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A new minimum component current feedback operational amplifier based sinusoidal oscillator

Li Ya[1,2]*, Qi Ya-ping[1]
[1]Faculty of Information Engineering and Automation,
Kunming University of Science and Technology, Kunming, Yunnan, (CHINA)
[2]Faculty of Land and Resource Engineering, Kunming University of Science and Technology, Kunming, (CHINA)
E-mail: sherly2001@sina.com

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 trans conductance 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[1],[33].

Inspection of TABLE 1 clearly shows that the maximum oscillation frequency reported is 40 MHz[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[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 band-width 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.

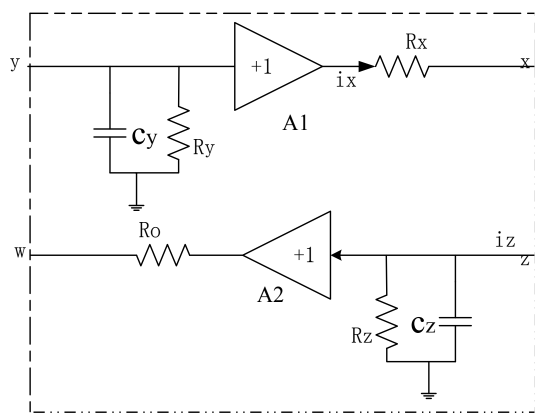

Figure 1 : Equivalent Schematic of AD844

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_z 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:

$$Z_{\text{input}} = -Z_2 \tag{1}$$

Where

$$-Z_2 = \frac{R_2}{1+SC_2R_2} \tag{2}$$

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:

$$Z_1 = R_1 + \frac{R_2}{SC_1} \quad \textbf{(3)}$$

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

$$\lambda_2 - \left(\frac{1}{C_2R_1} - \frac{1}{C_2R_2} - \frac{1}{C_1R_1}\right)\lambda + \frac{1}{C_1C_2R_1R_2} = 0 \quad \textbf{(4)}$$

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

$$\omega_0{}^2 = \frac{1}{C_1C_2R_2R_1} \quad \textbf{(5)}$$

And

$$\frac{1}{C_2R_1} - \frac{1}{C_2R_2} - \frac{1}{C_1R_1} = 0 \quad \textbf{(6)}$$

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:

$$\lambda_1,_2 = \frac{1}{2}\left(\frac{1}{C_2R_1} - \frac{1}{C_2R_2} - \frac{1}{C_1R_1}\right) \pm j\sqrt{\frac{1}{C_1C_2R_2R_1} - \frac{1}{4}\left(\frac{1}{C_2R_1} - \frac{1}{C_2R_2} - \frac{1}{C_1R_1}\right)} \quad \textbf{(7)}$$

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

$$\frac{1}{C_2R_1} - \frac{1}{C_2R_2} - \frac{1}{C_1R_1} = \varepsilon_1 > 0 \quad \textbf{(8)}$$

And

$$\frac{1}{C_1C_2R_2R_1} = \omega_0{}^2 > \frac{1}{4}\left(\frac{1}{C_2R_1} - \frac{1}{C_2R_2} - \frac{1}{C_1R_1}\right)^2 \quad \textbf{(9)}$$

The frequency of oscillation is then:

$$\omega^2 = \frac{1}{C_1C_2R_2R_1} - \frac{1}{4}\left(\frac{1}{C_2R_1} - \frac{1}{C_2R_2} - \frac{1}{C_1R_1}\right)^2 = \omega_0{}^2 - \varepsilon_1{}^2 \quad \textbf{(10)}$$

Inspection of equation (8) and (10) clearly shows that the frequency of oscillation can never be w_0, given by equation(5), as the condition of oscillation startup requires $\varepsilon_1>0$ moreover, inspection of equation (8) and (10) shows that while the frequency and the condition of oscillation can be controlled by adjusting the

Furthermore, equation (10) clearly shows that w_0 must be larger than $\varepsilon_1>0$ in order to get oscillation. Thus, with the values of R1 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 $R_1=50$, $C_1=200pf$ and $C_2=6.5pf$, the value of the resistance R_2 that can satisfy equation (8) must meet the condition:

$$R_2>51.7\Omega \quad \textbf{(11)}$$

And the value of R_2 that can satisfy equation (11) must meet the condition:

$$36.0\Omega<R_2<74.0\Omega \quad \textbf{(12)}$$

Thus, combining the conditions of equations (11) and (12), the resistance R2 must meet the condition:

$$51.7\Omega<R_2<74\Omega \quad \textbf{(13)}$$

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=50Ω, C_1=200pf and C_2=6.5pf, 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, Cz, 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].

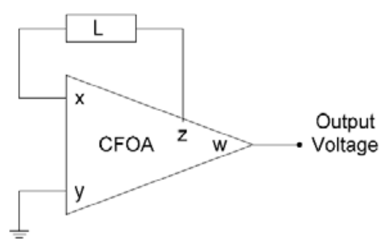

Figure 2 : Proposed oscillator circuit using one CFOA and one inductor

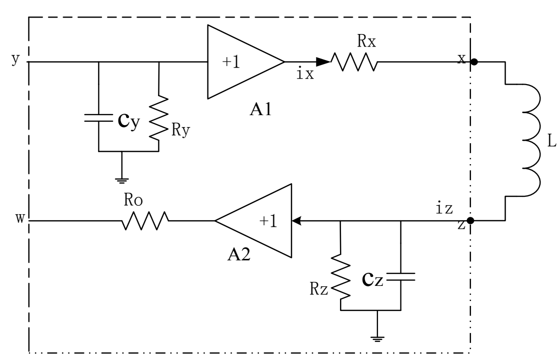

Figure 3 : Equivalent circuit of the proposed oscillator circuit of Figure 2. The circuit in the dotted box is a simplified equivalent circuit for the CFOA

In Figure 3 the capacitance Cx 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

$$\begin{aligned}&2R_z+s[C_xR_xR_z+L]+s^2[LC_zR_z+LC_xR_x]\\&+s^3[LC_zC_xR_zR_x]=0\end{aligned} \quad \textbf{(14)}$$

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

$$w_0{}^2=\frac{1+\dfrac{L}{C_xR_xR_z}}{LC_z} \quad \textbf{(15)}$$

And with C_x=5pF, C_z=5.5pF, R_x=50Ω, R_z=5MΩ, and L is of the order of few uH equations then equations (15) and (14) reduce to

$$w_0^{\ 2} \cong \frac{1}{LC_z} \tag{16}$$

And

$$L \cong C_x R_x R_z \tag{17}$$

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.

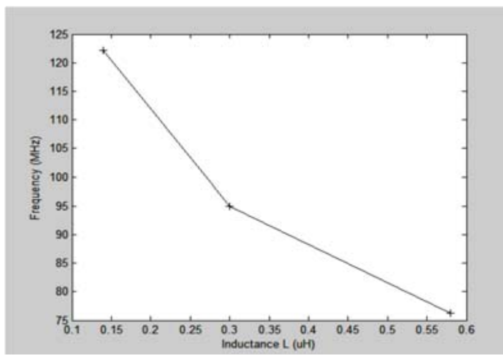

Figure 4 : Variation of the frequency of oscillation with the externally connected inductance L

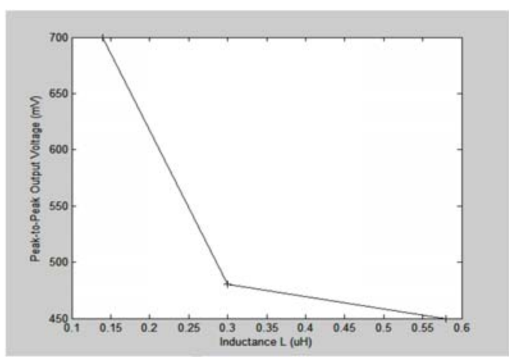

Figure 5 : Variation of the peak-to-peak output voltage with the externally connected inductance

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=5pF, $C_{Z=}$5.5pF, R_x=50Ω, R_z=5MΩ, 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 0.14*uH* 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

Reference Number	Number of AD844 CFOAs	Number of Passive elements	Maximum Reported Frequency (MHz)	Use of CFOA Parasitic Components
[1]	1	5	27.5	Yes
[2]	1	4	3.12	Yes
[3]	1	4	34.4	Yes
[4]	2	6-8	2.0	
[5]	1	5	16.1	Yes
[6]	1	5	0.123	No
[7]	2	5	0.310	No
[8]	1	4-7	4.5	No
[9]	3	6	0.147	No
[10]	1	3	12.0	Yes
[11]	1	6	28.5	Yes
[12]	2	2	10.3	Yes
[13]	2	3	40.0	Yes
[14]	1	5	22.0	Yes
[15]	1	4	13.0	Yes
[16]	1	4-6	1.2	No
[17]	2	2-3	6.25	Yes
[18]	1	5-6	0.6	No
[19]	1	6	10.0	Yes
[20]	1-3	4-7	0.174	No
[21]	1	4	2.3	No
[22]	2	4-5	0.040	No
[23]	3-6	5	15.2	No
[24]	2	5	0.370	No
[25]	2	5	6.0	No
[26]	2-3	5-7	0.0159	No
[27]	1	5	0.8	No
[28]	1	6	6.0	Yes
[29]	1	6	1.110	Yes
[30]	2	5	0.500	No
[31]	2	6	0.609	No
[32]	2	5	0.270	No
[33]	2	5	0.065	No
Proposed Circuit	1	1	122.1	Yes

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