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# วงจรกรองความถี่โหมดกระแสหลายหน้าที่หนึ่งเอาต์พุตที่ควบคุมแบบดิจิตอลโดยใช้วงจรสายพานกระแส*

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## บทคัดย่อ

บทความนี้นำเสนอ วงจรกรองความถี่หลายหน้าที่โหมดกระแสที่สามารถสังเคราะห์ฟังก์ชันที่มาตรฐานได้ทั้งหมด ได้แก่ Lowpass, Highpass, Bandpass, Band-reject และ All-pass โดยใช้วงจรสายพานกระแสที่ควบคุมด้วยกระแส (CCCII) จุดเด่นของวงจรคือ สามารถควบคุมความถี่ตัดและค่าควอลิตี้แฟกเตอร์ได้โดยอิสระจากกันด้วยวิธีการทางอิเล็กทรอนิกส์ยกเว้นฟังก์ชัน Lowpass กับ Highpass โครงสร้างของวงจรไม่ซับซ้อน โดยประกอบไปด้วยเพียง CCCII จำนวน 3 ตัว และตัวเก็บประจุที่ต่อลงกราวนด์ 2 ตัว นอกจากนี้ยังสามารถเลือกฟังก์ชันที่ต้องการด้วยวิธีการแบบดิจิตอล วงจรที่นำเสนอไม่ต้องการตัวต้านทานมาต่อภายนอก จึงมีความเหมาะสำหรับการพัฒนาไปสู่วงจรรวม เพื่อนำไปใช้ระบบสื่อสารแบบไร้สายที่ใช้แบตเตอรี่เป็นแหล่งจ่ายกำลัง ผลการจำลองการทำงานด้วยโปรแกรม PSPICE พบว่าวงจรทำงานได้สอดคล้องกับที่คาดการไว้ วงจรมีอัตราการบริโภคกำลังงานเท่ากับ 1.16mW ที่แหล่งจ่ายกำลังไฟฟ้า ±1.5V

***คำสำคัญ :*** โหมดกระแส, วงจรกรองความถี่หลายหน้าที่, CCCII

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* รับต้นฉบับเมื่อวันที่ 30 มิถุนายน 2549 และได้รับบทความฉบับแก้ไขเมื่อวันที่ 6 พฤศจิกายน 2549

# A Single-Output Digitally Programmable Current-Mode Universal Biquad Filter Using Current-controlled Current Conveyors (CCCII) *

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## ABSTRACT

This article presents a current-mode universal biquadratic filter performing completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions, based-on Current Controlled Current Conveyors (CCCIIs). The features of the circuit are that: the quality factor and pole frequency can be tuned orthogonally via the input bias currents except lowpass and highpass functions: the circuit description is very simple, consisting of merely 3 CCCIIs and 2 grounded capacitors. Additionally, each function response can be selected by digital method. Because of its simplicity, the proposed circuit can be conveniently facbricated. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The maximum power consumption is approximately 1.16mW at ±1.5V power supply voltages.

***Keywords :*** current-mode, biquadratic filter, CCCII

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# INTRODUCTION

In electrical engineering works, an analog filter is an important block and widely used for continuous-time signal processing. It can be found in many fields: for instance, communication, measurement and instrumentation, and control systems (Sedra and Smith. 1991 and Ibrahim et, al. 2005). One of most popular analog filters is a universal biquadratic filter since it can provide several functions. Nowadays, a universal filter working in current-mode has being been more popular than voltage-mode one. Since the last decade, there has been much effort to reduce the supply voltage of analog CMOS systems. This is because of the demand for portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current–mode technique is ideally suited for this purpose. Actually, a circuit using the current-mode technique has many other advantages: for example, larger dynamic range, higher bandwidth, greater linearity, simpler circuitry and lower power consumption (Toumazou et, al. 1990 and Bhaskar et, al. 1999).

From literature reviews, most of proposed current-mode universal filters need to employ a bulk number of passive and active components and require changing circuit topologies to achieve several functions (Shah and Malik. 2005, Chang et, al. 2001 and Tu et, al. 2002). Some of them manipulate a number of floating capacitors (Shah and Malink. 2005, Sagbas and Fidanboylu 2004 and Wu and El-masry. 1998), which is not appropriate to realize in a monolithic chip (Horng. 2005 and Bhusan and Newcomb. 1967). Furthermore, the most of presented works still cannot provide complete set of standard functions (Shah and Malik. 2005, Wang and Lee. 2005, Sharma and Senani. 2004, Shah and Malink. 2005, Sagbas and Fidanboylu 2004, Wu and El-masry. 1998 Pandey et, al. 2005 and Senani et, al. 2004),  they achieve only low-pass, high-pass and band-pass functions.

This work is arranged to propose a novel current-mode universal biquadratic filter, emphasizing on use of Current Controlled Current Conveyors (CCCIIs), which can be readily found in several commercial monolithic chips. The features of proposed circuits are its ability to provide complete set of standard functions without changing circuit topology, its wide range of operating frequency, its simplicity, and its suitability for monolithic integrated circuit fabrication. The performances of proposed circuits are illustrated by PSPICE simulations, they show good agreement as mentioned.

# PRINCIPLE OF OPERATION

## 1. Current Controlled Current Conveyor (CCCII)

Since the proposed circuit is based on CCCIIs, a brief review of CCCII is given in this section. The characteristic of ideal CCCIIs are represented by the following hybrid matrix

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

Where the positive and negative signs define a positive and negative current controlled current conveyor (CCCII+, CCCII-), respectively. The intrinsic x terminal current controlled resistance is given as

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

Where $I_B$ and $V_T$ are bias current and thermal voltage, respectively. The symbol and the equivalent circuit of the CCCII are illustrated in Fig. 1(a) and (b), respectively.

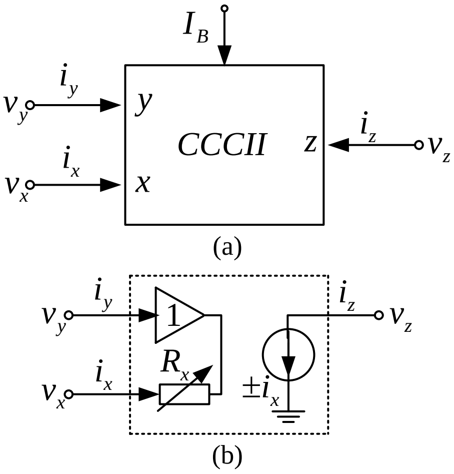


**Fig. 1:** *The CCCII (a) Symbol (b) Equivalent circuit*

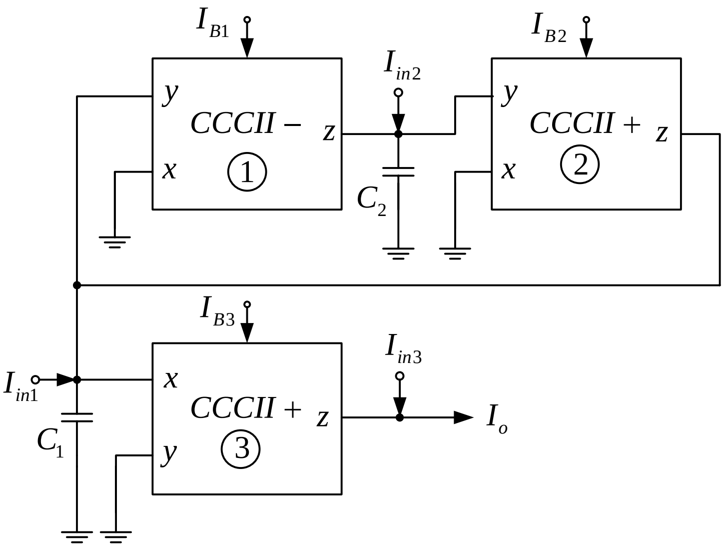


**Fig. 2** *Proposed Current-mode Universal Filter*

## 2. Proposed current-mode universal biquad filter

The proposed current-mode universal filter is shown in Fig. 2, where $I_{B1}$, $I_{B2}$ and $I_{B3}$ are input bias currents of CCCII1, CCCII2 and CCCII3, respectively. Straightforwardly analyzing the circuit in Fig. 2, the transfer functions of this network can be obtained as

$$I_O = \frac{I_{in3}s^2 + s\left(1/R_{x3}C_1\right)(I_{in3} - I_{in1}) + \left(1/C_1C_2R_{x1}R_{x2}\right)I_{in3} - \left(1/C_1C_2R_{x2}R_{x3}\right)I_{in2}}{s^2 + s\dfrac{1}{R_{x3}C_1} + \dfrac{1}{R_{x1}R_{x2}C_1C_2}} \tag{3}$$

From Eqn. (3), the magnitude of current input $I_{in1}, I_{in2}$ and $I_{in3}$ are digitally chosen as Table. 1 to obtain a standard function of the 2nd–order networks. From Eqn. (3), the pole frequency $\omega_0$ and quality factor $Q_0$ of each filter response can be expressed as

$$\omega_0 = \sqrt{\frac{1}{R_{x1}R_{x2}C_1C_2}} \tag{4}$$

and

$$Q_0 = R_{x3}C_1\sqrt{\frac{1}{R_{x1}R_{x2}C_1C_2}} \tag{5}$$

For simple consideration, if we assign $C_1 = C_2 = C$ and $I_{B1} = I_{B2} = I_B$, Eqns. (4) and (5) are subsequently modified to

$$\omega_0 = \frac{2I_B}{CV_T} \tag{6}$$

and

$$Q_0 = \frac{I_B}{I_{B3}} \tag{7}$$

Eqn. (6) shows that the pole frequency can be adjusted by $I_B$. Similarly, Eqn. (7) shows that the quality factor can be adjusted by $I_{B3}$. It should be pointed out that this adjustment does not affect the pole frequency. Reversely, the pole frequency can be controlled via $I_B$. In addition, bandwidth ($BW$) of the system can be expressed by

$$BW = \frac{\omega_0}{Q_0} = \frac{2I_{B3}}{CV_T} \tag{8}$$

We found that the bandwidth can be linearly controlled by $I_{B3}$. Moreover, the quality factor can be much high by controlling $I_{B3}$ to be much less than $I_B$. This differs from the conventional current-controlled universal filters in such that they use an input bias current to control the quality factor. However, it has a limited value of current in the circuits, the quality factor is then restricted.

| **Filter Responses** | $I_{in1}$ | $I_{in2}$ | $I_{in3}$ |
|---|---|---|---|
| LP | 0 | 1 | 0 |
| HP | 1 | 1 | 1 |
| BP | 1 | 0 | 0 |
| BR | 1 | 0 | 1 |
| AP | 2 | 0 | 1 |

**Table 1:** The $I_{in1}, I_{in2}$ and $I_{in3}$ logic conditions for each filter function response

Possible circuit characteristics, digital choosing by adding digitally selective circuit (Maruyama et, al. 2002) of the input terminals is shown in Table 1. It can be seen from this table that one of the realizations of the low-pass (LP), high-pass (HP), band-pass (BP), band-reject (BR) and all-pass (AP) transfer functions can be achieved as follows:

$$\text{LP: } T_{LP}(s)=\frac{\omega_0{}^2}{s^2+s\dfrac{1}{R_{x3}C_1}+\dfrac{1}{R_{x1}R_{x2}C_1C_2}} \tag{9}$$

$$\text{HP: } T_{HP}(s)=\frac{s^2}{s^2+s\dfrac{1}{R_{x3}C_1}+\dfrac{1}{R_{x1}R_{x2}C_1C_2}} \tag{10}$$

$$\text{BP: } T_{BP}(s)=\frac{\left(\omega_0/Q_0\right)s}{s^2+s\dfrac{1}{R_{x3}C_1}+\dfrac{1}{R_{x1}R_{x2}C_1C_2}} \tag{11}$$

$$\text{BR: } T_{BR}(s)=\frac{s^2+\omega_0{}^2}{s^2+s\dfrac{1}{R_{x3}C_1}+\dfrac{1}{R_{x1}R_{x2}C_1C_2}} \tag{12}$$

and

$$\text{AP: } T_{AP}(s)=\frac{s^2-s(\omega_0/Q_0)+\omega_0{}^2}{s^2+s\dfrac{1}{R_{x3}C_1}+\dfrac{1}{R_{x1}R_{x2}C_1C_2}} \tag{13}$$

In the low-pass and high-pass transfer functions, the circuit condition: $g_{m1}=g_{m3}$ is required. So, in case of low-pass and high-pass functions, the quality factor and pole frequency can not be tuned orthogonally by controlling $I_{B1}$.

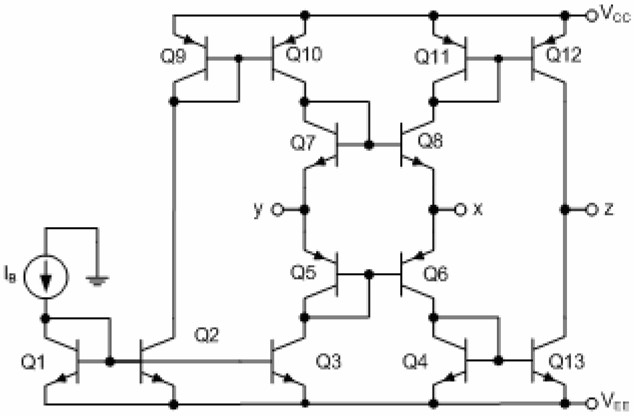


**Fig. 3** *Internal Construction of CCCII*

## 3. Circuit Sensitivities

The sensitivities of the proposed circuit are low and can be found as

$$S_{I_B}^{\omega_0} = 1;\ S_C^{\omega_0} = -1 \tag{14}$$

and

$$S_{I_B}^{Q_0} = 1;\ S_{I_{B3}}^{Q_0} = -1 \tag{15}$$

From Eqns.(14) and (15), we can see that the absolute magnitude of the sensitivities are equal unity.

## 4. Non-ideal case

In practice, the CCCII is possible to work with non-ideality. Its properties will change to

$$I_Z = \alpha I_x \tag{16}$$

and

$$V_x = \beta V_y \tag{17}$$

Where $\alpha$ and $\beta$ are transferred error values deviated from one. In the case of non-ideal and brief consideration, the $\omega_0$ is changed to

$$\omega_0 = \sqrt{\frac{\alpha_1\beta_1\alpha_2\beta_2}{R_{x1}R_{x2}}} \tag{18}$$

While $Q_0$ is still equal to Eqn. (5). Actually, these deviations are very small and can be ignored.

# SIMULATION RESULTS AND DISCUSSIONS

To prove the performances of the proposed circuits, the PSPICE simulation program was used for the examinations. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T (Frey. 1993). Fig. 3 depicts schematic description of the CCCII used in the simulations. Fig. 4 shows the frequency response of CCCII. It is seen that the CCCII can operate over wide range of frequency up to 59.46MHz. All CCCIIs were biased with ±1.5V power supplies and $C_1 = C_2 = 4.7nF$. The results shown in Fig. 5 are the magnitudes and phase responses of the proposed biquad filter obtained from Fig. 2, where $I_{B1}, I_{B2}$ and $I_{B3}$ are equal to $50\mu A$. The proposed biquad circuit function depends solely on the input current which can be digitally controlled as shown in Table 1.

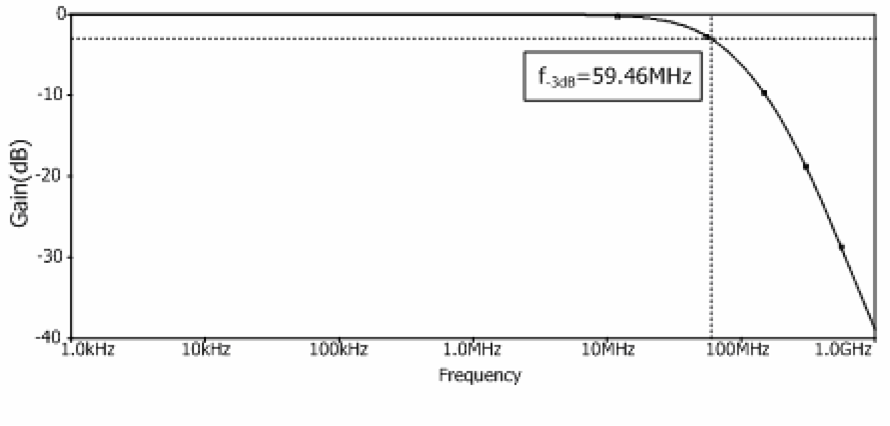
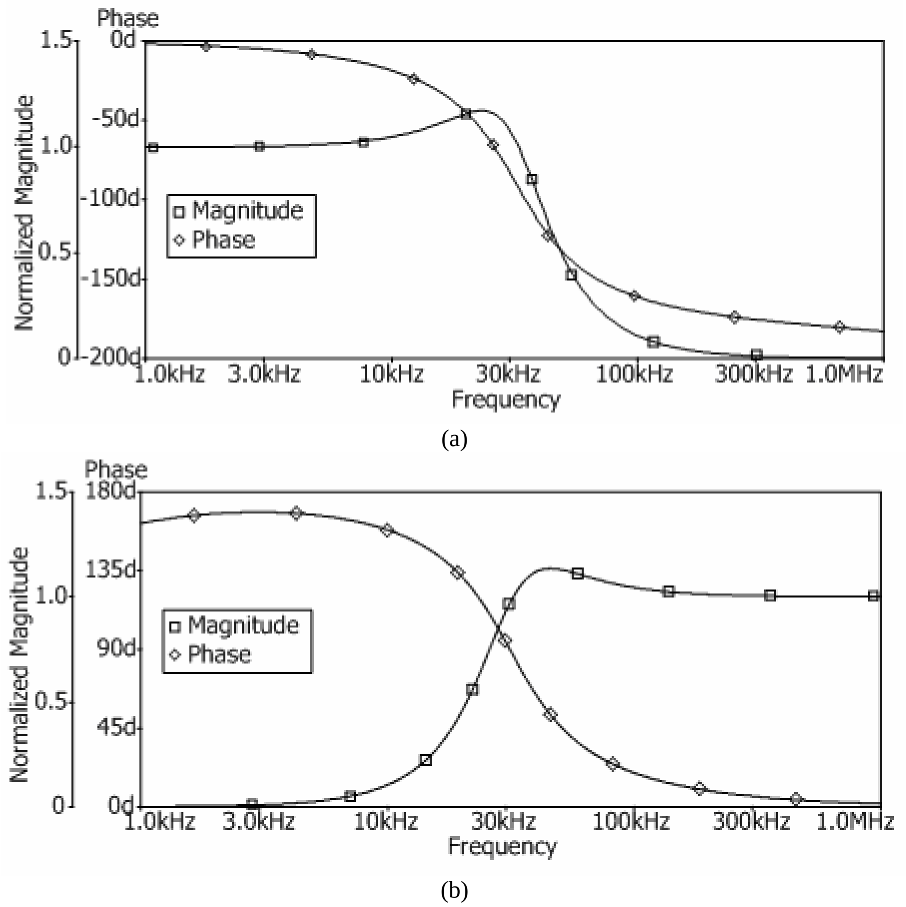
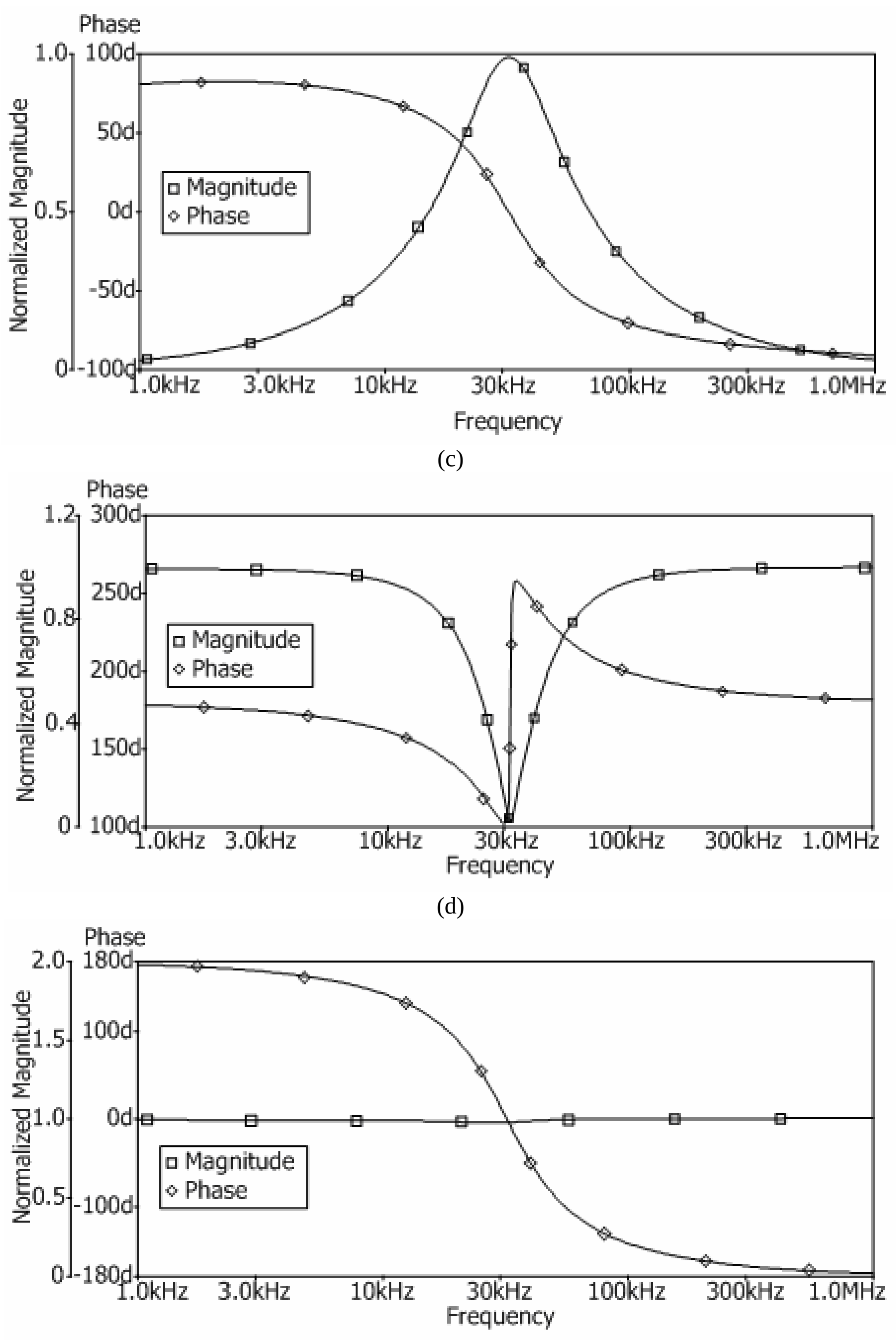


**Fig. 4** *Bandwidth of the CCCII*



(a)

(b)



(c)

(d)

(e)

**Fig. 5** *Normalized magnitude and phase responses of the proposed filter at*

*(a) LP (b) HP (c) BP (d) BR (e) AP*

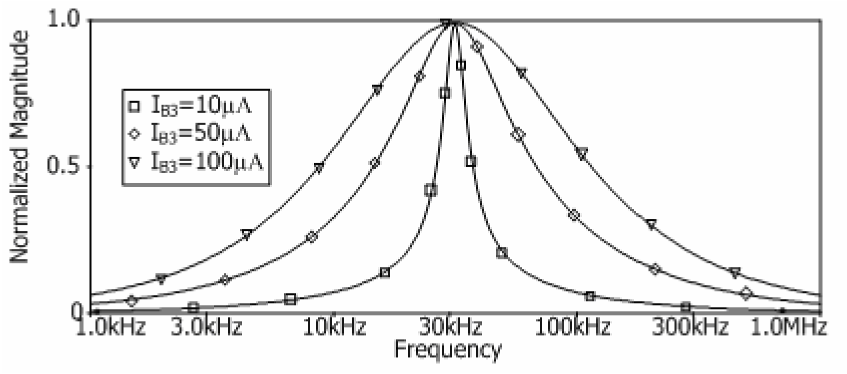


**Fig. 6** *Band-pass responses at different values of* $I_{B3}$

Fig. 6 and Fig. 7 display magnitude responses of band-pass and band-reject functions, respectively, with different $I_{B3}$ values. They are obviously shown that the bandwidths of the responses can be linearly adjusted by the input bias current $I_{B3}$ as depicted in Eqn. (8) without affecting the pole frequency as given in Eqn. (6). Similarly, the results in Fig. 8 are phase responses of all-pass function. It confirms the performances of proposed circuit in such controllability of the quality factor via $I_{B3}$ without affecting the pole frequency. Maximum power consumption is about 1.16mW.

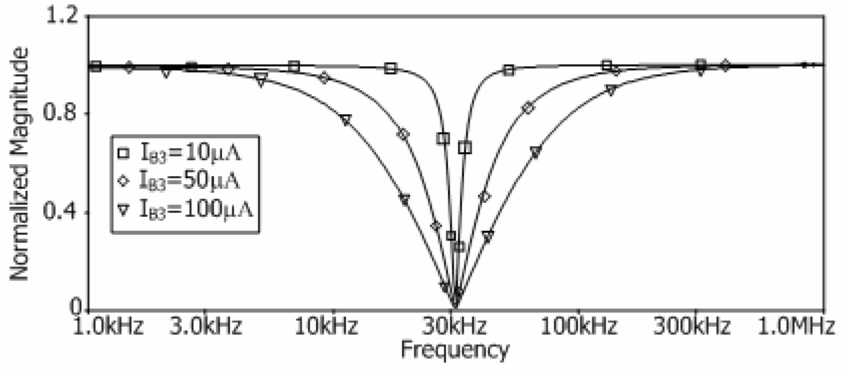


**Fig. 7** *Band-reject responses at different values of* $I_{B3}$

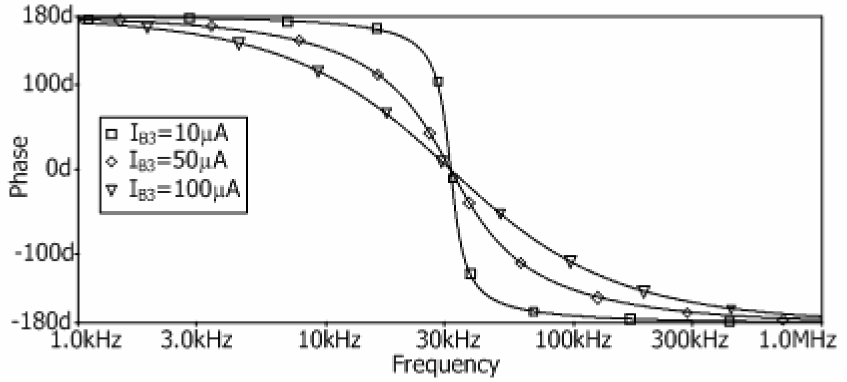


**Fig. 8** *Phase responses of all-pass at different values of* $I_{B3}$

# CONCLUSIONS

The current-mode universal biquadratic filter base on CCCIIs has been presented. There are three main advantages of proposed circuit. First, the circuit can perform all standard filter functions i.e. low-pass, high-pass, band-pass, band-reject and all-pass functions. Second, its quality factor can be controlled independently to its pole frequency and vise versa. Third, its performing function can be digitally controlled by its input bias current, this is easily modified to use in control systems using a microcontroller (Toumazou et, al. 1990). In addition, from simulation results, the proposed circuit can work at low supply voltages (±1.5V), low power consumption. The circuit description comprises only 3 CCCIIs and 2 grounded capacitors. With mentioned features, it is very suitable to realize the proposed circuits in monolithic chip for use in battery-powered, portable electronic equipments such as wireless communication system devices.

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