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Full Length Research Paper

Multiple-input single-output current-mode universal filter using translinear current conveyors

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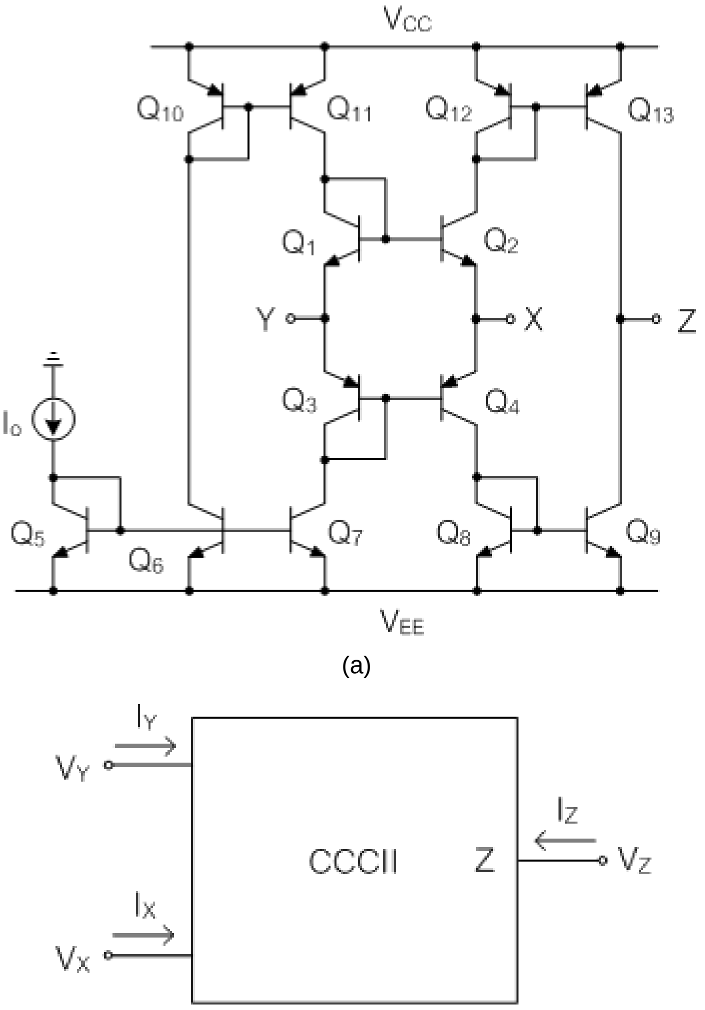
This paper presents a new current-controlled current-mode universal filter with multiple inputs and single output employing one translinear current conveyor (CCCII), one CCCII with controlled current gain and two grounded capacitors. The employment of grounded capacitors makes the circuit ideal for integration. The proposed circuit can provide low-pass, band-pass, high-pass, band-stop and all-pass current responses by appropriately connecting the input terminals. The natural frequency (ω_o) and the quality factor (Q) can also be controlled independently and electronically through adjusting the bias currents of the CCCIIs. Furthermore, no critical matching conditions are required for realizing all the filter responses. The characteristics of the proposed circuit are simulated using PSPICE to confirm the theory.

Key words: Universal filter, current-mode circuit, translinear current conveyor.

INTRODUCTION

In recent years, the design and implementation of current-mode active filters using second-generation current conveyors (CCIIs) have received considerable attention owing to the fact that their bandwidth, linearity, simple circuitry, low power consumption and dynamic range performances are better than those of their operational amplifier (op-amp) based counterparts (Roberts and Sedra, 1989). The current-mode filter can easily be cascaded to the next stage without additional current buffer, if it has the property of high impedance outputs. On the other hand, it is attractive for monolithic integrated circuit (IC) implementation, if the filters employ grounded capacitors (Bhusan and Newcomb, 1967). Since then, a number of current-mode CCII-based universal filters have been proposed (Chang, 1993; Ozoguz and Acar, 1993; Cicekoglu et al., 2002; Horng et al., 2007; Toker and Ozoguz, 2000; Senani et al., 2004, 2005; Wang and Lee, 2001; Tu et al., 2002; Abuelma'atti and Tasadduq, 1999). In Chang (1993), Ozoguz and Acar (1993), Cicekoglu et al. (2002), Horng et al. (2007), Toker and Ozoguz (2000) and Senani et al. (2004, 2005), a single-input multiple-output (SIMO) current-mode universal filter using CCIIs has been reported. Generally, SIMO filter can simultaneously realize three basic filter functions, that is, low-pass (LP), band-pass (BP) and high-pass (HP). However, for the realizations of all-pass (AP) and band-stop (BS) functions are usually required any component matching conditions. For more convenience and versatility, the multiple-input single-output (MISO) universal filters can be solved. The employment of the MISO configuration may lead to a reduction of number of active elements for circuit realization. This type of filter, in comparison with the SIMO filter, provides a variety of circuit characteristic with different input and output currents, and usually does not require any parameter matching conditions. Moreover, to realize all the standard biquadratic filter functions, the configuration with MISO seems to be more suitable than the single input configuration. In Toker and Ozoguz (2000) and Senani et al. (2004, 2005), CCIIs-based MISO current-mode universal filter have been presented. Most of the MISO universal filters suffer from a lack of electronic tenability and the use of large active components(Wang and Lee, 2001; Tu et al., 2002; Abuelma'atti and Tasadduq, 1999).

By using the second-generation current-controlled current conveyor (CCCII) introduced by Fabre et al. (1995), current conveyor applications can be extended to the domain of electronically tunable functions. Recently, multiple-input universal filter have been proposed using multiple-output CCCIIs (Tangsrirat and Surakampontorn, 2007; Tsukutani et al., 2007; Tangsrirat, 2007; Tangsrirat



(a)

(b)

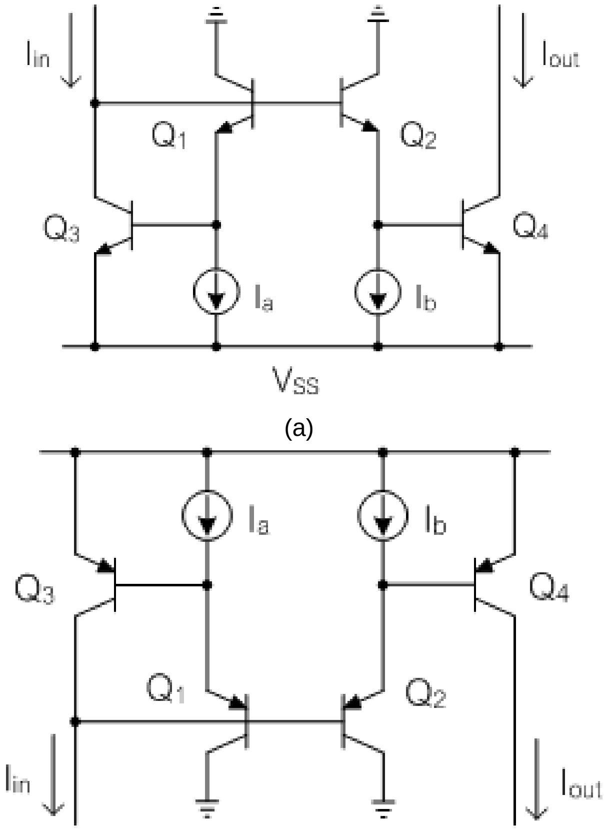
Figure 1. Bipolar implementation of the CCCII.

and Surakampontorn, 2006). However, most of these configurations suffer from the use of large number of CCCII. Moreover, CCCII-based multiple-input multiple-output universal filter in Tangsrirat and Surakampontorn (2007) and Tsukutani et al. (2007) can not benefit from orthogonal control of the natural frequency (ω_o) and quality factor (Q).

The purpose of this article is to introduce a new current-mode current-controlled universal filter with a reduced number of active and passive components. The proposed filter employs only two translinear current conveyors and two grounded capacitors, which is advantageous in view of integrated circuit implementation. By appropriately selecting the input and output terminals, the proposed circuit can simultaneously realize the LP, BP, HP, BS and AP current responses, all at a high impedance output, thus permitting easy cascadability. No critical matching condition is required in realizing all the filter responses, and all the incremental parameter sensitivities are low. The parameters ω_o and Q can be orthogonally and electronically tuned over a wide range through adjusting the dc bias current of the CCCII. Moreover, by using the current gain of CCCII, the high-Q filter can be obtained. PSPICE simulation results are also included to verify the theoretical analysis.

PROPOSED CIRCUIT

The second-generation current controlled current conveyor (CCCII) can be used to implement several applications such as amplifiers, filters, oscillators, and non-linear circuits. The well-known schematic implementation for CCCII, implemented with bipolar technology is shown in Figure 1 (Fabre et al., 1995). According to Figure 1, can be seen component of that CCCII has a unity voltage gain between terminal Y and X, then has an unity current gain between terminal X and Z, and also has an high impedance level between terminal Y and Z that in ideal is equal to infinite, whereas the X terminal has a



(a)

(b)

Figure 2. Current mirrors with djustable gain: (a) positive type; (b) negative type.

R_X and it can be obtained as:

$$R_x = \frac{V_T}{2I_o} \tag{1}$$

The R_X is an inner resistance of a translinear mixed loop (Q_1 to Q_4) with grounded resistor equivalent controlled by dc bias current I_o, where V_T is the thermal voltage. The translinear current conveyor with controlled current gain can be obtained by modifying the original circuit of the CCCII in Figure 1 and adding additional current mirror with adjustable gain as shown in Figure 2 (Toumazou, 1990) to obtain the required current gain at Z terminal. Also, the multiple-output translinear current conveyor can be obtained by adding additional current mirrors and cross-coupled current mirrors to obtain the required plus and minus type outputs (Abuelma'atti and Al-Qahtani, 1998) Figure 3 shows the schematic diagram of the multiple-output tranlinear plus/minus CCCII with controlled current gain (Kumngern et al., 2010). In Figure 3, a CCCII with controlled current gain has a unity voltage gain between terminals Y and X and tunable k current gain between terminals X and Z. The latter property makes it different from a current conveyor. A few current conveyors with controlled gain are described in Fabre and Mimeche (1996), Surakampontorn and Kumwachara (1992) and Mimaei et al. (2006). However, they are not suitable for electronic-control of ω_o and high Q-value biquad filter. The schematic of the CCCII with controlled gain in Figure 3 is characterized by the relationship

$$\begin{pmatrix} I_Y \\ V_X \\ I_Z \\ I_{Zk} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 1 & R_x & 0 & 0 \\ 0 & \pm 1 & 0 & 0 \\ 0 & \pm k & 0 & 0 \end{pmatrix} \begin{pmatrix} V_Y \\ I_X \\ V_Z \\ V_{Zk} \end{pmatrix}. \tag{2}$$

The current gain k of the current conveyor (Toumazou et al., 1990; Kumngern et al., 2010; Fabre et al., 1995) can be given by

$$k = \frac{I_a}{I_b} \tag{3}$$

It can note that the signal current is amplified by the factor k and this factor can be varied linearly controlled by adjusting the bias currents I_a and/or I_b.

The proposed current-controlled current-mode MISO universal filter is shown in Figure 4. The proposed circuit comprises two translinear current conveyors and two grounded capacitors, where I_{in1}, I_{in2} and I_{in3} denote the input current signal and I_{out} is the output signal. Using (2), the transfer functions of proposed filter in Figure 4 can be expressed as

$$I_{out} = \frac{\left(s^2 R_{x1} R_{x2} C_1 C_2 + s R_{x2} C_2 k_1 + 1\right) I_{in1} + s R_{x2} C_2 k_1 \, I_{in2} + I_{in3}}{s^2 R_{x1} R_{x2} C_1 C_2 + s R_{x2} C_2 k_1 + 1} \tag{4}$$

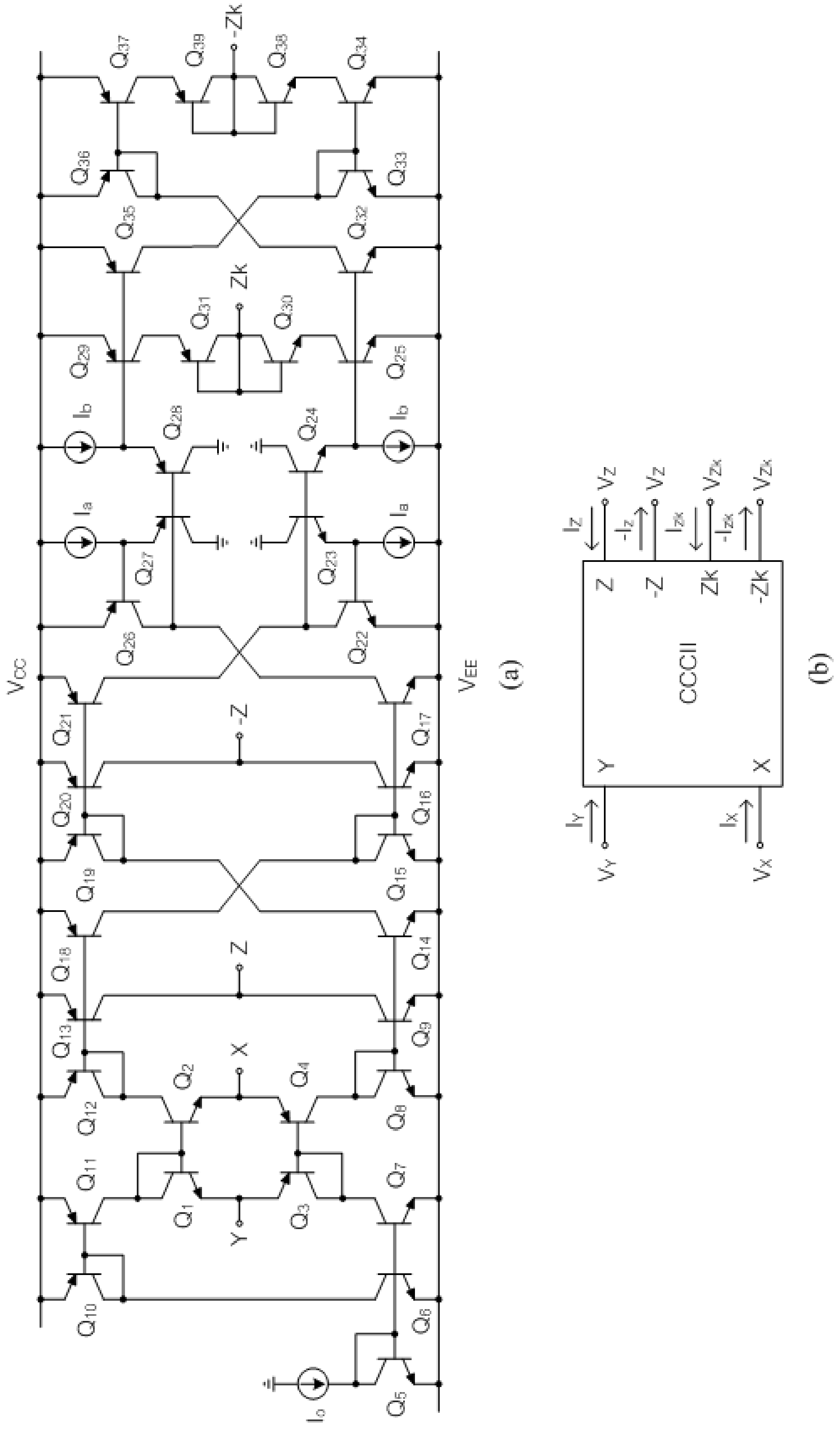


Figure 3. (a) Bipolar implementation of the CCCII with controlled current gain and (b) circuit symbol.

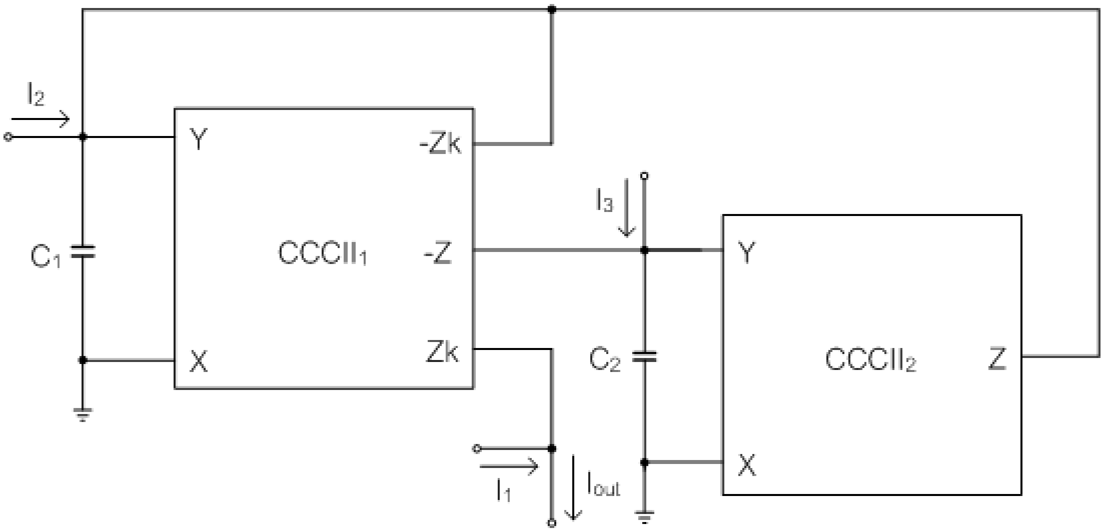


Figure 4. Proposed current-mode universal filter using translinear current conveyors.

Table 1. Sensitivities of circuit components.

x	$S_x^{\omega_0}$	S_x^Q
R_{x1}	-0.5	0.5
R_{x2}	-0.5	-0.5
C_1	-0.5	0.5
C_2	-0.5	-0.5
α_1	0.5	0.5
α_2	0.5	-0.5
β_1	0.0	1.0
β_2	0.5	-0.5
β_{k1}	0.0	-1.0
k_1	0.0	-1.0

The equations above imply that the circuit in Figure 4 provides a variety of circuit transfer functions with different input terminals. The LP, BP, HP, BS and AP transfer function can be realized as follows:

(1) The LP response can be obtained when $I_{in3}=I_{in}$ and $I_{in1}=I_{in2}=0$.
(2) The BP response can be obtained when $I_{in2}=I_{in}$ and $I_{in1}=I_{in3}=0$.
(3) The HP response can be obtained when $I_{in1}=I_{in}$ and $I_{in2}=I_{in3}= -I_{in}$.
(4) The BS response can be obtained when $I_{in1}=I_{in}$, $I_{in2}=-I_{in}$ and $I_{in3}=0$.
(5) The AP response can be obtained when $I_{in1}=I_{in}$, $I_{in2}=-2I_{in}$ and $I_{in3}=0$.

Therefore, the proposed filter can realize five types of standard biquadratic function from the same circuit configuration without component matching condition requirements. It should be noted that the HP and BS responses is not a major advantages. Practically, the minus input current ($-I_{in}$) can easily be obtained by using an additional CCCII with its Y-terminal grounded. From Figure 3, the input signal current (I_{in}) is then injected to the terminal X, while the currents $-I_{in}$, I_{in}, and $-2I_{in}$ can be taken from the –Z, +Z and -Zk terminals, respectively. A twice of minus input current ($-2I_{in}$) can be set the current gain k = 2.

The natural angular frequency (ω_o) and the quality factor (Q) are given by

$$\omega_o = \sqrt{\frac{1}{R_{x1}R_{x2}C_1C_2}} \qquad (5)$$

$$Q = \frac{1}{k_1}\sqrt{\frac{R_{x1}C_1}{R_{x2}C_2}} \qquad (6)$$

with

$$k_1 = \frac{I_{a1}}{I_{b1}} \qquad (7)$$

where R_{xj} is the input resistance at terminal of the j-th CCCII (j=1, 2) and k_1 is the current gain I_{a1}/I_{b1} of the $CCCII_1$. For more simplicity, if we set $R_{x1}=R_{x2}$, $C_1=C_2$ and substituting (7) into (6), (7) becomes

$$Q = \frac{I_{b1}}{I_{a1}} \qquad (8)$$

From Equations (5) and (8), the parameter ω_o for all filter responses can be electronically tuned by linearly varying I_{o1} and/or I_{o2} without affecting the parameter Q. For the Q-value, it can be controlled linearly and separately by adjusting the dc bias current ratio I_{b1}/I_{a1}, where the high-Q biquads can be realized when the appropriate current gain is chosen. Moreover, the Q-value is also temperature independent and parameters ω_o and Q can be independently tuned over a wide range.

NON-IDEAL EFFECTS

To consider the non-ideal effect of a CCCII, taking the non-idealities of the CCCII into account, the relationship of the terminal voltages and currents can be rewritten as

Table 2. Model parameters of NR100N and PR100N transistors.

Model parameters

NR100N-1X NPN TRANSISTOR

MODEL NX1 NPN (RB=524.6 IRB=0 RBM=25 RC=50 RE=1 IS=121E-18 EG=1.206 XTI=2 XTB=1.538 BF=137.5 IKF=6.974E-3 NF=1 VAF=159.4

ISE=36E-16 NE=1.713 BR=0.7258 IKR=2.198E-3 NR=1 VAR=10.73 ISC=0 NC=2

TF=0.425E-9 TR=0.425E-8 CJE=0.214E-12 VJE=0.5 MJE=0.28 CJC=0.983E-13 VJC=0.5 MJC=0.3 XCJC=0.034 CJS=0.913E-12 VJS=0.64 MJS=0.4 FC=0.5)

PR100N-1X PNP TRANSISTOR

MODEL PX1 PNP (RB=327 IRB=0 RBM=24.55 RC=50 RE=3 IS=73.5E-18 EG=1.206 XTI=1.7 XTB=1.866 BF=110.0 IKF=2.359E-3 NF=1 VAF=51.8 ISE=25.1E-16 NE=1.650 BR=0.4745 IKR=6.478E-3 NR=1 VAR=9.96 ISC=0 NC=2

TF=0.610E-9 TR=0.610E-8 CJE=0.180E-12 VJE=0.5 MJE=0.28 CJC=0.164E-12 VJC=0.8 MJC=0.4 XCJC=0.037 CJS=1.03E-12 VJS=0.55 MJS=0.35 FC=0.5)

$$\begin{pmatrix} I_Y \\ V_X \\ I_Z \\ I_{Zk} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ \alpha & R_x & 0 \\ 0 & \pm\beta & 0 \\ 0 & \pm\beta_k k_j & 0 \end{pmatrix} \begin{pmatrix} V_Y \\ I_X \\ V_Z \\ V_{Zk} \end{pmatrix} \qquad (9)$$

where $\alpha=1-\varepsilon_v$ and $\varepsilon_v(\varepsilon_v \ll 1)$ is the voltage tracking error from Y terminal to X terminal, $\beta=1-\varepsilon_i$ and $\varepsilon_i(\varepsilon_i \ll 1)$ is the current tracking error from X terminal to Z terminal and $\beta_k=1-\varepsilon_i$ and $\varepsilon_i(\varepsilon_i \ll 1)$ is the output current tracking error the current tracking error from X terminal to Zk terminal. Using (12), the non-ideal parameters ω_{on} and Q_n can be expressed as

$$\omega_{on} = \sqrt{\frac{\alpha_1\alpha_2\beta_1\beta_2}{R_{x1}R_{x2}C_1C_2}} \qquad (10)$$

and

$$Q = \frac{1}{k_1\beta_{k1}}\sqrt{\frac{R_{x1}C_1}{R_{x2}C_2}\frac{\alpha_1\beta_1}{\alpha_2\beta_2}} \qquad (11)$$

From Equations (10) and (11), the tracking errors slightly change the resonance angular frequency and the quality factor. However, the natural frequency and quality factor still can be orthogonally controllable. The incremental sensitivities of the parameters ω_o and Q are calculated as in Table 1. It is evident from Table 1 that all the active and passive sensitivities are equal or less than unity in magnitude. Thus, the proposed circuit exhibits a low sensitivity performance.

SIMULATION RESULTS

In order to verify the characteristics of the proposed circuit in Figure 4, PSPICE simulations have been carried out. The translinear conveyor in Figures 1 and 3 were performed with the transistor model of PR100N and NP100N of the bipolar arrays ALA400 from AT&T as tabulated in Table 2 (Frey, 1993), and select the dc supply voltages $V_{CC}=-V_{EE}=3$V. For example design, $C_1=C_2=10$ nF are given. Figure 5 shows the simulated frequency responses of the proposed filter with $I_{o1}=I_{o2}=100$ μA and $I_{a1}=I_{b1}=50$ μA. This setting has been designed to obtain the LP, BP, HP, BS and AP filter responses with $f_o \cong 127$ kHz and Q=1. Figure 6 shows the simulated frequency responses of the gain and phase characteristics of the AP filter at $f_o \cong 127$ kHz. It is clear from both figures that the proposed filter performs five standard biquadratic filtering functions well. Figure 7 shows the simulated a BP filter response when the dc bias currents I_o (that is, $I_o=I_{o1}=I_{o2}$) were simultaneously adjusted for the values 50, 100, 200 and 500 μA, respectively, while keeping $I_{a1}=I_{b1}=50$ μA for a constant Q=1. To demonstrate the current gain of current conveyor tuning of Q, the dc bias currents were set to be constant at $I_{o1}=I_{o2}=100$ μA and $I_{a1}=50$ μA. The corresponding current characteristics of the BP filter when I_{b1} is varied are shown in Figure 8.

Conclusion

In this paper a new three inputs and one output electronically tunable current-mode universal filter employing only two translinear current conveyors and two grounded capacitors which is very suitable for IC implementation, was proposed. It possesses the following properties: (i) ability of realizing the LP, BP, HP, BS and AP filter responses without component matching condition requirements; (ii) high impedance output which is property enables easy cascading in current-mode operation; (iv) orthogonal and electrical control of the parameters ω_o and Q, (v) high Q-value filter can be easily obtained by adjusting the current gain of CCCII. The configuration is suitable for bipolar technology implementations. Although CMOS technology more attractive for modern integrated circuit technologies, unlike bipolar technology that are small interest in

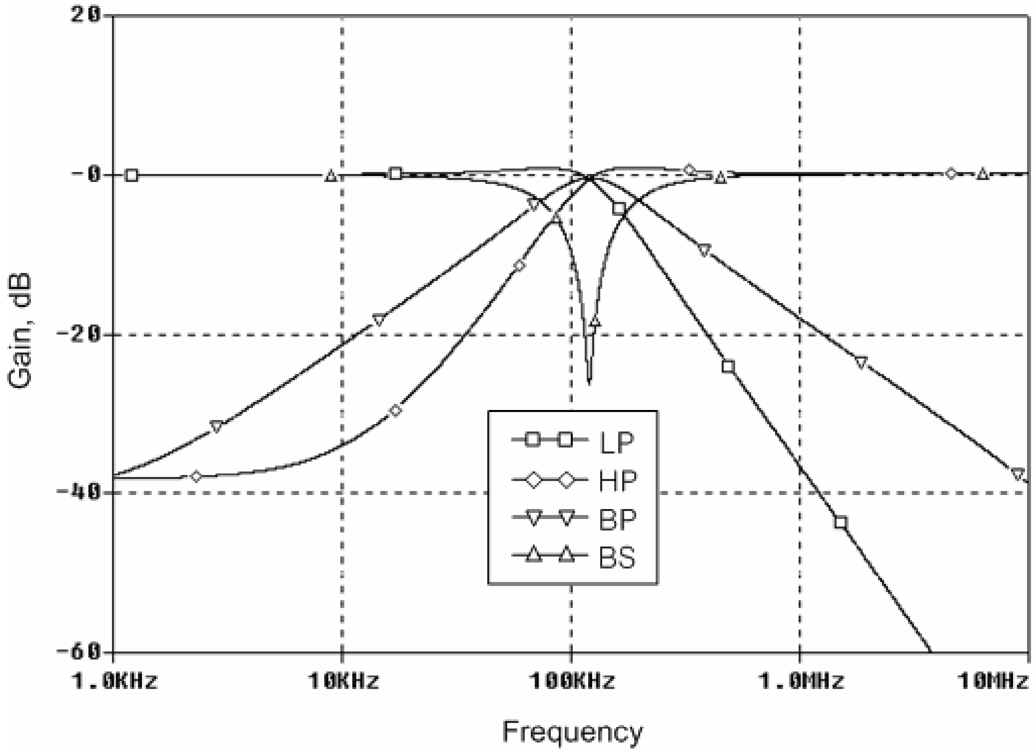


Figure 5. Simulated frequency characteristics of LP, HP, BP and BS of the proposed current-mode filter in Figure 4.

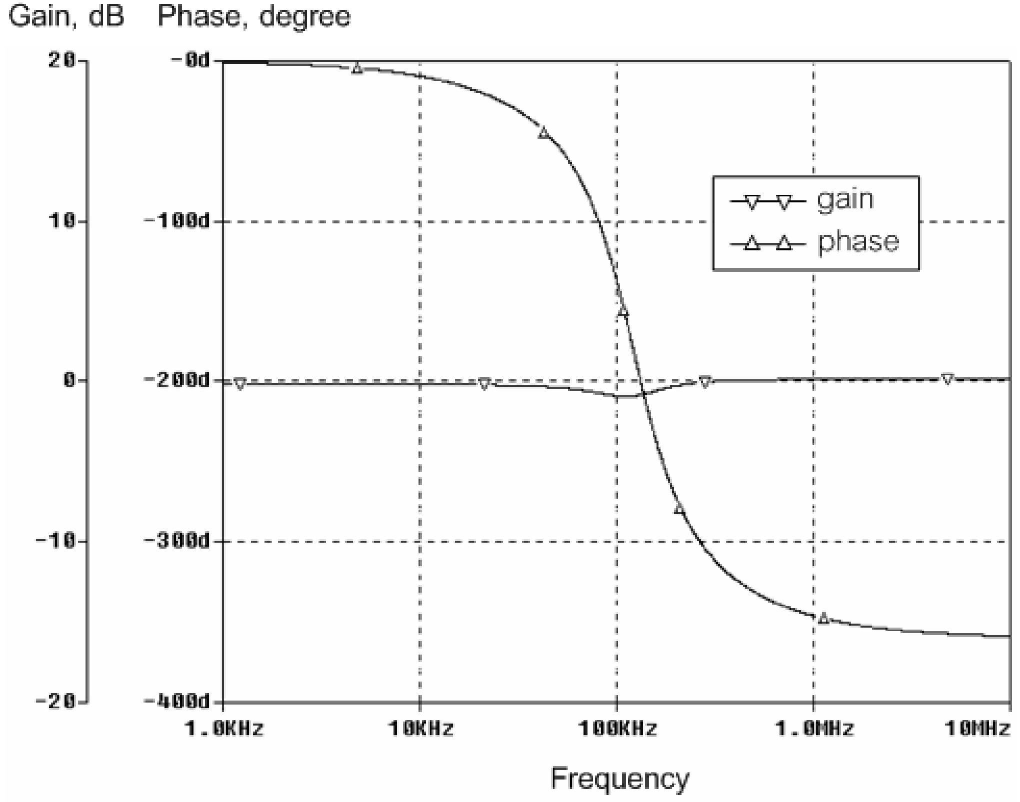


Figure 6. Gain and frequency responses of the AP filter.

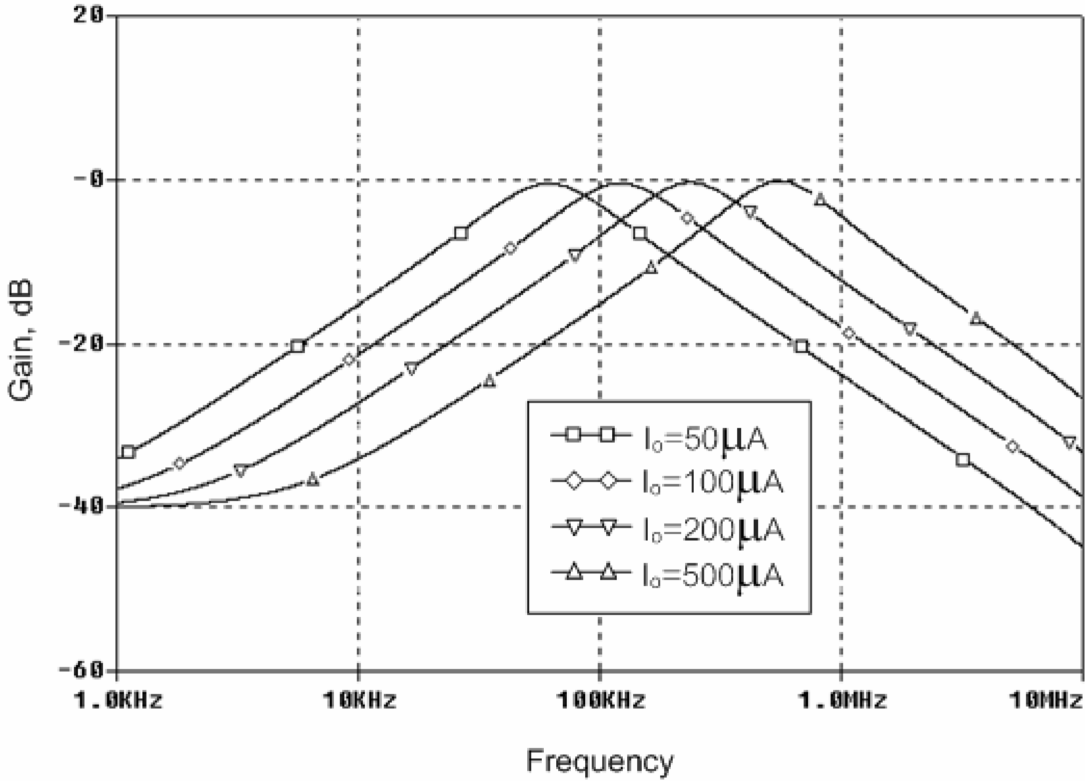


Figure 7. Simulated frequency responses of the BP filter when I_o (that is, $I_o=I_{o1}=I_{o2}$) is varied.

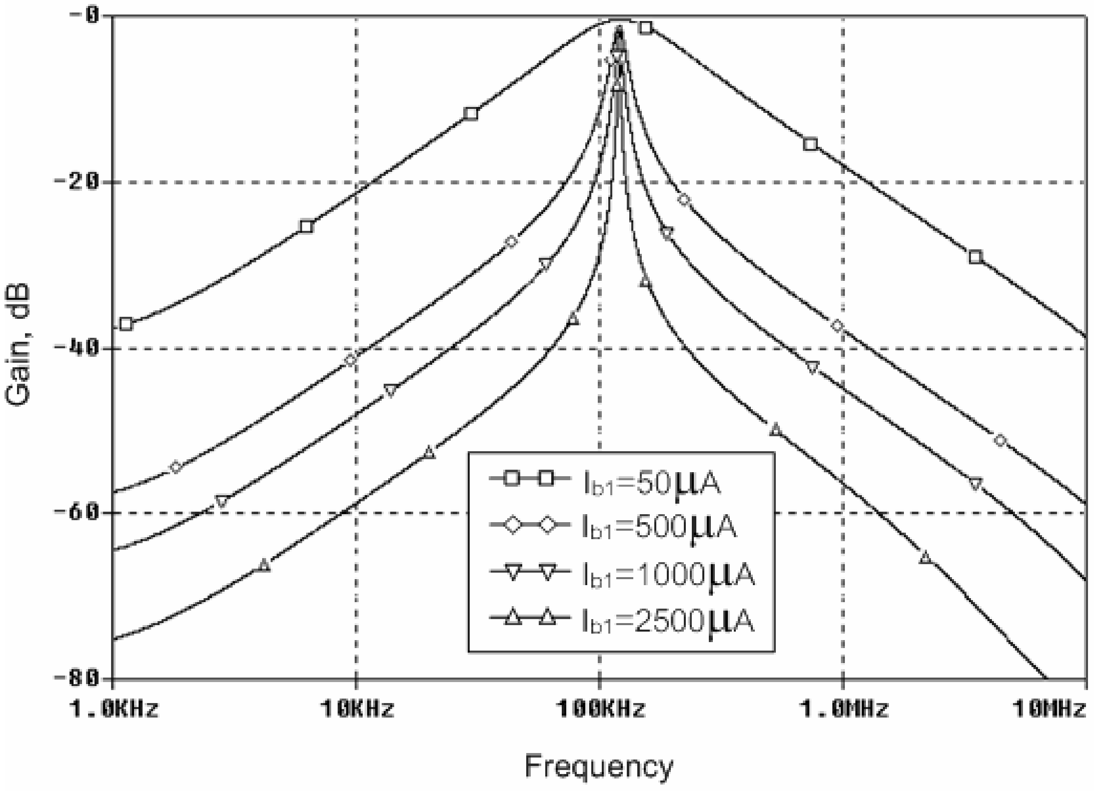


Figure 8. Simulated frequency responses of the BP filter when I_{b1} is varied.

integrated circuit from at the present, this does not affect their popularity amongst researchers, as is evident from the many published literature (Chang, 1993; Ozoguz and Acar, 1993; Cicekoglu et al., 2002; Horng et al., 2007; Toker and Ozoguz, 2000; Senani et al., 2004, 2005; Wang and Lee, 2001; Tu et al., 2002; Abuelma'atti and Tasadduq, 1999; Fabre et al., 1995; Tangsrirat and Surakampontorn, 2007; Tsukutani et al., 2007; Tangsrirat, 2007; Tangsrirat and Surakampontorn, 2006; Abuelma'atti and Al-Qahtani, 1998; Kumngern et al., 2010; Fabre and Mimeche, 1996). Moreover, the circuits based on bipolar CCCII can be controlled. The circuit parameters (that is, R_x and k) with linearity behavior which CMOS CCCII cannot be provided. PSPICE simulations are given to show the performance of the filter and verify the theory.

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