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Two Simple Analog Multiplier Based Linear VCOs Using a Single Current Feedback Op-Amp

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Abstract

Two simple voltage-controlled-oscillators (VCO) with linear tuning laws employing only a single current feedback operational amplifier (CFOA) in conjunction with two analog multipliers (AM) have been highlighted. The workability of the presented VCOs has been demonstrated by experimental results based upon AD844 type CFOAs and AD534 type AMs.

Keywords: Voltage-Controlled Oscillators, Current Feedback Op-Amps, Current-Mode Circuits, Analog Multipliers

1. Introduction

Although a number of new building blocks and circuit concepts related to current-mode circuits have been investigated in recent literature [1-3], the use of current feedback operational amplifiers (CFOAs) as an alternative to the traditional voltage-mode op-amps (VOA), has attracted considerable attention (see [4-7] and the references cited therein) in various instrumentation, signal processing and signal generation applications due to their commercial availability as off-the-shelf ICs as well as due to the well known advantages offered by CFOAs over the VOAs. Because of these reasons, use of CFOAs has been extensively investigated in realizing oscillators, for instance, see [6,8-11] and the references cited therein. Although, a variety of CFOAs are available from various manufacturers, AD844 (from Analog Devices) which contains a CCII+ followed by a voltage buffer is particularly flexible and popular due to the availability of z-terminal of the CCII+ therein as an externally accessible lead which permits AD844 to be used as a CCII+ (one AD844) or as CCII- (employing two AD844s) or as a general 4-terminal building block [6].

Voltage-Controlled Oscillators (VCO) are important building blocks in several instrumentation, electronic and communication systems, such as in function generators, in production of electronic music to generate variable tones, in phase locked loops and in frequency synthesizers [12-17].

A known method of realizing VCOs is to devise an RC-active oscillator configuration with two analog multipliers (AM) appropriately embedded to enable independent control of the oscillation frequency through an external control voltage V_C applied as a common multiplicative input to both the multipliers. When two AMs are appropriately embedded in such a configuration, this technique gives rise to a linear tuning law of the form

$$f_0 \propto V_C \tag{1}$$

Based upon this approach, a number of VCO configurations have been proposed by various researchers in the past [12,14-17] employing traditional VOAs and AMs.

A family of eight, CFOA-based linear VCOs of the above kind has recently been presented in [18]; however, all the circuits presented therein require two CFOAs along with two AMs. The main object of this communication is to highlight two simple linear VCOs of the above kind, which are realizable with only a single CFOA along with two AMs. Experimental results using AD844 CFOAs have been given and the advantages of the new

CFOA-based VCOs as compared to previously known VOA-based VCOs of [12,14-17] have been highlighted.

2. VCO Configurations Based on CFOAs

A CFOA is characterized by the instantaneous terminal equations $I_y = 0$, $V_x = V_y$, $I_z = I_x$ and $V_w = V_z$. On the other hand, the output of an AM with two inputs V_1 and V_2 is of the form $V_o = K\left(\frac{V_1V_2}{V_{ref}}\right)$, where V_{ref} is the reference voltage of the multiplier set internally (usually at 10 volts in case of AD534) and K can be set up +1 or –1 by grounding appropriate terminals of AD534. The value of K used for the various multipliers is shown on the symbolic notation itself.

The proposed circuits are shown in **Figure 1** and are derived from the op-amp-AM VCOs of **Figure 2** of [14] with the CFOA configured as a negative impedance converter (NIC).

Choosing the same V_{ref} for both the multipliers, the circuits of **Figures 1(a)**, **1(b)** have the condition of oscillation (CO) and frequency of oscillation (FO) given by

$$\text{CO:}\quad (C_1 - C_2) \le 0 \qquad (2)$$

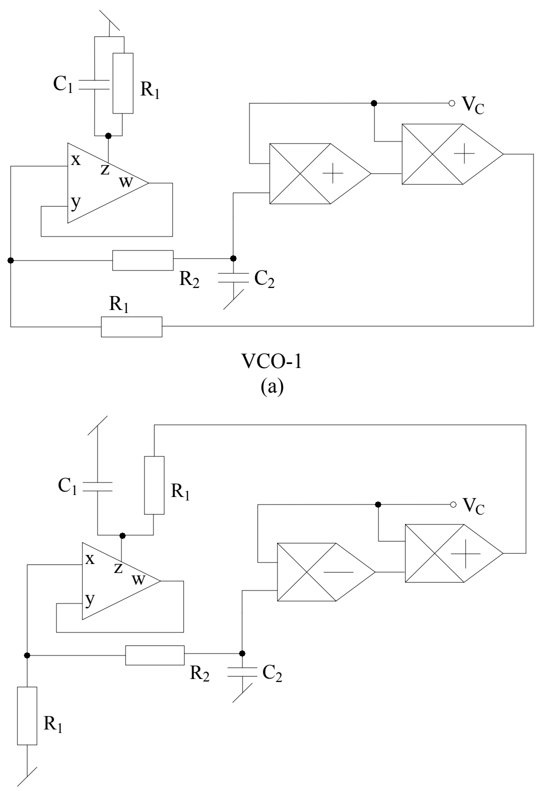

Figure 1. CFOA-based VCOs.

$$\text{FO:}\quad f_0 = \frac{\beta}{2\pi}\sqrt{\frac{1}{C_1C_2R_1R_2}}\ ;\ where\ \beta = \frac{V_C}{V_{ref}} \qquad (3)$$

Thus, it is seen that f_0 is linearly controllable by the external control voltage V_C, as desired. However, as per Equation (2), one needs a variable capacitor to adjust CO.

3. Consideration of CFOA Parasitics

The prominent non-idealities of the CFOAs include—a finite non-zero input resistance r_x at port-x (typically around 50 Ω), y-port parasitics consisting of a parasitic resistance R_y (typically 2 MΩ) in parallel with a parasitic capa- citance C_y (typically 2 pF) and z-port parasitic impedance consisting of a parasitic resistance R_p (typically 3 MΩ) in parallel with a parasitic capacitance C_p (typically, between 4-5 pF). In case of an analog multiplier, the finite non-zero output resistance $r_{out,}$ as per datasheet of AD534, is merely 1 Ω and hence, can be ignored in all the cases. On the other hand, the input impedance of the AM, being 10 MΩ, is sufficiently high and hence, its effect can be ignored since usually, R_2 and $1/\omega C_2$ would be relatively much smaller over the frequency range of interest.

For a quantitative assessment of the effect of the various CFOA non-idealities, we have carried out a re-analysis of both the VCOs and the nonideal expressions for CO and FO are given in **Tables 1** and **2** respectively. It may be noted that since CFOA has y-w shorted, the y-port parasitics do not affect the operation of the circuits and hence, do not appear in the nonideal expressions of CO and FO.

It is easy to infer from the expressions given in **Tables 1** and **2** that the errors caused by the influence of CFOA can be kept small by choosing all external resistors to be much larger than r_x but much smaller than R_p and choosing both external capacitors to be much larger than C_{p1} and C_{p2}.

Table 1. Ideal and non-ideal conditions of oscillation.

VCO	Ideal CO	Nonideal CO
1	$C_1 = C_2$	$C_1 = C_2\dfrac{\left\{1 - \frac{R_2}{R_p} - R_x\left(\frac{1}{R_1} + \frac{1}{R_p}\right)\left(1 + \frac{R_2}{R_1}\right)\right\}}{1 + R_x\frac{(1-\beta^2)}{R_1}} - C_p$
2	$C_1 = C_2$	$C_1 = C_2\dfrac{\left\{1 - \frac{R_2}{R_p} - R_x\left(\frac{1}{R_1} + \frac{1}{R_p}\right)\left(1 + \frac{R_2}{R_1}\right)\right\}}{1 + \frac{R_x}{R_1}} - C_p$

Table 2. Ideal and non-ideal frequency of oscillation.

VCO	Ideal FO	Nonideal FO
1	$\omega_0^2 = \frac{\beta^2}{C_1C_2R_1R_2}$	$\omega_0^2 = \frac{\beta^2 - \frac{R_1}{R_p} + R_x(1-\beta^2)\left(\frac{1}{R_1}+\frac{1}{R_p}\right)}{(C_1+C_p)C_2R_1R_2\left\{1+R_x\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\right\}}$
2	$\omega_0^2 = \frac{\beta^2}{C_1C_2R_1R_2}$	$\omega_0^2 = \frac{\beta^2 + \frac{R_1}{R_p} + R_x\left(\frac{1}{R_1}+\frac{1}{R_p}\right)}{(C_1+C_p)C_2R_1R_2\left\{1+R_x\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\right\}}$

An inspection of **Tables 1** and **2** shows that including the non-ideal parameters of the CFOA will result in a condition of oscillation that can not be controlled without disturbing the frequency of oscillation. Thus, it appears that the advantage of the proposed circuits in providing non-interacting controls of CO and FO is lost. However, the same can be circumvented by proper selection of the values of the resistors. This limits the ease of the design process and affects the highest frequency realizable by the proposed circuits.

A quantitative comparison of f_0 calculated from non-ideal formula and values obtained practically is given in Section 5.

4. Frequency Stability Properties

Frequency stability is an important figure of merit for oscillators. The frequency stability factor S_F is defined as $S_F = \frac{d\phi(u)}{du}$ where $u = \frac{\omega}{\omega_0}$ is the normalized frequency and $\phi(u)$ is the phase of the open-loop transfer function of the oscillator circuit. The expressions for the frequency stability factors for both the VCOs for $C_1 = C_2 = C$, $R_1 = R$ and $R_2 = R/n$ have been derived and are found to be $-\frac{2\sqrt{n}}{n+1}$.

It can be easily deduced that for $n = 1$, S_F is exactly 1 for both the VCOs. This figure is better than several classical oscillators such as Wein bridge oscillator and thus, both the proposed VCOs can be regarded to be quite satisfactory from this viewpoint.

5. Experimental Results

Both the VCOs have been experimentally studied using AD844 type CFOAs and AD534 type AMs biased with ±15 volts DC power supplies and it has been possible to generate oscillation frequencies from tens of kHz to several hundreds of kHz with tolerable errors in the frequency.

Experimental results of the proposed VCOs are shown in **Figures 2 (a)** and **2(b)**. The component values chosen were as under: For the circuits of **Figure 1**, $R_1 = R_2 = 1$ kΩ, $C_1 = 1$ nF and C_2 was taken as a variable capacitor to adjust the CO. **Figure 2(a)** shows the variation of oscillation frequency with control voltage V_C for the VCO of **Figure 1(a)** whereas **Figure 2(b)** shows a typical waveform ($f_0 = 68.7$ kHz, $V_{0p\text{-}p} = 3$ V) obtained from the VCO of **Figure 1(b)**.

The measured values of the THD for the two VCOs are found to be 1.88% and 1.52% respectively. The practical results show a reasonably good correspondence between the theoretical and experimental values and con- firm the workability of the two VCOs.

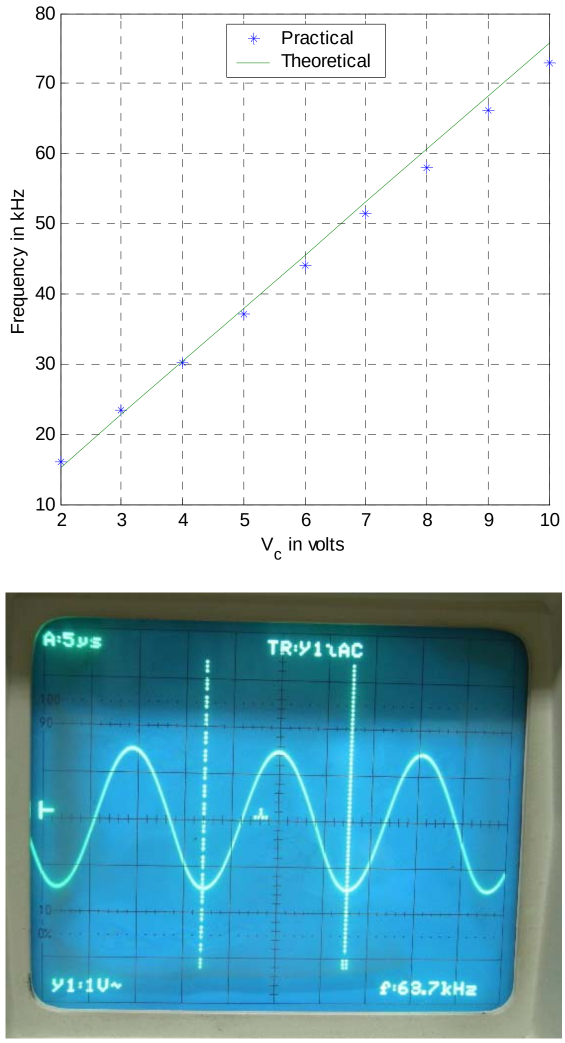

Figure 2. Experimental results of the VCOs: (a) Variation of frequency with VC for VCO-1; (b) A typical waveform generated from VCO-2 (f_0 = 68.7 kHz, $V_{0p\text{-}p}$ = 3 V).

6. Concluding Remarks

In this communication, we highlighted two simple CFOA-AM-based VCOs, providing linear tuning laws, which are derivable from previously known op-amp-AM based VCOs published in [14]. The workability of the new VCOs has been confirmed by the experimental results, based upon AD844 type CFOAs and AD534 type analog multipliers.

A comparison with the previously known linear VCOs of [12,14-17] is now in order. The VCOs presented here have the advantage of requiring fewer AMs than those of [15], fewer resistors than those of [14,16,17] and fewer active elements than those of [15-17]. When the single-CFOA-RC VCOs are compared with single-op-amp-RC VCOs of [14] (**Figure 2** therein), they have the advantage of employing two less resistors. Furthermore, when compared to op-amp-RC VCOs of [12,14-17], the CFOA- RC VCOs presented here not only offer relatively higher operational frequency range (several hundred kHz as compared to only a few kHz available from the op-amp- RC VCOs) they also exhibit lower distortion level (THD being less than 2%). Lastly, when compared with the CFOA-AM-RC circuits presented recently in [18] all of which require two CFOAs, the circuits presented here have the advantage of employing only a single CFOA.

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