Electrically tunable current mode high Q- bandpass filter

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Abstract: A novel current mode high Q bandpass filter with electronically tuable values of Q based on second generation current controlled conveyor CCCIIs is presented. The circuit offers the advantages of using a few passive elements. The center frequency and pole-Q can be independently adjusted by via dc bias current of CCCIIs, It is shown from SPICE simulation that the results agree well with theoretical analysis

Keyword: high Q- bandpass filter, current conveyor, current mode, circuit design

1. Introduction

Recently, current mode circuits have been receiving significant attention [1]. This is because of the fact that current mode devices have potential advantages of improved linearity, wider dynamic range and extended bandwidth over their voltage mode counterparts. Several current mode circuits are designed by using various active elements such as FTFN, CFOA and current conveyor (CCI, CCII, CCCII). Second generation current controlled conveyor (CCCII) as an active element introduced by Fabre et al [2] received great emphasis on the design and implementation of current mode circuits because they provide a wide rang of electronic adjustability of the circuit parameters and a broad frequency range operation. Therefore, most of analog circuits such as oscillator, filter and impedance inverter are still designed and developed.

One of the most versatile network is high Q bandpass filter. It can be wildly used in analog signal processing, electronic system and communication system. Several high Q bandpass filter structures are available in literature [3-10], which are realized by using different techniques such as two integrator loop[3], negative feedback with all-pass network[4-10]. While bandpass filter circuits proposed in [4-5] employ operational amplifiers operated in voltage mode, they suffer from limited bandwidth performance and used of large number of passive components. In order to overcome the drawback of opamps, high Q bandpass filter designed by integrable fixed gain amplifier is proposed [6]. It exhibits good performance but it lacks electronical tunablility and uses a lot of passive components. Then, this circuit structure was modified by using current controlled conveyor based realization [7-8] operates in voltage mode and enjoys electronic tunability. Although the circuits are significantly reduced a number of passive components, they still require voltage buffer at each stage of all-pass network. On the other hand, current mode bandpass filters proposed in [9-10] are powerful. Their topologies can eliminate the buffer by using the high impedance of the z terminal of CCCII thus the circuits are cascadable. However, the circuit in [10] does not enjoy electronical tunability. While the center frequency of the bandpass filter proposed in [9] can be controlled by employing cmos transistor operated in non-saturation region, it still consists of 5 or more passive components therefore it is not suitable for monolithic implementation.

In this paper, we present a novel high-Q bandpass filter using current controlled conveyor (CCCII). The circuit is composed of two allpass networks and a current amplifier in negative feedback loop. The circuit needs only one resistor, two capacitors and three CCCIIs. Each first order allpass section can be implemented by only a single CCCII and a single capacitor because we take advantage of the intrinsic resistance of the mixed translinear loop. That is the reason why high Q bandpass filter can be realized with a simple implementation compared to the aforementioned circuits[3-10]. Furthermore, the proposed circuit has the merit that the pole-Q of the filter can be controlled by adjusting the value of dc bias current of CCCII without disturbing its center frequency.

2. Proposed circuit

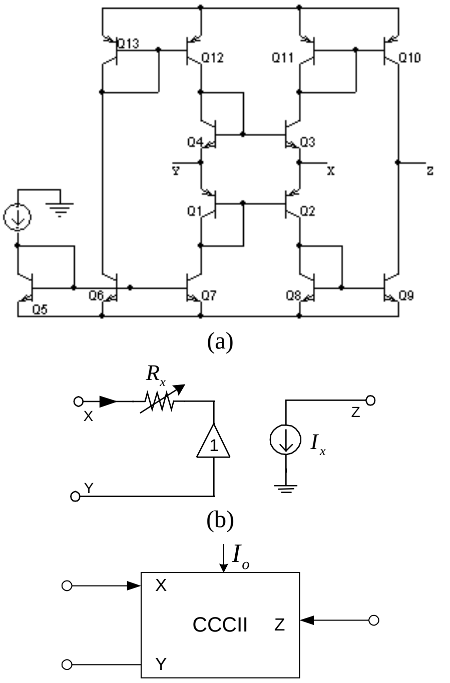
Since the proposed bandpass filter is based on CCCII, a review of CCCII is given briefly. CCCII is a building block with three ports described by following equation

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_x & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix} \qquad (1)$$

The plus and minus sign in equation (1) denote positive and negative types of the CCCII+ and CCCII-. The schematic of the CCCII+ can be obtained from Fig.1. It is composed of mixed translinear loop (Q1-Q4) and complementary current mirror (Q5-Q13). It is known that the CCCII has an intrinsic resistance R_x at the x terminal, which is tunable via dc bias current I_o of the CCCII and it can be approximated as

$$R_x = \frac{V_T}{2I_o} \qquad (2)$$

When $V_T = \frac{KT}{q} = 26$ mV at 27° is a thermal voltage. The equivalent circuits and the symbol of the positive CCCII are shown in fig.1b and 1c, respectively



(a)

(b)

(c)

Fig.1. Current controlled conveyor (CCCII+)
(a) schematic implementation. (b) equivalent circuit.
(c) its symbol

By using a capacitor and a CCCII+, a simple current mode first order allpass filter is obtained as showing in figure2 which is modified from current mode filter in literature [12]. By using intrinsic resistance at port x of CCCII instead external lumped resistor, a simple currernt mode allpass filter can be derived.

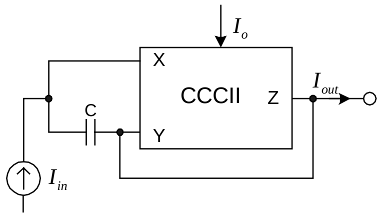


Fig.2 Current mode allpass filter.

The current transfer function of the circuit can be express as the following equation for the ideal case

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$$T(s) = \frac{I_{out}}{I_{in}} = \frac{s\tau - 1}{s\tau + 1} \qquad (3)$$

Where $\tau = \frac{V_T C}{2I_o}$.

The filter has the phase response as the following.

$$\angle T(j\omega) = \pi - 2\tan^{-1}(\tau\omega) \qquad (4)$$

The transfer function of the allpass filter in fig.2 can be rewritten for non-ideal case. In practice, there are some current tracking error between port x and port z, where $I_z = \alpha I_x, \alpha = 1 - \varepsilon_i, |\varepsilon_i|$ << 1. ε_i denotes the current tracking error. In this case, the current transfer function is found as:

$$T(s) = \frac{I_{out}}{I_{in}} = \frac{s\tau - \alpha}{s\tau + 1} \qquad (5)$$

The proposed high Q bandpass filter operated in current mode consists of two allpass filters and a current amplifier forming in the close loop structure based on the classical method [4] as shown in fig.3. Current amplifier circuit is implemented by a dual output CCCII- and one resistor. . For current amplifier circuit, the dual output CCCII- with an additional current mirror state to provide another Z-output terminal.

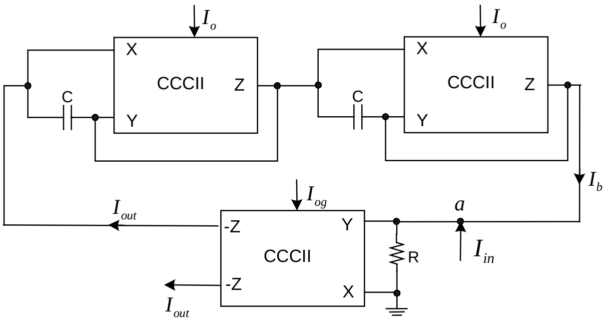

Fig.3 The proposed high Q bandpass filter

Current input I_{in} and output feedback current I_b are sum at node a caused voltage V_a to become

$$V_a = R(I_{in} + I_b) \qquad (6)$$

Thus the current of port Z of CCCII- is

$$I_{out} = \frac{2I_{og}R(I_{in} + I_b)}{V_T} \qquad (7)$$

where, I_{og} is dc bias current of CCCII in the current amplifier. Output of current amplifier I_{out} are feed to input of the cascaded allpass network which caused I_b to be equal to the following equation

$$I_b = -\left(\frac{s\tau - 1}{s\tau + 1}\right)^2 I_{out} \qquad (8)$$

Employing (7) and (8), The current transfer function of the proposed circuit can be obtained as

$$\frac{I_{out}}{I_{in}} = \frac{k}{1+k}\left[\frac{(s + 1/\tau)^2}{s^2 + 2s(1-k)/\tau(1+k) + 1/\tau^2}\right] \qquad (9)$$

where, $k = \frac{2I_{og}R}{V_T}$ is a current gain of the current amplifier circuits and τ is the inverse of the center frequency ω_o :

$$\omega_o = \frac{1}{\tau} = \frac{2I_o}{V_T C} \qquad (10)$$

The pole Q of the transfer function (9) is

$$Q=\frac{1}{2}\left(\frac{1+k}{1-k}\right)=\frac{1}{2}\left(\frac{2I_{og}R\ +V_T}{2I_{og}R\ -V_T}\right) \qquad (11)$$

Equation (9) can be rewritten as

$$\frac{I_{out}}{I_{in}}=\frac{1}{4}(2Q-1)\left[\frac{\frac{(s+\omega_o)^2}{Q}}{s^2+\frac{\omega_o}{Q}s+\omega_o^2}\right] \qquad (12)$$

Equation (12) is slightly different from bandpass transfer function because the numerator of equation (12) has double zero at a frequency ω_o, whereas an ideal bandpass filters have a zero at origin [13]. Therefore, the double zero will cause some deviation from ideal bandpass amplitude and phase response [5]. However, the transfer function in (12) can be approximated to bandpass transfer function near the center frequency. In fig.8 shows the magnitude and phase characteristic of the approximate bandpass filter when compared with an actual high Q bandpass filter. The response shows that the magnitude and phase response of the approximate bandpass filter is similar to magnitude and phase responses of the ideal bandpass filter near center frequency. At the above and below center frequency the magnitude and phase responses of the approximate bandpass filter show some deviations from ideal bandpass transfer function. However, although the transfer functions of the proposed circuit have frequency and phase responses slightly different from the responses of ideal bandpass filter, the propose circuit is useful in separating signal of different frequencies based upon the amplitude response rejection because it is seen in equation (11) that Q value depends on R and I_{og} which are current of the current amplifier, whereas the center frequency depends on I_o and C. Therefore, the value of Q is adjustable by I_{og} without effecting the center frequency.

In addition, the proposed circuit use less chip area because the circuit use only three passive components which less than the other existing high Q bandpass realization[3-9]. Thus the proposed circuit is suitable for monolithic implementation.

For high Q filter implementation $k\approx 1$, the sensitivity of Q respected to k can be calculated as follows:

$$S_k^Q=Q \qquad (13)$$

It shows that its sensitivity is the same value when compared with other bandpass filters [6-7,9], but the proposed circuit use the less passive components.

3. Simulation results

In order to verify the feasibility of the proposed circuit, the simulations of the circuit are given. The pnp and npn transistors were simulated using parameter of PR100 and NR100 bipolar transistors [11]. Fig. 4 shows the magnitude and phase characteristics of the first order allpass filter in fig.2. Dc bias current value is selected as: $I_o=50\mu A$ and $C=1\text{nF}$, which lead to 90^o phase shift at a natural frequency of 700 KHz. In addition, by using different dc bias current, $100\,\mu A$ and $150\,\mu A$, the phase characteristics of allpass filter can be easily adjusted.

The proposed bandpass filter is simulated using fixed value of the dc biases I_o and capacitors as $100\mu A$ and $C=1\text{nF}$, respectively, and then adjust I_{og} and R to control the Q value. Simulation results of the filter with $R=100\ \Omega$ and $I_{og}=100\,\mu A$, $120\,\mu A$, $130\,\mu A$, $135\,\mu A$ and $150\,\mu A$ (corresponding to Q value about 3.6, 8.9 26, 194 and 11.7) respectively are shown in fig.5. From the simulation result, it is seen that Q can be adjusted by changing value of bias current, whereas its center frequency is constant.

On the other hand, we fix Q by using $R=100\Omega$, I_{og} =135 μA and tune the center frequency of the filter, with varying I_o from $50\mu A$ to $80\mu A$. The results of the simulations are shown in Fig.6. The center frequencies of the circuit linearly changes in between 565kHz and 878kHz. It proves that the circuit possesses the tunability of the center frequency although gain of the filter at each center frequency seems to slightly deviate from the theoretical value because of the non-ideality of the CCCII. Fig7 shows relationships between center of frequency and dc bias current of CCCII when $C=10\text{nF}$.

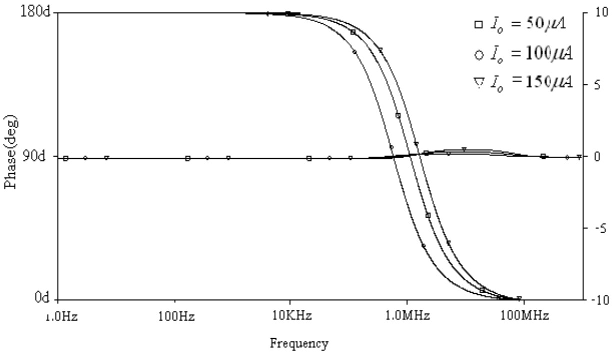

Fig. 4 The magnitude and phase characteristics of the first order allpass

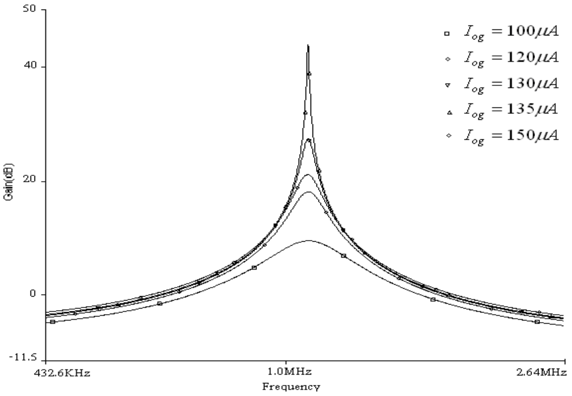

Fig.5 Frequency response of the proposed filter when Q value of filter is varied

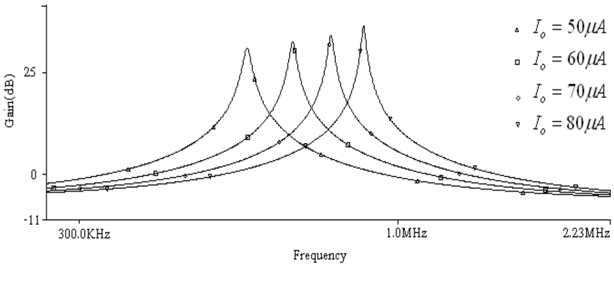

Fig.6 Frequency responses of the proposed filter when the center frequency of filter is varied

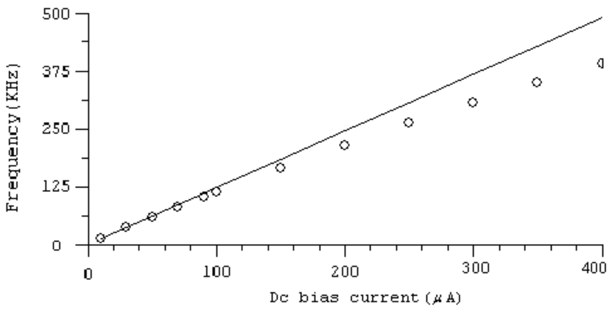

Fig.7 Center frequency of bandpass as dc bias current is varied

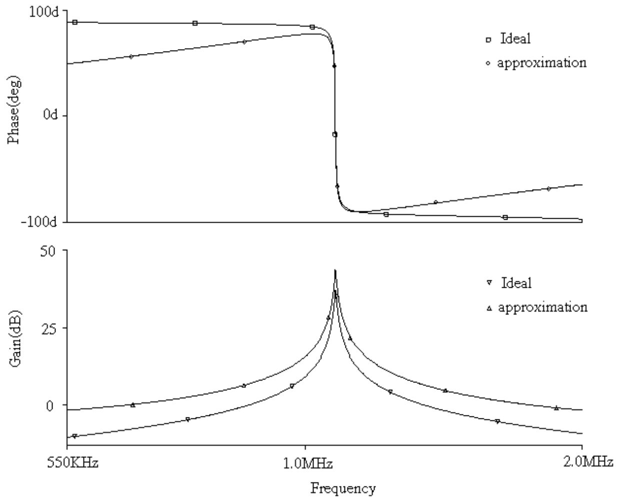

Fig.8 Frequency and phase response of the bandpass filter

4. Conclusions

A novel current mode high Q bandpass filter has been presented. This circuit offers a simpler circuit configuration compared with previously reported counterparts in [3-10]. The proposed circuit uses only three passive components and three CCCIIs. In addition, the proposed circuit operates in current mode thus allpass networks can be cascaded directly, it is no need buffer stage such as the bandpass filters in literature [7-9]. Moreover, the center frequency and Q value are easily adjusted by changing dc bias current of allpass circuits and current gain amplifier, respectively. Simulation results demonstrate the validity of the proposed circuit. Although the transfer function of the proposed circuit has double zero at center frequency which is different from ideal bandpass transfer function, The proposed circuit still have frequency and phase response similar to ideal bandpass filter at center frequency therefore the proposed circuit has the ability to select signals in different frequencies. However, non-ideal of CCCII, the current tracking errors and the voltage tracking errors of the CCCIIs are main culprits, which lead to slightly shift of the center frequency of the circuit from ideal case. However, using high current gain transistor can improve the accuracy of current mirror, which can alleviate the problem.

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