Int. J. Electron. Commun. (AEÜ) 65 (2011) 231–234

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.de/aeue

LETTER

A new current-mode current-controlled SIMO-type universal filter

Chunhua Wang[a,*], Jing Xu[a], Ali Ümit Keskin[b], Sichun Du[a], Qiujing Zhang[a]

[a] School of Computer and Communication, Hunan University, Changsha, 410082, China
[b] Yeditepe University, Department of Biomedical Engineering, Turkey

ARTICLE INFO

Article history:
Received 6 October 2008
Accepted 11 February 2010

Keywords:
Current-controlled conveyor
Universal filter
Current-mode circuit

ABSTRACT

This paper proposes a new current-mode current-controlled single input multiple output (SIMO) type universal filter. The proposed circuit employs two current-controlled current conveyors (CCCIIs), one MO-CCCA (current-controlled current amplifier with multi-outputs) and two grounded capacitors. The filter can simultaneously realize lowpass, bandpass, highpass, bandstop and allpass filter outputs, and offers an independent electronic control of the natural angular frequency (ω_0) and quality factor (Q) by means of adjusting the bias currents of the CCCIIs. The parameter sensitivities are small. Moreover, a high Q-value filter can be easily obtained by adjusting the ratio of two bias currents of MO-CCCA. PSPICE simulation results are given to demonstrate the advantages of the proposed circuit.

1. Introduction

Current-mode active filters using second-generation current conveyors (CCIIs) have received significant attention in the last decades [1–7]. A variety of CCII-based current-mode universal filters are proposed in [1–6]. However, these filters do not offer electronic adjustment properties, since the input port of CCII cannot be electronically tuned. In order to alleviate this problem, Fabre introduced the concept of second generation current-controlled conveyor (CCCII) [8], and many applications of this element have been reported in the literatures [9–23].

Current-mode current-controlled universal active filters proposed in [9–13,15,17,19–21] are using CCCIIs. The CCCII-based biquadratic filters have the capability of electronic tuning of natural angular frequency (ω_0), and the quality factor (Q) of the circuit. These filters can be either multi-input and multi-output (MIMO) type [11,21], or single input and multi-output (SIMO) structure [9,10,12,13,15,17,19,20]. The MIMO filters can realize multifunction outputs by altering the way in which the input signals are connected. However, such filters can realize multifunction filter outputs only when the input signals meet some constraint conditions. The SIMO filters can realize second-order lowpass (LP), bandpass (BP), highpass (HP), and bandstop (BS) and allpass (AP) filters simultaneously, without changing the connection of the input signal, and without imposing any restrictive conditions on the input signal.

In the CCCII-based SIMO-type current-mode filtering circuits reported in [10,12,13], three CCCII elements and two grounded capacitors are present. However, these filters cannot realize high-impedance outputs except for the BP output in [10]. The circuit in [19] involves two CCCIIs and two capacitors, but it contains floating passive elements (which is relatively disadvantageous from the IC fabrication point of view), and the characteristic parameters ω_0 and Q cannot be tuned orthogonally. The circuit proposed in [9] contains six CCCII elements and two grounded capacitors. The circuit in [17] enjoys very low sensitivities, orthogonal tuning capability of the characteristic parameters ω_0 and Q, grounded capacitors, and high-impedance outputs. However, it requires five CCCIIs and three capacitors. While the circuit in [15] involves three CCCIIs and two capacitors and provide high-impedance outputs, the characteristic parameters (ω_0 and Q) cannot be orthogonally adjusted. Recently, some authors [24] propose a new current-mode current-controlled SIMO universal filter which is based on non-inverting and inverting second-generation current-controlled conveyors (CCCII($\pm$)). This circuit (using four CCCIIs and two grounded capacitors) can provide high-impedance outputs and orthogonal tuning capability of the characteristic parameters ω_0 and Q.

In this paper, a new SIMO-type current-mode universal filter is proposed. The proposed circuit employs only two CCCIIs, one MO-CCCA (current-controlled current amplifier with multi-outputs) [25] and two grounded capacitors. The LP, BP, HP, BS and AP filters can be realized simultaneously. It enjoys orthogonal tuning capability of the characteristic parameters ω_0 and Q, having low component sensitivities. It uses only two grounded capacitors, while providing high impedances at the output terminals. Moreover, high Q filters can be obtained by adjusting the ratio of two independent bias currents.

---

* Corresponding author. Tel. +86 13973125061; fax: +86 731 8822417.
E-mail address: wch1227164@sina.com (C. Wang).

1434-8411/$ – see front matter
doi:10.1016/j.aeue.2010.02.010

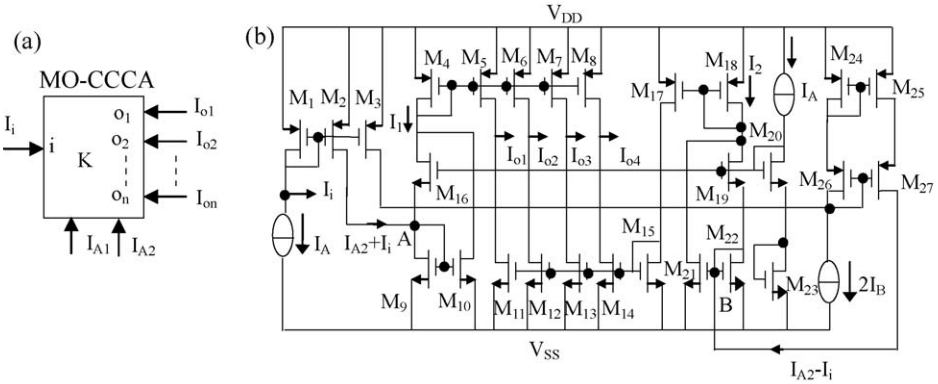

Fig. 1. Current-controlled current amplifier with multi-outputs. (a) The symbol of MO-CCCA. (b) The CMOS based structure of MO-CCCA.

2. MO-CCCA and CCCII(±)

The symbol of MO-CCCA is given in Fig. 1(a), where i represents input, $o_1 \sim o_n$ are n outputs respectively, and I_{A1} and I_{A2} denote bias DC currents. Fig. 1(b) is a CMOS realization of MO-CCCA which is introduced in [25]. Here I_i denotes the input signal; $I_{o1}, I_{o2}, I_{o3}, I_{o4}$ are the four output currents, respectively.

If the channel lengths of $M5 \sim M8$ are all n times of that of $M4$, and the channel size of $M17$ is n times that of $M18$, namely $(W/L)_{M5}/(W/L)_{M4} = (W/L)_{M6}/(W/L)_{M4} = (W/L)_{M7}/(W/L)_{M4} = (W/L)_{M8}/(W/L)_{M4} = (W/L)_{M17}/(W/L)_{M18} = n$, the output current expressions can obtained as

$$I_{o1} = I_{o2} = I_{o3} = I_{o4} = \frac{nI_{A2}}{2I_{A1}} I_i = KI_i \tag{1}$$

where K denotes the current gain. It is clear from (1) that the value of K can be set by I_{A2} and I_{A1}.

The circuit symbol of CCCII(±) is shown in Fig. 2. The port relations of the CCCII(±) can be characterized by the following equations:

$$i_y = 0, \quad v_x = v_y + i_x R_x, \quad i_{z+} = i_x, \quad i_{z-} = -i_x \tag{2}$$

where R_x is the parasitic resistance at terminal x.

This paper adopts CMOS CCCII(±) proposed in [26]. The parasitic resistance R_x is

$$R_x = \frac{V_{xy}}{I_x} = \left(2\sqrt{2K_{eff}I_b}\right)^{-1} \tag{3}$$

where $K_{eff} = K_n K_p / (\sqrt{K_n} + \sqrt{K_p})^2$. Here, K_n, and K_p are transconductance coefficients of NMOS and PMOS transistors, respectively.

3. Proposed universal filter and its analysis

Proposed new current-mode current-controlled SIMO CCCII(±) based filter circuit is shown in Fig. 3. The filter contains one MO-CCCA element, two CCCIIs(±) and two grounded capacitors.

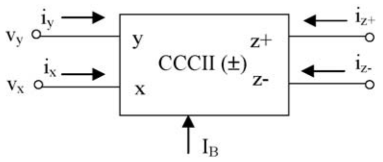

Fig. 2. Circuit symbol of CCCII(±).

Current transfer functions of the circuit are as follows:

$$\frac{I_{o1}}{I_{in}} = K \frac{1}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{4}$$

$$\frac{I_{o2}}{I_{in}} = K \frac{s\tau_2}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{5}$$

$$\frac{I_{o3}}{I_{in}} = K \frac{s^2\tau_1\tau_2}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{6}$$

$$\frac{I_{o4}}{I_{in}} = K \frac{s^2\tau_1\tau_2 + 1}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{7}$$

$$\frac{I_{o5}}{I_{in}} = K \frac{s^2\tau_1\tau_2 - s\tau_2 + 1}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{8}$$

In these equations, I_{o1}, I_{o2}, I_{o3}, I_{o4}, and I_{o5} are the LP, BP, HP, BS and AP current outputs, respectively. The quantities τ_1 and τ_2 are expressed as

$$\tau_1 = R_{x1}C_1, \quad \tau_2 = R_{x2}C_2 \tag{9}$$

Natural angular frequency (ω_0), and the quality factor (Q) of the circuit are

$$\omega_0 = \sqrt{\frac{1}{R_{x1}R_{x2}C_1C_2}}, \quad Q = \frac{I_{A1}}{I_{A2}}\sqrt{\frac{R_{x1}C_1}{R_{x2}C_2}} \tag{10}$$

where $R_{xi} = (2\sqrt{2K_{eff}I_{Bi}})^{-1}$ is the input resistance and I_{Bi} is the bias current of the ith CCCII(±) (i = 1, 2), respectively.

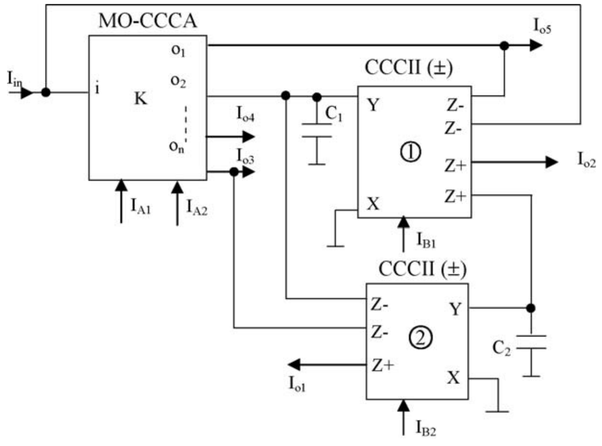

Fig. 3. Proposed current-mode current-controlled SIMO-type universal filter.

Table 1
0.5 μm CMOS technology parameters.

```
.model SEANMOS nmos (level=3 UO=460.5 TOX=1.0E−8 TPG=1 VTO=.62 JS=1.8
E−6 XJ=.15E−6 RS= 417 +RSH=2.73 LD=0.04E−6 ETA=0 VMAX=130E3
NSUB=1.71E17 PB=0.761 PHI=0.905 THETA=0.129 +GAMMA=0.69 KAPPA=0.1
AF=1 WD=0.11E−6 CJ=76.4E−5 MJ=0.357 CJSW=5.68E− 10 MJSW=0.302
+CGSO=1.38E−10CGDO=1.38E− 10 CGBO=3.45E− 10 KF=3.07E− 28 DELTA=.42
NFS=1.2E11)

.model SEAPMOS pmos (level=3 UO=100 TOX=1.0E−8 TPG=1 VTO=−0.58
JS=0.38E−6 XJ=0.1E−6 RS=886 +RSH=1.81 LD=0.03E−6 ETA=0 VMAX=113E3
NSUB=2.08E17 PB=0.911 PHI=0.905 THETA=0.120 +GAMMA=0.76 KAPPA=2 AF=1
WD=0.14E−6 CJ=85E−5 MJ=0.429 CJSW=4.67E− 10 MJSW=0.631+CGSO=1.38E−
10 CGDO=1.38E− 10 CGBO=3.45E− 10 KF=1.08E− 29 DELTA=.81 NFS=0.52E11)
```

Substituting $(2\sqrt{2K_{eff}I_{Bi}})^{-1}$ for R_{xi} in (10) yields the following expressions:

$$\omega_0 = 2\sqrt{\frac{K_{\text{eff}}\sqrt{I_{B1}I_{B2}}}{C_1C_2}}, \quad Q = \frac{I_{A1}}{I_{A2}}\sqrt{\frac{\sqrt{I_{B2}}C_1}{\sqrt{I_{B1}}C_2}} \tag{11}$$

It is seen from (11) that ω_0 can be tuned through I_{B1} and I_{B2}, and that Q can be adjusted independently through I_{A1} and I_{A2} without disturbing ω_0. It is also clear that Q can be adjusted independently by the ratio of I_{A1} and I_{A2}, and therefore a large Q value can be obtained by adjusting this ratio. Moreover, the Q-value is temperature independent for CMOS realization of the active components of the filter.

The passive sensitivities of the ω_0 and Q are calculated from (10) as $S^{\omega_0}_{R_{x1},R_{x2},C_1,c_2} = -1/2$, $S^{\omega_0}_{R_{x3},R_{x4}} = 0$, $S^{Q}_{R_{x1},C_1} = -S^{Q}_{R_{x2},C_2} = 1/2$, $S^{Q}_{R_{x3}} = -S^{Q}_{R_{x4}} = 0$. It is seen that magnitudes of all of these parameter sensitivities are small. Furthermore, for simplicity, when we set $I_{B1} = I_{B2} = I_B$, then (11) becomes

$$\omega_0 = 2I_B\sqrt{\frac{K_{\text{eff}}}{C_1C_2}}, \quad Q = \frac{I_{A1}}{I_{A2}}\sqrt{\frac{C_1}{C_2}} \tag{12}$$

Here, it can be seen that the natural angular frequency can be adjusted electronically/orthogonally by varying I_B, while the quality factor can be adjusted electronically/orthogonally by varying I_{A1} or I_{A2}.

4. Circuit simulation results

In order to confirm the validity of the theoretical results derived for the proposed filter shown in Fig. 3, the circuit has been simulated using PSPICE simulation program. The CMOS CCCII(±) circuit was realized using 0.5 μm CMOS technology parameters as given in Table 1[26]. DC supply voltage was ±1.5 V.

As an example, a filter with a natural frequency of $f_0 = \omega_0/2\pi = 39$ KHz and $Q = 1$ was designed. Bias currents and active and passive component values were chosen as: $I_{B1} = I_{B2} = 15\,\mu\text{A}$, $I_{A1} = I_{A2} = 10\,\mu\text{A}$, $C_1 = C_2 = 1nF$. The simulation results of the filter characteristics are shown in Fig. 4. Fig. 5 shows the simulated and theoretical frequency responses of the gain and phase characteristics of the AP filter. It is clear that all the simulated results agree quite well with the theoretical ones.

In order to demonstrate the electronic tuning of ω_0, the dc bias currents I_B (i.e. $I_B = I_{B1} = I_{B2}$) were set to the values of 5 μA, 15 μA, 20 μA, and 30 μA, respectively, while keeping $I_{A1} = I_{A2} = 10\,\mu\text{A}$ for a constant quality factor of $Q = 1$. The resulting responses of the BP filter corresponding to different bias currents I_B when $C_1 = C_2 = 1nF$ are given in Fig. 6. It is seen that the natural frequency is proportional to the bias current I_B. For the controllability of the Q-value, the dc bias currents were set to be constant at $I_{B1} = I_{B2} = 15\,\mu\text{A}$ and $I_{A2} = 10\,\mu\text{A}$. The corresponding current characteristics of the BP filter when I_{A1} is varied are shown in Fig. 7. It is important to note that high values of the quality factor Q can be easily obtained using high values for I_{A1}.

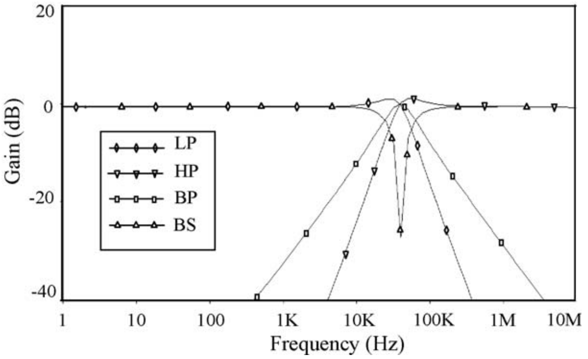

Fig. 4. Simulated frequency characteristics of LP, BP, BS and HP response of the proposed filter.

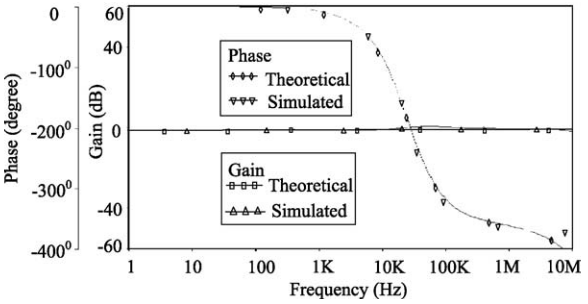

Fig. 5. Gain and phase characteristics of the allpass filter at $f_o = 39$ KHz.

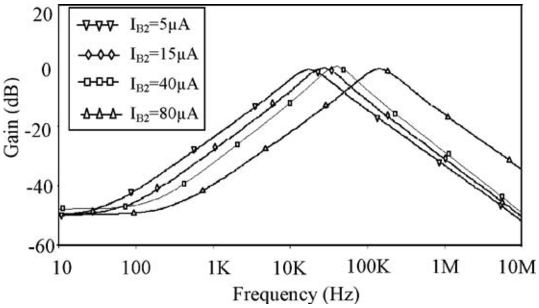

Fig. 6. Simulated frequency responses of the BP filter when I_B $(= I_{B1} = I_{B2})$ is varied.

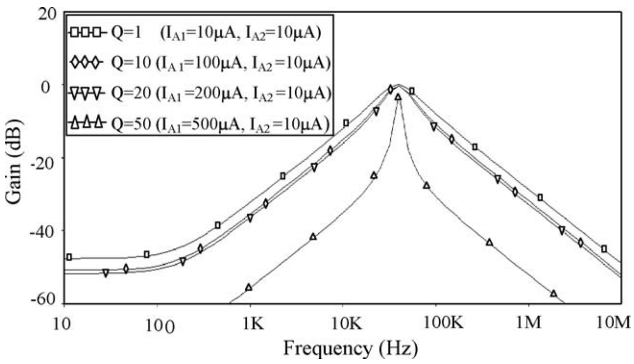

Fig. 7. Simulated frequency responses of the BP filter when I_{A1} is varied.

5. Conclusions

A new MO-CCCA and CCCII(±) based current-mode current-controlled universal filter with SIMO structure is proposed. The proposed circuit has the following advantages: (i) it has only three active elements and two capacitors (for example, this new circuit is simpler as compared to the circuit of [24]); (ii) it is truly universal in nature, it can simultaneously realize lowpass, bandpass, highpass, bandstop and allpass filtering responses; (iii) both capacitors are grounded, which is advantageous from the I_C fabrication point of view; (iv) The natural frequency (ω_0) and quality factor (Q) can be independently controlled; (v) the natural frequency (ω_0) and the quality factor (Q) sensitivities are low; (vi) all output terminals are at high impedance level; (vii) A current-mode high Q-value filter can be easily obtained by adjusting the ratio of two bias currents of MO-CCCA.

Acknowledgement

The authors would like to thank the National Nature Science Foundation of China for financially supporting this research under nos. 60676021 and 60776021.

References

[1] Abuelma'atti MT, Shabra AM. A novel current conveyor-based universal current mode filter. Microelectronics Journal 1996;27(6):471–5.
[2] Gunes EO, Toker A, Ozoguz S. Insensitive current-mode universal filter with minimum components using dual-output current conveyors. Electronics Letters 1999;35(7):524–5.
[3] Keskin AU, Cam U. Insensitive high-output impedance minimum configuration SITO-type current-mode biquad using dual-output current conveyors and grounded passive components. AEU - International Journal of Electronics and Communications 2007;61(5):341–4.
[4] Soliman AM. Current conveyor filters: classification and review. Microelectronics Journal 1998;29(3):133–49.
[5] Soliman AM. New inverting non-inverting bandpass and lowpass biquad circuit using current conveyors. International Journal of Electronics 1996;81(5):577–83.
[6] Wang HY, Lee CT. Versatile insensitive current mode universal biquad implementation using current conveyors. IEEE Transactions on Circuits and Systems-II: Analog and Digital Signal Processing 2001;48(4):409–13.
[7] Wilson B. Recent developments in current conveyors and current-mode circuits. IEE Proceedings of the Institute of Electrical Engineers, Part G 1990;137(2):63–77.
[8] Fabre A, Saaid O, Boucherron C. High frequency applications based on a new current controlled conveyor. IEEE Transactions on Circuits And Systems-I: Fundamental Theory and Applications 1996;43(2):82–91.
[9] Abuelma'atti MT, Tasadduq NA. A novel single-input multiple-output current-mode current-controlled universal filter. Microelectronics Journal 1998;29(11):901–5.
[10] Abuelma'atti MT, Tasadduq NA. New current-mode current-controlled filters using the current-controlled conveyor. International Journal of Electronics 1998;85(4):483–8.
[11] Chang CM, Al-Hashimi BM, Ross JN. Unified active filter biquad structures. IIEE proceedings Part G, Circuits, devices and systems 2004;151(4):273–7.
[12] Khan IA, Zaidi MH. Multifunctional translinear-C current-mode filter. International Journal of Electronics 2000;87(9):1047–51.
[13] Kiranon W, Kesorn J, Sangpisit W, Kamprasert N. Electronically tunable multifunctional translinear-C filter and oscillator. Electronics Letters 1997;33(7):573–4.
[14] Keskin P, Pal AU. Wide-band resistorless all-pass sections with single element tuning. International Journal of Electronics 2007;94(6):597–604.
[15] Maheshwari S, Khan IA. Novel cascadable current-mode translinear-C Universal filter. Active and Passive Electronic Components 2004;27(4):215–8.
[16] Maheshwari S. A new current-mode current-controlled all-pass section. Journal of Circuits Systems and Computers 2007;16(2):181–9.
[17] Minaei S, Turkoz S. New current-mode current-controlled universal filter with single input and three outputs. International Journal of Electronics 2001;88(3):333–7.
[18] Pandey N, Paul SK. All-pass filter based on CCII- and CCCII. International Journal of Electronics 2004;91(8):485–9.
[19] Sagbas M, Fidanboylu K. Electronically tunable current-mode second-order universal filter using minimum elements. Electronics Letters 2004;40(1): 2–4.
[20] Shah NA, Rather MF, Iqbal SZ. SITO electronically tunable high output impedance current-mode universal filter. Analog Integrated Circuits and Signal Processing 2006;47(3):335–8.
[21] Tangsrirat W. Current-tunable current-mode multifunction filter based on dual-output current-controlled conveyors. AEU - International Journal of Electronics and Communications 2007;61(8):528–33.
[22] Zouaoui-Abouda H, Fabre A. A new balanced CMOS controlled integrator for ultra high frequency applications. Analog Integrated Circuits and Signal Processing 2006;47(1):13–22.
[23] Zouaoui-Abouda H, Fabre A. New high-value floating controlled resistor in CMOS technology. IEEE Transactions On Instrumentation And Measurement 2006;55(3):1017–20.
[24] Chunhua W, Haiguang L, Yan Z. A new current-mode current-controlled universal filters based on CCCII(±). Circuits, systems and signal processing 2008;27(5):673–82.
[25] Chunhua W, Haiguang L, Yan Z. Universal current-mode filter with multiple inputs and one output using MOCCII and MO-CCCA. AEU - International Journal of Electronics and Communications 2009;63(9):448–53.
[26] Chunhua W, Zhixing S, Haiguang L. New CMOS current-controlled second generation current conveyors. In: 2008 the 4th IEEE International Conference on Circuits and Systems for Communications, May 26–28th. 2008. p. 333–7.

Chunhua Wang was born in Yongzhou, China, in 1963. He received the B.Sc degree from Hengyang Teacher's College, Hengyang, China, in 1983, the M.Sc. degree from Physics Department, Zheng Zhou University, Zheng Zhou, China, in 1994, the Ph.D. degree from School of Electronic Information and Control Engineering, Beijing University of Technology, Beijing, China.

He is currently a Professor of School of Computer and Communication, Hunan University, Changsha, China. From 2004 to 2005, he served as a Professor and the associate Dean of Information Engineering, Xiangtan University, Xiangtan, China.

His research interests include current-mode circuit design, filtering, radio frequency circuit and wireless communications.

Jing Xu was born in Xinyang, China, in 1987. He received the B.Sc. degree from Henan University of Technology, Henan, China, in 2008. He is currently studying in Hunan University for master degree now. His research interest is RFIC design with focus on RFID reader.

Ali Ümit Keskin was born in Bursa, Turkey. He received his BSEE degree from Bogazici University in 1978, MSEE from Yildiz University (1980) and PhD degree from the Institute of Science and Technology, Istanbul Technical University (1984). In 1985, he joined Siemens AG, Turkey. He was engaged in the field of Medical Instrumentation throughout his professional career. Since 2002, he is a staff member of Yeditepe University, Faculty of Engineering. His main research interests are analog circuits and signal processing, transducers, medical instrumentation theory and its applications.

Sichun Du received the M.E. degree in Computer Application Technology from Hunan University, Changsha, China. His current research interests include design and simulation of RF CMOS integrated circuits and mixed analog-digital circuits.

Qiujing Zhang was born in Jishou, Hunan, China, in 1982. She received the B.Sc. from School of Computer and Communication, Changsha University of science and technology, in 2005. She is now studying in Hunan University for doctor degree. She is interested in analog IC circuit and filter design.