Electronically Tunable Third-Order Quadrature Oscillator Using CDTAs

Jiun-Wei HORNG, Hung LEE, Jian-Yu WU

Dept. of Electronic Engineering, Chung Yuan Christian University, Chung-Li, 32023, Taiwan

jwhorng@cycu.edu.tw

Abstract. *A current/voltage-mode third-order quadrature oscillator based on current differencing transconductance amplifiers (CDTAs) is presented in this paper. Outputs of two current-mode and two voltage-mode sinusoids each with 90^o phase difference are available in the quadrature oscillator circuit. The oscillation condition and oscillation frequency are independently controllable. The proposed circuit employs only grounded capacitors and is ideal for integration. Simulation results are included to confirm the theoretical analysis.*

Keywords

Current differencing transconductance amplifiers, quadrature oscillator, current-mode, voltage-mode, active circuit.

1. Introduction

Various new current-mode active building blocks have received considerable attentions owing to their larger dynamic range and wider bandwidth with respect to operational amplifier based circuits. As a result, current-mode active components have been increasingly used to realize active filters, sinusoidal oscillators and immittances.

Quadrature oscillator is used because the circuit provides two sinusoids with 90^o phase difference, as for example in telecommunications for quadrature mixers and single-sideband generators or for measurement purposes in vector generators or selective voltmeters. Therefore, quadrature oscillators constitute an important unit in many communication and instrumentation systems [1-18]. Two-integrator loop technique was developed to realize quadrature oscillators by using operational amplifiers or transconductance elements in [1-2]. Soliman [6] describes several quadrature oscillator circuits based on the modification of two-integrator loop technique using current conveyors. Holzel [3] proposed a method for realizing quadrature oscillator consists of two allpass filters and an inverter using operational amplifiers. Keskin et al. [15], [17] proposed two quadrature oscillators that were designed out by the method in [3] using current differencing buffered amplifiers (CDBAs) or current differencing transconductance amplifiers (CDTAs). Ahmed et al. [4] proposed two quadrature oscillator circuits that were realized based on the allpass filters and the non-inverting integrators as building blocks using operational transconductance amplifiers (OTAs). This method was also used in [16] and [18] to obtain a quadrature oscillator using CDBAs and CDTA, respectively.

In 2003, a new current-mode active element that is called current differencing transconductance amplifier (CDTA) was introduced [19]. Owing to the current conveying property, the CDTA is one of the modifications of the current conveyor (CC). Many applications in the design of active filter [20] and multiphase sinusoidal oscillator [21] using CDTAs as active elements have received considerable attention. A second-order current-mode quadrature oscillator consists of two CDTAs, four resistors and two capacitors was presented in [17]. However, the capacitors used in this circuit are connected to the input terminals of the CDTAs. Since the input terminals of CDTA have parasitic resistances [21], this quadrature oscillator [17] is not ideal for high frequency applications. The CDTA based second-order current-mode quadrature oscillator in [22] was designed out using two-integrator loop technique. The main disadvantage of this oscillator is that there is no control on the condition of oscillation. In 2007, Tangsrirat proposed a second-order quadrature oscillator using three CDTAs and two grounded capacitors [23].

Because the high-order network has high accuracy and high quality factor, it gives good frequency response with low distortion [9-12]. A third-order current-mode quadrature oscillator using three CDTAs and three grounded capacitors was presented in [24]. However, the oscillation condition and oscillation frequency of the circuit presented in [24] cannot be controlled independently.

In this paper, a new CDTAs based current/voltage-mode third-order quadrature oscillator circuit is presented. The oscillation condition and oscillation frequency of the proposed quadrature oscillator can be independently controllable. The proposed quadrature oscillator uses grounded capacitors. The use of only grounded capacitors is especially of interest from the fabrication point of view [25].

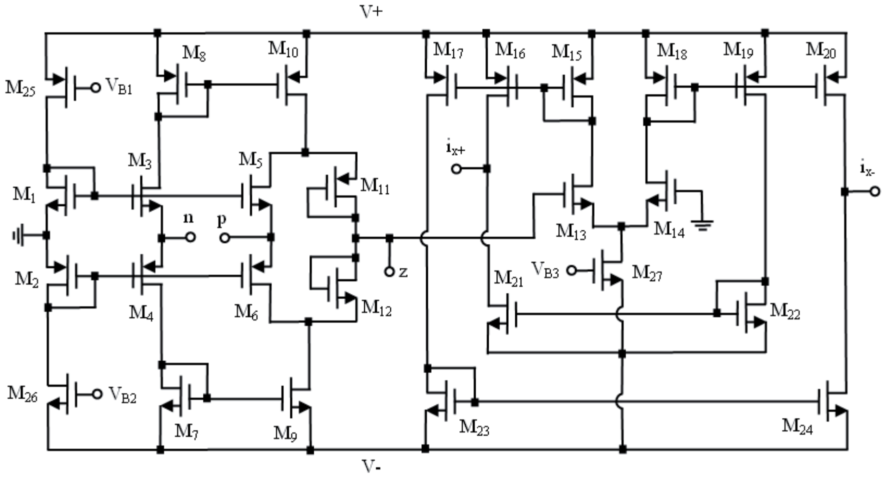


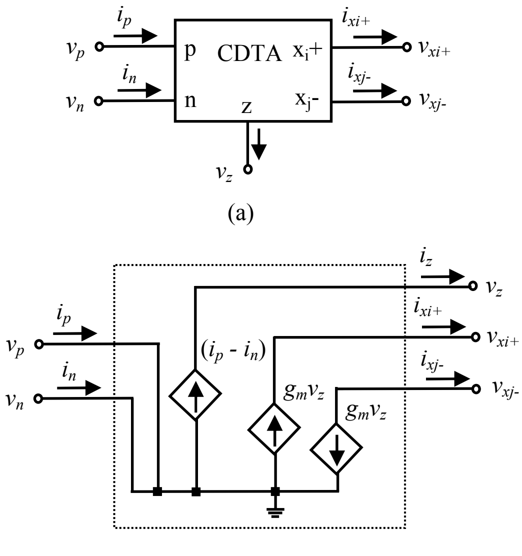
Fig. 2. CMOS-based CDTA.

2. Proposed Circuits

The circuit symbol and the equivalent circuit of the CDTA are shown in Fig. 1. The terminal characteristic of the CDTA can be described by the following equations [19]:

$$v_p = v_n = 0,\ i_z = i_p - i_n \text{ and } i_x = \pm g_m v_z = \pm g_m Z_z i_z \quad (1)$$

where p and n are input terminals, z and x± are output terminals, g_m is the transconductance gain, and Z_z is external impedance connected at the z terminal. According to the above equation and equivalent circuit of Fig. 1(b), the current flowing out of the terminal z (i_z) is a difference between the currents through the terminals p and n ($i_p - i_n$). The voltage drop at the terminal z is transferred to the currents at the terminal x_i+ by the transconductance gain (g_m), which is electrically controllable by an external bias voltage. These currents that are copied to a general number of output current terminals x_j-, are equal in magnitude but flow in opposite directions. A possible CMOS-based CDTA circuit realization is given in Fig. 2 [17].



(a)

(b)

Fig. 1. (a) Circuit symbol of CDTA.
(b) Equivalent circuit of CDTA.

The CDTAs based third-order quadrature oscillator is shown in Fig. 3. The characteristic equation of the circuit in Fig. 3 can be expressed as

$$s^3 C_1 C_2 C_3 + s^2 C_2 C_3 g_{m1} + s C_3 g_{m1} g_{m2} + g_{m1} g_{m2} g_{m3} = 0. \quad (2)$$

The oscillation condition and oscillation frequency can be obtained as

$$g_{m3} = \frac{C_3 g_{m1}}{C_1},\ \omega_o = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}} \quad (3),(4)$$

From equations (3) and (4), the oscillation frequency can be controlled by g_{m2}. The oscillation condition can be independently controlled by g_{m3}. From Fig. 3, the current transfer function from I_{o2} to I_{o1} is

$$\frac{I_{o2}(s)}{I_{o1}(s)} = -\frac{g_{m3}}{sC_3}. \quad (5)$$

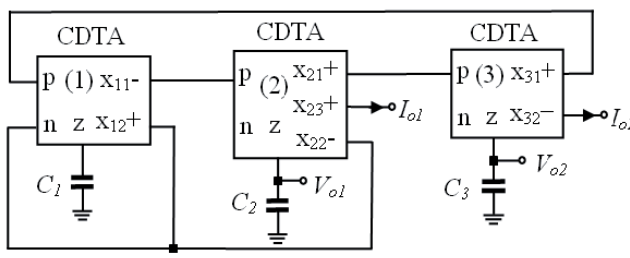


Fig. 3. The proposed current-mode quadrature oscillator.

Under sinusoidal steady state, equation (5) becomes

$$\frac{I_{o2}(j\omega)}{I_{o1}(j\omega)} = \frac{g_{m3}}{\omega C_3} e^{j90^o}. \quad (6)$$

The phase difference, ϕ, between I_{o2} and I_{o1} is

$$\phi = 90^o \quad (7)$$

ensuring the currents I_{o2} and I_{o1} to be in quadrature.

The voltage transfer function from V_{o2} to V_{o1} is

$$\frac{V_{o2}(s)}{V_{o1}(s)} = \frac{g_{m2}}{sC_3}. \tag{8}$$

Under sinusoidal steady state, equation (8) becomes

$$\frac{V_{o2}(j\omega)}{V_{o1}(j\omega)} = \frac{g_{m2}}{\omega C_3} e^{-j90^o}. \tag{9}$$

The phase difference, ϕ, between V_{o2} and V_{o1} is

$$\phi = -90^o \tag{10}$$

ensuring the voltages V_{o2} and V_{o1} to be in quadrature.

The proposed quadrature oscillator employs only grounded capacitors. The use of grounded capacitors is particularly attractive for integrated circuit implementation [25]. From equations (6) and (9), the magnitude of I_{o2} and I_{o1} or V_{o2} and V_{o1} need not to be the same. For the applications need equal magnitude quadrature outputs, another amplifying circuits are needed.

3. Non-Ideal Effects

Taking the non-idealities of the CDTA into account, Fig. 4 shows the simplified equivalent circuit that is used to represent the non-ideal CDTA [21]. In the figure, $\alpha_p = 1-\varepsilon_p$ and ε_p ($|\varepsilon_p| << 1$) is the current tracking error from the p terminal to the z terminal of the CDTA, $\alpha_n = 1-\varepsilon_n$ and ε_n ($|\varepsilon_n| << 1$) is the current tracking error from the n terminal to the z terminal of the CDTA, and $\beta = 1-\varepsilon_i$ and ε_i ($|\varepsilon_i| << 1$) is the output transconductance tracking error from the z terminal to x terminal of the CDTA.

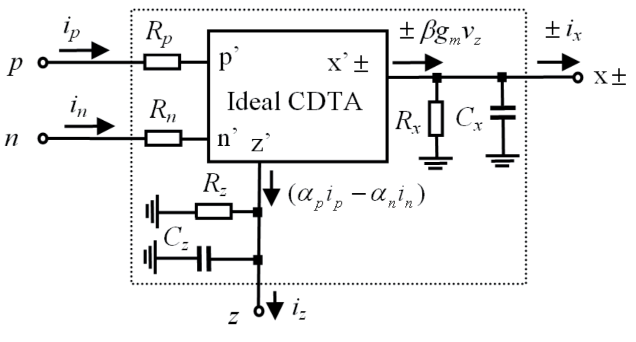


Fig. 4. The non-ideal CDTA.

Moreover, there are parasitic resistances (R_p and R_n) at terminals p and n, and parasitic resistances and capacitances (R_z, C_z and R_x, C_x) from terminals z and x to ground. Re-analysis of the proposed quadrature oscillator in Fig. 3 using the non-ideal CDTA model and assuming that the operation oscillation frequencies, ω, are very much smaller than $1/(C_x R_n)$ or $1/(C_x R_p)$ and the parasitic resistances at the x terminals are very much greater than the parasitic resistances at p or n terminals of CDTAs. The characteristic equation of Fig. 3 becomes

$$\begin{aligned}
&s^3 C_1' C_2' C_3' + s^2[C_2' C_3'(g_{m1}\alpha_{n1}\beta_{12} + G_{z1}) + C_1' C_2' G_{z3} + C_1' C_3' G_{z2}] + \\
&s[C_3'(g_{m1}g_{m2}\alpha_{p2}\alpha_{n1}\beta_{11}\beta_{22} + g_{m1}G_{z2}\alpha_{n1}\beta_{12} + G_{z1}G_{z2}) + \\
&C_1' G_{z2}G_{z3} + C_2'(g_{m1}G_{z3}\alpha_{n1}\beta_{12} + G_{z1}G_{z3})] + \\
&g_{m1}g_{m2}\alpha_{p2}\beta_{11}(g_{m3}\alpha_{p1}\alpha_{p3}\beta_{21}\beta_{31} + G_{z3}\alpha_{n1}\beta_{22}) + \\
&G_{z2}G_{z3}(G_{z1} + g_{m1}\alpha_{n1}\beta_{12}) = 0
\end{aligned} \tag{11}$$

where $C_1' = C_1 + C_{z1}$, $C_2' = C_2 + C_{z2}$, $C_3' = C_3 + C_{z3}$.

The modified oscillation condition and oscillation frequency are

$$\frac{g_{m1}g_{m2}\alpha_{p2}\beta_{11}(g_{m3}\alpha_{p1}\alpha_{p3}\beta_{21}\beta_{31} + G_{z3}\alpha_{n1}\beta_{22}) + G_{z2}G_{z3}(G_{z1} + g_{m1}\alpha_{n1}\beta_{12})}{C_2' C_3'(g_{m1}\alpha_{n1}\beta_{12} + G_{z1}) + C_1' C_2' G_{z3} + C_1' C_3' G_{z2}} =$$

$$\frac{C_3'(g_{m1}g_{m2}\alpha_{p2}\alpha_{n1}\beta_{11}\beta_{22} + g_{m1}G_{z2}\alpha_{n1}\beta_{12} + G_{z1}G_{z2}) + C_1' G_{z2}G_{z3} + C_2'(g_{m1}G_{z3}\alpha_{n1}\beta_{12} + G_{z1}G_{z3})}{C_1' C_2' C_3'}, \tag{12}$$

$$\omega_o = \sqrt{\frac{C_3'(g_{m1}g_{m2}\alpha_{p2}\alpha_{n1}\beta_{11}\beta_{22} + g_{m1}G_{z2}\alpha_{n1}\beta_{12} + G_{z1}G_{z2}) + C_1' G_{z2}G_{z3} + C_2'(g_{m1}G_{z3}\alpha_{n1}\beta_{12} + G_{z1}G_{z3})}{C_1' C_2' C_3'}}. \tag{13}$$

Because the values of α and β are slightly less than unity [26], the parasitic conductances (G_zs) at the z terminals of CDTAs are not zero and the capacitances C'_1, C'_2 and C'_3 are greater than C_1, C_2 and C_3, respectively. From (12) and (13), the oscillation condition and oscillation frequency are deviated from the ideal cases. Therefore, to compensate this effect, we can slightly adjust the g_{m2} value. The oscillation condition still can be controlled by g_{m3}. The active and passive sensitivities of the quadrature oscillator are all low and obtained as

$$S^{\omega_o}_{\alpha_{p2},\alpha_{n1},\beta_{11},\beta_{12},\beta_{22}} \cong \frac{1}{2};\ S^{\omega_o}_{g_{m1},g_{m2}} \cong -S^{\omega_o}_{C_1',C_2'} \cong \frac{1}{2};\ S^{\omega_o}_{C_3'} \cong 0.$$

4. Simulation Results

The quadrature oscillators were simulated using HSPICE. The CMOS CDTA implementation is shown in Fig. 2 (using 0.18 μm MOSFET from TSMC). The aspect ratios of the MOS transistors were chosen as in Tab. 1. The multiple current outputs can be easily implemented by adding output branches. Fig. 5 represents the voltage-mode quadrature sinusoidal output waveforms of Fig. 3 with $C_1 = C_2 = C_3 = 100$ pF, $g_{m1} = 0.269$ mS, $g_{m2} = 0.355$ mS and $g_{m3} = 0.401$ mS where g_{m3} was designed to be larger then the theoretical value to ensure the oscillations will start. The bias voltages are $V_{B1} = 0.7$V, $V_{B2} = -0.7$V, $V+ = 1.25$V and $V- = -1.25$V. The power dissipation is 2.8782 mW. The results of the V_{o1} and V_{o2} total harmonic distortion analysis are summarized in Tab. 2 and Tab. 3, respectively. Fig. 6 shows the simulation results of the oscillation frequencies of Fig. 3 by varying the value of the transconductance g_{m2}

with $C_1 = C_2 = C_3 = 100$ pF, $g_{m1} = 0.269$ mS and g_{m3} was varied with g_{m2} by equation (3) to ensure the oscillations will start. From Tab. 2 and 3, the total harmonic distortion of V_{o1} or V_{o2} is larger than 9%. For the applications need sinusoidal quadrature outputs, other filtering circuits are needed. Because the CDTA has parasitic capacitor from the z terminal to the ground (C_z) and the tracking errors of CDTA (α and β) are slightly less than unity, this can explain why simulated oscillation frequencies in Fig. 6 are lower than theoretical predicted. This effect can be minimized by slightly adjust the g_{m2} value.

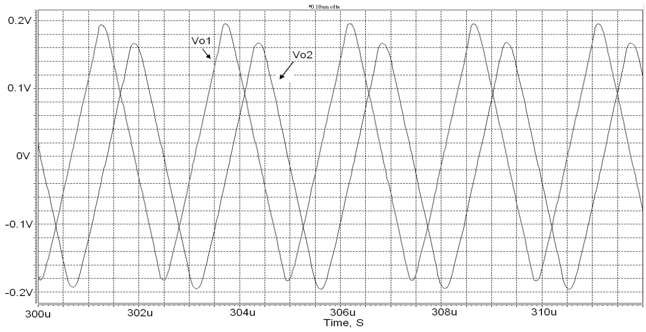


Fig. 5. The simulated voltage-mode quadrature output waveforms of Fig. 3.

MOS transistors	Aspect ratio (W/L)
$M_1, M_3, M_5, M_7, M_9, M_{12}, M_{21}, M_{22}, M_{23}, M_{24}, M_{26}$	27/1.8
$M_2, M_4, M_6, M_8, M_{10}, M_{11}, M_{13}, M_{14}, M_{25}, M_{27}$	72/1.8
$M_{15}, M_{16}, M_{17}, M_{18}, M_{19}, M_{20}$	63/1.8

Tab. 1. Aspect ratios of the MOSs in Fig. 2.

Harmonic no	Frequency (hz)	Fourier component	Phase (deg)
1	410.0000k	164.3047m	78.8907
2	820.0000k	1.1578m	28.9474
3	1.2300M	16.1485m	59.0586
4	1.6400M	633.3720u	-5.9456
5	2.0500M	4.9412m	45.7420
6	2.4600M	216.4871u	-53.4055
7	2.8700M	2.0743m	32.8476
8	3.2800M	64.7923u	143.9968
9	3.6900M	801.1292u	22.6329
dc component = 5.606D-03			
total harmonic distortion = 10.3989 percent			

Tab. 2. Total harmonic distortion analysis of V_{o1} in Fig. 3.

Harmonic no	Frequency (hz)	Fourier component	Phase (deg)
1	410.0000k	161.8072m	-15.8438
2	820.0000k	1.6354m	-151.6867
3	1.2300M	14.3267m	137.1491
4	1.6400M	576.4303u	-8.6467
5	2.0500M	3.4543m	-60.6587
6	2.4600M	170.3654u	-136.6209
7	2.8700M	839.9577u	118.0214
8	3.2800M	317.2807u	54.1174
9	3.6900M	459.2626u	6.8039
dc component = -1.593D-02			
total harmonic distortion = 9.1925 percent			

Tab. 3. Total harmonic distortion analysis of V_{o2} in Fig. 3.

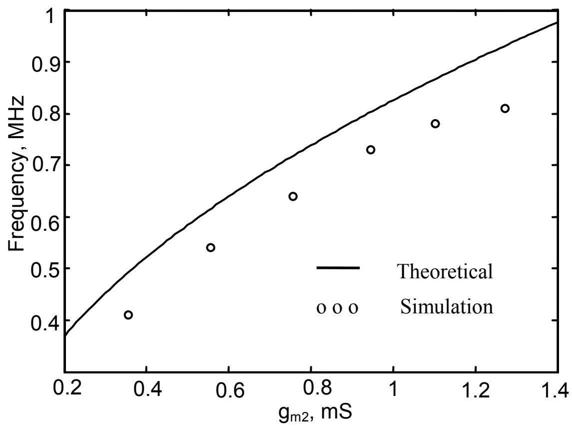


Fig. 6. Simulation result of the oscillation frequency of the circuit given in Fig. 3, which is obtained by varying the value of the transconductance g_{m2}.

5. Conclusion

In this paper, a new current/voltage-mode third-order quadrature oscillator using three CDTA and three grounded capacitors is proposed. Outputs of two current-mode and two voltage-mode sinusoids each with 90^o phase difference are available in the proposed circuit. The oscillation condition and oscillation frequency of the proposed quadrature oscillator are independently controllable. Simulation results verify the theoretical analysis.

Acknowledgment

The authors would like to thank the reviewers for their constructive comments.

References

[1] SEDRA, A. S., SMITH, K. C. *Microelectronic Circuits*. 4th edition. New York: Oxford University Press, pp. 984-986, 1998.

[2] KHAN, I. A., KHWAJA, S. An integrable gm-C quadrature oscillator. *International Journal of Electronics*, 2000, vol. 87, p. 1353-1357.

[3] HOLZEL, R. A simple wide-band sine wave quadrature oscillator. *IEEE Transactions on Instrumentation and Measurement*, 1993, vol. 42, p. 758-760.

[4] AHMED, M. T., KHAN, I. A., MINHAJ N. On transconductance-C quadrature oscillators. *International Journal of Electronics*, 1997, vol. 83, p. 201-207.

[5] ABUELMA'ATTI, M. T., ALZAHER, H. A. Comment on current-mode quadrature sinusoidal oscillator using single FTFN. *International Journal of Electronics*, 1998, vol. 85, p. 177-180.

[6] SOLIMAN, A. M. Synthesis of grounded capacitor and grounded resistor oscillators. *Journal of the Franklin Institute*, 1999, vol. 336, p. 735-746.

[7] HORNG, J. W. Current differencing buffered amplifiers based single resistance controlled quadrature oscillator employing grounded capacitors. *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*, 2002, vol. E85-A, p. 1416-1419.

[8] HORNG, J. W. Current-mode quadrature oscillator with grounded capacitors and resistors using two DVCCs. *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*, 2003, vol. E86-A, p. 2152-2154.

[9] PROMMEE, P., DEJHAN, K. An integrable electronic-controlled quadrature sinusoidal oscillator using CMOS operational transconductance amplifier. *International Journal of Electronics*, 2002, vol. 89, p. 365-379.

[10] HORNG, J. W., HOU, C. L., CHANG, C. M., CHUNG, W. Y., TANG, H. W., WEN, Y. H. Quadrature oscillators using CCIIs. *International Journal of Electronics*, 2005, vol. 92, p. 21-31.

[11] HORNG, J. W., HOU, C. L., CHANG, C. M., PAN, S. W., SHIE, J. Y., WEN, Y. H. Third-order quadrature oscillator with grounded capacitors using CCIIs. *WSEAS Transactions on Electronics*, 2007, vol. 4, p. 20-22.

[12] MAHESHWARI, S., KHAN, I. A. Current controlled third order quadrature oscillator. *IEE Proc.-Circuits, Devices and Systems*, 2005, vol. 152, p. 605-607.

[13] HORNG, J. W., HOU, C. L., CHANG, C. M., CHOU, H. P., LIN, C. T., WEN, Y. H. Quadrature oscillators with grounded capacitors and resistors using FDCCIIs. *ETRI Journal*, 2006, vol. 28, p. 486 to 494.

[14] HORNG, J. W., HOU, C. L., CHANG, C. M., CHENG, S. T., SU, H. Y. Current or/and voltage-mode quadrature oscillators with grounded capacitors and resistors using FDCCIIs. *WSEAS Transactions on Circuits and Systems*, 2008, vol. 7, p. 129-138.

[15] KESKIN, A. U., AYDIN, C., HANCIOLU, E., ACAR, C. Quadrature oscillator using current differencing buffered amplifiers (CDBA). *Frequenz*, 2006, vol. 60, p. 21-23.

[16] TANGSRIRAT, W., PISITCHALERMPONG, S. CDBA-based quadrature sinusoidal oscillator. *Frequenz*, 2007, vol. 61, p. 102-104.

[17] KESKIN, A. U., BIOLEK, D. Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA). *IEE Proc.-Circuits, Devices and Systems*, 2006, vol. 153, p. 214-218.

[18] JAIKLA, W., SIRIPRUCHYANUN, S., BAJER, J., BIOLEK, D. A simple current-mode quadrature oscillator using single CDTA. *Radioengineering*, 2008, vol. 17, p. 33-40.

[19] BIOLEK, D. CDTA-Building block for current-mode analog signal processing. In *Proceedings of the ECCTD'03*, Krakow, Poland, 2003, vol. III, p. 397-400.

[20] KESKIN, A. U., BIOLEK, D., HANCIOGLU, E., BIOLKOVA, V. Current-mode KHN filter employing current differencing transconductance amplifiers. *AEU International Journal of Electronics and Communications*, 2006, vol. 60, p. 443-446.

[21] TANGSRIRAT, W., TANJAROEN, W. Current-mode multiphase sinusoidal oscillator using current differencing transconductance amplifiers. *Circuits, Systems and Signal Processing*, 2008, vol. 27, p. 81-93.

[22] BIOLEK, D., BIOLKOVA, V., KESKIN, A. Current mode quadrature oscillator using two CDTAs and two grounded capacitors. In *Proceedings of the 5th WSEAS Int. Conf. on System Science and Simulation in Engineering*. Tenerife, Canary Islands, (Spain), December 16-18, 2006, p. 368-370.

[23] TANGSRIRAT, W. Current differencing transconductance amplifier-based current-mode four-phase quadrature oscillator. *Indian Journal of Engineering and Material Sciences*, 2007, vol. 14, p. 289-294.

[24] HORNG, J. W. Current-mode third-order quadrature oscillator using CDTAs. *Active and Passive Electronic Components*, 2009, Article ID 789171, p. 1-5.

[25] BHUSHAN, M., NEWCOMB, R. W. Grounding of capacitors in integrated circuits. *Electronic Letters*, 1967, vol. 3, p. 148-149.

[26] FABRE, A., SAAID, O., BARTHELEMY, H. On the frequency limitations of the circuits based on second generation current conveyors. *Analog Integrated Circuits and Signal Processing*, 1995, vol. 7, p. 113-129.

About Author ...

Jiun-Wei HORNG was born in Tainan, Taiwan, Republic of China, in 1971. He received the B.S. degree in Electronic Engineering from Chung Yuan Christian University, Chung-Li, Taiwan, in 1993, and the Ph.D. degree from National Taiwan University, Taipei, Taiwan, in 1997. From 1997 to 1999, he served as a Second-Lieutenant in China Army Force. From 1999 to 2000, he joined CHROMA ATE INC. where he worked in the area of video pattern generator technologies. Since 2000, he was with the Dept. of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan as an Assistant Professor. He is now an Associate Professor. Dr. Horng joins the editorial board of Active and Passive Electronic Components from 2010. His teaching and research interests are in the areas of circuits and systems, analog electronics, active filter design and current-mode signal processing.

Hung LEE received the B.S. degree in Electronic Engineering from Fu Jen Catholic University, Taipei, Taiwan, in 2009. Presently, he is working toward the M.S. degree in Electronic Engineering at Chung Yuan Christian University, Chung-Li, Taiwan. His research interests are in the area of analog filter design, electronic circuit design and simulation.

Jian-Yu WU is now working toward the M.S. degree in Electronic Engineering at Chung Yuan Christian University, Chung-Li, Taiwan. His research interests are in the area of analog filter design, electronic circuit design and simulation.