以電流差分緩衝放大器及最少被動元件所建構之正弦振盪器
A Sinusoidal Oscillator Employing Current Differencing Buffered Amplifier and Minimum Passive Components

侯俊禮*[1] 黃振權[1] 張俊明[2]
Chun-Li Hou*[1], Chen-Chuan Huang[1], Chun-Ming Chang[2]

Abstract

In this work, a sinusoidal oscillator that employs only a single current differencing buffered amplifier (CDBA) as the active component is proposed. This oscillator not only has minimum passive component count properties but also utilize all terminals of the CDBA component. The oscillator circuit has been analyzed theoretically, simulated and experimentally. The Hspice simulation and experiment results verifying the theoretical analysis are also given.

Keywords: current differencing buffered amplifier (CDBA), minimum component CDBA oscillators.

摘要

本篇文章提出以主動元件電流差分緩衝放大器(CDBA)所建構之正弦振盪器。此型振盪器不但使用最少之被動元件數且完全使用電流差分緩衝放大器的所有端點。而此振盪器電路也以理論、Hspice 模擬與實驗來驗證分析。所提供的模擬與實驗結果亦證明其理論分析。

關鍵詞: 電流差分緩衝放大器(CDBA)，最少元件之 CDBA 振盪器

I. INTRODUCTION

In the past decades, current-mode circuits have been receiving considerable attention due to their potential advantages such as inherently wider bandwidth, higher slew-rate, greater linearity, wider dynamic range, simpler circuitry and lower power consumption [1]. Since the CDBA consists of a unity gain current differential amplifier and a unity gain voltage amplifier, this component would be the most reasonable for high-frequency operation and free from many parasitic capacitances [2]. Mostly important, the main advantage of CDBA based oscillators compared to those based on CFA and CCII arises from behavior of the input terminals, the input parasitic capacitance effect on oscillator performance can be ignored since its input terminals are virtually grounded [3]. Besides, the CDBA not only can be cascadable because of the high impedance of the z-terminal but also not require an element-matching condition [4]. In addition, many of analog signal processing applications require voltage mode operations. Therefore, it is advantageous to implement current-mode active elements over voltage-mode circuits. It is suitable for analog signal processing applications [4-5].

Minimum passive component oscillators seem to be received much interest in literature. Although the oscillators using plus type second generation current conveyors (CCII+) [6], operational transconductance amplifiers (OTA) [7], operational transresistance amplifiers (OTRA) [8], current feedback amplifiers (CFA) [9-10], and current and voltage followers [11], current differencing buffered amplifiers (CDBA) [12] as active components were presented, the oscillator utilizing all terminals of the CDBA component and minimum passive components has not been yet studied sufficiently.

II. CIRCUIT DESCRIPTION

Current differencing buffered amplifier:

The circuit symbol of the CDBA is shown in Fig. 1(a) where p and n are the input terminals and w and z are the output terminals.

The equivalent circuit of the CDBA is given in Fig. 1(b). The current differencing buffered amplifier [5,13] is characterized by

[1] 中原大學電子工程系　　[2] 中原大學電機工程系
* Corresponding author. E-mail: clhou@cycu.edu.tw
[1] Department of Electronic Engineering, Chung Yuan Christian University, Chung Li, Taiwan 320, R.O.C.
[2] Department of Electrical Engineering, Chung Yuan Christian University, Chung Li, Taiwan 320 , R.O.C
Manuscript received 19 May 2006; revised 7 July 2006; accepted 3 August 2006.

$$\begin{bmatrix} I_z \\ V_w \\ V_p \\ V_n \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_z \\ I_w \\ I_p \\ I_n \end{bmatrix} \quad (1)$$

It should be noted from the above expression that the differential input current I_p-I_n is converted to the output voltage V_w through the impedance connected at the port z. Thus the CDBA basically consists of two unity gain cells, i.e., a current differencing circuit (current subtractor) and a voltage follower. Usually, this CDBA can be constructed using various techniques; one possible realization is based on the use of two CFAs as shown in Fig. 1(c) [14].

Minimum component CDBA oscillators:

Fig. 2 shows the proposed CDBA-based oscillator configuration. Using standard notation from expression (1), its characteristic equation (CE) of this minimum component oscillator circuit is

$$s^2C_1C_2R_1R_2 + \left(\frac{R_1}{R_2} + \frac{C_2}{C_1} - 1\right)sC_1R_2 + 1 = 0 \quad (2)$$

As the design scheme mentioned in the literatures [15-18], the minimum components to construct a 2nd-order characteristic equation require at least 2 capacitors and 2 resistors to meet the terms of $\mathbf{s^2}$, $\mathbf{s^1}$ and $\mathbf{s^0}$.

The frequency of oscillations (FO), condition of oscillations (CO), and the component sensitivities are

$$\omega_0^{\,2} = \frac{1}{C_1C_2R_1R_2} \quad (3)$$

$$R_1C_1 + R_2C_2 = R_2C_1 \quad (4)$$

$$S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = S_{R_1}^{\omega_0} = S_{R_2}^{\omega_0} = -\frac{1}{2} \quad (5)$$

respectively. Here the frequency of oscillations (FO), condition of oscillations (CO) cannot be independently controlled in this oscillator circuit due to its minimum passive components. Since the CDBA tracking errors influence the CO in the non-ideal case, the relationship of the terminal voltages and currents can be rewritten as

$$V_p = 0,\quad V_n = 0,\quad I_z = \beta_p I_p - \beta_n I_n \quad \text{and} \quad V_w = \alpha V_z \quad (6)$$

where $\beta_p = 1-\varepsilon_p$ and ε_p ($|\varepsilon_p|<<1$) is the current-tracking error from p terminal to z terminal, $\beta_n = 1-\varepsilon_n$ and ε_n ($|\varepsilon_n|<<1$) is the current-tracking error from n terminal to z terminal and $\alpha = 1-\varepsilon_v$ and ε_v ($|\varepsilon_v|<<1$) is the voltage-tracking error from z terminal to w terminal of the CDBA.
The equation (2) can be rewritten as

$$s^2C_1C_2R_1R_2 + \left(\alpha\beta_n\frac{R_1}{R_2} + \frac{C_2}{C_1} - \alpha\beta_p\right)sC_1R_2 + \alpha\beta_n = 0 \quad (7)$$

and the oscillation condition

$$\alpha\beta_n R_1C_1 + R_2C_2 = \alpha\beta_p R_2C_1 \quad (8)$$

While equations for the frequency of oscillations and component sensitivities of the oscillator shown in Fig. 2(b) are the same as those given for the circuit of Fig. 2(a).

III. SIMULATION AND EXPERIMENTAL RESULTS

In order to verify the above given theoretical analysis, all of the circuits introduced in this study have been constructed and simulated in the laboratory.

The oscillator was designed with an ideal center frequency of f_0 = 83.9 kHz, by selecting C_1 = 200 pF, C_2 = 100 pF, R_1 = 9 kΩ, R_2 = 20 kΩ. The circuit simulations were performed using a CFA equivalent circuit of the CDBA [5,19], as shown in Fig. 1(c). An Hspice macromodel of AD 844 IC CFA (supplied by Analog Devices Inc.) was employed during circuit simulations. The performances of the circuits have been verified by using the CDBA circuit models [4]. In the minimum component oscillator circuit, the simulated frequency of oscillator was 82 kHz, as shown in Fig. 3. The frequency spectrum of this oscillator is also illustrated in Fig. 4.

Nevertheless, this CDBA-based oscillator is also experimentally tested to verify the theory. In the test circuit, CDBA and passive component values were chosen as in simulations. The output waveform observed on the oscilloscope is shown in Fig. 5.

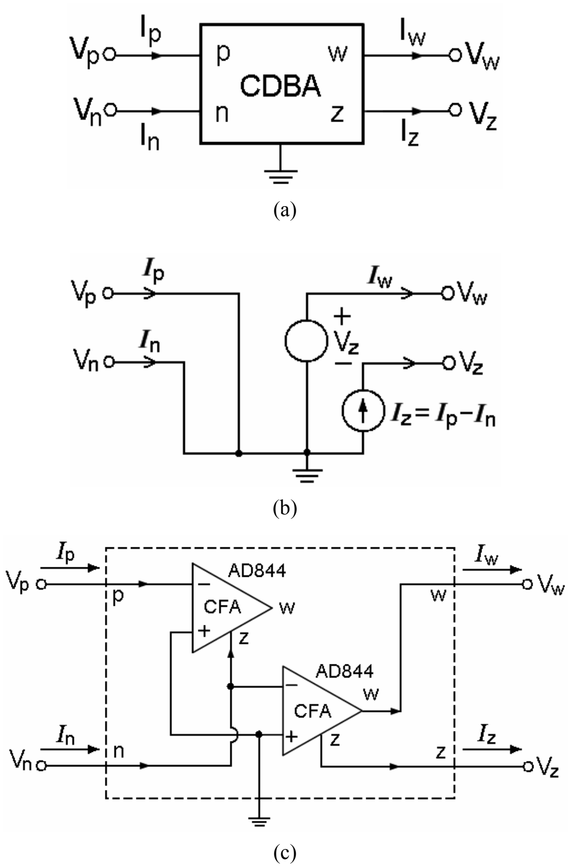


Fig. 1 (a) Circuit symbol of CDBA; (b) equivalent circuit of CDBA; (c) CFA implementation of CDBA

The experiment result exhibits the oscillation frequency 81.94 kHz. Deviations from theory mainly originate from passive component tolerances (≈ 2%) used throughout simulation and experiment tests.

Results are well in agreement with theoretical predictions.

To proceed further, it is worth mentioning that the harmonic distortion (HD) issue should be considered when the performance is concerned. The Fourier analysis of the output wave indicates the HD of the oscillator by using Hspice. These results of the Fourier analysis are listed in Table 1, while the fundamental frequency is 82 kHz.

Moreover, the difference between the fundamental frequency 82 kHz and ideal frequency 83.9 kHz is due to component imperfection.

We can observe that the value of THD is within the reasonable range.

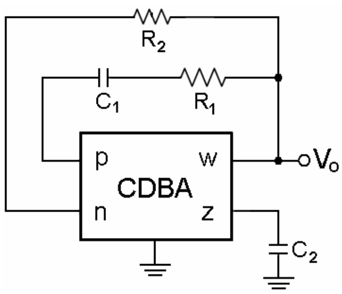
Using the definition of the frequency stability factor (S_F) as in [20],

$$S_F = \left. \frac{d\phi(u)}{du} \right|_{u=1}$$

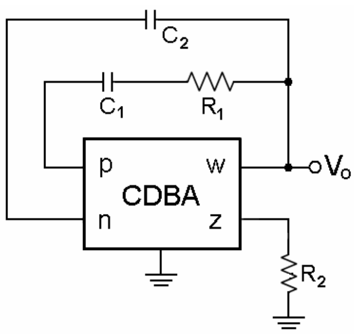
where $u=\omega/\omega_0$ is normalized frequency and $\Phi(u)$ represents the phase function of the open loop transfer function. The stability factor S_F can be obtained to be

$$S_F = \frac{2\sqrt{C_1 C_2 R_1 R_2}}{(C_1 R_1 + C_2 R_2)}$$

It is obviously to find the value of S_F.



(a)



(b)

Fig. 2 2 CDBA-based oscillator configuration

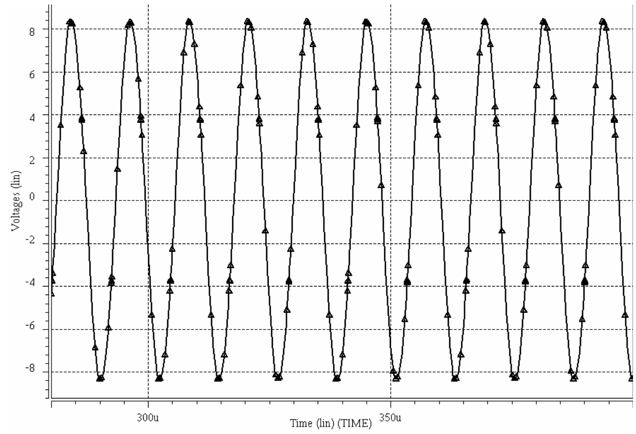


Fig. 3 The output waveform of the CDBA-based oscillator (simulation)

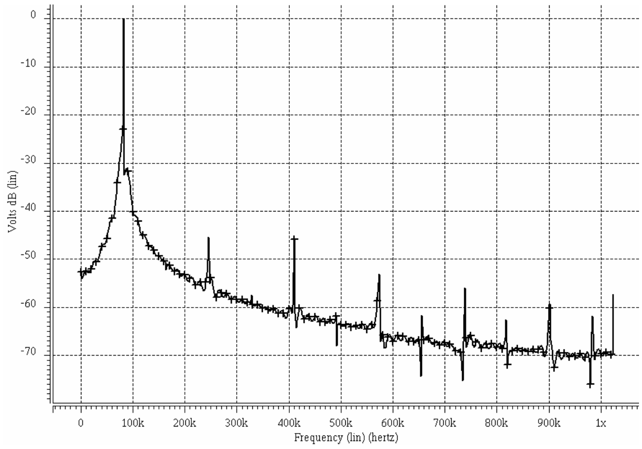


Fig. 4 The frequency spectrum of the CDBA-based oscillator (simulation)

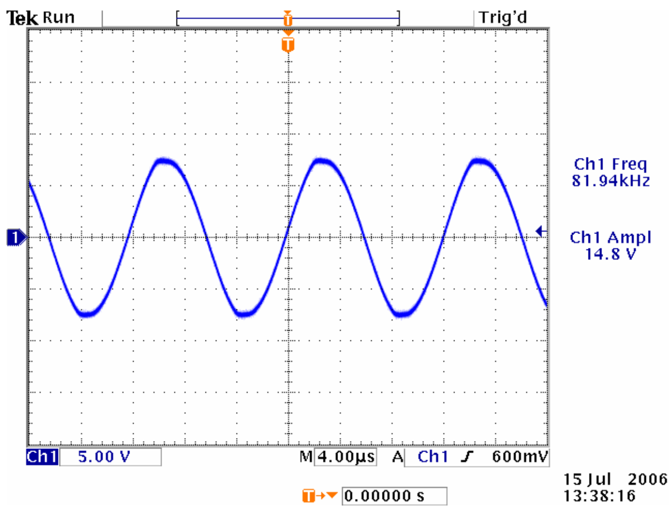


Fig. 5 The output waveform of the CDBA-based oscillator (experiment)

Table 1 Summary lists of fourier analysis for Fig. 2

Harmonic No.	Frequency (kHz)	Fourier component	Normalized component	Phase (deg)	Normalized phase (deg)
1	82.0000	8.3543	1.0000	-22.7105	0
2	164.0000	7.1895m	860.5832u	-11.8805	10.8300
3	246.0000	61.6627m	7.3810m	-162.4987	-139.7882
4	328.0000	3.2664m	390.9903u	-6.5985	16.1119
5	410.0000	45.9197m	5.4966m	-6.4184	16.2920
6	492.0000	2.2474m	269.0092u	-13.2669	9.4435
7	574.0000	20.5010m	2.4540m	126.9918	149.7023
8	656.0000	1.8211m	217.9836u	6.8057	29.5162
9	738.0000	13.4853m	1.6142m	-45.6661	-22.9556

Total harmonic distortion = 0.9712 percent

IV. CONCLUSIONS

This paper presented a CDBA-based oscillator topology. Design considerations of topology achieving control of oscillation condition and oscillation frequency with a minimum number of components are given. The effects of the CDBA non-idealities are also investigated. The performances of the proposed oscillator are verified through Hspice simulation and experiment.

REFERENCES

[1] C. Toumazou, F. J. Lidjey and D. Haigh, "Analog IC design: the current-mode approach," *Exeter, UK: Peter Peregrinus*; 1990.

[2] S. Celma, J. Sabadell and P. Martinez, "Universal filter using unity-gain cells," *Electronics Letters,* vol. 31, pp. 1817-1818, 1995.

[3] S. Özcan, A. Toker, C. Acar, H. Kuntman and O. Çiçekoğlu, "Single resistance-controlled sinusoidal oscillators employing current differencing buffered amplifier," *Microelectronics Journal*, vol. 31, pp. 169-174, 2000.

[4] A. Toker, S. Özcan, O. Çiçekoğlu, O. and C. Acar, "Current mode allpass filters using CDBA and a new high Q bandpass filter configuration," *IEEE Transactions on Circuits and Systems, 2, Analog and Digital Signal Processing*, vol. 47, pp. 949-954, 2000.

[5] C. Acar and S. Özoġuz, "A versatile building block: current differencing buffered amplifier suitable for analog signal processing filters," *Microelectronics Journal*, vol. 30, pp. 157-160, 1999.

[6] M. T. Abuelma'ati and N. A. Humood, "Two new minimum-component Wien-bridge oscillators using current conveyors," *International Journal of Electronics*, vol. 63, pp. 669-672, 1987.

[7] R. Senani, and A. K. Banerjee, "Linearly tunable Wien bridge oscillator realized with operational transconductance amplifiers," *Electronics Letters,* vol. 25, pp. 19-21, 1989.

[8] K. N. Salama and A. M. Soliman, "Novel oscillators using the operational transresistance amplifier," *Microelectronics Journal,* vol. 31, pp. 39-47, 2000.

[9] P. A. Martinez, S. Celma and C. Aldea, "Designing sinusoidal oscillators with current feedback amplifiers," *International Journal of Electronics*, vol. 80, pp. 637-646, 1996.

[10] A. M. Soliman, "Wien oscillators using current feedback op amps," *AEU International Journal of Electronics and Communications*, vol. 51, pp. 314-319, 1997.

[11] A. M. Soliman, "Novel oscillators using current and voltage followers," ***J. Franklin Inst.***, 335B, pp. 997-1007, 1998.

[12] A. Ű. Keskin, "Voltage-mode high-Q band-pass filters and oscillators employing single CDBA and minimum number of components," *International Journal of Electronics*, vol. 92, pp. 479-487, 2005.

[13] S. Özoġuz, A. Toker, and C. Acar, "Current-mode continuous time fully integrated universal filters using CDBA," *Electronics Letters*, vol. 35, pp. 97-98, 1999.

[14] J. A. Svoboda, L. Mcgory and S. Webb, "Applications of a commercially available current conveyor," *International Journal of Electronics*, vol. 70, pp. 159-164, 1991.

[15] S. I. Liu, C. S. Shih and D. S. Wu, "Sinusoidal oscillators with single element control using a current feedback amplifier," *International Journal of Electronics*, vol. 77, pp. 1007-1013, 1994.

[16] M. T. Abuelma'atti, and S. M. Al-Shahrani, "A novel low-component-count single-element- controlled sinusoidal oscillator using the CFOA pole," *International Journal of Electronics*, vol. 80, pp. 747-752, 1996.

[17] M. T. Abuelma'atti, and S. M. Al-Shahrani, "Novel CFOA-based sinusoidal oscillators," *International Journal of Electronics*, vol. 85, pp. 437-441, 1998.

[18] A. Û. Keskin, "Voltage-mode high-Q band-pass filters and oscillators employing single CDBA and minimum number of components," *International Journal of Electronics*, vol. 92, pp. 479-487, 2005.

[19] C. Acar and S. Özoġuz, "nth order transfer function synthesis using current differencing buffered amplifier: signal-flow graph approach," *Microelectronics Journal*, vol. 31, pp. 49-53, 2000.

[20] A. S. Sedra and K. C. Smith, *Microelectronic Circuits*, Oxford University Press, NY, U.S.A., 4th Ed., pp. 975-976, 1998.