A new minimum component current feedback operational amplifier based sinusoidal oscillator

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ABSTRACT

A new current-feedback operational amplifier (CFOA) based sinusoidal oscillator circuit is presented and tested. The circuit uses only one externally connected inductor and exploits to advantage the internal poles of the CFOA. A complete analysis of this circuit with respect to its dynamic properties is given. The AD844 can be used in place of traditional op amps, but its current feedback architecture results in much better ac performance, high linearity, and an exceptionally clean pulse response. Experiments show that sinusoidal oscillation at frequency of 122.1 MHz was obtained using the AD844 CFOA and an inductor of inductance = 0.14uH with peak-to-peak output voltage=700 mV. This is the highest frequency of oscillation obtained using the AD844 CFOA. The offset voltage and input bias currents of the circuit are laser trimmed to minimize dc errors; VOS drift is typically 1 μV/°C and bias current drift is typically 9 nA/°C. Peak output rate of change can be over 2000 V/μs for a full 20 V output step. Settling time is typically 100 ns to 0.1%, and essentially independent of gain.

KEYWORDS

AD844; CFOA; Operational amplifier; Highest frequency.
INTRODUCTION

Sinusoidal oscillators are indispensable building blocks in many instrumentation, control, communication and other analog signal processing systems. Over the years several sinusoidal oscillator circuits have been developed and reported in the literature using off-the-shelf integrated circuits like the voltage-mode operational-amplifiers, operational transconductance amplifiers, plus-type second-generation current conveyors and the current-feedback operational amplifiers (CFOA). Of particular interest here are the CFOA based realizations. This is attributed to the attractive features of the CFOA like the larger bandwidth and the higher slew-rate. Thus, sinusoidal oscillator circuits built around the CFOA are expected to work at relatively higher frequencies than their counterpart using the voltage-mode operational amplifiers. Moreover, by exploiting to advantage the parasitic components of the CFOA it is possible to further extend the operating frequency range of CFOA-based oscillator circuits. TABLE 1 shows a comparison between a selected number of the CFOA-based sinusoidal oscillators reported in the open literature\(^\text{[1],[33]}\).

Inspection of TABLE 1 clearly shows that the maximum oscillation frequency reported is 40 MHz\(^\text{[13]}\). This was obtained using two CFOAS, 3 resistors and the parasitic components (internal poles) of the CFOAs. While using inductors is expected to result in higher oscillating frequencies, the maximum frequency of oscillation reported using a single CFOA, 6 passive components; one of them is an inductor, and the parasitic components of the CFOA is 10MHz. According to the Analog Devices data sheet of the AD844 CFOA\(^\text{[34]}\), the bandwidth is 60 MHz at gain = 1. Thus, it appears that the full bandwidth capability of the AD844 is not exploited to advantage yet. The major intention of this paper is to present a new CFOA-based sinusoidal oscillator using only one CFOA and one inductor that can oscillate at frequencies up to 122.1MHz. Thus, exploiting to advantage the high speed capability of the AD844 CFOA.

PROPOSED CIRCUIT

The AD844 is a high speed monolithic operational amplifier fabricated using the Analog Devices, Inc., junction isolated complementary bipolar (CB) process. It combines high bandwidth and very fast large signal response with excellent dc performance. The AD844 can be used in ways similar to a conventional op amp while providing performance advantages in wideband applications. However, the bandwidth is 60 MHz at gain = 1. In many applications, the bandwidth is not enough. Figure 1 shows AD844 current feedback amplifier reduced to essentials. Sources of fixed dc errors. Such as the inverting node bias current and the offset voltage, are excluded from this model.

![Figure 1: Equivalent Schematic of AD844](image)

The current feedback operational amplifier-based sinusoidal oscillator, \(x\) and \(y\) are differential inputs to the CFOA, \(z\) is a slewing node, and \(w\) is the output pin. The equivalent circuit of this oscillator structure is shown in FIG 1. Where in the dotted box represent a simplified equivalent circuit for the CFOA. In this equivalent circuit, \(R_x\) and \(R_o\) represent the output resistances of the unity-gain buffers A1 and A2, respectively, \(C_y\) is the internally of the gain node; and \(C_y\) and \(R_y\) represent the input impedances at terminal \(y\) of the CFOA. In FIG 1, assuming that \(i_x=i_z, i_y=0, U_x=U_y\) and \(U_z=U_w\), the input impedance seen at terminal \(x\) of the CFOA can be expressed as:

\[
Z_{\text{input}} = -Z_2
\]

Where

\[
-Z_2 = \frac{R_2}{1 + SC_2 R_2}
\]
In equation (2), \( R_2 = R_y / R_z \) and \( C_2 = C_y + C_z \). The negative impedance of equation (2) will be in parallel with the positive impedance \( Z_1 \) given by:

\[
Z_1 = R_1 + \frac{R_2}{SC_1}
\]  

(3)

In equation (3), \( R_1 = R_x \). Routine analysis shows that the circuit can be expressed as:

\[
\lambda_2 - \left( \frac{1}{C_2 R_1} - \frac{1}{C_2 R_2} - \frac{1}{C_1 R_1} \right) \lambda + \frac{1}{C_1 C_2 R_2 R_1} = 0
\]  

(4)

Applying the Barkhausen criterion equation (4) yields the frequency and condition of oscillation, given by:

\[
\omega_0^2 = \frac{1}{C_1 C_2 R_2 R_1}
\]  

(5)

And

\[
\frac{1}{C_2 R_1} - \frac{1}{C_2 R_2} - \frac{1}{C_1 R_1} = 0
\]  

(6)

However, equations (4) and (6) do not provide the correct frequency of oscillation and the condition for a successful startup for the oscillator. In order to find a better approximation for the frequency of oscillation and oscillation startup condition, the roots of equation (4) must be obtained. These roots are:

\[
\lambda_{1,2} = \frac{1}{2} \left( \frac{1}{C_1 R_1} - \frac{1}{C_2 R_2} - \frac{1}{C_1 R_1} \right) \pm j \sqrt{\frac{1}{C_1 C_2 R_2 R_1} - \frac{1}{4 \left( C_2 R_2 - C_1 R_1 \right)}}
\]  

(7)

To startup and maintain oscillation, these two roots must lie in the right-hand plane. This can be satisfied if:

\[
\frac{1}{C_1 R_1} - \frac{1}{C_2 R_2} - \frac{1}{C_1 R_1} = \epsilon_1 > 0
\]  

(8)

And

\[
\frac{1}{C_1 C_2 R_2 R_1} = \omega_0^2 > \frac{1}{4 \left( C_2 R_2 - C_1 R_1 \right)}
\]  

(9)

The frequency of oscillation is then:

\[
\omega^2 = \frac{1}{C_1 C_2 R_2 R_1} \left( \frac{1}{C_2 R_2} - \frac{1}{C_1 R_1} \right)^2 = \omega_0^2 - \epsilon_1^2
\]  

(10)

Inspection of equation (8) and (10) clearly shows that the frequency of oscillation can never be \( \omega_0 \), given by equation (5), as the condition of oscillation startup requires \( \epsilon_1 > 0 \) moreover, inspection of equation (8) and (10) shows that while the frequency and the condition of oscillation can be controlled by adjusting the values of \( R_1 \) imposed by the parasitic resistance at terminal \( x \) and \( C_2 \) imposed by the parasitic capacitances at terminals \( y \) and \( z \), it is possible to calculate the value of the resistance \( R_2 \) required to obtain a specific frequency of oscillation for a selected value of the capacitor \( C_1 \). For example, with \( R_1 = 50 \), \( C_1 = 200 \text{pf} \) and \( C_2 = 6.5 \text{pf} \), the value of the resistance \( R_2 \) that can satisfy equation (8) must meet the condition:

\[ R_2 > 51.7 \Omega \]  

(11)

And the value of \( R_2 \) that can satisfy equation (11) must meet the condition:
Thus, combining the conditions of equations (11) and (12), the resistance $R_2$ must meet the condition:

$$51.7 \Omega < R_2 < 74 \Omega$$  \hspace{1cm} (13)$$

Using this condition it is possible to select values for the resistance $R_2$ to support starting up and sustaining sinusoidal oscillations when $R_1=50 \Omega$, $C_1=200 \text{pf}$ and $C_2=6.5 \text{pf}$, in a similar way, it is always possible to find the values of the resistance $R_2$ required to support starting up and sustaining sinusoidal oscillations using the circuit of FIG 1 for any scenario of value for $R_1$, $C_1$ and $C_2$.

The important parameters defining ac behavior are the trans capacitance, $C_z$, and the external feedback resistor (not shown). The time constant formed by these components is analogous to the dominant pole of a conventional op amp and thus cannot be reduced below a critical value if the closed-loop system is to be stable. In practice, $C_z$ is held to as low a value as possible (typically 5.5 pF) so that the feedback resistor can be maximized while maintaining a fast response. The finite $R_y$ also affects the closed-loop response in some applications.

The proposed circuit is shown in Figure 2 where $L$ is an externally connected inductor and $r$ represents its internal resistance. The equivalent circuit of the circuit of Figure 2 is shown in Figure 3 where the dotted box represents a simplified equivalent circuit for the CFOA$^{[34]}$.

Figure 2: Proposed oscillator circuit using one CFOA and one inductor

Figure 3: Equivalent circuit of the proposed oscillator circuit of Figure 2. The circuit in the dotted box is a simplified equivalent circuit for the CFOA

In Figure 3 the capacitance $C_x$ represents the parasitic capacitance at node $x$ of the CFOA. Routine analysis of the circuit of Figure 3 yields the characteristic equation of the oscillator circuit of Figure 2 that can be expressed as

$$2R_z + s[C_x R_x R_z + L] + s^2[L C_z R_z + L C_x R_x] + s^3[L C_x C_z R_x R_z] = 0$$  \hspace{1cm} (14)$$

Applying the Barkhausen criterion to equation (14) the frequency of oscillation and the condition of oscillation of the circuit of Figure 2 can be expressed as

$$w_0^2 = \frac{1 + \frac{L}{C_x R_x R_z}}{L C_z}$$  \hspace{1cm} (15)$$

And with $C_x=5 \text{pF}$, $C_z=5.5 \text{pF}$, $R_x=50 \Omega$, $R_z=5 \text{M} \Omega$, and $L$ is of the order of few $\mu$H equations then equations (15) and (14) reduce to
\[ w_0^2 \approx \frac{1}{LC_z} \]  

(16)

And

\[ L \approx C_x R_x R_z \]  

(17)

It is worth mentioning here that extreme care must be taken when using equations (14)-(17) obtained using the Barkhausen criterion. In fact this criterion is questionable and its results must be used as guidelines only.

**EXPERIMENTAL RESULTS**

The proposed circuit of Figure 2 was tested using the AD844 CFOA. The variations of the frequency of oscillation and the peak-to-peak amplitude with the value of the externally connected inductance are shown in Figs. 4 and 5.

**Figure 4** : Variation of the frequency of oscillation with the externally connected inductance \( L \)

**Figure 5** : Variation of the peak-to-peak output voltage with the externally connected inductance

Comparison between the results obtained from the circuit of Figure 2 clearly shows that the frequency of oscillation obtained is the highest. The proposed circuits were tested using the AD844 CFOA element operated with a 0±12V dc supply. The internal device parameters were measured to be \( C_x = 5 \text{pF}, C_z = 5.5 \text{pF}, R_x = 50\Omega, R_z = 5 \text{M}\Omega \), the tuning characteristics were verified in the range of 75MHz to 122.1MHz and \( L \) from 0.15uH to 0.58uH. Thus it appears that the circuit of Figure 2 can produce high frequencies of 122.1 MHz using only one externally connected inductor exploiting to advantage the internal poles of the CFOA. Figure 5 is shown the Variation of the peak-to-peak output voltage with the externally connected inductance. The inductor of inductance is 0.14uH with peak-to-peak output voltage=700 mV.

**CONCLUSIONS**

In this article a skeleton circuit for generating sinusoidal oscillations has been presented. The proposed circuit exploits to advantage the internal poles of the CFOA and uses only one externally connected inductor. The proposed circuit produces sinusoidal signals with frequencies much higher than any previously reported frequencies using the CFOA. As expected from equation (17) the frequency of oscillation decreases as the inductance increases. It is worth mentioning here
that the proposed circuit was used for generating FM signals that was successfully received using an FM receiver at a
distance around 3 meters. The proposed circuit can, therefore, be used as a simple FM generator.

TABLE 1 : Comparison between a selected number of the CFOA-based sinusoidal oscillators reported in the open
literature

<table>
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REFERENCES