ANALYSIS AND DESIGN OF ACTIVE-R OSCILLATORS USING THE CURRENT-FEEDBACK OP-AMP

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***Abstract* - A systematic approach has been employed to synthesize sinusoidal active-R oscillators using the current feedback op-amps. This approach is an extension to the method employed in [1] for the design of active-R oscillators using voltage op-amp. It is found that the active-R technique applied to current-feedback op-amps will be suitable for high frequency oscillator circuits with high output amplitude. A design procedure is developed providing sinusoidal oscillations up to 50 MHz with several volts of amplitude. The presented experimental results are in good agreement with the theoretical predictions.**

I. INTRODUCTION

Most active-R oscillators have been implemented using the operational amplifier (OA) as the active component. However, oscillators based on operational amplifiers are limited to low-medium frequency applications, owing to the inherent limitations of voltage-mode operation, such as slew-rate limiting and low frequency dominant pole.

Within the last decade, the current feedback op-amp (CFOA) has become commercially available as a high-frequency alternative to the OA. Because CFOAs possess more extended bandwidths and higher slew rates than conventional OAs, they have been widely used in place of OAs as active devices in analog circuit applications.

Many active-R sinusoidal oscillators using the CFOA have been proposed [2]-[3]. However, in most of those oscillator circuits the frequency of oscillation is well bellow the maximum bandwidth capabilities of the op-amps.

In [1] it can be found a generic model for active-R oscillators based in a two-pole transfer function model for the open-loop gain of the OA. Using this model, low-distortion sinusoidal oscillators can be designed at frequencies near to the gain-bandwidth product of the OA.

The aim of this paper is to present a general approach to the systematic generation of low-distortion, high amplitude, high frequency active-R oscillators, based on this previous work and using a two pole frequency model for the CFOA.

II. MODEL DESCRIPTION

The generic model for active-R oscillators is shown in Fig.1, where I_{in1} and I_{in2} represent the output current from the inverting input of each CFOA and V_{o1} and V_{o2}, the corresponding output voltage. In this block diagram, Z(s) represents the open-loop transimpedance gain of the CFOA, and the parameters a1, a2, b1 and b2 are function of external resistors (in units of mhos). It can be shown that previous structures found in the literature [2]-[3] are particular cases of this generic model.

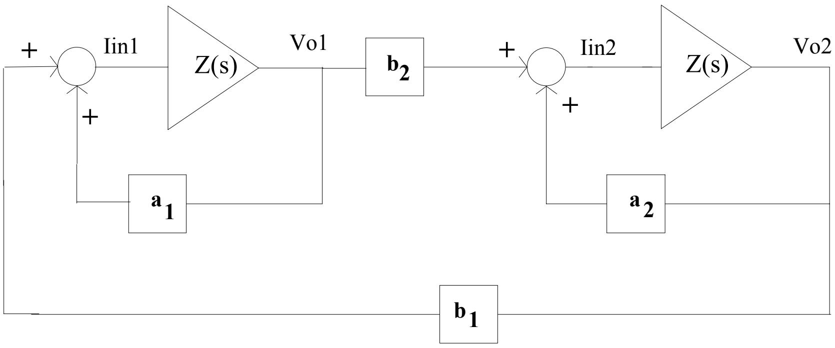

Figure 1: Block diagram representation of the proposed circuit for active-R design.

The open-loop transimpedance gain of each CFOA is modeled by the two pole transfer function

$$Z(s) = \frac{Vo(s)}{Iin(s)} = \frac{Ro \cdot \omega_1 \cdot \omega_2}{(s+\omega_1)(s+\omega_2)} \quad \textbf{(1)}$$

where Ro is the DC transimpedance gain, ω1 is the open-loop dominant pole and ω2 is a second pole much higher than ω1 due to the internal current mirrors of the device [4].

Taking into account this model and assuming that the two CFOA are identical, the loop gain T(s) of the block diagram of Fig. 1 can be expressed as follows

$$T(s) = \frac{k}{(s-p_1^{(1)}) \cdot (s-p_2^{(1)}) \cdot (s-p_1^{(2)}) \cdot (s-p_2^{(2)})} \quad \textbf{(2)}$$

where

$$k = -b_1 \cdot b_2 \cdot (Ro \cdot \omega_1 \cdot \omega_2)^2 \quad \textbf{(3)}$$

and

$$p_{1,2}^{(i)} = \frac{-(\omega_1+\omega_2) \pm \sqrt{\omega_2^2 - 4 \cdot \omega_2 \cdot \omega_1 (1 - a_i \cdot Ro)}}{2} \quad \textbf{(4)}$$

$(i = 1,2)$

As it is shown in [1] a necessary condition for oscillation is that the signs of b1 and b2 must be different. On the other hand, the values of a1 and a2 determine the starting point of the root locus corresponding to T(s), thus their respective bounds can be established depending on the range of the oscillation desired.

Applying the Routh's criterion to the characteristic polynomial, we obtain the minimum theoretical value of the product b1b2 that provides a sinusoidal oscillation.

$$\min(b_1 b_2) = -\frac{(a_1+a_2)}{4 \cdot Ro \cdot \omega_1}\left[2 \cdot \omega_2 - (a_1+a_2) \cdot Ro \cdot \omega_1\right] - a_1 a_2 \quad \textbf{(5)}$$

The corresponding oscillation frequency will be given by

$$\omega_o^2 = \frac{2(a_1 a_2 - b_1 b_2) \cdot (Ro \cdot \omega_1)^2 \cdot \omega_2}{2\omega_2 - (a_1+a_2) \cdot Ro \cdot \omega_1} \quad \textbf{(6)}$$

A simpler expression can be found if the approximation of the root locus obtained in [5] is applied here. This approximation consist of fourth order dynamics reduction to second order in the vicinity of the imaginary axis. In this case the oscillation will be given by

$$\omega_o^2 = \frac{\omega_1 \cdot \omega_2}{2}\left[2 - (a_1+a_2) \cdot Ro\right] \quad \textbf{(7)}$$

which is valid if the absolute value of the real part of $p_{1,2}^{(i)}$ is considerably smaller than $\omega_2/2$.

III. CIRCUIT IMPLEMENTATION

As an example of the use of the generic model and equations, the design of a high frequency oscillator is presented. On one hand, it has to be consider that the signs of the parameters b1 and b2 must be different. On the other hand, it can be shown that a high frequency design requires parameters a1 and a2 to be negative.

Fig. 2 shows a circuit with a minimum number of components that implements a high frequency active-R oscillator corresponding to the proposed generic model.

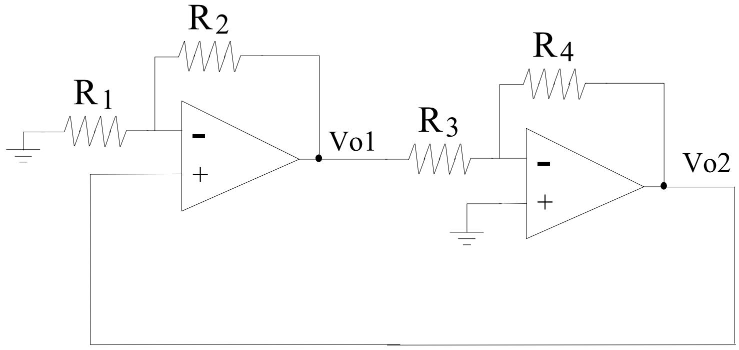

Figure 2: High Frequency active-R oscillator based on the model of Fig. 1.

From the analysis of the circuit we find

$$\mathrm{Iin1} = \frac{\mathrm{Vo2}}{\mathrm{R1}} + \frac{\mathrm{Vo2} - \mathrm{Vo1}}{\mathrm{R2}} \qquad \mathrm{Iin2} = \frac{-\mathrm{Vo1}}{\mathrm{R3}} - \frac{\mathrm{Vo2}}{\mathrm{R4}} \qquad \textbf{(8)}$$

The identification of these previous expressions with the generic model of Fig.1 gives the following value for parameters a1, a2, b1 and b2

$$\begin{aligned} a_1 &= -\frac{1}{\mathrm{R2}} \qquad b_1 = \frac{1}{\mathrm{R1}} + \frac{1}{\mathrm{R2}} = \frac{1}{\mathrm{R1}//\mathrm{R2}} \\ a_2 &= -\frac{1}{\mathrm{R4}} \quad \text{and} \quad b_2 = -\frac{1}{\mathrm{R3}} \end{aligned} \qquad \textbf{(9)}$$

As it can be seen, all parameters can be independently adjusted.

IV. EXPERIMENTAL RESULTS

Results are achieved using Elantec EL2020 which is a CFOA with 50 MHz unity gain stable bandwidth. From equations (5) and (7), and the values of Ro, ω1 and ω2 included on the manufacturer macromodel of the EL2020 [6], the value of the resistors R1 to R4 can be calculated.

Several designs at different frequencies have been experimentally tested. Some differences (less than 10%) are found between the experimental and the theoretical frequencies due to the amplitude stabilization process (in the same way as in the OA based active-R oscillators [1]) and to second order parasitic effects of the CFOA. The most important of those parasitic effects is the resistance of its inverting input. The inclusion of this impedance (Rinv) doesn't modify the design equations (1) to (6) but changes the realization of parameters a1, a2, b1 and b2. The oscillator circuit proposed for high frequency design is showed in Fig.3, where Rinv is represented.

Taking into account the resistance Rinv, the expression of the parameters a1, a2, b1 and b2 is

$$a_1 = -\frac{\mathrm{R1}}{\mathrm{R1}+\mathrm{Rinv}} \cdot \frac{1}{\mathrm{R2}+\mathrm{R1}//\mathrm{Rinv}} \qquad b_1 = \frac{1}{\mathrm{R1}//\mathrm{R2}+\mathrm{Rinv}}$$

$$a_2 = -\frac{\mathrm{R3}}{\mathrm{R3}+\mathrm{Rinv}} \cdot \frac{1}{\mathrm{R4}+\mathrm{R3}//\mathrm{Rinv}}$$

and **(10)**

$$b_2 = -\frac{\mathrm{R4}}{\mathrm{R4}+\mathrm{Rinv}} \cdot \frac{1}{\mathrm{R3}+\mathrm{R4}//\mathrm{Rinv}}$$

As it can be seen the inclusion of Rinv makes these parameters no longer independent. If those expressions are taken into account, resistors R1 to R4 must be something lower that the value calculated from (9).

Fig. 3 shows the output waveform corresponding to the oscillator depicted in Fig. 2, with the parameters a1=a2= $-7 \cdot 10^{-4}$, $-b1b2=2.4 \cdot 10^{-6}$. The theoretical oscillation frequency is 38.7 MHz while the actual frequency is 35 MHz being the amplitude 2 Vpp and the distortion about -35 dB. The resistor values are R2=R4=1330 Ω, R1=1600 Ω and R2=780 Ω obtained from expression (10).

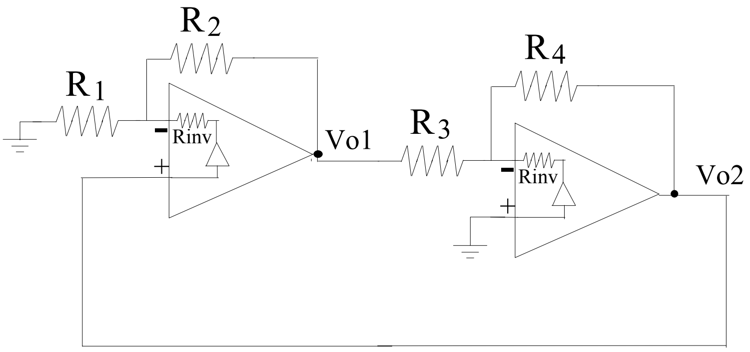

Figure 3: Active-R oscillator circuit with the representation of the output resistance of the inversor input of the CFOA.

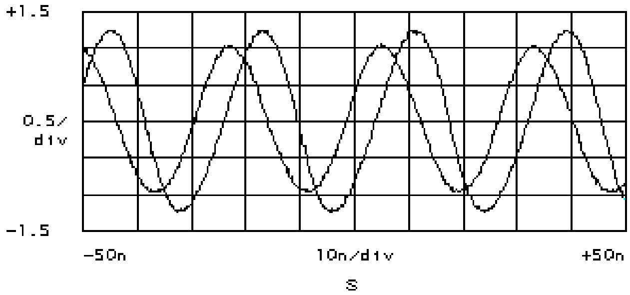

Figure 4: Output waveform of Vo1 and Vo2 of the active-R oscillator in Fig.2.
The horizontal scale is 10 ns div^{-1} and the vertical one is 0.5 V div^{-1}.

V. CONCLUSIONS

A generic model for active-R oscillators using the current feedback op-amps has been presented. Based on this model high frequency oscillators up to the unity gain bandwith of the CFOA can be designed. The oscillation condition and frequency can be controlled by resistors, therefore the design is suitable for been electronically tunable. Several designs at different frequencies have been experimentally tested with good agreement with theoretical predictions. It has been shown that the use of the CFOA in active-R oscillators allows obtaining high frequency oscillators with high amplitude voltage.

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