วงจรกรองความถี่หลายหน้าที่โหมดกระแสที่ควบคุมด้วยวิธีการทางอิเล็กทรอนิกส์โดยใช้ CC-CCTAs

A Current-mode Electronically Controllable Multifunction Biquadratic Filter Using CC-CCTAs

สมชาย ศรีสกุลเตียว[1], ศุภวัฒน์ ลาวัณย์วิสุทธิ์[2], นรา บุรีพันธ์[3] มนตรี ศิริปรัชญานันท์[4]

Received: April, 2011; Accepted: December, 2012

บทคัดย่อ

บทความนี้นำเสนอ วงจรกรองความถี่หลายหน้าที่โหมดกระแสโดยใช้ CC-CCTA สามารถสังเคราะห์ฟังก์ชันที่จำเป็นได้ทั้งหมด ได้แก่ กรองความถี่ต่ำผ่าน สูงผ่าน แถบความถี่ผ่าน กำจัดแถบความถี่ผ่าน และผ่านทุกความถี่ ซึ่งอุปกรณ์หลักในวงจร ได้แก่ วงจรสายพานกระแสส่งผ่านความนำที่สามารถควบคุมได้ด้วยกระแส (CC-CCTA) ที่มี 3 อินพุต และมี 1 เอาต์พุต จุดเด่นของวงจรคือ สามารถควบคุมความถี่โพล และค่าควอลิตี้แฟกเตอร์ได้ด้วยวิธีทางอิเล็กทรอนิกส์จากการปรับกระแสไบแอส โครงสร้างของวงจรไม่ซับซ้อน โดยใช้เพียง CC-CCTA 2 ตัว และตัวเก็บประจุที่ต่อลงกราวนด์ 2 ตัว ปราศจากความต้านทานภายนอก และใช้อุปกรณ์ชนิดที่ต่อลงกราวนด์ วงจรที่นำเสนอนี้ จึงเหมาะสมกับการนำไปพัฒนาเป็นวงจรรวม ผลการจำลองการทำงานด้วยโปรแกรม PSpice พบว่าวงจรทำงานได้สอดคล้องกับที่คาดการณ์ไว้ตามทฤษฎี วงจรมีอัตราดึงกำลังไฟฟ้าเท่ากับ 7.93mW ที่แหล่งจ่ายกำลังไฟฟ้า ±3V

คำสำคัญ : โหมดกระแส, วงจรกรองความถี่หลายหน้าที่, วงจรสายพานกระแส-ส่งผ่านความนำที่สามารถควบคุมได้ด้วยกระแส

[1] *คณะวิศวกรรมศาสตร์และสถาปัตยกรรมศาสตร์ มหาวิทยาลัยเทคโนโลยีราชมงคลอีสาน นครราชสีมา*
[2] *คณะเทคโนโลยีอุตสาหกรรม มหาวิทยาลัยราชภัฏเทพสตรี*
[3] *คณะวิศวกรรมศาสตร์ มหาวิทยาลัยธนบุรี*
[4] *คณะครุศาสตร์อุตสาหกรรม มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าพระนครเหนือ*
E - mail : somchaikorat2008@hotmail.com

Abstract

This article presents a current-mode multifunction biquadratic filter performing completely standard functions low-pass, high-pass, band-pass, band-reject and all-pass functions. The circuit principle is based on current controlled current conveyor transconductance amplifiers (CC-CCTAs) with three input terminals and one output terminal. The features of the circuit are that, the pole frequency and quality factor can be electronically tuned via the input bias currents. The circuit topology is very simple, consisting of merely 2 CC-CCTAs and 2 grounded capacitors, without any external resistor and using only grounded elements. The proposed circuit is very suitable to further develop into an integrated circuit architecture. The PSpice simulation results agree well with the theoretical anticipation. The total power consumption is approximately 7.93mW on power supply voltage of ±3V.

Keywords : Current-mode, Multifunction biquadratic filter, CC-CCTA

Introduction

An analog filter is an important building block, widely used for continuous-time signal processing. It can be found in many fields: including communications, measurement, instrumentation, and control systems (Sedra A. S. and Smith K.C., 2003; Ibrahim, M. A., Minael S. and Kuntman H. A., 2005). One of most popular analog filters is multi-purpose and universal filters that can be classified either as multi-input and single-output (MISO) filter (Chunhua W., Haiguang L. and Yan Z., 2009) or single-input and multi-output (SIMO) filter (Minaei S., Kuntman H., Cicekoglu O., Turkoz S. and Tarim N., 2000). Among these filters, the MISO filters have rather simple structures (Chumhua W., Yan Z., Qiujing Z. and Sichun D., 2009). Recently, a universal filter working in current-mode has being been more popular than the voltage-mode type. Since the last two decade, there has been much effort to reduce the supply voltage of analog systems. This is due to the demand for portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for this purpose. Actually, a circuit using the current-mode technique has many other advantages such as: larger dynamic range, higher bandwidth, greater linearity, simpler circuitry and lower power consumption (Toumazou C., Lidgey F.J. and Haigh D.G., 1990; Bhaskar D.R., Sharma V.K., Monis and Rizvi S.M.I., 1999).

From our survey, it is found that several implementations of current-mode filters have been reported (Biolek D. and Biolkova V., 2003; Biolek D. and Biolkova V., 2003; Keskina A. Ü, Biolek D., Hancioglu E. and Biolková V., 2006; Tangsrirat W. and Surakampontorn W., 2007; Tangsrirat W., Dumawipata T. and Surakampontorn W., 2007; Prasada D., Bhaskara D.R. and Singhb A.K., 2008; Siripruchyanun M. and Jaikla W., 2008; Jaikla W. and Siripruchyanun M., 2006; Jaikla W. and Siripruchyanun M., 2007). Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Pole frequency and quality factor cannot be controlled orthogonally (Biolek D. and Biolkova V. 2003; Keskina A.Ü, Biolek D., Hancioglu E. and Biolková V., 2006; Tangsrirat W., Dumawipata T. and Surakampontorn W., 2007; Prasada D., Bhaskara D.R. and Singhb A.K., 2008; Siripruchyanun M. and Jaikla W., 2008).
- Require changing circuit topologies to achieve several functions (Biolek D., and Biolkova V., 2003; Tangsrirat W. and Surakampontorn W., 2006).
- Some outputs of the filter responses are not in high output impedance (Biolek D. and Biolkova, 2003; Keskina A.Ü, Biolek D., Hancioglu E. and Biolková V., 2006; Prasada D., Bhaskara D.R. and Singhb A.K., 2008; Jaikla W. and Siripruchyanun M., 2006; Jaikla W. and Siripruchyanun M., 2007).
- Cannot provide completely standard functions (Biolek D. and Biolkova, 2003; Biolek D. and Biolkova V., 2003; Keskina A.Ü, Biolek D., Hancioglu E. and Biolková V., 2006; Tangsrirat W. and Surakampontorn W., 2006; Prasada D., Bhaskara D.R. and Singhb A.K., 2008; Jaikla W., Siripruchyanun M., 2006; Jaikla W., Siripruchyanun M., 2007).

A reported 5-terminals active element, namely current convey or transconductance amplifier (CCTA) (Prokop R. and Musil V., 2005) has been proposed in 2005, it seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters. It is a really current-mode element whose input and output signals are currents. In addition, the output current gain can be adjusted. However, the CCTA cannot be controlled by the parasitic resistance at current input port. Recently, (Siripruchyanun and Jaikla, 2008) have proposed the modified-version CCTA, whose parasitic resistance at current input port can be controlled by an input bias current. It is newly named current controlled current conveyor transconductance amplifier (CC-CCTA). It seems to be a useful building block, since many circuits and systems can be implemented by employing only single CC-CCTA. Presently, the CC-CCTA has been extensively used, such as filters

(Lawanwisut S. and Siripruchyanun M., 2010; Kaetkaew O., Lawanwisut S., Chantafong K. and Siripruchyanun M., 2009), oscillators (Lawanwisut S. and Siripruchyanun M., 2009; Jaikla W. and Siripruchyanun M., 2009), inductance simulator (Silapan P., Srisakul T., Jaikla W. and Siripruchyanun M., 2009), and etc.

The aim of this paper is to propose a current-mode multifunction biquadratic filter, emphasizing on use of the CC-CCTAs and grounded capacitors. The features of the proposed circuit are that, the proposed multifunction biquadratic filter can completely provide 5 functions which are low-pass, high-pass, band-pass, band-reject and all-pass functions without changing circuit topology. The circuit description is very simple, employing only grounded capacitors as passive components, thus it is suitable for fabricating in monolithic chip. The quality factor and pole frequency can be electronically adjusted. The PSpice simulation results agree with the theoretical analysis.

Principle of Operation

Basic Concept of CC-CCTA

Since the proposed circuit is based on CC-CCTA, a brief review of CC-CCTA is given in this section. Generally, CC-CCTA properties are similar to the conventional CCTA, except that the CC-CCTA has finite input resistance at the x input terminal. This parasitic resistance can be controlled by the bias current: as shown in the following equation (Siripruchyanun M. and Jaikla W., 2008).

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix} \quad (1)$$

where

$$R_x = \frac{V_T}{2I_{B1}} \quad (2)$$

and

$$g_m = \frac{I_{B2}}{2V_T} \quad (3)$$

Where and are the thermal voltage, input current and the transconductance gain of the CC-CCTA, respectively. The symbol and equivalent circuit of the CC-CCTA are illustrated in Fig. 1 (a) and (b), respectively.

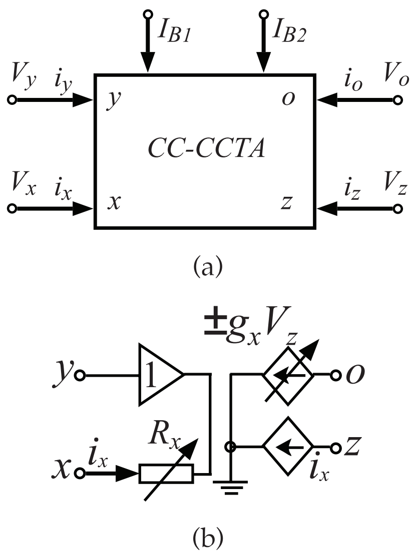


Fig. 1. The CC-CCTA (a) Sym±bol (b) Equivalent circuit.

Proposed Current-mode Multifunction Biquadratic Filter

The completed current-mode multifunction biquadratic filter is shown in Fig. 2.

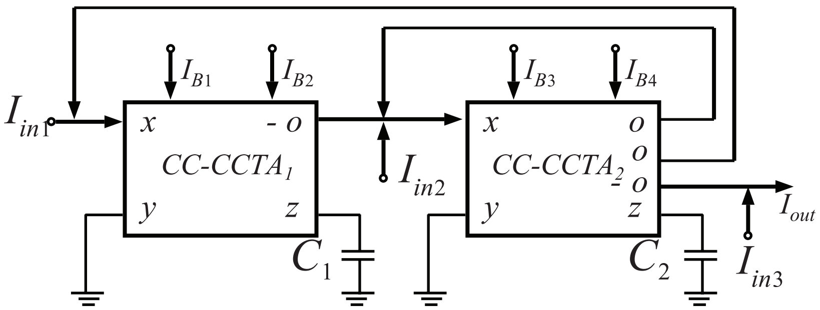


Fig. 2. Proposed current-mode multifunction biquadratic filter.

From circuit in Fig. 2, the output current transfer function can be obtained as

$$I_{out} = \frac{\left(s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}\right)I_{in3} + s\frac{g_{m2}}{C_2}I_{in2} + \frac{g_{m1}g_{m2}}{C_1C_2}I_{in1}}{s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}} \qquad (4)$$

From Eq. (4), the all standard transfer functions can be obtained by selecting appropriate inputs by following conditions

1) If $I_{in} = I_{in1}$, and $I_{in2} = I_{in3} = 0$, a low-pass function is achieved at the output. The transfer function can be written to be

$$\frac{I_{out}}{I_{in}} = \frac{\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}}. \qquad (5)$$

2) If $I_{in} = -I_{in1} = -I_{in2} = I_{in3}$, a high-pass function can be obtained. The transfer function can be written to be

$$\frac{I_{out}}{I_{in}} = \frac{s^2}{s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}}. \qquad (6)$$

3) If $I_{in} = I_{in2}$, and $I_{in1} = I_{in3} = 0$, the obtained output function is a band-pass. The transfer function can be given by

$$\frac{I_{out}}{I_{in}} = \frac{s\frac{g_{m2}}{C_2}}{s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}}. \qquad (7)$$

4) If $I_{in} = I_{in3} = -I_{in2}$, and $I_{in1} = 0$, a band-reject function is provided. The transfer function can be written to be

$$\frac{I_{out}}{I_{in}} = \frac{s^2 + \frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}}. \qquad (8)$$

5) If $I_{in} = I_{in3} = -2I_{in2}$, and $I_{in1} = 0$, an all-pass filter is obtained. The transfer function can be written to be

$$\frac{I_{out}}{I_{in}} = \frac{s^2 - s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}}, \qquad (9)$$

where $g_{m1} = \frac{I_{B2}}{2V_T}$,

$g_{m2} = \frac{I_{B4}}{2V_T}$.

The pole frequency (ω_0) and quality factor (Q_0) can be expressed to be

$$\omega_0 = \frac{1}{2V_T}\sqrt{\frac{I_{B2}I_{B4}}{C_1C_2}}, \tag{10}$$

and

$$Q_0 = \sqrt{\frac{C_2 I_{B2}}{C_1 I_{B4}}}. \tag{11}$$

From Eqs. (10) and (11), the pole frequency can be adjusted by I_{B2} and I_{B4} without affecting the quality factor. Moreover, for example when the pole frequency was adjusted by I_{B2} equals I_{B4} as shown in Eqs. (10) and (11), therefore the quality factor without I_{B2} and I_{B4}.

Sensitivity Analysis

The sensitivities of the proposed circuit can be found as

$$S^{\omega_0}_{C_1,C_2} = -\frac{1}{2}, S^{\omega_0}_{I_{B2},I_{B4}} = \frac{1}{2}, S^{\omega_0}_{V_T} = -1, \tag{12}$$

and

$$S^{Q_0}_{I_{B2},C_2} = \frac{1}{2}, S^{Q_0}_{I_{B4},C_1} = -\frac{1}{2}. \tag{13}$$

Therefore, all active and passive sensitivities are equal or less than unity in manitude.

Simulation and Results

To investigate the performances of the proposed circuit, the PSpice simulation program was used for the examination. The PNP and NPN transistors employed in the CC-CCTA were simulated by using the parameters of the PR 200N and NR 200N bipolar transistors of ALA 400 transistor array from AT&T (Frey D.R., 1993). Fig. 3 depicts schematic description of the CC-CCTA used in the simulation. The circuit was bias with ±3V power supplies voltage, $C_1 = C_2 = 1nF$, $I_{B1} = I_{B3} = 50\mu A$, and I_{B2} and I_{B4} $= 120\mu A$. The results shown in Fig. 4 are the gain responses of the proposed multifunction biquadratic filter. It is clearly seen that it can provide low-pass, high-pass, band-pass, band-reject and all-pass functions dependent on selection as depicted in Eqs. (5)-(9), without modifying circuit topology. Fig. 5 shows gain responses of band-pass function where I_{B2} and I_{B4} are equally set to keep the ratio to be constant. It is found that pole frequency can be adjusted without affecting the quality factor. Total power consumption obtained from PSpice is about 7.93mW.

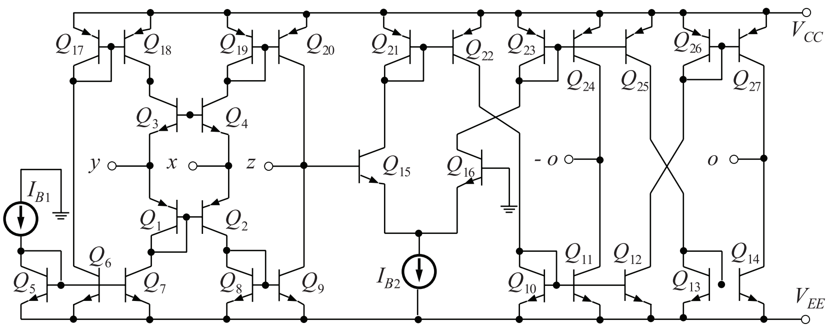
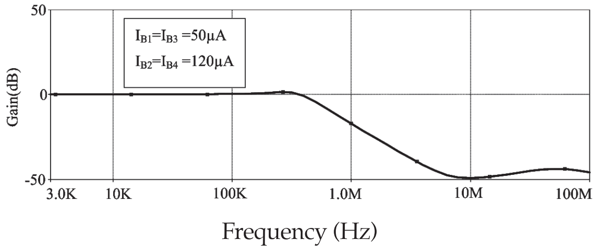
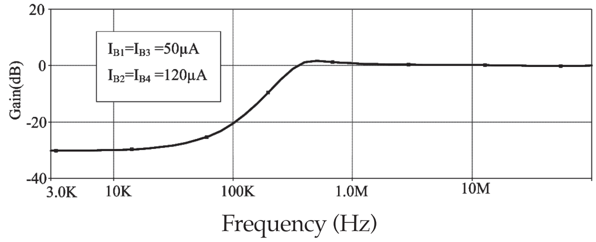


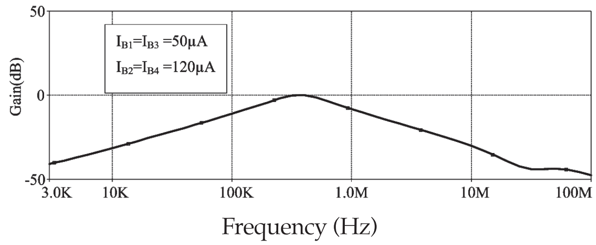
Fig. 3. Internal construction of CCCCTA



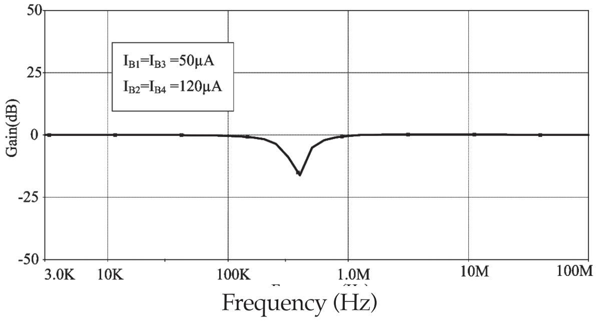
(a) Low-pass filter,



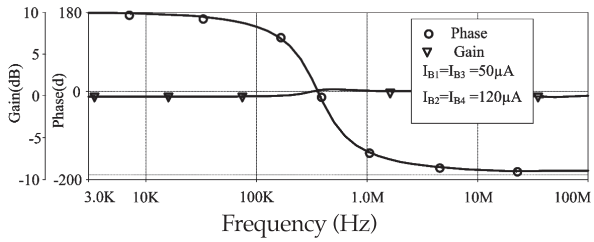
(b) High-pass filter,



(c) Band-pass filter.



(d) Band-reject filter and



(e) All-pass filter.

Fig. 4. Gain responses of the biquadratic filter.

Conclusions

The current-mode multifunction biquadratic filter with three input terminals and one output terminal based on CC-CCTAs has been presented. The advantages of the proposed circuit are that it performs completely standard functions, low-pass high-pass band-pass band-reject and all-pass functions from the same circuit configuration without component matching conditions and changing circuit topology. The pole frequency can be electronically tuned without affecting the quality factor. The circuit description comprises only 2 CC-CCTAs and 2 grounded capacitors. With mentioned features, it is very suitable to realize the proposed circuit in monolithic chip to use in battery-powered, portable electronic equipments such as wireless communication system devices.

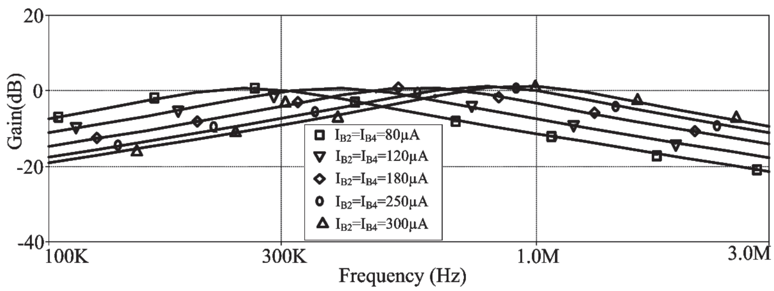


Fig 5. Band-pass responses for different values of I_{B2} and I_{B4} with keeping their ratios constant $I_{B2} = I_{B4} = I_B$

References

Bhaskar, D.R., Sharma, V.K., Monis, M. and Rizvi, S.M.I. (1999). **New curren-mode universal biquad filter.** Micro-elec tronics Journal, vol. 30. pp. 837-839.

Biolek, D. and Biolkova, V., (2003). **CDTA-C current-mode universal 2nd-order filter.** Proceedings of the 5th WSEAS Int. Conf. on Applied Informatics and Communications. pp. 411-414.

Biolek, D., and Biolkova, V. (2003). **Universal biquads using CDTA elements for cascade filter design.** Proceedings of the multi conference CSCC.

Chumhua, W., Yan Z., Qiujing Z. and Sichun, D. (2009). **A new current mode SIMO-type universal biquad employing multi-output current conveyors (MO-CCII).** Radioengi-neering, vol. 18. pp. 83-88, April 2009.

Chunhua, W., Haiguang, L. and Yan, Z. (2009). **Universal current-mode filter with multiple inputs and one output using MO-CCII and MO-CCCA.** (AEÜ) Int. J. Electronics and Communications, vol. 63. pp. 448-453. June 2009.

Frey, D. R. (1993). Log-domain filtering: an approach to current-mode filtering. IEE Proceeding of Circuit Devices Systems. vol. 140. pp. 406-416.

Ibrahim, M.A., Minaei, S. and Kuntman, H.A. (2005). A 22.5 MHz current-mode KHN-biquad using differential voltage current conveyor and grounded passive elements. International journal of electronics and Communications. vol. 59. pp. 311-318.

Jaikla, W. and Siripruchyanun, M. (2006). A versatile quadrature oscillator and universal biquad filter using dual-output current controlled current differencing transconductance amplifier, Proceedings of ISCIT. pp. 1072-1075.

Jaikla, W. and Siripruchyanun, M. (2007). CC-CDTAs based versatile quadrature oscillator and universal biquad filter. The Proceedings of ECTI-CON. pp. 1065-1068.

Jaikla, W. and Siripruchyanun, M. (2009). A simple oscillator using only single CC-CCTA and grounded capacitors. Research and development Journal. Rajamangala University of Technology, Tawan-ok. vol. 1. pp. 55-59.

Kaetkaew, O., Lawanwisut, S., Chantafong, K. and Siripruchyanun, M. (2009). High output-impedance current-mode universal filter using CC-CCTAs. The Proceeding of 47th Kasetsart University Annual Conference. pp. 361-368.

Keskina, A.Ü., Biolek, D., Hancioglu, E., and Biolková, V. (2006). Current-mode KHN filter employing current differencing transconductance amplifiers. International Journal of Electronics and Communications. vol. 60. pp. 443-446.

Lawanwisut S. and Siripruchyanun, M. (2009). An active-only high-output impedance current-mode quadrature oscillator using CC-CCTA basedlossless differentiators. The proceedings of IEEE TENCON. pp. 1-4.

Lawanwisut, S. and Siripruchyanun, M. (2010). An active-only current-mode electronically controllable multi-function biquadratic filter using CC-CCTAs. The Proceedings of the 33rd Electrical Engineering Conference. vol. 2. pp. 1097-1100.

Minaei, S., Kuntman, H., Cicekoglu O., Turkoz, S. and Tarim, N. (2000). A new high output impedance current-mode universal filter with single input and three outputs using dual output CCIIs. Proceedings of the 7th IEEE International Conference on Electronics. Circuits and Systems. vol. 1. pp. 379-382.

Prasada, D., Bhaskara, D.R. and Singhb, A.K. (2008). Universal current-mode biquad filter using dual output current differencing transconductance amplifier. International Journal of Electronics and Communications.

Prokop, R. and Musil, V. (2005). **New modern circuit block CCTA and some its applications.** The Fourteenth International Scientific and Applied Science Conference - Electronics ET'2005. Book 5. Sofia: TU Sofia. pp. 93-98.

Sedra, A.S., and Smith, K.C. (2003). **Microelectronic circuits.** 5rd ed., Florida: Holt, Rinehart and Winston.

Silapan, P., Srisakul, T., Jaikla, W. and M. Siripruchyanun. (2009). **Current controlled CCTA (CC-CCTA) based novel floating and grounded inductance simulators.** Research and development Journal, Rajamangala University of Technology, Tawan-ok, vol. 1, pp. 48-54.

Siripruchyanun, M. and Jaikla, W. (2008). **Current controlled current conveyor transconductance amplifier (CC-CCTA): a building block for analog signal processing.** Electrical Engineering, vol. 90, pp. 443-453, 2008.

Siripruchyanun, M. and Jaikla, W. (2008). **Electronically controllable current-Mode universal biquad filter using single DO-CCCDTA.** Circuits Systems and Signal Processing, vol. 27, pp. 113-122.

Tangsrirat, W. and Surakampontorn, W. (2006). **Systematic realization of cascadable current-mode filters using CDTAs.** Frequenz. vol. 60. pp. 241-245.

Tangsrirat, W., Dumawipata, T. and Surakampontorn, W. (2007). **Multiple-input single-output current-mode multifunction filter using current differencing transconductance amplifiers.** International Journal of Electronics and Communications, vol. 60, pp. 209-214.

Toumazou, C., Lidgey, F.J. and D. Haigh, G. (1990). **Analogue IC design: the current-mode approach.** Peter Peregrinus. London.