, India
[2]Division of Electronics and Communication Engineering, Netaji Subhas Institute of Technology, Sector-3, Dwarka, New Delhi, India
[3]Department of Electronics Engineering, Institute of Engineering and Technology, Lucknow, India
*Corresponding author: senani@ieee.org

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 (CCCII) as an attractive building block for realizing electronically controllable analog signal processing circuits. Since a CCCII 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 CCCII-based oscillator configuration which fills this void.

2. New Fully-uncoupled Current-controlled Sinusoidal Oscillator

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

$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_x & 0 \\ 1 & \pm1 & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix} \qquad (1)$$
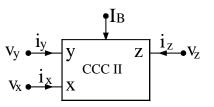

Figure 1. Symbolic notation of CCCII

In the above equation (1), R_x is the intrinsic (parasitic) resistance of CCCII which is controllable through the bias current. The positive and negative signs of the z-port current i_z denote the positive (CCCII+) and negative CCCII-respectively. The proposed oscillator configuration is shown in Figure 2.
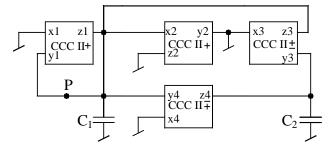
Figure 2. New fully-uncoupled current-controlled sinusoidal oscillators

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:

$$s^2 C_1 C_2 R_{x3} R_{x4} + s C_2 R_{x3} R_{x4} \left(\frac{1}{R_{x2}} - \frac{1}{R_{x1}} \right) + 1 = 0 \quad (2)$$

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

$$(R_{x1} - R_{x2}) \leq 0$$

and FO:

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{1}{C_1 C_2 R_{x3} R_{x4}}} \quad (3)$$

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 ($R_x = \frac{V_T}{2 I_B}$), 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 ω_0 with respect to passive elements can be obtained as $S_{C1}^{\omega 0} = S_{C2}^{\omega 0} = S_{Rx3}^{\omega 0} = S_{Rx4}^{\omega 0} = -\frac{1}{2}$ and

$$S_{Rx1}^{\omega 0} = S_{Rx2}^{\omega 0} = 0 \quad (4)$$

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 $S^F = \frac{d\varphi(u)}{du} \Big|_{u=1}$, where $u = \frac{\omega}{\omega_0}$ is the normalized frequency and $\varphi(u)$ represents the phase of the open loop transfer function of the oscillator circuits. The open loop transfer function (with link broken at point 'P' as shown in Fig. 2) is given by:

$$T(s) = \frac{\dfrac{s}{C_1 R_{x1}}}{s^2 + \dfrac{s}{C_1 R_{x2}} + \dfrac{1}{C_1 C_2 R_{x3} R_{x4}}} \quad (5)$$

Thus, from equation (5), the phase of the T(s) with the selection of $C_1 = C_2 = C$, $R_{x1} = R_{x2} = R_{x3} = R_x$ and $R_{x4} = R_x/n$, is represented by the following equation:

$$\varphi(u) = \tan^{-1} \frac{(u/\sqrt{n})}{0} - \tan^{-1} \left(\frac{u\sqrt{n}}{1 - u^2 n} \right) \quad (6)$$

Now differentiating equation (6) with respect to u, we obtain $\frac{d}{du} \varphi(u) = \frac{\sqrt{n}(1+u^2)}{n(1-u^2)^2 + u^2}$, hence, the value of S^F 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_{x3} and R_{x4} simultaneously i.e., $R_{x3} = R_{x4} = R/n$, 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_{x2} as a function of the D.C. bias current I_{B2} while keeping R_{x1} fixed. The CCCIIs were biased with ± 2.5V D.C. power supplies. The value of R_{x3} was fixed through I_{B3} and the control of frequency was done through the variation of I_{B4}.
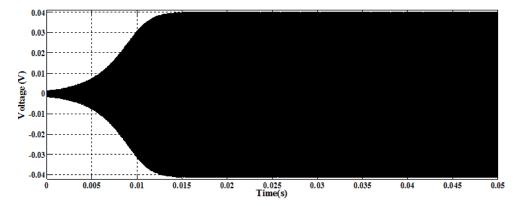

Figure 3(a). PSPICE simulation results (Transient waveform)

Figure 3(b). PSPICE simulation results (Steady state response)

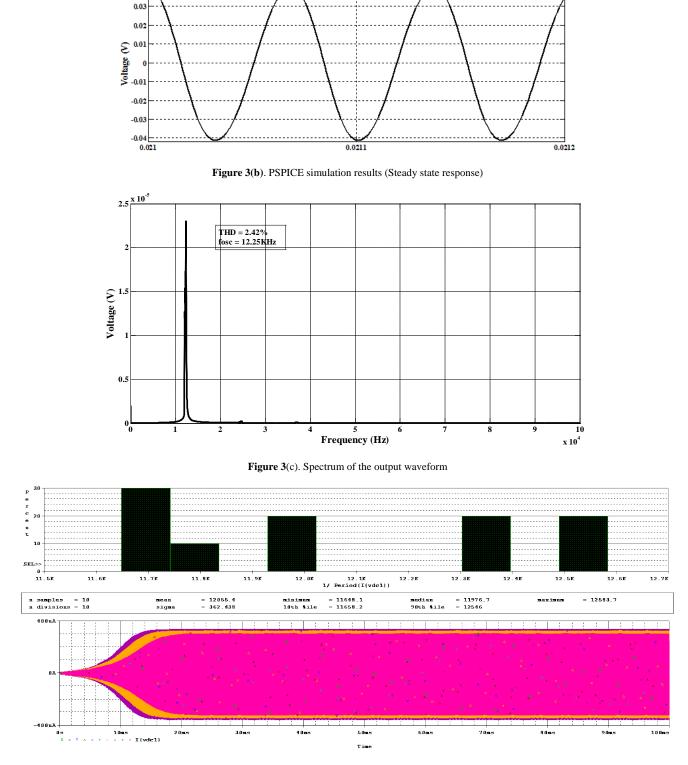**Figure 3**(c). Spectrum of the output waveform

Figure 3(d). Results of the Monte-Carlo Analysis

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.

Acknowledgement

References

[1]   Fabre, A., Saaid, O., Wiest F.and Boucheron C., "Current controlled bandpass filter based on translinear conveyors", Electronics Letters, 31(29), 1727-1728, September 1995.

[2]   Fabre, A., Saaid, O., Wiest F.and BoucheronC., "High frequency applications based on a new current controlled conveyor", IEEE Trans Circuits Syst, 43(2), 82-91, February1996.

[3]   Kiranon, W., Kesorn, J. and Wardkein, P., "Current controlled oscillator based on translinear conveyors", Electronics Letters, 32(15), 1330-1331, July 1996.

[4]   Kiranon, W., Kesorn, J., Sangpisit, W. and Kamprasert, N.,"Electronically tunable multifunctional translinear-C filter and oscillator", Electronics Letters, 33(7), 573-574, March 1997.

[5]   Abuelma'atti M.T. and Tasadduq, N. A., "A novel current controlled oscillator using translinear current conveyors", Frequenz, 52(5-6), 123-124, 1998.

[6]   Abuelma'atti M.T. and Al-Qahtani, M.A. "A new current controlled multiphase sinusoidal oscillator using two translinear conveyors", IEEE Trans Circuits Syst–II, 45(7), 881-885, July1998.

[7]   Horng, J.W., "A sinusoidal oscillator using current-controlled current conveyors", Int. J. Electronics, 88(6), 659-664, 2001.

[8]   Fongsamut,C., Anuntahirunrat, K., Kumwachara K.nd Surakampontorn, W.,"Current-conveyor-based single-element-controlled and current-controlled sinusoidal oscillators", Int. J. Electronics, 93(7), 467-478, July 2006.

[9]   Maheshwari, S., "Current-mode third-order quadrature oscillator", IET Circuits Devices Syst, 4(3), 188-195, 2010.

[10]   Bhaskar D. R. and Senani, R., "New CFOA-based single-element-controlled sinusoidal oscillators", IEEE Trans Instrumentation and Measurement, 55(6), 2014-2021, December 2006.

[11]   Senani, R., Bhaskar D. R. and Singh, A. K., "Current Conveyors: variants, applications and hardware implementations", Springer International Publishing, Switzerland, 2015, Ch. 8, pp. 395-423.

[12]   Senani, R., Bhaskar D. R. and Singh, A. K., "Sinusoidal Oscillators and Waveform generators using modern electronic circuit building blocks", Springer International Publishing, Switzerland, Ch. 8, pp. 395-425, 2016.

[13]   Frey, D.R., "Log domain filtering: an approach to current-mode filtering", IEE Proc. G., Circuits Devices Syst., 140(6), 406-416, December 1993.