New single resistance controlled oscillators employing a reduced number of unity-gain cells

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Abstract: Recently, the authors introduced two new second-order single-resistance-controlled oscillators (SRCO) employing four/three unity-gain cells (unity-gain voltage followers and unity-gain current followers). In this communication, a novel family of SRCOs has been presented which employ a reduced number of (only two) unity-gain cells as active elements. The workability of the new circuits has been confirmed by the SPICE simulations of their CMOS-implementable versions.

Keywords: Sinusoidal Oscillators, Voltage Followers, Current Followers

Classification: Analog circuit design

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1 Introduction

Recently, in [1], the present authors proposed two novel configurations of second-order *canonic*¹ single-resistance-controlled oscillators (SRCO) which employ four and three unity-gain cells, respectively and offer a number of significant advantages over the previously published unity-gain follower-based oscillators of [2-10]. Note that the current interest in unity-gain-cell-based structures [11-14] as alternatives to those realized from other more complex building blocks, stems from their wider bandwidth, lower power consumption and simpler architectures.

The object of this communication is to introduce, as a sequel to [1], a new family of follower-based *canonic* second-order SRCOs which retain most of the advantageous features of their predecessors of [1] but, by contrast, employ a reduced number of (only two) unity-gain cells. The workability of the new SRCOs has been confirmed by PSPICE simulations using CMOS-based followers.

2 Proposed circuits

The proposed new SRCOs are shown in Fig. 1. The symbolic notations of VF and CFs are marked in Fig. 1 itself where the VF is characterised by the equations $i_y = 0$, $v_w = v_y$ with i_w being arbitrary and the CFs are characterised by $v_x = 0$; $i_z = i_x$ for CF⁻, and $i_z^+ = i_z^- = i_x$ for dual-output current follower (DOCF), with v_z being arbitrary in both the cases.

¹ *Canonic* SRCOs are those which employ only three resistors and only two capacitors (which are necessary and sufficient) to achieve non-interacting controls of the frequency of oscillation as well as condition of oscillation.

Fig. 1. Proposed new SRCOs

A straight forward analysis of the circuits gives the condition of oscillation (CO) as:

$$\begin{aligned} R_1 &= \frac{C_2}{C_1} R_3 \text{ for } SRCO-1, & R_1 &= \frac{C_1}{C_2} R_3 \text{ for } SRCO-2, \\ R_1 &= \frac{C_2 R_3}{C_1 + C_2} \text{ for } SRCO-3 \text{ and } R_1 = \frac{C_1 R_3}{C_1 + C_2} \text{ for } SRCO-4 \text{ and } 5 \end{aligned} \quad (1)$$

Whereas the frequency of oscillation (FO) is given by:

$$f_0 = \frac{1}{2\pi\sqrt{C_1 C_2 R_2 R_3}} \text{ for all the circuits} \quad (2)$$

It is seen that CO and FO can be independently controlled through R_1 and R_2 , respectively. Note that, in SRCO-5, we have used a dual-output CF instead of simple CF which has facilitated the employment of both grounded-capacitors which is attractive from integrated circuit implementation view-point (see [15] and references cited therein). Note that all the circuits provide an explicit voltage-mode output from a low-impedance terminal. An explicit current-mode output can also be obtained in all the cases by augmenting the CF^- and DOCF with an additional current output terminal (as in SRCO-2 of Fig. 1 (c) of [1]).

3 Nonideal analysis and sensitivity properties

Considering the nonideal gain of the VF as α and that of CF as β , the nonideal expressions of CO and FO of the SRCO-1-5 are determined and are tabulated in Table I.

Table I. Effect of nonideal parameters of the followers

Circuit	Nonideal expressions for CO and FO	
	CO	FO (ω_0)
SRCO-1	$R_1 = \frac{C_2}{C_1} R_3 \left[\frac{\alpha\beta}{1 + \frac{C_2}{C_1}(1-\beta) + \frac{C_2}{C_1}(1-\alpha)\frac{R_3}{R_2}} \right]$	$\sqrt{\frac{2-\alpha}{C_1 C_2 R_2 R_3}}$
SRCO-2	$R_1 = \frac{C_1}{C_2} R_3 \left[\frac{\alpha\beta}{1 + \frac{C_1}{C_2}(1-\alpha) + \frac{C_1}{C_2}(1-\beta)\frac{R_3}{R_2}} \right]$	$\sqrt{\frac{1}{C_1 C_2 R_2 R_3}}$
SRCO-3	$R_1 = \frac{C_2}{C_1} R_3 \left[\frac{\alpha\beta}{1 + \frac{C_2}{C_1} + \frac{C_2}{C_1}(1-\alpha)\frac{R_3}{R_2}} \right]$	$\sqrt{\frac{1}{C_1 C_2 R_2 R_3}}$
SRCO-4 and 5	$R_1 = \frac{C_1}{C_2} R_3 \left[\frac{\alpha\beta}{1 + \frac{C_1}{C_2} + \frac{C_1}{C_2}(1-\beta)\frac{R_3}{R_2}} \right]$	$\sqrt{\frac{1}{C_1 C_2 R_2 R_3}}$

Thus, it is seen that after consideration of the nonideal gains of the followers, the frequency controlling resistor (R_2) also appears in the CO of the proposed oscillator circuits. However, it is clear from Table I that the term containing R_2 in the nonideal expressions of the CO is very small due to the factor $(1 - \alpha)$ or $(1 - \beta)$. Additionally, this can be made even smaller if we choose R_2 to be much larger than R_3 . Furthermore, note that in SRCO-1, as $S_{\alpha}^{\omega_0} = -\frac{\alpha}{4-2\alpha}$ which approaches $1/2$ as $\alpha \rightarrow 1$, the presence of α does not alter the value of ω_0 significantly. On the other hand, SRCOs-2-5 are completely unaffected by the nonideal gains α and β of the followers.

4 Frequency stability properties

The frequency stability factor $S_F = \left. \frac{d\phi(u)}{du} \right|_{u=1}$ (where $u = \frac{\omega}{\omega_0}$ is the normalized frequency and $\phi(u)$ represents the phase function of the open loop transfer function) with $C_1 = C_2 = C$ and $R_1 = R_3 = R$ and $R_2 = R/n$, is found to be $S_F = \frac{\sqrt{n}}{n+1}$ for SRCO-1, $S_F = \frac{2\sqrt{n}}{n+1}$ for SRCO-3 and $S_F = \sqrt{n}$ for SRCO-2, 4 and 5. Thus, it is seen that by keeping 'n' large, SRCO-2, 4 and 5 would have high values of S_F and therefore, enjoy very good frequency stability properties.

5 Simulation results

For the simulation of the proposed SRCOs in PSPICE, we have used the CMOS VF and CFs as in [1]. The SRCOs were designed to have $f_0 = 1$ MHz by choosing component values as $R_2 = R_3 = 4$ k Ω , $C_1 = C_2 = 39.8$ pF and R_1 was adjusted to meet the CO. We present here some sample results for the

proposed circuits. PSPICE generated transient response of SRCO-1 is shown in Fig. 2 (a) whereas the variation of f_0 (from 1.6 MHz to 0.21 MHz) with R_2 varied from 1 k Ω –100 k Ω for SRCO-1, using $R_3 = 4$ k Ω , $C_1 = C_2 = 39.8$ pF, is shown in Fig. 2 (b). Simulation results of Fig. 2, thus, confirm the workability of the proposed configurations.

(a)

(b)

Fig. 2. (a) Transient response of SRCO-1 ($f_0 = 0.93$ MHz; 550 mV p-p)
(b) Variation of f_0 with R_2 for SRCO-1 (1.6 MHz–0.21 MHz for $R_2 = 1$ k Ω – 100 k Ω)

6 Concluding remarks

In a recent publication [1] the authors have proposed two new SRCO configurations which were realised from only four/three followers and provided a number of advantages as compared to the previously known follower-based oscillators of [2-10]. In this communication, we have introduced a number of new follower-based oscillators which offer the following advantages:

- (i) are second-order single-resistance-controlled oscillators
- (ii) provide explicit VM output and can provide explicit CM output with an additional current output terminal in the used CF
- (iii) are *canonic* in number of passive elements, and
- (iv) enjoy very low sensitivity property.

Furthermore, three of the new circuits (namely SRCO-2, 4 and 5) have large frequency stability factor like their predecessors of [1] and one of these circuits (namely SRCO-5) has the additional feature of employing both grounded-capacitors as preferred from the viewpoint of IC implementation (see [15] and references cited therein).

Thus, the new circuits retain most of the advantages of their predecessors of [1] while requiring a reduced² number of (only two) followers.

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²Discovering any 'second-order canonic SRCO employing no more than a single CF or a single VF' appears to be a very challenging problem!