5

Realization of lowpass and bandpass leapfrog filters using OAs and CCCIIs*

Xi Yanhui[1,2] and Peng Hui[1]
[1]*School of Information Science & Engineering, Central South University, Changsha 410083, China*
[2]*Electrical and Information Engineering College, Changsha University of Science & Technology, Changsha 410077*

Abstract

The systematic procedure for realizing lowpass and bandpass leapfrog ladder filters using only active elements is presented. The proposed architecture is composed of only two fundamental active building blocks, i.e., an operational amplifier(OA) and a Current Controlled Conveyor II (CCCII), without external passive element requirement, making the approach conveniently for further integrated circuit implementation with systematic design and dense layout. The characteristic of the current transfer function can be adjusted by varying the external bias currents of CCCIIs. As illustrations to demonstrate the systematic realization of current-mode ladder filters, a 3rd-order Butterworth low-pass filter and a 6th-order Chebyshev bandpass filter are designed and simulated using PSPICE.

Keywords: operational amplifier (OA); current controlled conveyor II (CCCII); leapfrog filters; ladder structure; active-only circuits

EEACC: 1270
CLC number: TN713 **Document code:** A

1. Introduction

Analog designs have been viewed as a voltage-dominated form of signal processing for a long time. However in the last decade current-mode signal-processing circuits have been demonstrated and well appreciated over their voltage-mode counterparts due to the main featuring of wide bandwidth capability. Designs for active filter circuits using high performance active devices, such as, operational amplifier(OA), operational transconductance amplifier(OTA), second generation current conveyor(CCII) and so on, have been discussed previously[1-2]. Due to the fact that active filter designs utilizing the

---

* Project supported by the Natural Science Foundation of Hunan Province (NO. 06JJ50117)
Corresponding author Email: xiyanhui@126.com

finite and complex gain nature of an internally compensated type operational amplifier are suitable for integrated circuit(IC) fabrication and high frequency operation. Several implementations in continuous-time filters using only active components are recently available in the literature[3-6]. They have been demonstrated that the realizations of the resistor-less and capacitor-less active-only circuit would be attractive for simplicity, integratability, programmability and wide frequency range of operation. However, a design approach with only active architectures that are efficient for systematic design and very large scale integration(VLSI) has not been reported sufficiently.

The paper deals with the alternative systematic approach that has been used the leapfrog structure to obtain current-mode ladder active filters with the employment of all-active elements. The proposed design approach is quite simple and systematic which has no passive element requirements. The basic building blocks of all circuits mainly consist of OA and CCCII. The obtained feature of the filter constructed in this way is a general structure and is able to adjust the characteristic of the current transfer function by electronic means. Owing to all-resulting circuits are implemented such a way that employs only active-element sub-circuits and minimizes the number of different fundamental building blocks. It is not only easy to construct from readily available IC type, but also significantly simplified in the IC design and layout. As examples to illustrate that the approach considerably simplifies for the current-mode ladder filter realizations, the leapfrog-based simulation of a 3rd-order Butterworth lowpass and a 6th-order Chebyshev bandpass filters are designed.

2. Basic active building blocks

2.1 Operational Amplifier(OA)

The first fundamental active device is to be an internally compensated type operational amplifier(OA) as shown with its symbolic representation in Fig. 1. As is known in practice, the open-loop amplifiers have a finite frequency-dependent gain. If ω_a is the -3dB bandwidth and by considering for the frequencies $\omega >> \omega_a$, the open-loop voltage gain $A(s)$ of an OA will be henceforth characterized by

$$A(s) = \frac{A_O \omega_a}{s + \omega_a} \cong \frac{B}{s} \tag{1}$$

where B denotes the gain-bandwidth product(GBP) in radian per second, which is the product of the open-loop DC gain A_O and the -3dB bandwidth ω_a

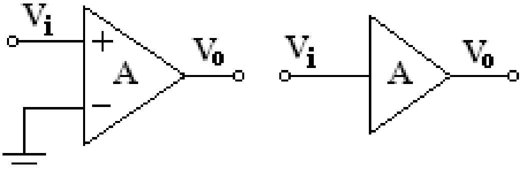


Fig. 1. Symbol of an OA

2.2 Current Controlled Conveyor II (CCCII*)*

A CCCII is a three-port active element. The port relations of a CCCII is shown in Fig. 2, characterized by the relationship

$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_x & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix} \tag{2}$$

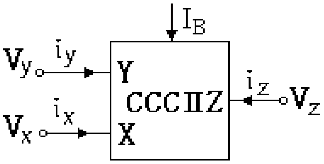


Fig. 2. Electric symbol of CCCII

The positive and the negative sign are corresponding to the CCCII+ and CCCII- respectively, and R_x is input resistance at port X. For the circuit of Fig. 2 the parasitic resistance , can be expressed as

$$R_x = \frac{V_T}{2I_B} \tag{3}$$

Where V_T is the thermal voltage $V_T \approx 26$ mV at 27℃ and I_B is the bias current of the CCCII. It is seen from equation (3) that the internal resistance R_x is adjustable electronically through the biasing current I_B.

3. Realization of lowpass and bandpass leapfrog ladder filters

Since the doubly terminated LC ladder network has been receiving considerable attention and popular due to it shares all the low sensitivity and low component spread of the RLC prototypes[7-12]. An systematic approach to realize current-mode ladder filters using only active elements is proposed. It is based on the leapfrog structure representation, which is derived from the passive RLC ladder prototypes. To demonstrate the proposed design approach, consider the general resistively terminated current-mode ladder filter with parallel impedances and series admittances shown in Fig. 3. The relations of the currents-voltages for the branches, the meshes and the nodes in this filter can be interrelated by

$$\begin{array}{lcl}
I_1 = I_S - \dfrac{V_1}{R_S} - I_2 \,, & & V_1 = I_1 Z_1 \\
I_2 = V_2 Y_2 & , & V_2 = V_1 - V_3 \\
I_3 = I_2 - I_4 & , & V_3 = I_3 Z_3 \,, \\
\vdots & , & \vdots
\end{array}$$

$$\begin{array}{ll} I_j = V_j Y_j & , \quad V_j = V_{j-1} - V_{j+1} \\ I_i = I_{i-1} - I_{i+1} & , \quad V_i = Z_i I_i \\ \vdots & , \quad \vdots \\ I_{n-1} = V_{n-1} Y_{n-1} & , \quad V_{n-1} = V_{n-2} - V_n \end{array}$$

and

$$I_n = I_{n-1} - I_{n+1} \quad , \quad V_n = I_n Z_n \tag{4}$$

Where $(i = 1,3,5,\ldots,n)$ and $(j = 2,4,6,\ldots,n)$. Equation (4) can be represented by leapfrog block diagram depicted in Fig. 4, where the output signal of each block is fed back to the summing point input of the preceding block. In contrast with the conventional simulation topology, however, we will present a simple, systematic and more efficient method unique to active-only current mode ladder filters by using the features of an OA and a CCCII.

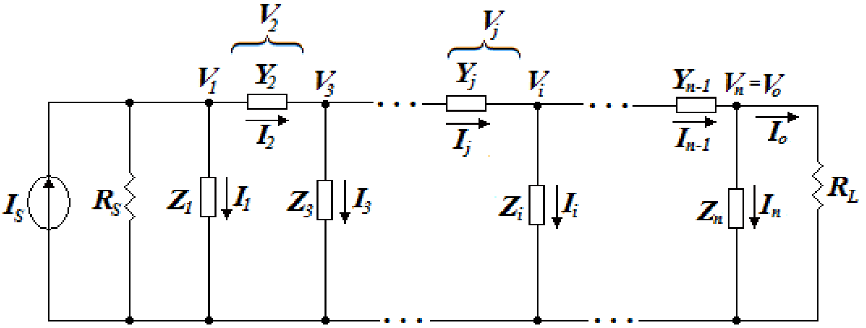


Fig. 3. General resistively terminated current-mode ladder prototype

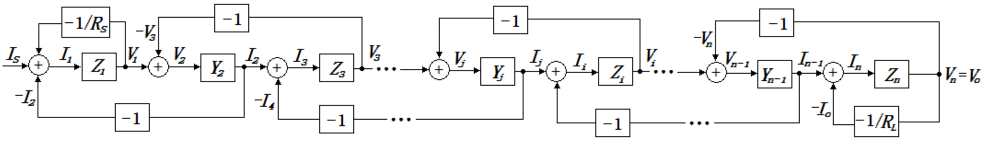


Fig. 4. Leapfrog block diagram of the general ladder prototype of Fig. 3

3.1 Lowpass leapfrog realization

As an example to illustrate the design procedure, consider the current-mode 3rd-order all-pole LC ladder lowpass prototype with regarding the terminating resistors shown in Fig. 5. The design techniques of these partial conversions can be accomplished in the way as shown in Fig. 6, through the use of only an OA and a CCCII as mentioned. Therefore, the circuit parameters have the typical values calculated by

$$R_{xi} = \frac{1}{B_i C_i} \quad \text{for} \quad i = 1,3,5,7,\ldots,n$$

and

$$R_{xj} = B_j L_j \quad \text{for} \quad j = 2,4,6,8,\ldots,n-1 \tag{5}$$

Where B_k(k=i or j)represents the GBP of the k-th OA.
Based on the directed simulation of the LC branch as shown in Fig. 6, the system diagram thus straightforwardly derived from the passive RLC ladder circuit of Fig. 5 can be shown in Fig. 7. The design equations of the circuit parameters can be expressed as follows

$$R_x = R = R_S = R_L$$

$$R_{x1} = \frac{1}{B_1 C_1}$$

$$R_{x2} = B_2 L_2$$

and

$$R_{x3} = \frac{1}{B_3 C_3} \tag{6}$$

Note that all elements, which simulate the behavior of capacitor and inductor, are tunable electronically through adjusting the resistor parameters, R_x.

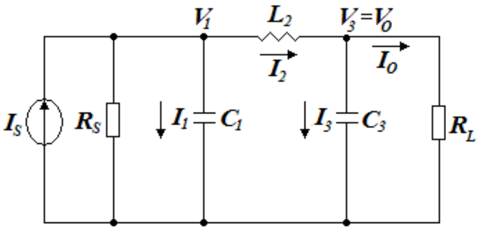
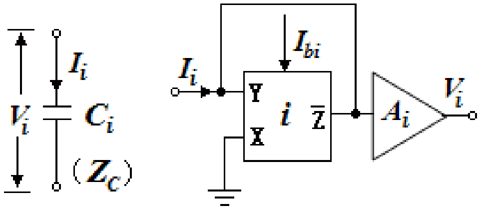
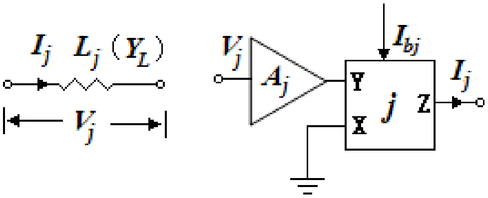


Fig. 5. 3rd-order all-pole LC ladder lowpass prototype



$$V_i = Z_C I_i \qquad R_{xi} = \frac{1}{B_i C_i}$$

(a) parallel branch impedance



$$I_j = Y_L V_j \qquad R_{xj} = B_j L_j$$

(b) series branch admittance

Fig. 6. Partial branch simulations using OA and CCCII of the lowpass network of Fig. 5

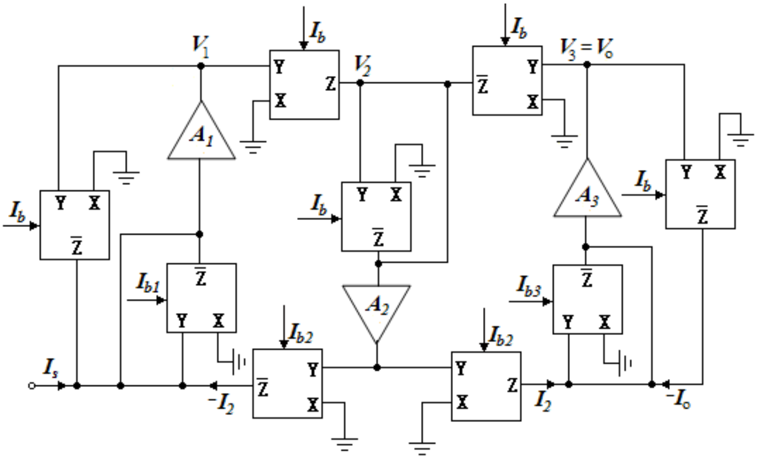


Fig. 7. Systematic diagram for current-mode 3rd-order lowpass filter using active-only elements

3.2 Bandpass leapfrog realization

The proposed approach can also be employed in the design of current-mode LC ladder bandpass filters. Consider the current-mode 6th-order LC ladder bandpass prototype shown in Fig. 8, having parallel resonators in parallel branches and series resonators in series branches. Observe that the repeated use of the bandpass LC structure branches typically consisting of parallel and series combinations of capacitor and inductor, shown respective in Figs.9(a) and 9(c), makes up the complete circuit. The voltage-current characteristic of these partial operations can be derived respectively as follows

$$V_i = Z_C(I_i - Y_L V_i) = \frac{1}{sC_i}\left(I_i - \frac{V_i}{sL_i}\right) \tag{7}$$

for $i = 1,3,5,7,\ldots,n$.

$$I_j = Y_L(V_j - Z_C I_j) = \frac{1}{sL_j}\left(V_j - \frac{I_j}{sC_j}\right) \tag{8}$$

for $j = 2,4,6,8,\ldots,n-1$.

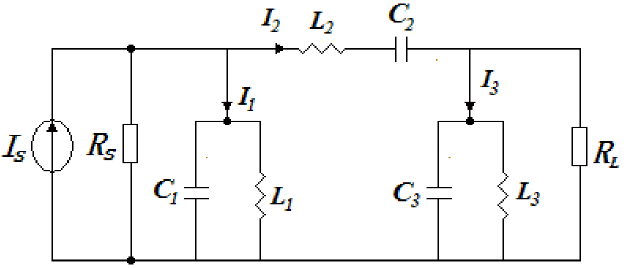
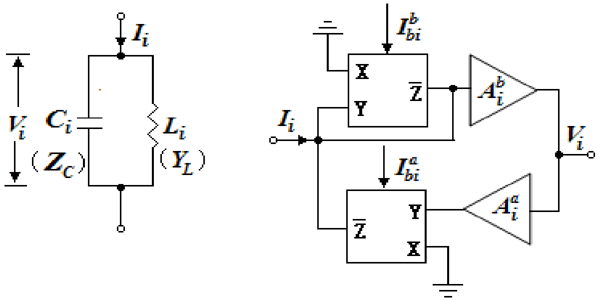
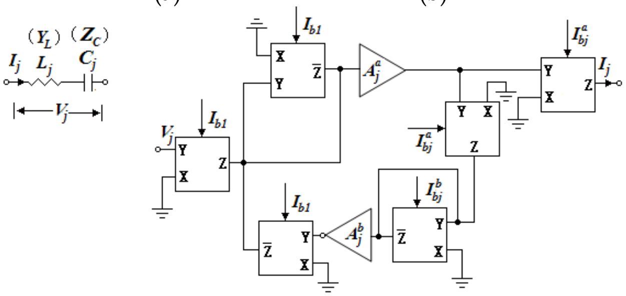


Fig. 8. 6th-order LC ladder bandpass prototype



$$V_i = Z_C(I_i - Y_L V_i) \qquad R_{xi}^a = B_i^a L_i \text{ , } R_{xi}^b = \frac{1}{B_i^b C_i}$$

(a) (b)



$$I_j = Y_L(V_j - Z_C I_j) \qquad R_{xj}^a = B_j^a L_j \text{, } R_{xj}^b = \frac{1}{B_j^b C_j}$$

(c) (d)

Fig. 9. Sub-circuit simulation using all-active elements of the bandpass network of Fig. 8

The resulting circuits for the active-only implementation of these structures corresponding to the sub-circuit operations of Fig. 9(a) and 9(c) are then resulted in Figs.9(b) and 9(d), respectively. The design formulas for the circuit parameters of each branch can be summarized below

$$R_x = R_S = R_L = R$$

$$R_{xi}^a = B_i^a L_i \text{ , } \quad R_{xi}^b = \frac{1}{B_i^b C_i}$$

and

$$R_{xj}^a = B_j^a L_j \text{, } R_{xj}^b = \frac{1}{B_j^b C_j} \tag{9}$$

The structure realization diagram of the bandpass filter, thus obtained by directly replacing each sub-circuit from Fig. 9 into the ladder bandpass prototype of Fig. 8, can be shown in Fig. 10.

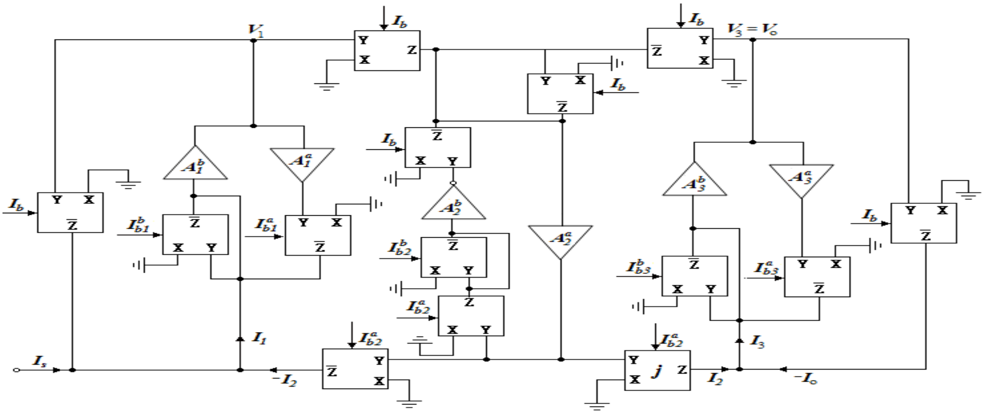


Fig. 10. Systematic diagram for current-mode 6th-order bandpass filter using active-only elements

Since all circuit parameters depend on R_x the values, a property of the proposed filter implementations is, therefore, possible to tune the characteristic of the current transfer function proportional to external or on-chip controlled internal resistance R_x. It is shown that for the employment of all active elements, a further advantage is to allow integration in monolithic as well as in VLSI fabrication techniques.

4. Simulation results

To demonstrate the performance of the proposed ladder filter, a design of current-mode 3rd-order Butterworth lowpass filter of Fig. 7 with a cut-off frequency of f_c=100kHz was realized. This condition leads to the component values chosen as follows, $R_x = 1$ kΩ, $R_{x1} = R_{x3} = 106.5$ Ω, $R_{x2} = 18.87$ kΩ. The simulated result shown in Fig. 11 exhibits reasonably close agreement with the theoretical value. For another illustration a sixth-order Chebyshev bandpass filter response of Fig. 10 is also designed with the following specifications: center frequency = 50kHz, bandwidth = 1.0 and ripple width = 0.5dB. The approcimation of this filter resulted in the following components values:

$R_x = 1$ kΩ, $R_{x1}^a = R_{x3}^a = 11.765$ kΩ, $R_{x1}^b = R_{x3}^b = 33.33$ Ω, $R_{x2}^a = 20.62$ kΩ, $R_{x2}^b = 58.41$ Ω. The simulated response of the designed filter verifying the theoretical value is shown in Fig. 12. In these simulations, The implementations of 0.25µm CMOS OAs, 0.25µm CMOS CCCII and their aspect ratio with ±2 volts power supplies are illustrated in Fig. 13 and Fig. 14, respectively[13-14]. The W/L parameters of MOS transistors are given in Table 2 and 3, respectively. The CMOS OAs using $C_1 = 30$ pF with bias voltage V_{B1} and V_{B2} set to -1V and -2V, respectively.

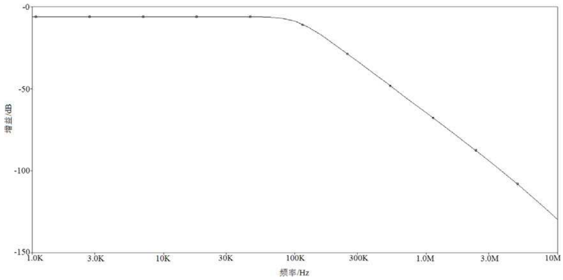


Fig. 11. Simulated frequency response of Fig. 7

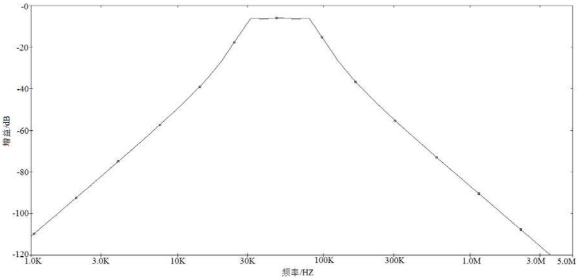


Fig. 12. Simulated frequency response of Fig. 10

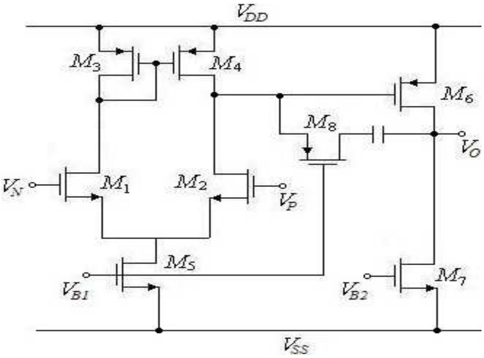


Fig. 13. CMOS OA implementation

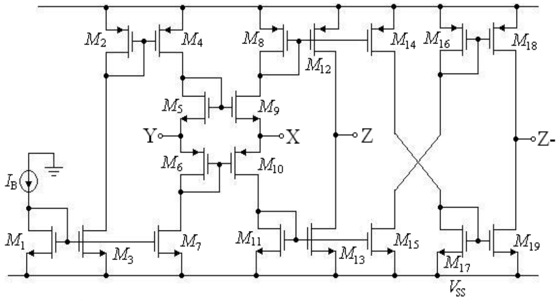


Fig. 14. CMOS CCCII implementation

Transistor	W (μm)	L (μm)	Transistor	W (μm)	L (μm)
M_1, M_2	250	3	M_6	392	1
M_3, M_4	100	3	M_7	232	3
M_5	80	32	M_8	39	1

Table 2. Transistors aspect ratio of COMS OA

Transistors	W(μm)	L(μm)
M_1,M_3, M_7, M_{11}, M_{13}, M_{15}, M_{17}, M_{19}	5	0.5
M_2,M_4, M_{12}, M_{14}, M_{16}, M_{18}	15	0.5
M_8	14.2	0.5
M_5, M_9	2	0.5
M_6, M_{10}	4	0.5

Table 3. Transistors aspect ratio of COMS CCCII

5. Conclusion

This paper presented an alternative systematic approach for realizing active-only current-mode ladder filters based on the leapfrog structure of passive RLC ladder prototypes. The proposed design approach are realizable with only two fundamental building blocks, i.e., OA and CCCII, which does not require any external passive elements. A property of this approach is the possibility of tuning the current transfer function by the controlled resistance R_x. Because of their active-only nature, the approach allows to realize filtering functions which are suitable for implementing in monolithic integrated form in both bipolar and CMOS technologies as well as in VLSI fabrication techniques. Since the synthesis technique utilizes an internally compensated pole of an OA, it is also suitable for high frequency operation. The fact that simulation results are in close agreement with the theoretical prediction verified the usefulness of the proposed design approach in current-mode operations.

6. References

[1] Nagasaku T, Hyogo A and Sekine K. A synthesis of a novel current-mode operational amplifier, Analog Integrated Circuits and Signal Processing, 1996, 1(11):183.

[2] Wu J. Current-mode high-order OTA-C filters. International Journal of Electronics, 1994, 76:1115.

[3] Abuelma'atti M T and Alzaher H A. Universal three inputs and one output current-mode filter without external passive elements. Electronics Letters, 1997, 33:281.

[4] Singh A K and Senani R. Low-component-count active-only imittances and their application in realizing simple multifunction biquads. Electronics Letters, 1998, 34:718.

[5] Tsukutani T, Higashimura M, Sumi Y and Fukui Y. Electronically tunable current-mode active-only biquadratic filter. International Journal of Electronics, 2000,87:307.

[6] Tsukutani T, Higashimura M, Sumi Y and Fukui Y. Voltage-mode active-only biquad. International Journal of Electronics, 2000,87:1435.

[7] Gerling F E J and Good E F. Active filters 12: the leapfrog or active-ladder synthesis. Wireless Word, 1970, 76(1417): 341.

[8] Tangsrirat W, Fujii N and Surakampontorn W. Current-mode leapfrog ladder filters using CDBAs, Circuits and Systems, 2002, 12(5): 26.

[9] Tangsrirat W, Dumawipata T and Unhavanich S. Design of active-only highpass and bandpass leapfrog filters using multi-current-output differentiators, Electronics, Circuits and Systems, 2003, 5(1): 14.

[10] Tangsrirat W, Dumawipata T and Unhavanich S. Realization of lowpass and bandpass leapfrog filters using OAs and OTAs, SICE 2003 Annual Conference, 2003, 4(3): 4.

[11] Fragoulis N and Haritantis I. Leapfrog-type filters that retain the topology of the prototype ladder filters, IEEE international symposium on circuits and systems, 2000, 5(6): 161.

[12] Prommee P, Kumngern M, Dejhan K. Current-mode active-only universal filter Circuits and Systems, APCCAS, 2006:896.

[13] Eser S, Ozcan S, Yamacli S et al. Current-mode Active-only universal bi-quad filter employing CCIIs and OTAs. 2009 international conference on applied electronics, sep 9-10, Pilsen, Czech Republic,2009, 107-110.

[14] Pipat Prommee, Montri Somdunyakanok and Kobchai Dejhan. Universal filter and its oscillator modification employing only active components. 2008 International symposium on intelligent signal processing and communications systems, Jan 8-10, Bangkok, Thailand, 2009, 1-4.

Management and Services
Edited by Mamun Habib

ISBN 978-953-307-118-3
Hard cover, 112 pages
Publisher Sciyo

Published in print edition October, 2010

Management in all business areas and organisational activities are the acts of getting people together to accomplish desired goals and objectives. Service is intangible, therefore, it is not too easy to define the theory application in varieties of service industries. Service Management usually incorporates automated systems along with skilled labour; it also provides service development. Due to enormous demand of service industries and management development, the book under the title "Management and Services" would create a milestone in management arena for all categories of readers including Business Administration, Engineering and Architecture. This book covers educational service development, service-oriented-architecture and case research analysis, including theory application in network security, GRID technology, integrated circuit application. The book is comprised of five chapters and has been divided into two parts. Part A contains chapters on service development in educational institutions and it depicts the application of supply chain management concept in service industries like tertiary educational institutions and multiple ways of web 2.0 applications transforming learning patterns and pathways. To understand the subject in a practical manner, Part B of this book consists of noteworthy case studies and research papers on management and services and represents theory application of Data mining, Fuzzy Cluster, Game theory, GRID Technology, simulation of Operational Amplifier and Current Controlled Conveyor II in network security, architecture, and integrated circuit application.

How to reference

Yanhui Xi and Hui Peng (2010). Realization of Lowpass and Bandpass Leapfrog Filters Using OAs and CCCIIs, Management and Services, Mamun Habib (Ed.), ISBN: 978-953-307-118-3, InTech, Available from: http://www.intechopen.com/books/management-and-services/realization-of-lowpass-and-bandpass-leapfrog-filters-using-oas-and-ccciis

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820

Fax: +385 (51) 686 166
www.intechopen.com

Fax: +86-21-62489821