Research Article

New Topologies of Lossless Grounded Inductor Using OTRA

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Two alternate topologies of lossless grounded inductor have been proposed using operational transresistance amplifier (OTRA). Three applications using the proposed inductors are also included. PSpice simulation and experimental results have been included to demonstrate the performance and verify the theoretical analysis.

1. Introduction

Recently the operational transresistance amplifier (OTRA) has emerged as alternate important analog building block as it inherits all the advantages offered by current mode techniques. The OTRA is a high-gain current input voltage output device. The input terminals of OTRA are internally grounded, thereby eliminating response limitations due to parasitic capacitances and resistances at the input. Although the OTRA is commercially available from several sources under the name of current differencing amplifier or Norton amplifier, it has not gained attention until recently. These commercial realizations do not provide internal ground at the input port and allow the input current to flow in one direction only. The former disadvantage limits the functionality of the OTRA where as the later forces to use external DC bias current leading to complex and unattractive designs [1]. Several high-performance CMOS OTRA topologies have been proposed in literature [1–4] leading to growing interest in OTRA-based analog signal processing circuits. In the recent past OTRA has been extensively used as an analog building block for realizing a number of signal processing circuits such as filters [5–8], oscillators [9, 10], multivibrators [11, 12], and immittance simulation circuits [9, 13–15], an application which has been dealt with in this paper. A number of grounded parallel immittance topologies using single OTRA are proposed in [13]. However

none of these configurations can realize a lossless grounded inductor. The structure in [14] presents simulation of lossless negative grounded inductance. Lossless grounded inductor simulators using two OTRAs, five resistors, and one capacitor are presented in [9, 15].

In this paper two additional topologies of lossless grounded inductor using two OTRAs, five resistors, and one capacitor are reported. In these topologies five passive elements out of six are grounded as compared to four grounded elements in [9, 15]. Some applications of the proposed topologies are also presented.

2. Circuit Description

OTRA is a three-terminal device, shown symbolically in Figure 1 and its port relations can be characterized by the following matrix:

$$\begin{bmatrix} V_p \\ V_n \\ V_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_o \end{bmatrix}. \quad (1)$$

For ideal operations the transresistance gain R_m approaches infinity and forces the input currents to be equal. Thus OTRA must be used in a negative feedback configuration.

The proposed lossless grounded inductor topologies are shown in Figure 2. Routine analysis of the circuit of

FIGURE 1: OTRA circuit symbol.

FIGURE 2: Inductor simulation topologies.

FIGURE 3: CMOS implementation of OTRA [4].

Figure 2(a) results in the following expression for input admittance:

$$Y_{in}(s) = \left(G_1 + G_3 + G_5 - \frac{G_1 G_5}{G_4} \right) + \frac{C_1 G_4}{s G_2 G_3 G_5}, \quad (2)$$

Y_{in} will be purely inductive if the following condition is met

$$G_1 + G_3 + G_5 = \frac{G_1 G_5}{G_4}. \quad (3)$$

Similarly for inductor topology of Figure 2(b), input admittance is given by

$$Y_{in}(s) = \left(G_1 + G_2 + G_4 - \frac{G_2 G_4}{G_3} \right) + \frac{C_1 G_3}{s G_1 G_2 G_5}. \quad (4)$$

This input admittance will be purely inductive provided that

$$G_1 + G_2 + G_4 = \frac{G_2 G_4}{G_3}. \quad (5)$$

The equivalent inductance values along with conditions are given in Table 1.

It is clear from Table 1 that for both the topologies the inductance value can be controlled independent of condition of realization.

The proposed topologies are verified through simulations using the CMOS implementation of the OTRA [4] as given in Figure 3. The SPICE simulation is performed using $0.5 \mu\text{m}$ CMOS process parameters provided by MOSIS (AGILENT) and supply voltages taken are $\pm 1.5 \text{ V}$. Aspect ratios used for different transistors are given in Table 2.

An inductor of value $L_{eq} = 0.1 \text{ mH}$ is designed using the inductor topology of Figure 2(a) with the component values of $R_1 = R_2 = R_3 = R_5 = 1 \text{ K}\Omega$, $R_4 = 3 \text{ K}\Omega$, $C_1 = 300 \text{ pF}$. The frequency response of the impedance as obtained using this inductor is shown in Figure 4(a). The inset depicts the enlarged view of impedance response in lower frequency range.

TABLE 1: Inductors realized by the topologies shown in Figure 2.

Figure	Condition	L_{eq}	Non-interactive control of L_{eq}
Figure 2(a)	$G_1 + G_3 + G_5 = \frac{G_1 G_5}{G_4}$	$\frac{C_1 G_4}{G_2 G_3 G_5}$	Independent control of value of L_{eq} through G_2
Figure 2(b)	$G_1 + G_2 + G_4 = \frac{G_2 G_4}{G_3}$	$\frac{C_1 G_3}{G_1 G_2 G_5}$	Independent control of value of L_{eq} through G_5

(a)

(b)

FIGURE 4: (a) Impedance versus frequency response of topology of Figure 2(a). (b) Impedance versus frequency response of topology of Figure 2(b).

TABLE 2: Aspect ratio of the transistors.

Transistor	$W(\mu m)/L(\mu m)$
M_1-M_3	100/2.5
M_4	10/2.5
M_5, M_6	30/2.5
M_7	10/2.5
M_8-M_{11}	50/2.5
M_{12}, M_{13}	100/2.5
M_{14}	50/0.5

Similarly, Figure 4(b) shows the frequency response of the impedance of the inductor of value $L_{eq} = 10 \mu H$ as obtained with component values of $R_1 = R_2 = R_4 = R_5 = 1 K\Omega$, $R_3 = 3 K\Omega$, and $C_1 = 30 pF$ for inductor topology given in Figure 2(b). In the inset, the variation of impedance in lower frequency range is shown.

3. Applications

In this section some applications of the proposed topologies have been presented. Both the topologies may be used for constructing filter and oscillator circuits.

3.1. High-pass Filter. A high pass filter, as shown in Figure 5(a), can be constructed using proposed inductors. The transfer function for high pass response is obtained as

$$\frac{V_o}{V_{in}} = \frac{s^2}{s^2 + s/CR + 1/L_{eq}C}, \quad (6)$$

where

$$\omega_0 = \frac{1}{\sqrt{L_{eq}C}}, \quad Q = R\sqrt{\left(\frac{C}{L_{eq}}\right)}. \quad (7)$$

The functionality of the high pass filter is verified using the inductor topology of Figure 2(a) and designed for lower cutoff frequency of 503.3 KHz. The component values are obtained as $R = 300 \Omega$ and $C = 1 nF$ for $L_{eq} = 0.1 mH$. The value of $L_{eq} = 0.1 mH$ is obtained using inductor topology of Figure 2(a) with component values of $R_1 = R_2 = R_3 = R_5 = 1 K\Omega$, $R_4 = 3 K\Omega$, and $C_1 = 300 pF$. The frequency response of the filter simulated using PSPICE is depicted in Figure 5(b). Simulated value of lower cutoff frequency is obtained as 505 KHz which is in close agreement to the theoretical value of 503.2 KHz.

3.2. Band Pass Filter. The proposed inductor topologies may also be used to obtain band-pass response using the circuit

FIGURE 5: (a) High-pass filter. (b) Frequency response of high pass filter.

FIGURE 6: (a) Band-pass filter. (b) Frequency response of band-pass filter.

FIGURE 7: (a) LC oscillator. (b) Output of LC oscillator.

FIGURE 8: CFOA based OTRA implementation.

FIGURE 9: Frequency response of the high-pass filter.

given in Figure 6(a). The transfer function for band-pass response is obtained as

$$\frac{V_o}{V_{in}} = \frac{s/CR}{s^2 + s/CR + 1/L_{eq}C}, \quad (8)$$

where

$$\omega_0 = \frac{1}{\sqrt{(L_{eq}C)}}, \quad Q = R \sqrt{\left(\frac{C}{L_{eq}}\right)}. \quad (9)$$

FIGURE 10: Experimental output of LC oscillator.

The theoretical proposition is verified using the topology of Figure 2(b). A band-pass filter is designed having center frequency of 503.3 KHz. The component values are obtained as $R = 1 \text{ K}\Omega$ and $C = 1 \text{ nF}$ for $L_{eq} = 0.1 \text{ mH}$. The value of $L_{eq} = 0.1 \text{ mH}$ is obtained for inductor topology of Figure 2(b) with component values of $R_1 = R_2 = R_4 = R_5 = 1 \text{ K}\Omega$, $R_3 = 3 \text{ K}\Omega$, $C_1 = 300 \text{ pF}$. The frequency response of the filter simulated using PSPICE is depicted in Figure 6(b). The simulated results are in close agreement with the theoretical prediction.

3.3. LC Oscillator. An LC Oscillator can be realized using the proposed inductor topologies. Figure 7(a) shows the schematic of an LC oscillator using topology of Figure 2(a) for which the condition of oscillation (CO) and frequency of oscillation (FO) are obtained as

$$\text{CO} : G_1 + G_3 + G_5 = \frac{G_1 G_5}{G_4}, \quad (10)$$

$$\text{FO} : f_o = \frac{1}{2\pi\sqrt{CC_1R_2R_3R_5/R_4}}. \quad (11)$$

Figure 7(b) shows the output of the oscillator for $L_{eq} = 0.1 \text{ mH}$ and $C = 330 \text{ pF}$. Simulated frequency of oscillation is 860 KHz as against the calculated value of 876.2 KHz with % error of 1.85%.

3.4. Experimental Verification. The proposed inductor topologies are also tested experimentally to verify the theory. The OTRA is implemented using two CFOAs (IC AD844AN) as shown in Figure 8 with a supply voltage of $\pm 5 \text{ V}$.

The high pass filter of Figure 5(a) is prototyped with $C = 1 \text{ nF}$, $R = 680 \Omega$, and $L_{eq} = 1 \text{ mH}$. The inductor of value $L_{eq} = 1 \text{ mH}$ is implemented using inductor topology of Figure 2(a) with component values of $R_1 = R_2 = R_3 = R_5 = 1 \text{ K}\Omega$, $R_4 = 3 \text{ K}\Omega$, and $C_1 = 3 \text{ nF}$. Theoretical, simulated and experimental frequency responses are shown in Figure 9. It is observed that the experimental values more or less follow the theoretical and simulated values. The oscillator circuit of Figure 7(a) is also tested experimentally. The output waveform observed on oscilloscope is shown in Figure 10. The observed frequency of oscillation is found to be 872.5 KHz, which is in close agreement to theoretically calculated value of 876.2 KHz.

4. Conclusion

Two new OTRA-based lossless grounded inductor topologies are presented. A high pass filter, band-pass filter, and an oscillator are realized using the proposed inductor topologies to illustrate their applications. PSpice simulation and experimental results are included to verify the theoretical propositions. It is found that the results obtained are in close agreement with the ideal values. Hence it is expected that the proposed inductors will provide an option to integrated circuit designer where lossless grounded inductor is required.

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