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OTAs-based Positive/Negative Floating Inductance Simulator

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***Abstract*—This paper presents a method to realize floating inductance simulator using Operational Transconductance Amplifiers (OTAs). Both positive and negative floating inductances can be achieved without changing the circuit topology. The realization method is based on the use of commercially available OTAs and a grounded capacitor. The proposed circuit is attractive in terms of simple configuration and low cost. The resulting inductances can be electronically tuned by varying the external bias current of OTAs. Experimental results demonstrating the circuit performances are included.**

***Index Terms*—floating inductance simulator, OTA, grounded capacitor.**

I. Introduction

Floating inductance simulator is one of the useful building blocks in analog electronic circuit design, such as active filters, oscillators and analog phase shifters [1], [2]. Several approaches to implement the floating inductance based on the use of current conveyors have been reported in the literature [3]-[5]. A method based on the requirement of the resistor matching has been introduced in [3]-[4]. Therefore the performance of this method is disturbed by component matching condition. Alternative approach to avoid the component matching requirement has been proposed in [5]. The advantage of electronic tuning properties is attractive for design the floating inductance. Hence, the approaches based on the use of second-generation current controlled conveyors (CCCIIs) [6], current differencing buffered amplifiers (CDBAs) [7], and current amplifiers (CAs) [8] have been described. Nevertheless, these approaches are unavailable in commercial integrated circuit form. The economical attraction in the circuit design is one of the important factors to be considered. It is known that Operational Transconductance Amplifier (OTA) contains the feature of linearly controlled transconductance gain over more than four decades [9]. Moreover, OTA is a commercial and low cost device. Therefore, the realization of the floating inductance simulator based on OTA is attractive. In this paper, the floating inductance simulator based on the use of OTAs is presented. Both positive and negative floating inductances can be achieved in the same scheme. The proposed circuit employs a grounded capacitor as only passive element. The resulting inductance can be electronically adjusted by changing the external bias current of OTAs. Experimental results verifying the performances of the proposed circuit are given.

II. Circuit Description

The proposed electronically adjustable floating inductance simulator is shown in Fig. 1. The input voltage v_{in} assigned to equal $v_A - v_B$ is applied across the input of OTA_1 at node A and B. Thus the current i_1 of OTA_1 can be given by

$$i_1 = g_{m1}(v_A - v_B) \quad (1)$$

The output node of OTA_1, v_x, connected with grounded capacitor can be expressed as

$$v_x = \frac{i_1}{Cs} \quad (2)$$

where $s = j\omega$ and ω denotes the angular frequency of operation. The voltage $v_x - v_B$ becomes the input voltage across OTA_2 and causes the output current i_2 of OTA_2 equal to

$$i_2 = g_{m2}(v_x - v_B) \quad (3)$$

where $g_{mi} = I_{Bi}/2V_T$ is the transconductance gain of OTA_i, I_{Bi} and V_T denote the bias current of OTA_i and the thermal voltage, respectively.

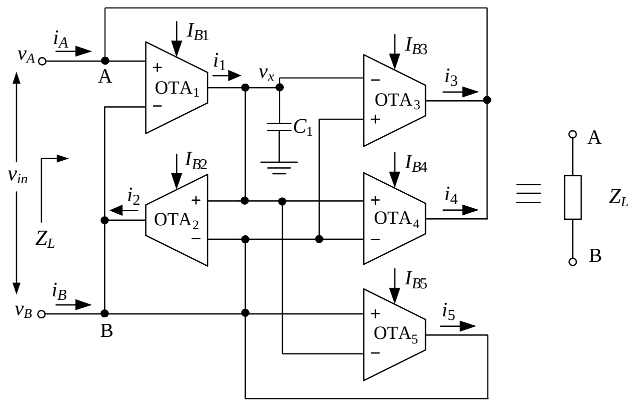

Fig. 1 The proposed floating inductor.

Substituting the current i_1 from (1) and the voltage v_x from (2) into (3), the current i_2 can be rewritten as

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$$i_2 = \frac{g_{m1} g_{m2}}{Cs}(v_A - v_B) - g_{m2} v_B \quad (4)$$

If $(g_{m1}g_{m2}/C\omega) >> g_{m2}$ is chosen, then the current i_2 can be approximated as

$$i_2 = \frac{g_{m1} g_{m2}}{Cs}(v_A - v_B) \quad (5)$$

Also, the voltage $v_x - v_B$ is used as the input voltage across the OTA_3, OTA_4, and OTA_5. Therefore the relation between the output currents i_3, i_4, and i_5 of OTA_3, OTA_4, and OTA_5, respectively, and the current i_2 can be given by

$$i_3 = -\frac{g_{m3}}{g_{m2}} i_2 = -\frac{I_{B3}}{I_{B2}} i_2 \quad (6)$$

$$i_4 = \frac{g_{m4}}{g_{m2}} i_2 = \frac{I_{B4}}{I_{B2}} i_2 \quad (7)$$

$$i_5 = -\frac{g_{m5}}{g_{m2}} i_2 = -\frac{I_{B5}}{I_{B2}} i_2 \quad (8)$$

The bias currents I_{B2} and I_{B4} are assigned to equal I_{B3} and I_{B5}, respectively. The currents i_3, i_4, and i_5 can be rewritten as

$$i_3 = -i_2 \quad (9)$$

$$i_4 = K i_2 \quad (10)$$

$$i_5 = -K i_2 \quad (11)$$

where $K = I_{B4}/I_{B2} = I_{B5}/I_{B2}$ is the bias current ratio. The currents i_A and i_B at node A and B, respectively, can be obtained as

$$i_A = -i_3 - i_4 \quad (12)$$

$$i_B = -i_2 - i_5 \quad (13)$$

Substituting the currents i_3 and i_4 from (9) and (10), respectively, into (12) and i_5 from (11) into (13), the current i_A and i_B can be state as

$$i_A = i_2 - K i_2 = (1-K) i_2 \quad (14)$$

$$i_B = -i_2 + K i_2 = -(1-K) i_2 \quad (15)$$

It can be seen that the currents i_A and i_B are equal in magnitude, but opposite in their flowing directions. Considering the voltages v_A and v_B across node A and B and the current directions i_A and i_B, the obtained impedance of proposed inductance simulator Z_L can be state as

$$Z_L = \frac{v_A - v_B}{i_A} = \frac{Cs}{g_{m1} g_{m2}(1-K)} = \frac{4V_T^2 Cs}{I_{B1} I_{B2}(1-K)} \quad (16)$$

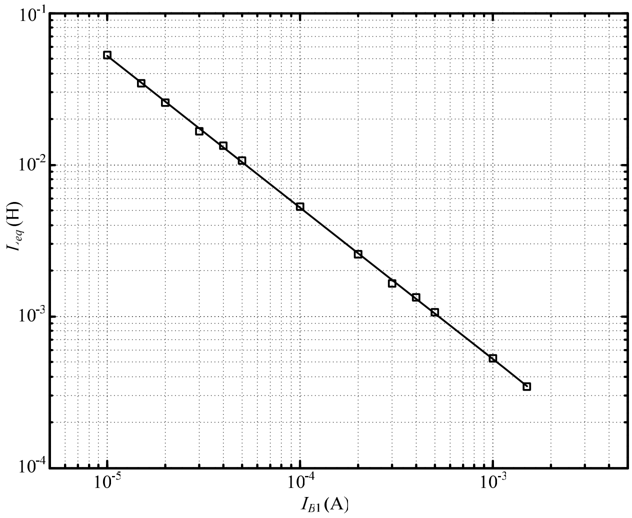
Thus the value of the resulting inductance L_{eq} from circuit in Fig. 1 can be given by

$$L_{eq} = \frac{4V_T^2 C}{I_{B1} I_{B2}(1-K)} \quad (17)$$

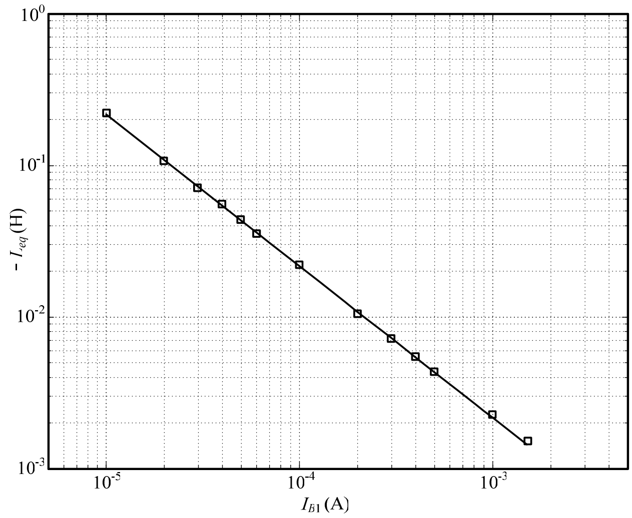
From (17), it clearly seems that proposed floating inductance can be obtained in the same circuit by adjusting either the bias current ratio K or the current I_{B1}. Moreover, the positive inductance can be achieved for $K < 1$. Otherwise, the resulting inductance will be negative for $K > 1$.

III. Experimental Results

To demonstrate the performances of the proposed inductance simulator, the floating inductor as shown in Fig. 1 was experimentally implemented using the commercially available OTA CA3280 devices. The grounded capacitor C_1 of the proposed inductor in Fig. 1 was set to 100nF. The bias currents $I_{B2} = I_{B3}$ and $I_{B4} = I_{B5}$ were varied to achieve the current gain variation.



(a)



(b)

Fig. 2 The plots of the measured floating inductances against the varied bias current I_{B1}.
(a) positive inductance
(b) negative inductance

Figs. 2(a) ~ 2(b) show the plots of the measured values of the positive and negative floating inductances L_{eq}, respectively, against the bias current I_{B1} varied from 10μA to 1.5mA. The bias current gain $K = 0.82$ and $K = 1.5$ are chosen to achieve the positive value in Fig. 2(a) and negative value in Fig. 2(b), respectively. It is evident that both positive and negative inductances can be achieved in the same scheme by adjusting the external bias current of OTAs.

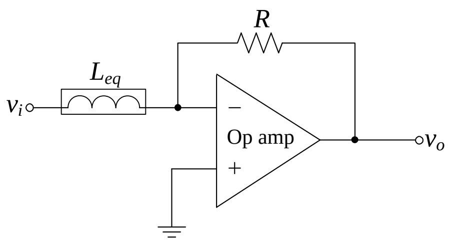
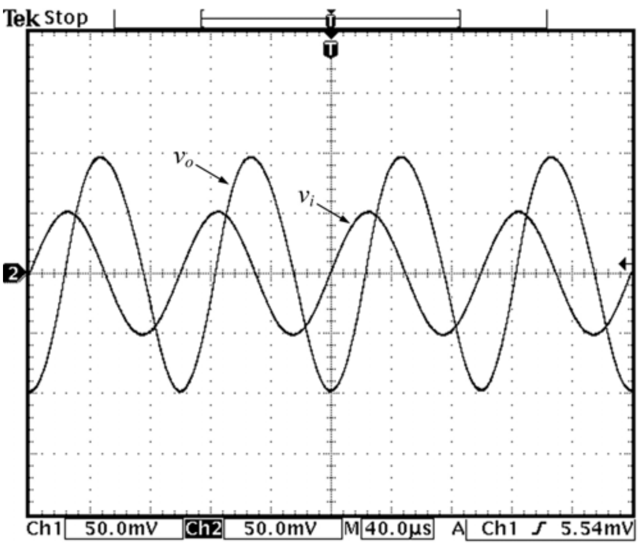
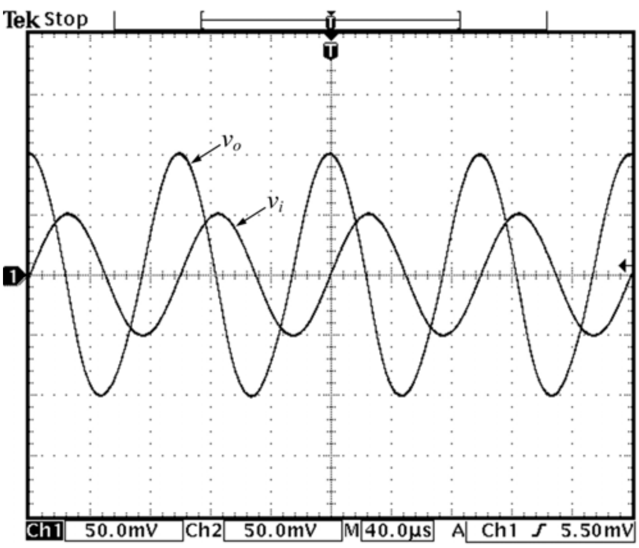


Fig. 3 The proposed positive and negative floating inductances in voltage amplifier.



(a)



(b)

Fig. 4 The measured results of the voltage amplifier.
(a) for positive inductance
(b) for negative inductance

The proposed positive and negative floating inductors employed in voltage amplifier is shown in Fig. 3, where R = 1kΩ is the constant resistor. Figs. 4(a) ~ 4(b) demonstrate the measured results of the voltage amplifier for positive and negative inductances, where 20 kHz sinusoidal input voltage v_i of peak amplitude 50mV was applied and L_{eq} = 7.98mH and L_{eq} = -7.98mH were chosen to obtain the output voltage $v_o = 2v_i$ and $v_o = -2v_i$, respectively.

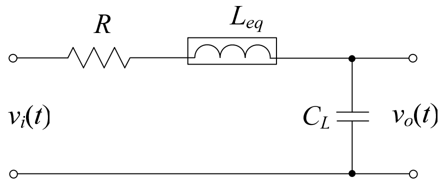


Fig. 5 The proposed positive floating inductor in RLC low-pass filter.

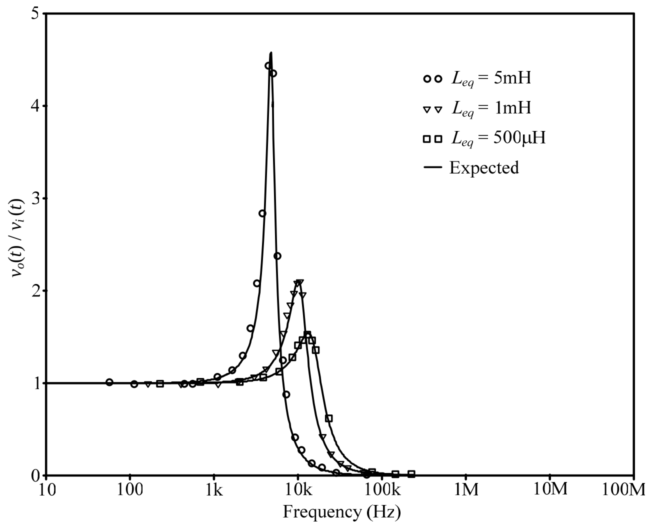


Fig. 6 Frequency responses of the low-pass filter.

The proposed floating inductor is applied in RLC low-pass filter as shown in Fig. 5. From Fig. 5, the resistor R and the capacitor C_L were set to 33Ω and 0.22μF, respectively. The proposed floating inductances L_{eq} = 5mH, 1mH and 500μH were chosen to achieved the resonance frequencies of the low-pass filter at 5kHz, 10kHz and 15kHz, respectively. Fig. 6 shows plots of the frequency responses of the low- pass filter in Fig. 5. It should be noted that both proposed positive and negative floating inductance simulators can be employed in analog electronic circuit design.

IV. Conclusion

The electronically adjustable floating inductance simulator has been described in this paper. The proposed inductance simulator is based on the use of OTAs and a grounded capacitor. Both positive and negative inductances are obtained in the same circuit. The magnitude of the resulting inductance can be electronically varied by changing the external bias current of OTAs. Experimental results verifying the basic performances of the proposed floating inductor are agreed with the expected values.

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