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Electronically tunable current-mode universal biquadratic circuit using current controlled unity gain cells

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Abstract

This paper introduces an electronically tunable current-mode universal biquadratic circuit employing current controlled unity gain cells. The circuit is constructed with two current controlled current followers (CCCFs), two CCCFs with voltage buffers (CCCFBs) and two grounded capacitors. The circuit can realize low-pass (LP), band-pass (BP), high-pass (HP), band-stop (BS) and all-pass (AP) transfer functions by the selection and addition of appropriate current outputs without any component matching conditions. Additionally, the circuit parameters ω_0 and Q can be tuned orthogonally through adjusting the bias currents. The biquadratic circuit enjoys very low sensitivities with respect to the circuit components. An example is given together with simulation results by PSPICE.

Keywords: *current controlled current follower, voltage follower, current-mode circuit, biquadratic characteristic*

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I. Introduction

High performance active circuits have received much attention. Since current-mode circuits have many advantages compared with their voltage-mode counterparts, circuit designs employing active devices such as operational transconductance amplifiers (OTAs), second generation current conveyors (CCIIs) and current controlled current conveyors (CCCIIs) have been discussed in the literature [1]-[5].

It is well known that the active circuits using unity gain cells (i.e. current followers (CFs) and voltage followers (VFs)) have wider bandwidth, wide dynamic range, low power consumption and so on. The circuit designs employing the unity gain cells have been discussed previously [6]-[8].

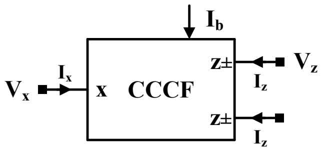
In the active devices, the CCCII provides electronic tunability and wide tunable range of x-terminal resistance by the bias current [1],[5]. Practically, the CCCF can be realized by grounding the y-terminal of the CCCII. Also, the CCCF is easily extended to the CCCFB with a voltage buffer (i.e, VF). Thus, the CCCF and CCCFB have electronic tuning capability for the x-terminal resistance as like as the CCCII. The CCCF- and CCCFB-based circuits require no resistors, so it is well suited for integration. These features are very attractive to circuit designers.

A biquadratic circuit is a very useful second-order function block for realizing high-order circuit transfer functions. The biquadratic circuits using the OTAs, CCIIs and CCCIIs have been reported in the past [1],[2],[4],[5]. The OTA-based circuits have electronic tuning capability like as the CCCF- and CCCFB-based ones. Additionally, the CCCF and CCCFB have wider bandwidth compared with the OTA due to the unity gains. Furthermore, the OTA has not wide dynamic range, hence the range of the input voltage is limited in the OTA-based circuits. Up till the present, a biquadratic circuit with such performances of the current controlled unity gain cells has not yet been studied sufficiently.

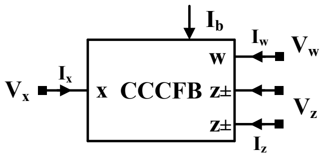
This paper introduces an electronically tunable current-mode universal biquadratic circuit employing the current controlled unity gain cells. The circuit is constructed with two CCCFs, two CCCFBs and two grounded capacitors. The circuit can realize the LP, BP, HP, BS and AP transfer functions by choosing and adding the appropriate current outputs. The circuit requires no component matching conditions for realizing the transfer functions above. Additionally, the circuit parameters ω_0 and Q can be tuned orthogonally by adjusting the bias currents. It is made clear that the biquadratic circuit has very low sensitivities with respect to the circuit components. An example is given together with simulation results by PSPICE. The workability was confirmed.

II. CCCF and CCCFB

Figure 1 shows the symbols for the CCCF and CCCFB. This shows dual current output CCCF and CCCFB.



(a)



(b)

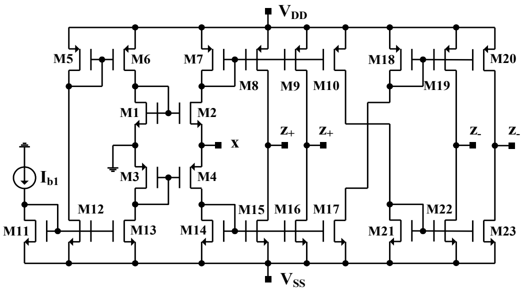
Figure 1: Symbols for CCCF and CCCFB.

The standard CCCF and CCCFB can be characterized by:

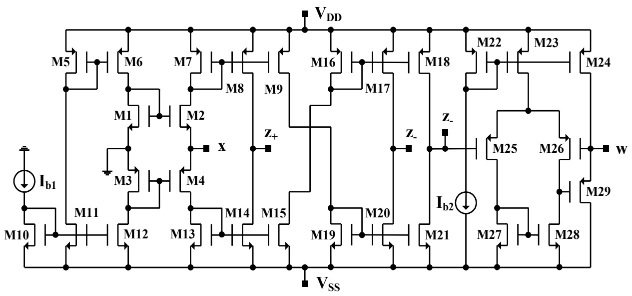
$$V_x = R_x I_x, \quad I_z = \pm I_x \tag{1}$$

$$V_x = R_x I_x, \quad V_w = V_z$$
$$I_z = \pm I_x, \quad I_w = 0 \tag{2}$$

where R_x denotes the intrinsic resistances at the x-terminal. In (1) and (2), the sign ± shows the plus or minus polarity of the z-terminal current I_z.



(a)



(b)

Figure 2: CCCF and CCCFB with MOS transistors.

Figure 2 (a) shows the CCCF with MOS transistors, and the CCCFB is shown in Fig.2 (b). This shows multiple current output CCCF and CCCFB.
The x-terminal resistance R_x is given by

$$R_x = K\left(\mu C_{ox}\frac{W}{L}I_{b1}\right)^{-\frac{1}{2}} \quad (3)$$

where K, μ, C_{ox}, W/L and I_{b1} are the constant parameter, electron mobility, gate oxide capacitance per unit area, transistor aspect ratio and bias current, respectively. Thus, it is shown that the resistance R_x can be adjusted by a supplied bias current I_{b1}.

III. Circuit configuration and analysis

Figure 3 shows the biquadratic circuit configuration. The circuit is constructed with two CCCFs, two CCCFBs and two grounded capacitors.
Routine analysis yields the circuit transfer functions $T_{LP}(s)$ $(=I_{LP}(s)/I_{in}(s))$ and $T_{BP}(s)$ $(=I_{BP}(s)/I_{in}(s))$ for two current outputs $I_{LP}(s)$, $I_{BP}(s)$ given by:

$$T_{LP}(s) = -\frac{1}{s^2C_1C_2R_{x2}R_{x3} + sC_2R_{x2}R_{x3}/R_{x1} + 1} \quad (4)$$

$$T_{BP}(s) = -\frac{sC_2R_{x2}R_{x3}/R_{x1}}{s^2C_1C_2R_{x2}R_{x3} + sC_2R_{x2}R_{x3}/R_{x1} + 1} \quad (5)$$

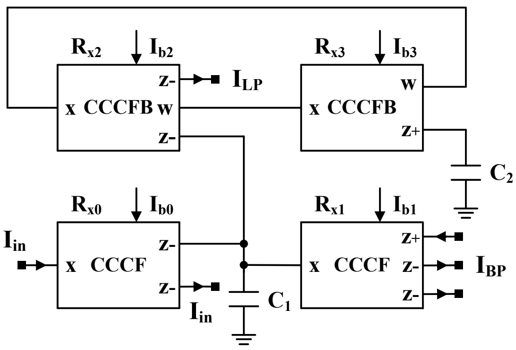


Figure 3: Current-mode biquadratic circuit configuration.

The circuit can realize simultaneously the LP and BP transfer functions at the current outputs $I_{LP}(s)$ and $I_{BP}(s)$, respectively.
The HP, BS and AP transfer functions $T_{HP}(s)$ $(=I_{HP}(s)/I_{in}(s))$, $T_{BS}(s)$ $(=I_{BS}(s)/I_{in}(s))$, $T_{AP}(s)$ $(=I_{AP}(s)/I_{in}(s))$ can be obtained easily by the current addition of $I_{HP}(s)=I_{in}(s)+I_{BP}(s)+I_{LP}(s)$, $I_{BS}(s)=I_{in}(s)+I_{BP}(s)$ and $I_{AP}(s)=I_{BS}(s)+I_{BP}(s)$, respectively.

$$T_{HP}(s) = \frac{s^2C_1C_2R_{x2}R_{x3}}{s^2C_1C_2R_{x2}R_{x3} + sC_2R_{x2}R_{x3}/R_{x1} + 1} \quad (6)$$

$$T_{BS}(s) = \frac{s^2C_1C_2R_{x2}R_{x3} + 1}{s^2C_1C_2R_{x2}R_{x3} + sC_2R_{x2}R_{x3}/R_{x1} + 1} \quad (7)$$

$$T_{AP}(s) = \frac{s^2C_1C_2R_{x2}R_{x3} - sC_2R_{x2}R_{x3}/R_{x1} + 1}{s^2C_1C_2R_{x2}R_{x3} + sC_2R_{x2}R_{x3}/R_{x1} + 1} \quad (8)$$

It can be seen that five standard circuit transfer functions are realized by the selection and addition of suitable current outputs without any component matching conditions. The circuit parameters ω_0, Q and H can be expressed as:

$$\omega_0 = \sqrt{\frac{1}{C_1C_2R_{x2}R_{x3}}}, \quad Q = R_{x1}\sqrt{\frac{C_1}{C_2R_{x2}R_{x3}}}, \quad H = 1.0 \quad (9)$$

Thus the biquadratic circuit has orthogonal tuning capability for the circuit parameters ω_0 and Q. But, as the circuit parameter H is 1.0, an additional amplification stage (i.e. current amplifier) is needed to achieve the desirable gain constant.

We consider below the effect of deviation of the circuit components on the biquadratic characteristic.

Table 1 Sensitivity to circuit components.

x	ω_0	Q
R_{x1}	0.0	1.0
R_{x2}	-0.5	-0.5
R_{x3}	-0.5	-0.5
C_1	-0.5	0.5
C_2	-0.5	-0.5

Table 1 shows the sensitivities with respect to the circuit components (R_{x1}, R_{x2}, R_{x3}, C_1 and C_2). The sensitivity takes the values of within 1.0. These values demonstrate that the biquadratic circuit enjoys very low sensitivities. It is also noted that the sensitivities do not depend upon the circuit component values.

IV. Design example and simulation results

To verify the theoretical analysis, the biquadratic circuit was simulated using PSPICE simulation program. As an example, we consider realization of a biquadratic characteristic with the cut-off frequency f_0 ($=\omega_0/2\pi$)=1MHz, quality factor Q=1.0 and gain constant H=1.0. For the PSPICE simulation, we have used the macro models of the CCCF and CCCFB shown in Fig.2. Figure 4 shows the characteristic of the x-terminal resistance R_x versus the bias current I_{b1}. It is found that the resistance R_x can be tuned by the bias current.

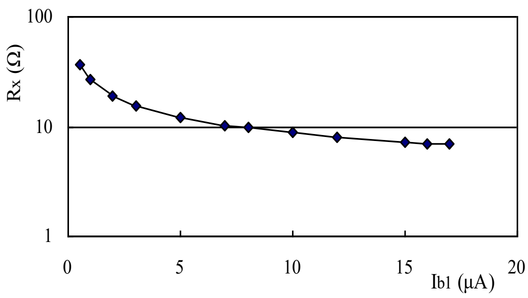
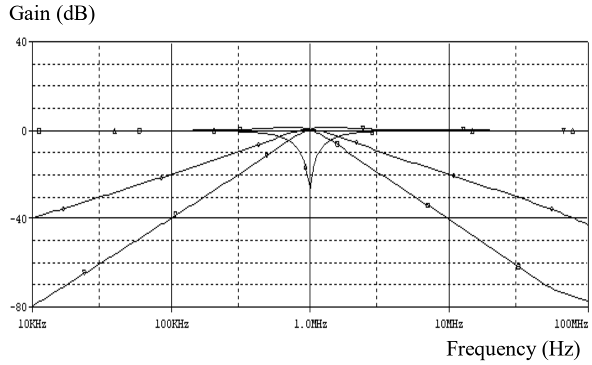


Figure 4: Characteristic of R_x versus I_{b1}.

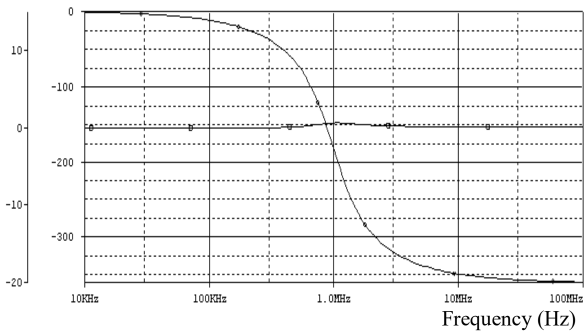
In order to realize the biquadratic characteristic above, we have determined that the bias currents and capacitors were $I_{b0}=I_{b1}=I_{b21}=I_{b31}=12\mu A$, $I_{b22}=I_{b32}=40\mu A$ and $C_1=C_2=20pF$, respectively. Also, we have set the supply voltages and input current at $V_{DD}=-V_{SS}=1.85V$ and $I_{in}=10\mu A$.

Figure 5 (a) shows the simulated LP, BP, HP and BS responses with PSPICE. The AP response is shown in Fig.5 (b). Although small departures occur, the responses are sufficiently favorable over a wide frequency range. In this simulation, the dimensions of MOS transistors are determined as listed in Table 2. Additionally, we have used the model parameters of 0.5μm MOS technology obtained through MOSIS.



□: $|T_{LP}(j\omega)|$ ◇: $|T_{BP}(j\omega)|$ ▽: $|T_{HP}(j\omega)|$ △: $|T_{BS}(j\omega)|$

(a)



(b)

Figure 5: Simulation responses.

In this simulation, the dimensions of MOS transistors are determined as listed in Table 2. Additionally, we have used the model parameters of 0.5μm MOS technology obtained through MOSIS.

Table 2 Dimensions of MOS transistors.

Transistors	W / L (μm)
M1-15	4 /2
M16-23	8 / 2

V. Conclusions

An electronically tunable current-mode universal biquadratic circuit using current controlled unity gain cells has been proposed. The circuit is constructed with two CCCFs, two CCCFBs and two grounded capacitors. We have demonstrated that the circuit can realize LP, BP, HP, BS and AP transfer functions by the selection and addition of the current outputs without any component matching conditions. Additionally, the circuit parameters ω_0 and Q can be set orthogonally by adjusting the bias currents. Furthermore, it has been made clear that the biquadratic circuit enjoys very low sensitivities with respect to the circuit components. The simulation responses have been quite good over a wide frequency range. The biquadratic circuit configuration is very suitable for implementation in CMOS technology.
The non-idealities of CCCF and CCCFB may affect the biquadratic characteristic. A solution on this must be discussed further.

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