Variable Lossy Series Inductance Simulator Using Single Voltage Differencing Buffered Amplifier (VDBA)

Tattaya Pukkalanun, Natchanai Roongmuanpha, and Worapong Tangsrirat, *Member, IAENG*

***Abstract*—Actively simulated lossy series RL-type inductor with voltage differencing buffered amplifier (VDBA) is described. The proposed inductance simulator is simulated using one VDBA, one grounded capacitor and one floating resistor. The realized equivalent value of the simulator is electronically controllable by the transconductance parameter of the VDBA. The effect of the VDBA non-idealities on the realized equivalent resistance and inductance values is also investigated in detail. As an application, active second-order current-mode lowpass filter is designed using the proposed variable lossy inductance simulator. The results obtained from PSPICE simulation demonstrate a close agreement with the theory, and also confirm the workability of the proposed simulator and its filter application.**

***Keywords* — Voltage Differencing Buffered Amplifier (VDBA), inductance simulator, lossy inductor**

I. Introduction

Simulators for lossy series RL-type inductors play an important role in several areas like active RC filters, sinusoidal oscillator design, circuit cancellation and reduction of unavoidable parasitic element values [1]. Numerous specific topologies for the simulation of actively series R-L lossy inductors employing various active components have been developed in the technical literature [2]-[17]. In [3]-[5], they have been paid for realizing such type simulator circuits by using three CCIIs and four passive components. The works in [2], [12] provide an actively simulated grounded inductors using two active elements, and a large number of external passive elements, i.e. at least five passive elements. On the other hand, the circuits of [6]-[11], [13]-[15], [17] although use only one active component to realize grounded lossy inductors, but require three to four passive components. Other simulators in [2], [6]-[17] require a floating capacitor for their realization.

Recently, modern day active components are reviewed and discussed in [18], where the voltage differencing buffered amplifier (VDBA) is one of them. Attention was then paid to realize analog signal processing circuits and solutions by the use of VDBAs [19]-[22]. The purpose of this communication is to present a lossy series type grounded inductance simulator, which requires one VDBA, one grounded capacitor and one floating resistor. The equivalent resistance and inductance values of the proposed simulator can be tuned electronically through the transconductance parameter (g_m) of the VDBA. The performance of the simulator was evaluated through the PSPICE simulation using TSMC 0.25-μm CMOS technology.

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II. Description of Voltage Differencing Buffered Amplifier (VDBA)

The circuit representation of the VDBA element is shown in Fig.1. Ideally, the device consists of the transconductance amplifier as an input stage, and the voltage follower as an output stage. Thus, the ideal characteristic of the VDBA device can be described by the following matrix equation :

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

where g_m is the small-signal transconductance gain of the VDBA. Generally, the g_m-value is electronically controllable over several decades by a supplied bias current/voltage, which lends electronic tunability to design circuit parameters. From eq.(1), the differential input voltage between the terminals p and n (v_p-v_n) is converted to a current at the z-terminal (i_z) by a g_m-parameter. The voltage across the z-terminal (v_z) is then conveyed to the output voltage at the w-terminal (v_w).

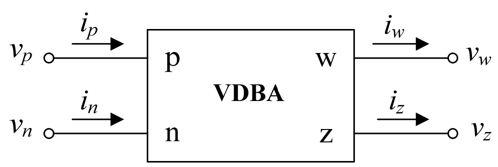

Fig. 1. Circuit symbol of the VDBA.

III. Proposed Lossy Series Inductance Simulator

The proposed actively simulated R-L series impedance function is shown in Fig.2. The simulator employs only one VDBA as an active component together with one grounded

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capacitor C_1 and one floating resistor R_1 as external passive components. Deriving the proposed circuit of Fig.2 with eq.(1), the expression for the input impedance Z_{in} is found to be

$$Z_{in} = \frac{v_{in}}{i_{in}} = R_{eq} + sL_{eq} = \frac{1}{g_m} + s\left(\frac{R_1C_1}{g_m}\right) , \tag{2}$$

which represents the series connection of equivalent resistance (R_{eq}) and equivalent inductance (L_{eq}) as :

$$R_{eq} = \frac{1}{g_m} \tag{3}$$

and

$$L_{eq} = \frac{R_1C_1}{g_m} . \tag{4}$$

From above expression, the proposed circuit can simulate series R and L impedance. The realized values of the proposed simulator circuit do not require any element-matching condition. Since the g_m-value of the VDBA directly depends on the external biasing current, the simulated value is electronic programmability.

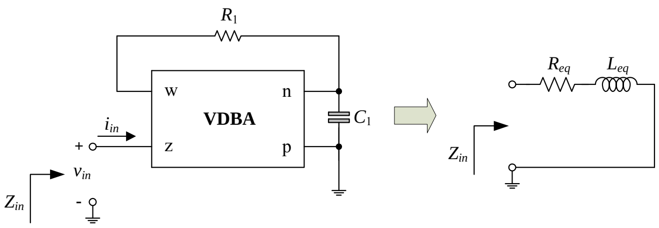

Fig. 2. Proposed lossy series inductance simulator and its equivalent behavior.

IV. Tracking Error Analysis

The non-ideal relations for the VDBA can be described as :

$$\begin{bmatrix} i_p \\ i_n \\ i_z \\ v_w \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \alpha g_m & -\alpha g_m & 0 & 0 \\ 0 & 0 & \beta & 0 \end{bmatrix} \cdot \begin{bmatrix} v_p \\ v_n \\ v_z \\ i_w \end{bmatrix} \tag{5}$$

where $\alpha = (1 - \varepsilon_{gm})$ and $\beta = (1 - \varepsilon_v)$. Also, $|\varepsilon_{gm}| << 1$ denotes the transconductance inaccuracy, and $|\varepsilon_v| << 1$ denote the voltage tracking error from terminal z to terminal w, respectively. Taking into account the VDBA non-idealities in the proposed circuit of Fig.2, the equivalent non-ideal input impedance is found as :

$$Z_{in} = R_{eq} + sL_{eq} = \frac{1}{\alpha\beta g_m} + s\left(\frac{R_1C_1}{\alpha\beta g_m}\right) . \tag{6}$$

In non-ideal condition, the parasitic gains α and β of the VDBA have slightly alter on the realized Z_{in} value. However, this small discrepancy can be reduced by properly adjusting the value of g_m of the VDBA.

The active and passive sensitivities of the circuit parameters are calculated and obtained as :

$$S_{\alpha}^{R_{eq}} = S_{\beta}^{R_{eq}} = S_{g_m}^{R_{eq}} = -1 \tag{7}$$

$$S_{\alpha}^{L_{eq}} = S_{\beta}^{L_{eq}} = S_{g_m}^{L_{eq}} = -1 \tag{8}$$

$$S_{R_1}^{R_{eq}} = S_{C_1}^{R_{eq}} = 0 \tag{9}$$

and

$$S_{R_1}^{L_{eq}} = S_{C_1}^{L_{eq}} = 1 . \tag{10}$$

All the component sensitivity values are within unity in magnitude.

V. Results of Computer Simulations

The designed simulator circuit of Fig.2 is simulated with PSPICE program using a particularly simple CMOS implementation of VDBA shown in Fig.3. In Fig.3, the transconductance gain of this structure can be given by :

$$g_m = \sqrt{\mu C_{ox}\left(\frac{W}{L}\right) I_{B1}} . \tag{11}$$

Here, μ is the mobility of the carriers, C_{ox} is the gate-oxide capacitance per unit area, W is the effective channel width, and L is the effective channel length. For simulations, the MOS transistors are simulated using TSMC 0.25-μm process parameters with the aspect ratios (W/L) provided in Table I. The DC supply voltages were taken as : +V = -V = 0.75V, and the DC bias currents were given by : I_{B2} = 100 μA and I_{B3} = 50 μA.

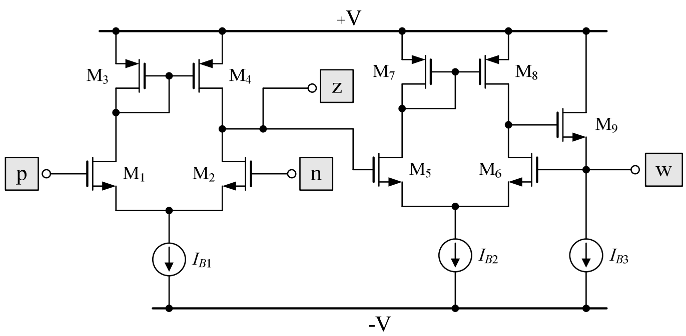

Fig. 3. CMOS realization of the VDBA.

TABLE I
TRANSISTOR ASPECT RATIOS FOR THE VDBA IN FIG.3.

Transistor	W/L (μm/μm)
M_1-M_2 , M_5-M_6	5/0.25
M_3	19.87/0.25
M_4 , M_8	32.9/0.25
M_7	33.07/0.25
M_9	25/0.25

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The proposed inductance simulator of Fig.2 is simulated with the following component values : I_{B1} = 50 μA ($g_m \cong$ 550 μA/V), R_1 = 1.5 kΩ and C_1 = 0.2 nF. According to eqs.(3) and (4), the realized R_{eq} and L_{eq} are obtained as : R_{eq} = 1.82 kΩ and L_{eq} = 0.55 mH. The simulated transient waveforms for v_{in} and i_{in} of the simulator are shown in Fig.4, where the amplitude and the frequency of v_{in} are 50 mV (peak) and f = 1 MHz, respectively. From Fig.4 it can be measured that the current i_{in} lag the voltage v_{in} by approximately 55°, which is very close to the calculated value equal to 62°. The total power dissipation is approximately found to be : 0.316 mW. With the above designed element values, the simulated frequency responses for the input impedance Z_{in} of the proposed circuit in Fig.2 comparing with the ideal responses are also plotted in Fig.5. The resulting characteristics indicate that the simulator operates pretty well between 1 kHz and 2 MHz approximately.

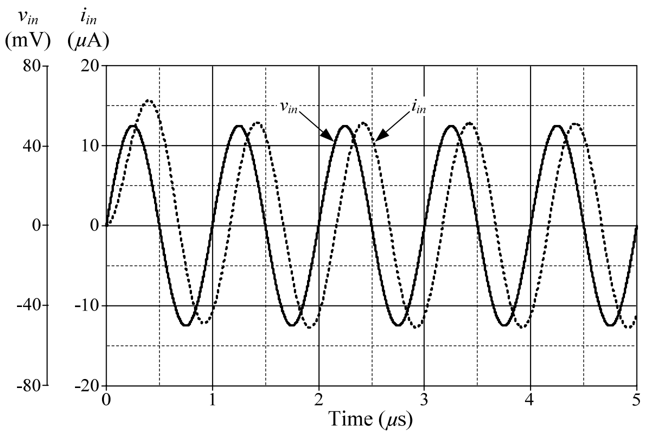

Fig. 4. Simulated transient responses for v_{in} and i_{in} of the proposed lossy inductance simulator in Fig.2.

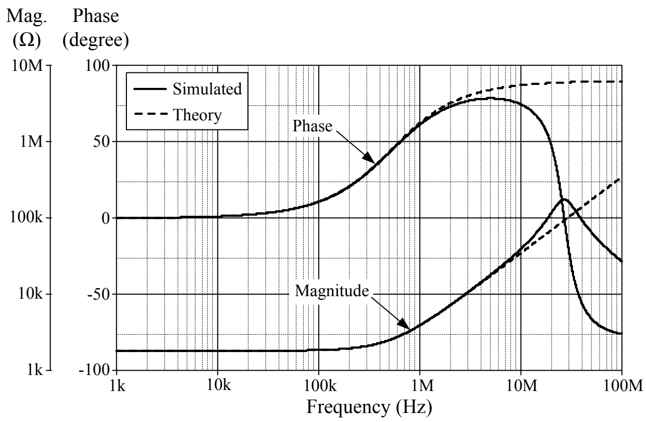

Fig. 5. Simulated frequency responses for Z_{in} of the proposed lossy inductance simulator in Fig.2.

To test the electronic tunability of R_{eq}, the circuit of Fig.2 was simulated with C_1 = 0.2 nF. For this purpose, the external DC biasing current I_{B1} of the VDBA is varied for three different values, i.e. I_{B1} = 20 μA ($g_m \cong$ 373 μA/V), 80 μA ($g_m \cong$ 660 μA/V), and 300 μA ($g_m \cong$ 1 mA/V), which leads to R_{eq} = 2.68 kΩ, 1.51 kΩ, and 1 kΩ, respectively. In order to obtain a constant value of L_{eq} = 0.55 mH, the R_1 is also adjusted from 1.02 kΩ, 1.81 kΩ, to 2.77 kΩ. The simulation results of the three frequency responses for Z_{in} with different R_{eq} while keeping L_{eq} in variant is shown in Fig.6. It is proven from the results that the proposed circuit provides an electronically tunable R_{eq} by changing the g_m-value of the VDBA. Also note that due to the major goal of this work is to design a grounded lossy inductance simulator configuration with minimum number of components, an independent electronic tuning of R_{eq} and L_{eq} is not expected.

To test for controllability of the L_{eq} without changing the value of R_{eq}, the component values were taken as : I_{B1} = 50 μA ($g_m \cong$ 550 μA/V) and C_1 = 0.2 nF, with three different values for R_1 namely 2 kΩ, 3.3 kΩ and 7.5 kΩ. This leads to give a constant value of R_{eq} = 1.82 kΩ, and the corresponding three values of L_{eq} as : 0.73 mH, 1.2 mH, and 2.73 mH, respectively. The three frequency responses are plotted in Fig.7, which demonstrate the variability of the L_{eq}-value accordingly.

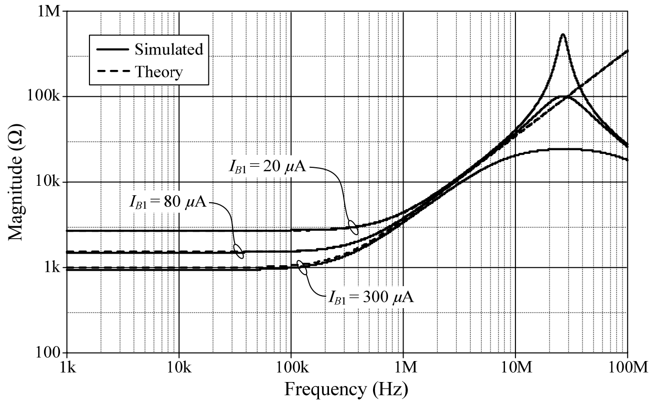

Fig. 6. Simulation results of frequency responses for Z_{in} with different R_{eq} while keeping L_{eq} in variant.

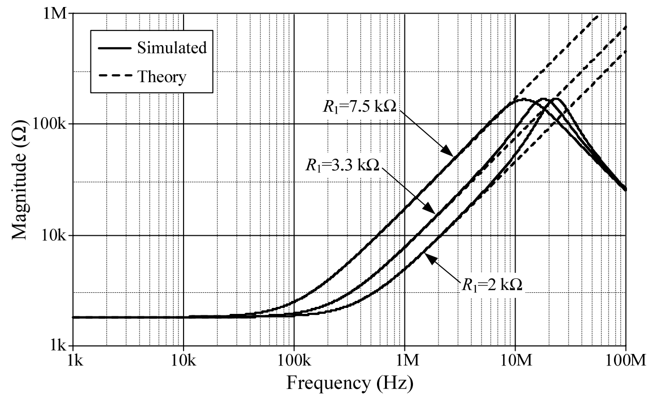

Fig. 7. Simulation results of frequency responses for Z_{in} with different L_{eq} while keeping R_{eq} in variant.

VI. Application Example

To demonstrate an application of the proposed lossy inductance simulator in Fig.2, a second-order lowpass current-mode filter shown in Fig.8 was designed and simulated. In this structure, the proposed actively inductance simulator in Fig.2 replaces the series R-L component. The component values of the designed lowpass filter were selected as : I_{B1} = 50 μA, R_1 = 1.45 kΩ, C_1 = 0.2

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nF, and C_{LP} = 0.1 nF; therefore the lossy inductor with R_{eq} = 1.82 kΩ and L_{eq} = 0.53 mH is realized, which results in a pole frequency $f_p = \omega_p/2\pi \cong$ 691 kHz and a quality factor Q = 1.26. Fig.9 shows the theory and simulated frequency responses of the active lowpass filter of Fig.8, where the corresponding f_p obtained from the simulated results is approximated to 720 kHz.

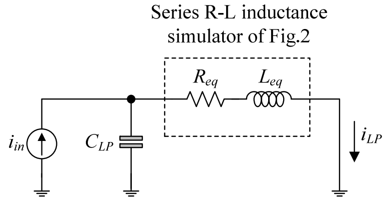

Fig. 8. Second-order current-mode lowpass filter with the proposed lossy inductance simulator in Fig.2.

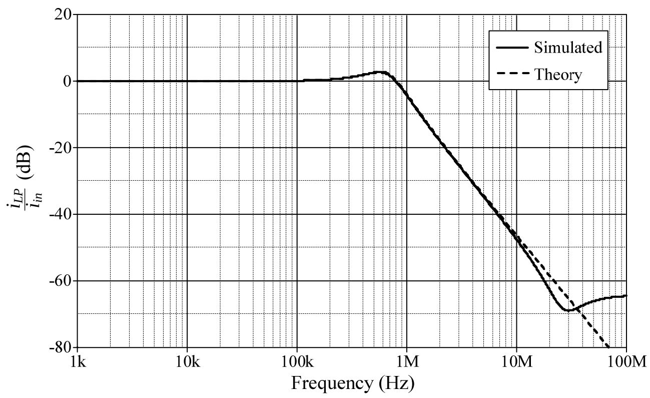

Fig. 9. Simulated frequency responses of the lowpass filter in Fig.8.

VII. Conclusion

This work presents the variable lossy R-L series inductance simulator circuit with minimum number of active and passive components. The proposed inductance simulator is simulated with a single VDBA and only two passive components. The equivalent values of the realized simulator can be tuned electronically through the VDBA's transconductance. The effectiveness of the simulator is verified by the simulation results, which demonstrate good agreement with the theoretical analysis.

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