Design of A 10MHz Bandpass Filter Using Grounding and Floating CDTA Active Inductors

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그라운딩과 플로팅 CDTA 능동인덕터를 사용한 10MHz 대역통과필터 설계

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Abstract This paper presents a bandpass filter using a current differencing transconductance amplifier (CDTA)s for application to low-voltage and low-power analog signal processing systems. The presented filter employs grounding and floating active inductors, which are composed of two or three CDTAs, and is capable of realizing all the standard functions of the filter without requiring any component matching criteria or extra active components. The HSPICE simulation result of the designed active bandpass filter showed that it had a 10MHz center frequency with -2.5dB attenuated bandwidth from 9.5 MHz to 10.5 MHz, and -50dB from 8 MHz to 17 MHz.

요 약 본 논문에서는 저전압, 저전력 아날로그 신호처리 시스템에 활용할 수 있도록 전류 차동 트랜스컨덕턴스 증폭기 (CDTA)를 사용하여 대역통과 필터를 설계하였다. 대역통과 필터는 그라운딩 인덕터와 플로팅 능동 인덕터를 사용하여 설계 하였고, 설계된 능동 인덕터는 각각 두 개 또는 세 개의 CDTA를 활용하여 구성하였다. 본 논문에서 설계된 능동 인덕터를 활용하여 대역통과 필터를 구성할 때, 소자 값 들을 조정하기 위한 외부의 추가적인 정합회로의 필요 없이 필터를 구현할 수 있다는 장점이 있다. 설계된 능동 대역통과 필터 특성의 검증은 HSPICE 시뮬레이션 프로그램을 활용하였다. 시뮬레이션 결과, 설계된 필터는 10MHz의 중심주파수, 통과대역에서는 -2.5dB의 감쇄율을 가진 9.5~10.5MHz의 대역폭을 얻을 수 있었으며, 차단대역에서는 8MHz이하와 17MHz이상에서 -50dB의 감쇄율을 가진 대역통과 특성을 얻을 수 있다.

Key Words : Active filter, Bandpass filter, CDTA, Floating inductor, Grounding inductor

1. Introduction

Recently studies regarding current differential transconductance amplifier(CDTA) are widely in progress and its usefulness is especially recognized in analog circuit design fields as shown in [1-3] and [4]. The input of CDTA is current, and the difference between two input currents creates the initial voltage.

This voltage is determined by the impedance of the initial output terminal, and also, this voltage drives the transconductance amplifier connected at the back terminal, creating current in CDTA output. Due to this structure, CDTA is capable of having high linearity and wide frequency bandwidth and is possible to minimize its size as a circuit when used in constructing analog circuits[5].

In this paper, a synthesis method is present to realize active floating

inductors using CDTA. The presented method has some improvement in aspects of number of small sized circuits, simplicity of the realization method and the area the circuit as well as reduction in the power. Chapter 2 introduces basic characteristics and existing methods for the realization of floating and grounding inductors using CDTA. Chapter 3 presents the band pass filter with 10MHz center frequency is constructed using the designed CDTA inductor for checking its usability and verified through simulation.

2. The synthesis of floating and ground inductors with CDTAs

CDTA is an active filter with five terminals shown in Fig. 1. In Fig. 1, I_p and I_n are differential current input signals and these current signals are converted into voltage signal by the impedance determined at terminal z. The signals converted into voltage are converted again into output currents $I^+{}_x$ and $I^-{}_x$. According to this structure, CDTA can be seen as a current amplifier.

(a)

(b)
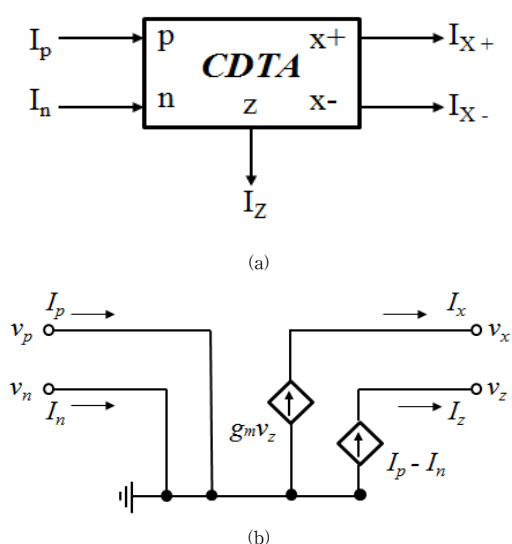
[Fig. 1] (a) Symbol of CDTA, (b) Small signal equivalent circuit for CDTA

The current and the voltage from equivalent circuit can be written as equation (1).

$$V_p = V_n = 0$$
$$I_z = I_p - I_n$$
$$I_x^+ = g_m V_z$$
$$I_x^- = -g_m V_z$$
(1)

Also, when the current gain from equation (1) is a it can be written as equation (2)

$$I_z = \alpha_p I_p - \alpha_n I_n$$
(2)

a_p and a_n from equation(2) are current gains, and each can be written as equation (3)

$$\alpha_p = 1 - \beta_p$$
$$\alpha_n = 1 - \beta_n$$
(3)

Here, β_p and β_n are current error values, and the values are smaller than 1. When input differential current ($I_z = I_x - I_n$) is converted into voltage signals at terminal z, the external impedance value is connected to terminal z, and the g_m value of the voltage from terminal z determines positive output current ($I^+{}_x = g_m V_z$) and negative output current ($I^-{}_x = -g_m V_z$). At that time, the g_m value of the transconductance can be adjusted by external bias current and this also can adjust output current. There is an important circuit design method for designing a circuit in order to construct a circuit resistant to noises produced during constructing integrated circuits and this is by composing all devices in a passive circuit with grounded devices as shown in [6-8] and [9-12]. From this point of view, CDTA is grounded by terminal z and this makes it strong to noises produced during construction. Because all input differential currents flow into terminal z, differential currents can be converted into voltage by using one or more grounded passive devices.

(a)

(b)
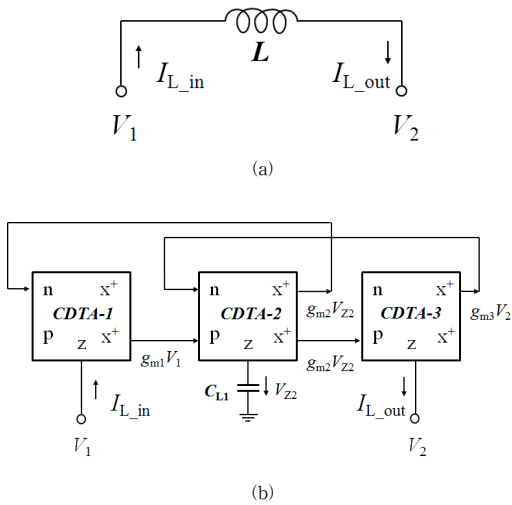
[Fig. 2] (a) Passive floating Inductor (b) CDTA floating inductor

Fig. 2(a) is a passive floating Inductor and 2(b) shows a CDTA floating inductor. The structural characteristics shown above allow the size of the circuit to become small when using CDTA to compose circuits.

$$I_L = \frac{v_1 - v_2}{sL} \tag{4}$$

This floating inductor shows a equivalently composed circuit using CDTAs, as in Fig. 2(b). The voltage V_{Z2} that is put in the capacitor C_L in Fig. 2(b) can be obtained from equation (5).

$$V_{Z2} = \alpha 2 \frac{g_{m1} v_1 - g_{m3} v_2}{s C_L} \tag{5}$$

In equation (5), α_2 is the current gain from the internal current source in *CDTA-2*, and g_{m1} and g_{m3} are the transconductance of *CDTA-1* and *CDTA-3*. Current I_{L_in} and I_{L_out} can be obtained from equation(6).

$$I_{L\_in} = \alpha_1 g_{m1} V_{Z2}, I_{L\_out} = \alpha_3 g_{m2} V_{Z2} \tag{6}$$

Set the values of α_1 and α_3 as α and g_{m1} and g_{m3}

as g_m, and from the relations of equation (1), equation (5) and equation (6), equation (7) which shows the inductance L value can be obtained.

$$L = \frac{C_L}{\alpha \alpha_2 g_m g_{m2}} \tag{7}$$

From the equation (7), it can be seen that inductance L can be determined by CDTA's current gain, the transconductance and capacitor's C_L value. Next, Fig. 3(a) is the grounding inductor with one side of terminal grounded, and the equation for the current flowing through the inductor can be written as equation (8). Also, the circuit composing the grounding inductor with two CDTAs used is shown in Fig. 3(b).

(a)

(b)
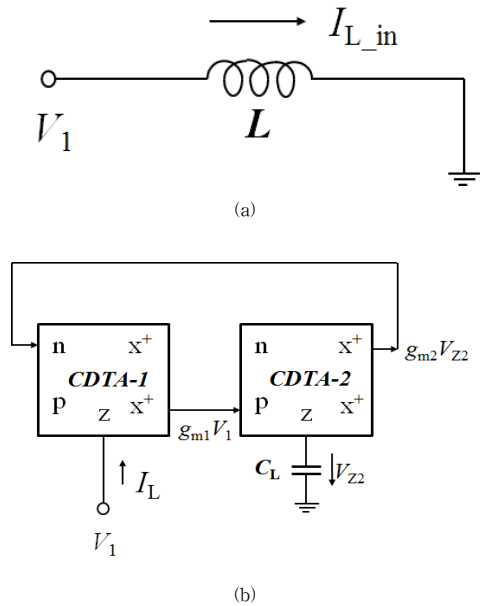
[Fig. 3] (a) Passive grounding Inductor, (b) CDTA grounding inductor

$$I_L = \frac{V_1}{s_L} \tag{8}$$

The voltage V_{Z2} put into the capacitor's C_L in Fig. 3(b) can be obtained from equation (9).

$$V_{z2} = \alpha_2 \frac{g_{m1}V_1}{SC_L} \quad (9)$$

In equation (9), α_2 is the current gain from the internal current source in *CDTA-2*, and g_{m1} is the transconductance of *CDTA-1*. The current I_L can be obtained from equation (10).

From the relations of equation (8), equation (9) and equation (10), the L value of the grounding inductance can be written as equation (11).

$$I_L = \alpha_1 g_{m2} V_{Z2} \quad (10)$$

$$L = \frac{C_L}{\alpha\alpha_2 g_m g_{m2}} \quad (11)$$

This shows that similar to the floating inductor, the grounding inductor's L value can be determined by CDTA's current gain, transconductance and the capacitor's C_L value.

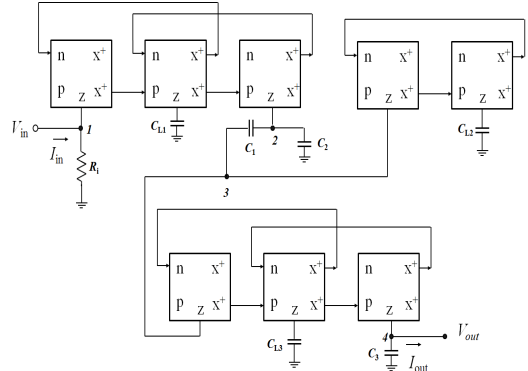## 3. Design of a band pass filter using CDTA.

Because an inductor can be composed of CDTA, which itself is an active circuit, passive filters can be easily replaced with active filters. Fig. 4 shows a passive band pass filter with center frequency value designed to be 10 MHz and the device value is as in Table 1. Fig. 5 shows the active bandpass filter with the floating inductors L_1 and L_3 each composed of three CDTA's, and the grounding inductor L_2 composed of two CDTAs from Fig. 5.
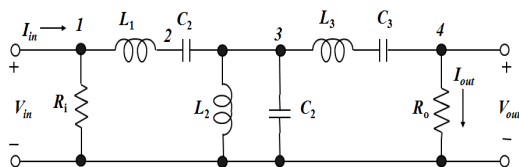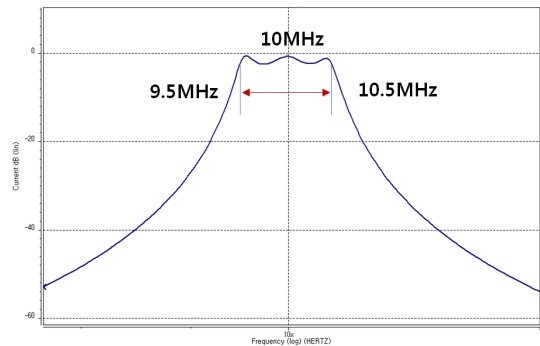

[Fig. 4] Passive band pass filter

[Table 1] Device values for active filter

Parameter	value	Parameter	value
C_1	1.17pF	g_{m3}	1ms
C_2	0.202nF	C_{L1}	0.215nF
C_3	0.898pF	C_{L2}	1.25pF
g_{m1}	1ms	C_{L3}	0.281nF
g_{m2}	1ms	R_i	1kΩ

[Fig. 5] Active band pass filter using CDTA

The HSPICE simulation result of the designed active band pass filter is shown as in Fig. 6. The device values of the active filter obtained from the converted device values (Table 1) of the passive filter have 10MHz of center frequency with 9.5MHz to 10MHz of -2.5dB attenuated bandwidth, 8MHz to 17MHz of -50dB attenuated bandwidth, and has the cutoff characteristics.

[Fig. 6] Simulation results of the active band pass filter using CDTA

4. Conclusion

A CDTA based tunable band pass active filter is proposed. The proposed filter employs grounding and floating active inductors which are composed of two or three CDTAs, and is capable of realizing all the standard functions of the filter without requiring any component matching criterions and any extra active components. The HSPICE simulation result of the designed active band pass filter showed that it had 10MHz of center frequency with 9.5 MHz to 10.5 MHz of -2.5dB attenuated bandwidth, 8 MHz to 17 MHz of -50dB attenuated bandwidth, and had the cutoff characteristics. The designed band pass filter will be applied to design the low-voltage and low-power analog signal processing systems.

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