Electronically Tunable Floating Inductance Simulation Based on Current-Controlled Current Differencing Buffered Amplifiers

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Abstract

A new bipolar-based realization of a current-controlled current differencing buffered amplifiers (CC-CDBAs) is introduced. It is a novel electronically tunable lossless floating inductance simulator. The proposed floating inductance circuit uses only three proposed CC-CDBAs and a grounded capacitor. Its equivalent inductance can linearly be tuned by means of the external bias current of the CC-CDBA. Without the employment of any external passive resistors, the proposed inductance simulation circuit is particularly attractive for integrated circuit (IC) implementation. PSPICE simulations of the proposed circuits give results that agree well with the theoretical analysis.

Keywords : current differencing buffered amplifier (CDBA), floating inductance (FI), electronically tunable, current-controlled, active filters.

1. Introduction

Owing to the desirability of building active filters without the employment of physical coils, much attention is focused on inductance simulation using various high-performance active building blocks, such as, current conveyor (CC), current feedback op-amp (CFOA) and four terminal floating nullor (FTFN). There are several applications of inductance simulators such as active filter design, oscillator design, and cancellation of parasitic elements. Early implementations of a simulated inductance have been reported in the literature [1]-[10]. However, all of these existing circuits suffer from one or more of the following disadvantages :

1. Require an excessive number of active elements [1], [2], [5], [9], [10].
2. Use different types of active elements [1], [3], [7], [8].
3. Lack electronic controllability [1],[2],[4], [5], [9], [10].
4. Require some external passive resistors [6], [9], [10].

For ease of monolithic IC fabrication processes, it is advantageous to realize an inductance simulation circuit by using only one type and a minimum number of active elements.

Recently, a current differencing buffered amplifier (CDBA), which is a new active circuit building block especially suitable for the realization of a class of continuous-time filters, has been proposed [11]. It can also offer advantageous features such as high-slew rate, freedom from parasitic capacitances, wide bandwidth and simple implementation [12]. Although CDBA-based floating inductance simulators have been recently reported in [13]and [14], they still require some additional MOS resistive circuits (MRCs) for providing an electronic tuning capability [15]. Moreover, their equivalent inductance value is dependent on the gate voltage of the MOSFETs in MRCs, which is a square function. This means that an electronic tuning property of the circuits is nonlinear. From a practical point of view, it is preferable for the mentioned circuits that their tuning ability is linearly tunable.

The focus of this study is to present a translinear-based current-controlled current differencing buffered amplifier (CC-CDBAs). Its parasitic input resistances can electronically be varied. We then propose a novel electronically tunable lossless floating inductance simulation circuit employing the proposed CC-CDBAs as active elements, whose equivalent inductance can linearly be tuned though adjusting the external bias currents of the CC-CDBAs. The proposed scheme uses only three CC-CDBAs and one grounded capacitor, which requires fewer active and passive components than most of the counterparts in the literature. Without external passive resistor requirements, the configuration has remarkable advantages in ease of IC fabrication processes [16],[17]. PSPICE simulation results are included to confirm the presented technique. Also, the performance of the proposed inductance simulator is demonstrated on a series RLC resonance circuit.

2. Circuit Description

2.1 CDBA

Basically, the CDBA is a four-terminal active element represented symbolically as shown in Fig.1. For ideal operation, its current and voltage relations can be described by the following equation [11]-[12].

$$\begin{bmatrix} v_p \\ v_n \\ i_z \\ v_w \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_z \\ i_z \\ i_p \\ i_n \end{bmatrix} \quad (1)$$

Equation (1) shows that the difference of the input currents i_p and i_n is $(i_p - i_n)$ and is conveyed into the output voltage v_w via an external impedance connected at the terminal z. The terminals z and w of the CDBA can be considered as the current and voltage outputs, respectively. Ideally, the input terminals p and n are internally grounded or $r_p = r_n \cong 0\ \Omega$. However, the CDBA can be considered as a more flexible and versatile active circuit building block, if the values of r_p and r_n can be varied and controlled by electronic means. Therefore, a circuit configuration of a current-controlled CDBA (CC-CDBA) will be introduced in the next section. Then, it will be used as an active element for realizing the proposed electronically tunable CC-CDBA-based lossless floating inductance simulation circuit which requires only a grounded capacitor as a passive element.

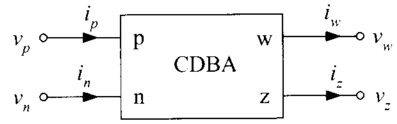

Fig.1 Symbol of the CDBA

2.2 Proposed CC-CDBA

The circuit diagram of the proposed CC-CDBA and its symbolic representation are shown in Fig.2. The input stage providing the difference current $(i_p - i_n)$ consists of transistors Q_1-Q_{24}, where groups of transistors Q_1, Q_2, Q_3, Q_4 and Q_1, Q_3, Q_5, Q_6 constitute the input translinear loop [18]. In this case, the circuit presents the parasitic resistances r_p and r_n at the terminals p and n respectively, which can be given by :

$$r_p \cong r_n = R_x = \frac{V_T}{2I_A} \quad (2)$$

where V_T = 26 mV at 300°K is the thermal voltage. Therefore, it is possible to electronically tune the value of the resistance R_x by means of an external dc bias current I_A.

The input currents i_p and i_n are subtracted at the collectors of Q_7 and Q_8, and flow from the terminal z into an external load by the current mirrors Q_{17}-Q_{20} and Q_{21}-Q_{24}. The voltage across the terminal z (v_z) is transferred to the terminal w (v_w) by a unity-gain voltage amplifier Q_{25}-Q_{28}. Here, transistors Q_{25}, Q_{27} and Q_{26}, Q_{28} are constructed as a cascade emitter follower. Let us assume that all transistors are well matched, the routine circuit analysis gives the equivalent input resistance at the terminal z (r_z) as:

$$r_z \cong \beta_n \beta_p \left(\frac{r_e}{2} + R_w \right) \quad (3)$$

where $\beta_n = \beta_{25} \cong \beta_{27} >> 1$, $\beta_p = \beta_{26} \cong \beta_{28} >> 1$, $r_e = V_T/I_B = r_{e25} \cong r_{e26} \cong r_{e27} \cong r_{e28}$, and R_w is a load resistor connected at the terminal w. The parasitic resistance looking at terminal w (r_w) is low and given by :

$$r_w \cong \left(\frac{r_e}{2} + \frac{R_z}{\beta_n \beta_p} \right) \qquad (4)$$

where R_z is a converting resistor connected to the terminal z. From the circuit operation, the current-voltage characteristics of the proposed CC-CDBA can be summarized by the following matrix.

$$\begin{bmatrix} v_p \\ v_n \\ i_z \\ v_w \end{bmatrix} = \begin{bmatrix} 0 & 0 & R_x & 0 \\ 0 & 0 & 0 & R_x \\ 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_z \\ i_z \\ i_p \\ i_n \end{bmatrix} \qquad (5)$$

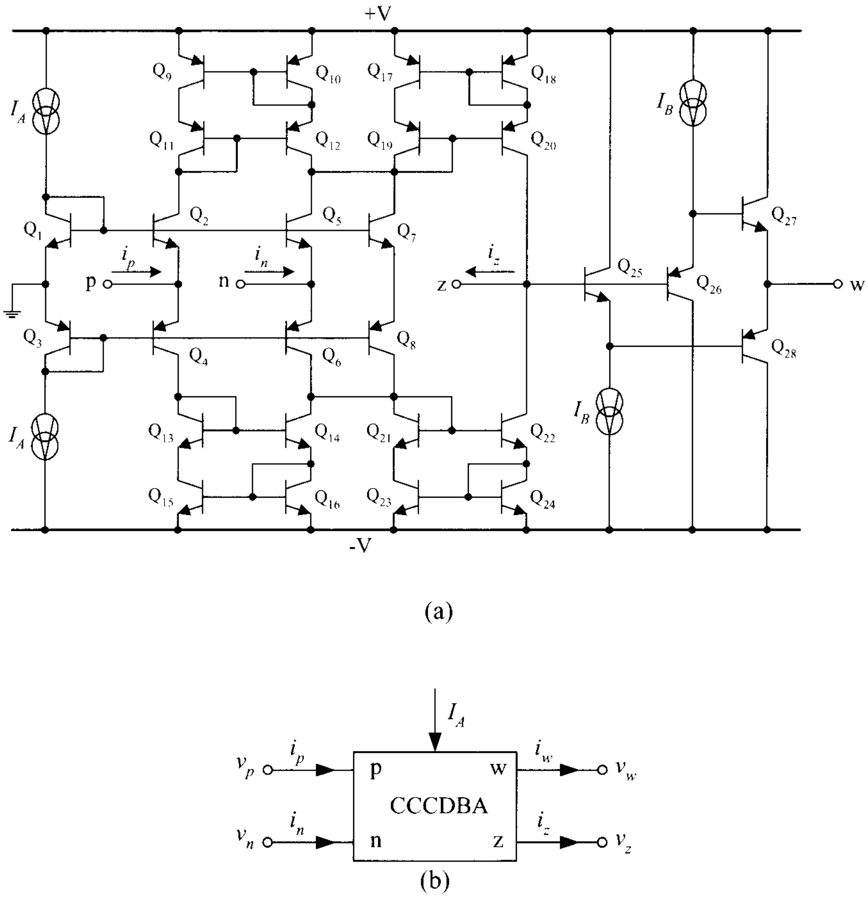

Fig.2: The proposed CC-CDBA
(a) circuit diagram (b) circuit symbol

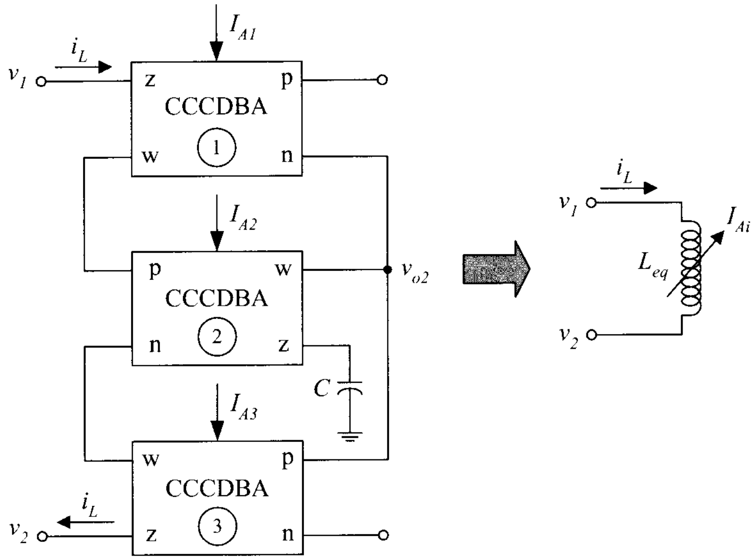

Fig.3 The proposed electronically tunable floating inductor using CC-CDBAs

3.Proposed Inductance Simulation Circuit

Fig.3 shows the proposed electronically tunable lossless floating inductor. It consists of only three CC-CDBAs and a grounded capacitor. According to the property of the CC-CDBA from equation (5), an input impedance Z_{in} can be written as :

$$Z_{in} = \frac{v_1 - v_2}{i_L} = s(R_{x1}R_{x2}C) \qquad (6)$$

where R_{xi} is the parasitic resistance R_x of the i-th CC-CDBA (i = 1, 2, 3), and the resistances R_{x1} and R_{x3} are identical. From the above equation, the proposed inductance simulation circuit of Fig.3 provides inductive impedance with an equivalent inductance L_{eq} :

$$L_{eq} \cong R_{x1}R_{x2}C \qquad (7).$$

Note that the L_{eq} value obtained from the proposed circuit has the same value as that proposed in [5], [9], [10], but the number of conveyors is reduced by one and it does not require any external passive resistors. In addition, the proposed circuit requires a minimum number of active and passive elements as in [14], but without requiring any additional MRCs. Since all the resistance's R_{xi} directly depend on the bias current I_{Ai} of the CC-CDBAi, the L_{eq} value can also be linearly controllable by I_{Ai}. Although the value of R_{xi} is found to be sensitive to the temperature, a bias circuit with a current linearly proportional to temperature can be employed for the temperature compensation [19]. By using only a grounded capacitor in the circuit realization, the proposed floating inductor is particularly suitable for monolithic IC implementations [16],[17]. Furthermore, if the capacitor C of Fig.3 is replaced by an external passive resistor R, the proposed circuit performs as a resistance multiplier.

4. Simulation results

The proposed circuits were simulated by PSPICE using the AT&T ALA400-CBIC-R bipolar process parameters [20]. The power supply voltages were $\pm$V = $\pm$3 V and all the bias currents I_B were set to be constant at 250 μA. The simulated characteristics of the proposed CC-CDBA in Fig.2(a) are listed in Table 1, when I_A = 100 μA, R_z = 1 kΩ and R_w = 10 kΩ.

Table 1: Characteristics of the proposed CC-CDBA

Parameters	Value	Unit
Total power dissipation	7.37	mW
-3dB bandwidth	40	MHz
Maximum offset current (from i_p and i_n to i_z)	2	μA
Maximum offset voltage (from v_z to v_w)	13	mV
r_p , r_n	140	Ω
r_z	650	kΩ
r_w	53	Ω

The simulation result showing the typical waveforms of the voltage and current through the proposed floating inductor L_{eq} of Fig.3 is illustrated in Fig.4, when I_A = 100 μA and C = 10 nF. The deviation in the current response i_L from the ideal value is mainly caused by the non-idealities of the CC-CDBA, i.e., the error values of r_p and r_n from the calculation values, and the effects from the parasitic resistances at the terminals z and w.

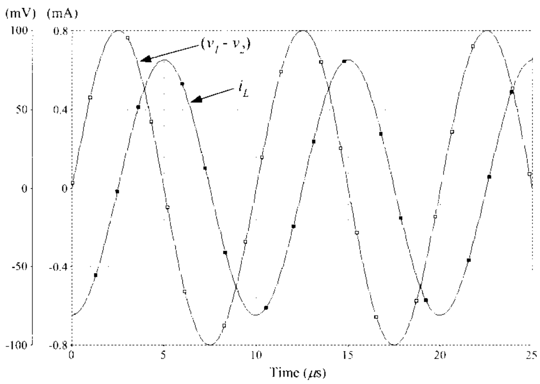

Fig.4 Typical waveforms of voltage and current of the proposed floating inductor L_{eq}

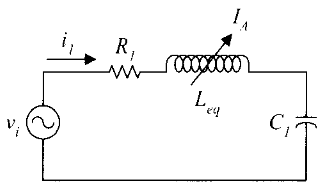

Fig.5 Series RLC resonance circuit

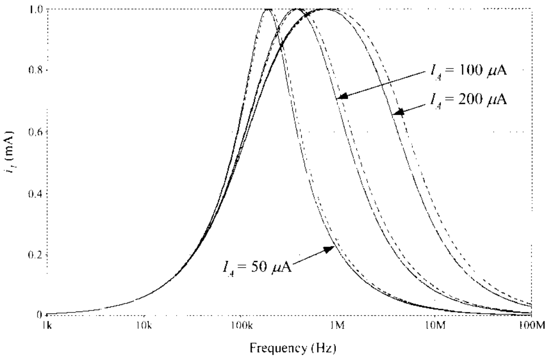

Fig.6: Simulated current characteristics of the resonance circuit of Fig.5, when I_A is varied.

In order to demonstrate the performance of the proposed floating inductor of Fig.3, the basic series RLC resonance circuit shown in Fig.5 was built, where the physical coil L is replaced by the proposed L_{eq}. For R_1 = 1 kΩ, C_1 = 1 nF and three different values of I_A ($I_A = I_{A1} = I_{A2} = I_{A3}$), the simulated current characteristics of the resonance circuit are shown in Fig.6 as the solid lines. The dashed lines are the ideal results corresponding to calculations when L = 0.676 mH, 0.169 mH and 0.042 mH, respectively. The simulation results show good agreement with the ideal calculation results.

5. Conclusion

A design of the current-controlled current differencing buffered amplifier (CC-CDBA) has been proposed. Based on the use of the proposed CC-CDBA as an active element, a novel current-controlled lossless floating inductance simulation circuit has also been proposed. The proposed inductance simulation circuit offers the following advantageous features, namely:

(i) requires a minimum number of active components,

(ii) linearly electronic control,

(iii) only one grounded capacitor,

(iiii) no external passive resistors.

PSPICE simulation and calculation results are in agreement and verify the usefulness of the proposed floating inductor for building active filter implementations.

6. Acknowledgment

This work is funded by the Thailand Research Fund (TRF) under the Senior Research Scholar Program, grant number RTA4680003.

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