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Realization of a New Current Mode Second-Order Biquad Using Two Current Follower Transconductance Amplifiers (CFTAs)

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Abstract

A new circuit for realization of universal current-mode filter using current Follower Transconductance Amplifiers (CFTAs) is presented. The proposed circuit realizes current-mode low pass, high pass and band pass filter functions simultaneously with a single current source at the input. The band reject and all pass filters can also be obtained from the proposed circuit without any extra hardware. The proposed circuit employs three passive grounded elements and two CFTAs. Linear electronic control of natural frequency ω_0 is available in the proposed circuit. The quality factor can be independently adjusted through grounded resistor. The proposed circuit employs two grounded capacitors and a grounded resistor along with two CFTAs. The grounded resistor can be replaced by an OTA based circuit for linear electronic control of quality factor Q_0. The circuit exhibits low active and passive sensitivities for ω_0 and Q_0. Simulation results are obtained using PSPICE software which is in conformity with the theoretical findings.

Keywords

Current Follower Transconductance Amplifier (CFTA), Current-Mode Circuit, Biquad Filter, Voltage-Mode Circuit, Current Conveyor (CC)

1. Introduction

Current mode circuits are very popular due to some of their advantages over their voltage mode counter parts.

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They are very suitable for high frequency, low voltage and low power applications in portable equipments such as mobile phones, aviation industry, water quality monitoring equipments, medical instrumentation and in satellite communication equipments. Current mode approach in analog processing blocks offers high slew rates, low node impedances, greater linearity, wider bandwidth and sometimes electronic tunability compared with voltage mode circuits. There have been steady and gradual interests to find new schemes for analog building blocks which may serve as an excellent current mode device. Some of the popular and off-the-shelf items have been Current Feedback Amplifiers (AD844) [1], Current Conveyors [2], Operational Transconductance Amplifiers (CA 3080) [3] etc., which have been used for decades as excellent current mode devices. Recently introduced current mode building blocks are Current Differencing Transconductance Amplifiers (CDTAs) [4]-[7], and Current Follower Transconductance Amplifiers (CFTAs) [8]-[23] which provide simple design facility with ample numbers of choices for output current ports for excellent current mode signal processing. CFTA in addition to possessing single current input compared with CDTA also exhibits excellent current mode characteristics along with electronic control of parameters of interest and is therefore attracting the attention of analog circuit designers. CFTA is extensively used in the realization of signal processing as well as signal generation in current mode circuits [7]-[23]. In this paper, a new circuit using two CFTAs and two grounded capacitors along with a grounded resistor is presented. The proposed circuit realizes basic current mode filter functions such as low pass (LP), band pass (BP), and high pass (HP) for a single input current source. Also, band reject (BR) and all-pass (AP) filter functions can be realized by proper combinations of current responses. Various papers are published on different applications of CFTAs such as current-mode (CM) or voltage-mode (VM) universal filters, oscillators, amplifiers, etc. [7]-[23]. In this paper, a new current-mode second-order CFTA biquad filter is presented which uses two active elements and three passive grounded elements. The main attractive feature of this circuit is the facility of linear control of pole frequency ω_0 and quality factor Q_0. While pole frequency can be changed electronically through g_m, the quality factor Q_0 can be adjusted independently through grounded resistor. The grounded resistor can further be realized through an additional transconductance amplifier making this control again an electronic one. The simulation results are obtained using PSPICE software. Simulation results validate the theoretical findings.

2. Proposed circuit Realization of Current Follower Transconductance Amplifier (CFTA)

The Current Follower Transconductance Amplifier (CFTA) [6], whose schematic symbol and behavioral model are shown in **Figure 1(a)-(b)**, consists of an input current follower that transfers the input current to the *z* terminal and an output transconductance amplifier stage, which is used to convert the voltage at the *z*-terminal into output currents. Relations between the individual terminals of CFTA can be described by the following hybrid matrix:

$$\begin{bmatrix} v_f \\ i_z \\ i_{x+} \\ i_{x-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & g_m & 0 & 0 \\ 0 & -g_m & 0 & 0 \end{bmatrix} \begin{bmatrix} i_f \\ v_z \\ v_{x+} \\ v_{x-} \end{bmatrix} \tag{1}$$

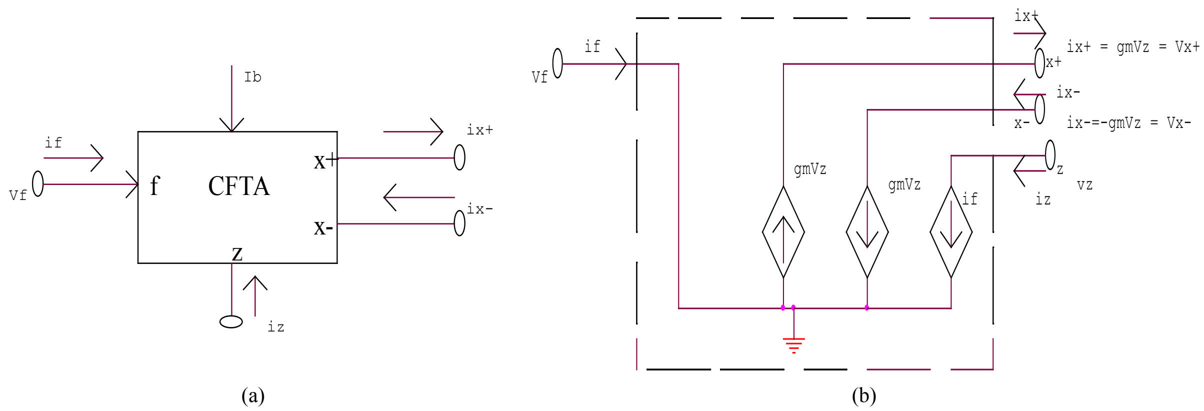


Figure 1. (a) The CDTA schematic symbol; (b) Behavioral model of CFTA.

Assuming the standard notations, the terminals defining relations of this device can be characterized by the following set of equations

$$v_f = 0, i_z = i_f \text{ and } i_{x+} = g_m v_z = g_m z_z i_z, i_{x-} = -g_m v_z \quad (2)$$

where g_m is transconductance gain of the CFTA which is directly proportional to the external bias current I_B, which is given by Equation (3)

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

where the V_T is the thermal equivalent voltage (= 26 mV at 27˚C) and I_B is the control bias current adjusting the transconductance g_m of the CFTA. The operation of the CFTA will be dependent on temperature variations. z_z is external impedance connected to the z-terminal.

The proposed current mode biquad filter is shown in **Figure 2**. It consists of two CFTAs, one grounded resistor and two grounded capacitors. The internal construction of CFTA used for simulation is shown in **Figure 3**.

A routine analysis of the proposed circuit as shown in **Figure 2** yields the following current transfer functions.

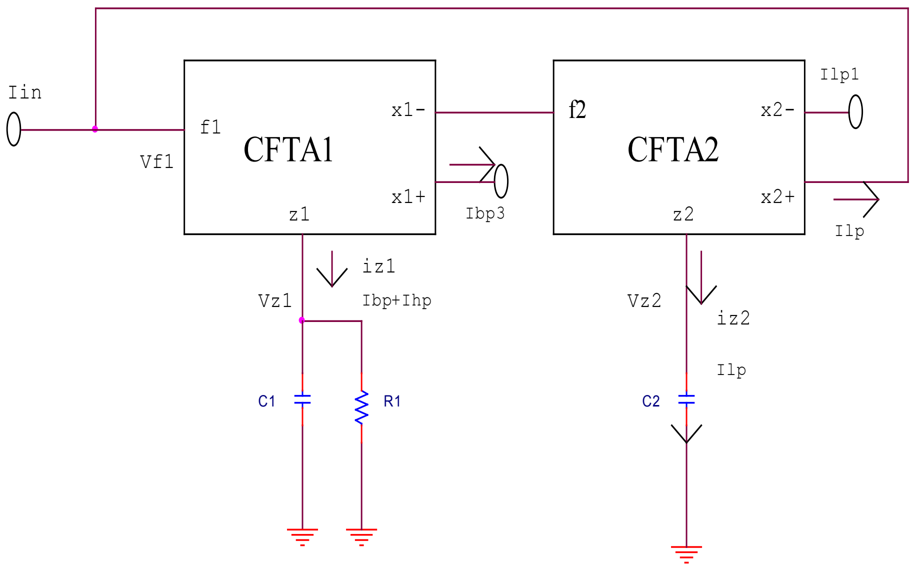


Figure 2. Proposed current mode second-order biquad filter using CFTAs.

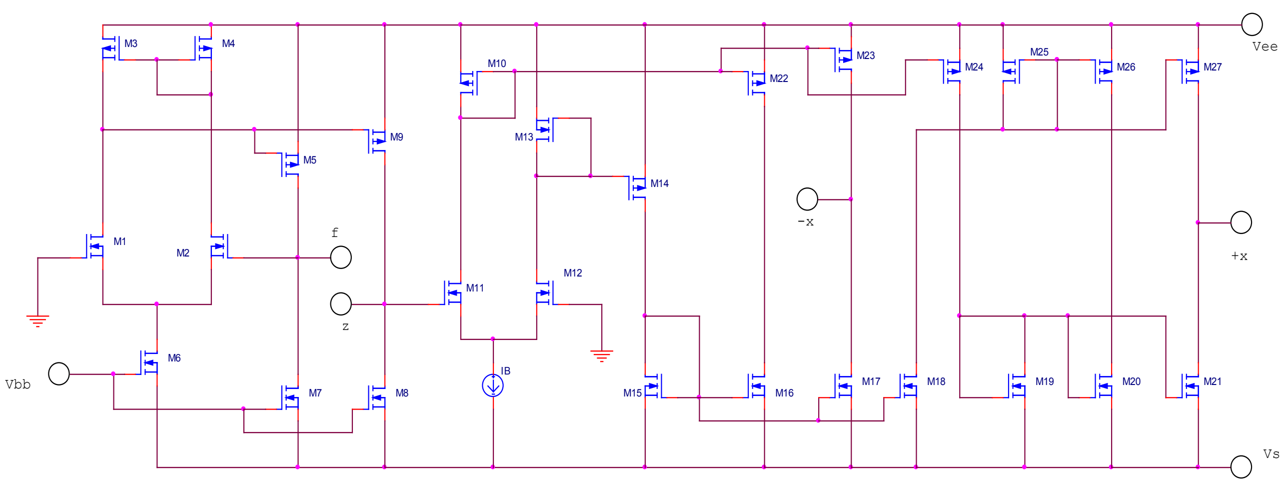


Figure 3. A CMOS implementation of CFTA used for simulations.

$$\frac{I_{hp}}{I_{in}} = \frac{s^2}{D(s)} \tag{4}$$

$$\frac{I_{bp}}{I_{in}} = \frac{-s\left(\frac{G_1}{C_1}\right)}{D(s)} \tag{5}$$

$$\frac{I_{lp}}{I_{in}} = \frac{\left(\frac{g_{m1}g_{m2}}{C_1C_2}\right)}{D(s)} \tag{6}$$

Adding the output current reponses I_{lp} and I_{hp}, one obtains

$$\frac{I_{br}}{I_{in}} = \frac{s^2 + \left(\frac{g_{m1}g_{m2}}{C_1C_2}\right)}{D(s)} \tag{7}$$

whereas for current-mode all-pass filter response

$$\frac{I_{ap}}{I_{in}} = \frac{s^2 - s\left(\frac{G_1}{C_1}\right) + \left(\frac{g_{m1}g_{m2}}{C_1C_2}\right)}{D(s)} \tag{8}$$

where $D(s)$ is given by

$$D(s) = s^2 + s\left(\frac{G_1}{C_1}\right) + \left(\frac{g_{m1}g_{m2}}{C_1C_2}\right) \tag{9}$$

From (4)-(9), the pole frequency ω_0 and quality factor Q_0 are given as

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{10}$$

$$Q_0 = \frac{1}{G_1}\sqrt{\frac{g_{m1}g_{m2}C_1}{C_2}} \tag{11}$$

For $g_{m1} = g_{m2} = g_m$ and $C_1 = C_2 = C$ Equations (10) and (11) become

$$\omega_0 = \frac{g_m}{C} \tag{12}$$

and

$$Q_0 = \frac{g_m}{G_1} \tag{13}$$

Equations (12) and (13) show that ω_0 can be linearly and electronically varied through g_m .Whereas quality factor Q_0 can be linearly changed through grounded resistor R_1 independent of ω_0 .

3. Tracking Errors

There are Current Tracking Errors of the proposed circuit. The characteristic equations of CFTA are

$$v_f = 0, i_z = \alpha i_f, i_{x+} = g_m v_z, i_{x-} = -g_m v_z \tag{14}$$

where $\alpha = 1 - \epsilon_i$ where ϵ_i denotes the current tracking error of the current follower from the terminal f into the terminal-z ($\|\epsilon_i \ll 1$). from the non-ideal properties of CFTAs, the characteristic equation of the proposed circuit according to **Figure 2** is

$$D(s) = s^2 c_1 c_2 + \alpha_2 s c_2 G_1 + \alpha_1 \alpha_2 g_{m1} g_{m2} = 0 \tag{15}$$

It is thus, seen that the proposed circuit is capable of realizing all the five basic functions, without requiring any component-matching or realization conditions. From (4)-(9), the various filter parameters are given by

$$\omega_0 = \sqrt{\frac{\alpha_1 \alpha_2 g_{m1} g_{m2}}{C_1 C_2}} \tag{16}$$

$$Q_0 = \frac{1}{G_1} \sqrt{\frac{g_{m1} g_{m2} C_1}{C_2}} \tag{17}$$

4. Sensitivity Analysis

The effect of changes in active and passive element values is determined by evaluating sensitivity coefficients which are found to be

$$S_{\alpha_1 \alpha_2}^{\omega_0} = S_{g_{m1}}^{\omega_0} = S_{g_{m2}}^{\omega_0} = -S_{c_1}^{\omega_0} = -S_{c_2}^{\omega_0} = \frac{1}{2} \tag{18}$$

$$S_{G_1}^{Q_0} = -1 \tag{19}$$

$$S_{g_{m1}}^{Q_0} = S_{g_{m2}}^{Q_0} = S_{c_1}^{Q_0} = S_{\alpha_1}^{Q_0} = S_{\alpha_2}^{Q_0} = -S_{C_2}^{Q_0} = \frac{1}{2} \tag{20}$$

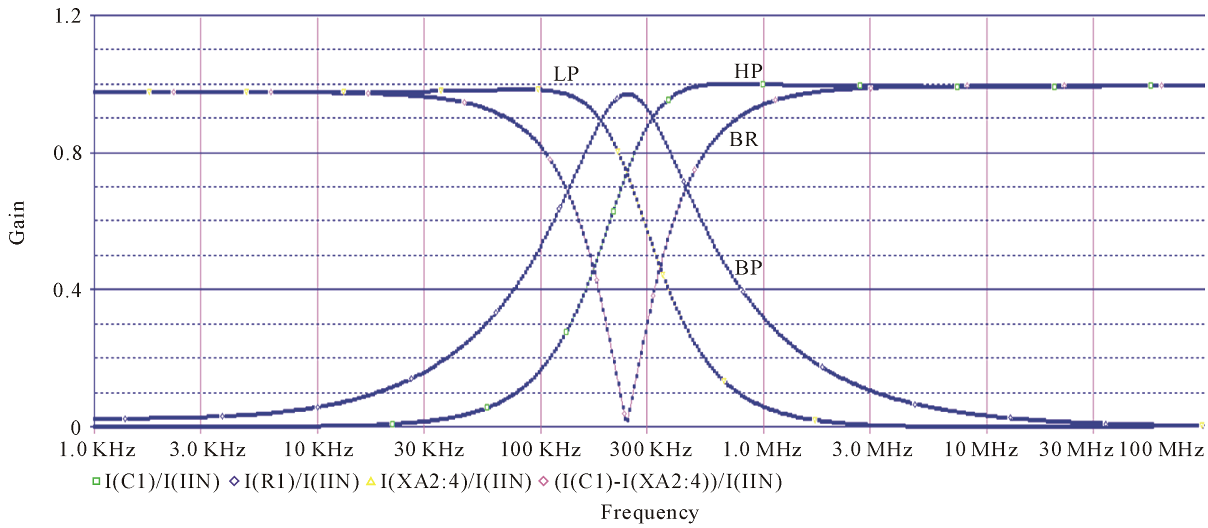
From (12)-(20), it is clear that all the sensitivities of the various parameters of the filters realized from the proposed configuration are very low.

5. Simulation Results

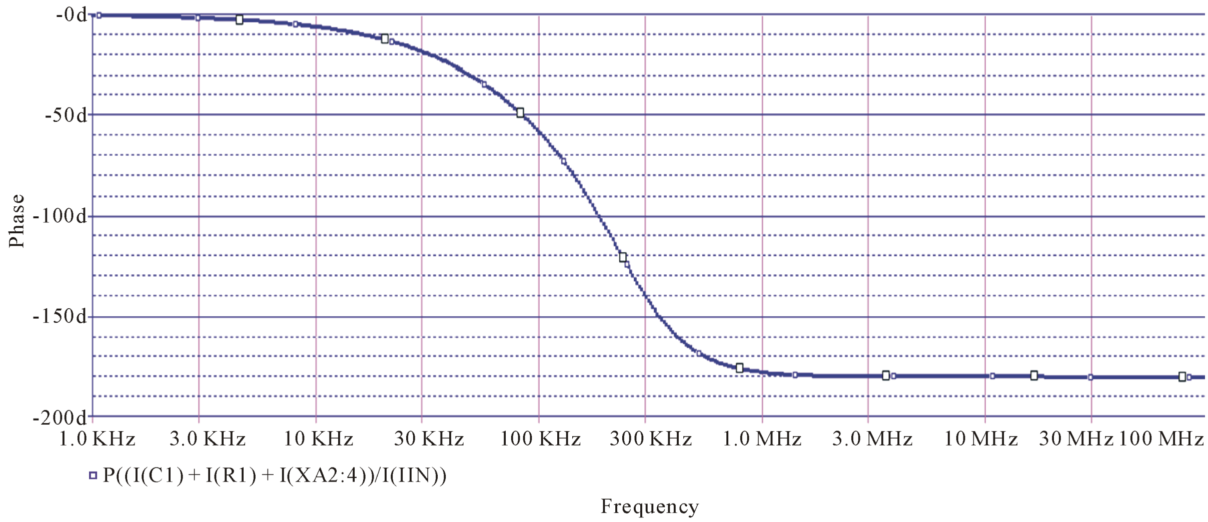
The performance of the proposed circuit in **Figure 2** has been verified by PSPICE simulation results. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0.25 µm TSMC CMOS technology [9] as shown in **Table 1**. The aspect ratios of PMOS and NMOS transistors are indicated in **Table 2**. The circuit was biased with ±1.5 V power supply voltage, $V_{BB} = -0.55\text{V}$, $I_{B1} = I_{B2} = 80$ µA. The values of the capacitors and resistor were chosen as: $C_1 = C_2 = 1\text{n}F$, $R_1 = 0.5$ kΩ. In **Figure 4(a)**, simulated results of proposed LP, HP, BP, BR filters are shown using PSPICE 16.3 which shows the validity of design equations of filter shown in Equations (10) and (11). Pole frequency was found to be $f_0 = 245$ kHz and quality factor $Q_0 = 0.7$ which are very close to theoretical values. In **Figure 4(b)**, phase response of current mode all-pass filter is shown. In **Figure 4(c)**, simulation results are shown for the pole frequency $f_0 = 245$ kHz and quality factor Q_0 which varies from 0.7 to 3. The results show independent control of Q_0. Similarly, in **Figure 4(d)** for the quality factor $Q_0 = 0.7$, pole frequency f_0 is varied from 245.6 kHz to 245 MHz. However it is seen that H_0 in this case is slightly changing with frequency which may be the effect of output parasitic capacitance of CFTA or due to tracking errors between I_f and I_z. Hence, from the PSPICE simulation results it is proved that the practical results nearly match to the theoretical results.

Table 1. The SPICE model parameters of MOS transistors for level 3, 0.25 µm CMOS process from TSMC.

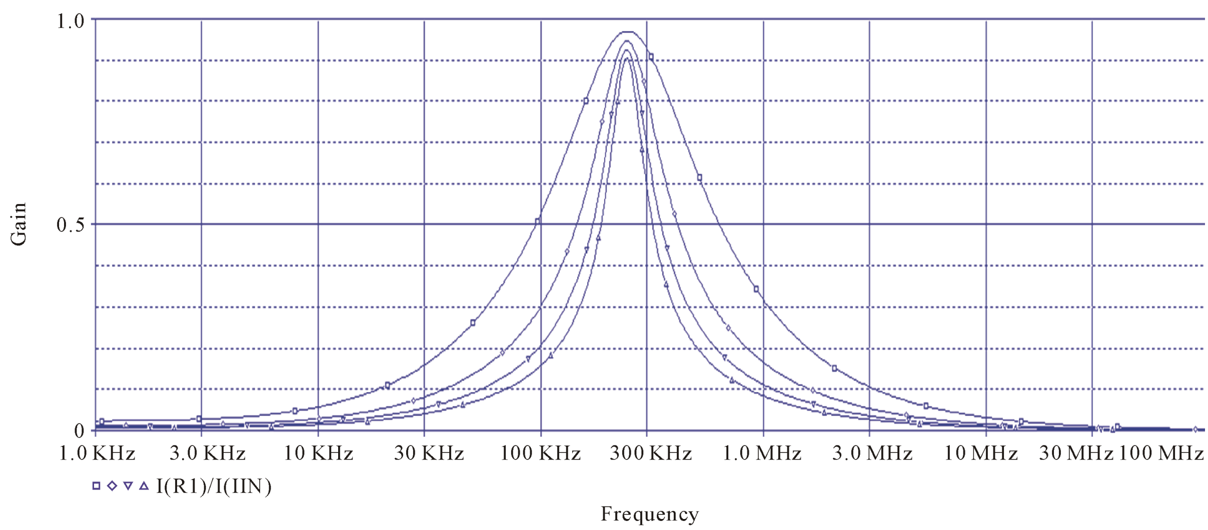
NMOS	NMOS (LEVEL = 3 TOX = 5.7E-9 NSUB = 1E17+ GAMMA = 0.4317311 PHI = 0.7 VTO = 0.4238252 DELTA = 0 UO = 425.6466519 ETA = 0 THETA = 0.1754054 KP = 2.501048E-4 VMAX = 8.287851E4 KAPPA = 0.1686779 RSH = 4.062439E-3 NFS = 1E12 TPG = 1 XJ = 3E-7 LD = 3.162278E-11WD = 1.232881E-8 CGDO = 6.2E-10 CGSO = 6.2E-10 CGBO = 1E-10 CJ = 1.81211E-3 PB = 0.5 MJ = 0.3282553 CJSW = 5.341337E-10 + MJSW = 0.5)
PMOS	(LEVEL = 3 TOX = 5.7E-9 NSUB = 1E17 GAMMA = 0.6348369 PHI = 0.7 VTO = −0.5536085 DELTA = 0 UO = 250 ETA = 0 THETA = 0.1573195 KP = 5.194153E-5 VMAX = 2.295325E5 KAPPA = 0.7448494 RSH = 30.0776952 NFS = 1E12 TPG = −1 XJ = 2E-7 LD = 9.968346E-13 WD = 5.475113E-10 CGDO = 6.66E-10 CGSO = 6.66E-10 CGBO = 1E-10 CJ = 1.893569E-3 PB = 0.9906013 MJ = 0.4664287 CJSW = 3.625544E-10 MJSW = 0.5)


1.2
0.8
0.4
0
Gain
LP
HP
BR
BP
1.0 KHz
3.0 KHz
10 KHz
30 KHz
100 KHz
300 KHz
1.0 MHz
3.0 MHz
10 MHz
30 MHz
100 MHz
I(C1)/I(IIN) I(R1)/I(IIN) I(XA2:4)/I(IIN) (I(C1)-I(XA2:4))/I(IIN)
Frequency

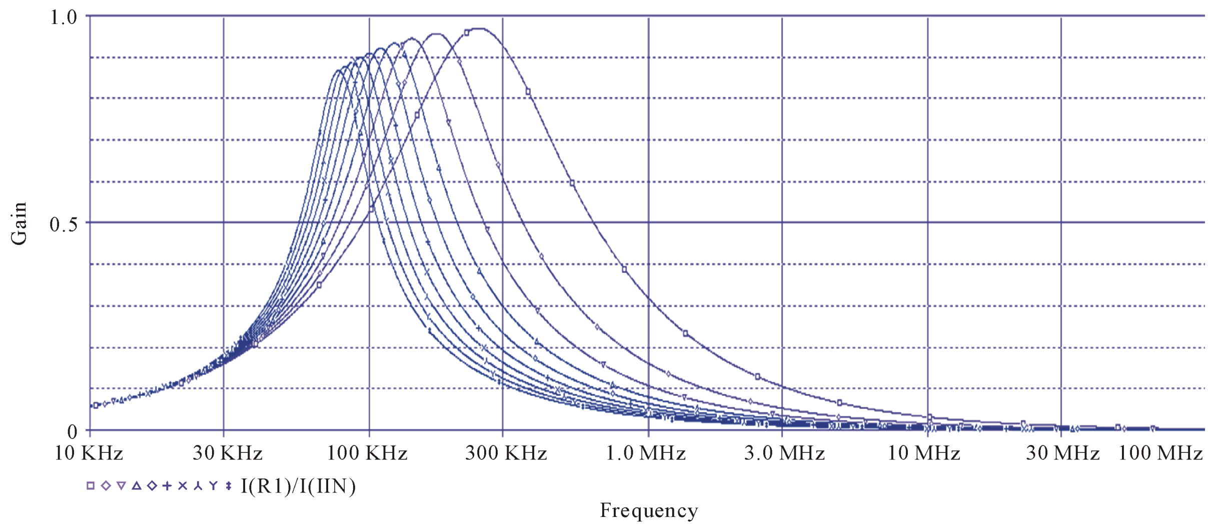
(a)


-0d
-50d
-100d
-150d
-200d
Phase
1.0 KHz
3.0 KHz
10 KHz
30 KHz
100 KHz
300 KHz
1.0 MHz
3.0 MHz
10 MHz
30 MHz
100 MHz
P((I(C1) + I(R1) + I(XA2:4))/I(IIN))
Frequency

(b)


1.0
0.5
0
Gain
1.0 KHz
3.0 KHz
10 KHz
30 KHz
100 KHz
300 KHz
1.0 MHz
3.0 MHz
10 MHz
30 MHz
100 MHz
I(R1)/I(IIN)
Frequency

(c)



(d)

Figure 4. (a) Simulated frequency response of LP, HP, BP, and BR proposed CFTA current-mode second order biquad filter according to **Figure 2**; (b) Phase response of all pass proposed biquad filter; (c) Simulated frequency responses of the BP filter when Q_0 is varied for f_0 = 245 khz; (d) BP filter with different f_0 (keeping Q_0 approximately constant).

Table 2. Dimensions of the transistors.

Transistor	*W* (um)	*L* (um)
M1-M2, M19-M20	1	0.25
M3-M5, M9-M10, M13, M22-M27	5	0.25
M6-M8, M15-M21	3	0.25
M11-M12	25	0.25
M14	4.5	0.25

6. Conclusion

In this paper, a new current-mode second-order biquad filter using CFTAs (Current Follower Tranconductance Amplifier) is presented. The circuit realizes all types of filter functions, *i.e.* LPF, BPF, HPF, and BRF simultaneously for a single current input. It consists of two CFTAs, one grounded resistor and two grounded capacitors. Hence, the low numbers of active and passive elements are used. The circuit has the features of low voltage supply, and large bandwidth. It has low-input and high-output impedances and also is convenient for electronic controllability through transconductance gain g_m of CFTAs, so it can be used in battery-powered or portable electronic equipments. The only apparent drawback is the use of a grounded resistor. However, grounded resistor can be simulated with additional transconductor and its value can be controlled through g_{m3}. Hence, electronic control of quality factor is possible.

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