

# Tunable Capacitance Multiplier with a Single Voltage Differencing Buffered Amplifier

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**Abstract**—This work describes the grounded electronically tunable capacitance multiplier circuit using voltage differencing buffered amplifier (VDBA) as an active element. The proposed capacitance simulator is simulated using one VDBA, one floating capacitor and one grounded resistor. The realized equivalent capacitance can be tuned electronically through the transconductance gain of the VDBA. The effect of the VDBA non-idealities on the realized equivalent capacitance has also been discussed in detail. As an application, active RC lowpass filter is realized using the proposed tunable capacitance simulator. PSPICE simulation results show a good agreement with the theoretical analysis, and verify the behaviors of the proposed simulator and its application.

**Keywords** — capacitance multiplier, Voltage Differencing Buffered Amplifier (VDBA), impedance simulator

## I. INTRODUCTION

A capacitance multiplier circuit is a useful active building block in many very large-scale integration (VLSI) analog circuits, especially for active RC filter and oscillator designs and cancellation of parasitic elements. This is well recognized that the large-valued physical capacitor is either not impractical or permitted to fabricate in the integrated circuit technology. Accordingly, the need for designs grounded capacitance multiplication topology with high equivalent integrated capacitance value is important for VLSI implementation point of view. Many capacitance multiplier circuit realizations employing more than two active elements were introduced [1]-[8]. In view of low power consumption and small silicon area on the chip, it is preferable to realize the simulator with a minimum number of active and passive components. Nowadays, modern electronic active building blocks are gaining importance in analog signal processing applications and designs. In [9], modern day active components have been reviewed and discussed. One of them is the circuit principle called as VDBA (voltage differencing buffered amplifier). Its several applications, such as active filters, sinusoidal oscillators and immittance function simulators, were also introduced to demonstrate its usefulness and versatile [10]-[13].

In this work, we largely consider a grounded capacitance simulator realization using one VDBA as active components together with one floating capacitor and one grounded resistor as passive components. The equivalent capacitance value ( $C_{eq}$ ) of the proposed simulation scheme can be controlled electronically through the transconductance parameter ( $g_m$ ) of the VDBA. The behavior of the proposed capacitance simulator was evaluated through the PSPICE simulation. A first-order RC lowpass filter using the proposed circuit was also simulated.

## II. VOLTAGE DIFFERENCING BUFFERED AMPLIFIER (VDBA)

The schematic symbol of the VDBA is shown in Fig.1. Basically, the VDBA device consists of the transconductance amplifier as an input stage, and the unity-gain voltage buffer as an output stage. Thus, the basic operation of this device can be characterized by the following equations [9]-[10] :

$$i_p = i_n = 0, \quad i_z = g_m(v_p - v_n) \quad \text{and} \quad v_w = v_z \quad (1)$$

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 ( $v_w$ ).

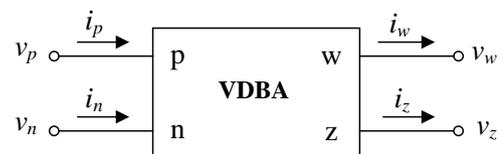


Fig. 1. Schematic symbol of the VDBA.

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### III. DESCRIPTION OF THE PROPOSED CAPACITANCE MULTIPLIER

The proposed capacitance multiplier circuit is shown in Fig.2. It employs only one VDBA, one capacitor floating  $C_1$ , and one grounded resistor  $R_1$ . Using eq.(1) and deriving the proposed circuit of Fig.2, its input impedance  $Z_{in}$  is realized of value :

$$Z_{in} = \frac{v_{in}}{i_{in}} = \frac{1}{s(1 + g_m R_1)C_1} = \frac{1}{sC_{eq}} \quad (2)$$

It can easily be realized that the proposed circuit of Fig.2 simulates a grounded capacitance with its equivalent value :

$$C_{eq} = (1 + g_m R_1)C_1 \quad (3)$$

From above expression, it is relevant to note that an external capacitor  $C_1$  has to be multiplied by the resistance  $R_1$  and transconductance  $g_m$ . Since the  $g_m$ -value usually depends on the biasing current of the VDBA, the realized  $C_{eq}$  is electronic programmability.

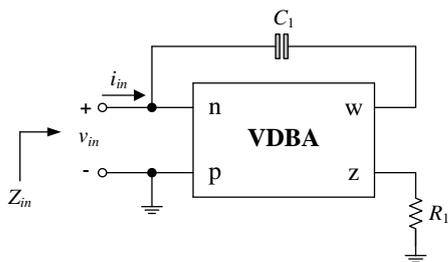


Fig. 2. Proposed tunable capacitance multiplier circuit.

### IV. TRACKING ERROR ANALYSIS

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

$$i_p = i_n = 0, \quad i_z = \alpha g_m (v_p - v_n) \quad \text{and} \quad v_w = \beta v_z \quad (4)$$

where  $\alpha = (1 - \varepsilon_{gm})$  and  $\beta = (1 - \varepsilon_v)$ . Also,  $|\varepsilon_{gm}| \ll 1$  denotes the transconductance inaccuracy, and  $|\varepsilon_v| \ll 1$  denote the voltage tracking error from terminal z to terminal w, respectively. Considering the VDBA non-idealities in the proposed circuit of Fig.2, and solving for  $C_{eq}$  will obtain :

$$C_{eq} = (1 + \alpha \beta g_m R_1)C_1 \quad (5)$$

It should be noted that the non-ideal transfer gains of the VDBA have slightly effect on the realized  $C_{eq}$ . However, this small discrepancy can be compensated by appropriately tuning the transconductance parameter  $g_m$  of the VDBA.

### V. SIMULATION RESULTS AND EXAMPLE

The performance of the proposed circuit of Fig.2 has been simulated by PSPICE program. For simulations, the bipolar realization of the VDBA given in Fig.3 [12] has been employed using the typical parameters bipolar transistor model PR100N (PNP) and NP100N (NPN). The DC supply voltages and bias currents were chosen as :  $+V = -V = 1.5V$  and  $I_Q = 50 \mu A$ , respectively. In this structure, the small-signal transconductance gain ( $g_m$ ) is approximated to :

$$g_m = \frac{I_Q}{2V_T} \quad (6)$$

where  $V_T$  is the thermal voltage that is equal to 26 mV at 27°C.

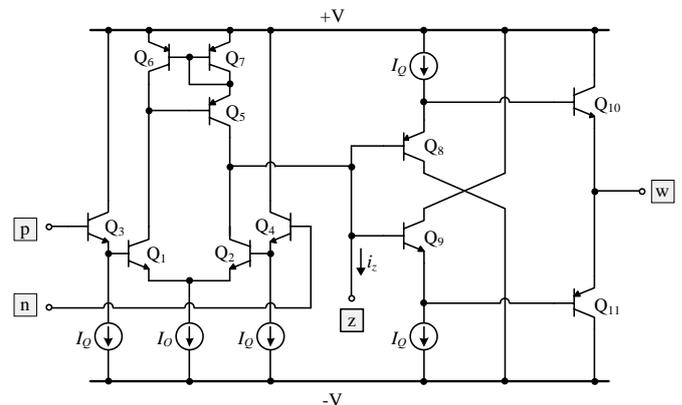


Fig. 3. Bipolar realization of the VDBA used in simulations [12].

As an example, the proposed capacitance multiplier of Fig.2 is realized with the following component values :  $I_Q = 50 \mu A$  ( $g_m = 0.96 \text{ mA/V}$ ),  $R_1 = 10 \text{ k}\Omega$  and  $C_1 = 0.1 \text{ nF}$ . The simulated time waveforms of  $v_{in}$  and  $i_{in}$  through the capacitance simulator are shown in Fig.4, where the frequency of  $v_{in}$  is  $f = 100 \text{ kHz}$ . As expected, the results indicate that the current  $i_{in}$  leads the voltage  $v_{in}$  by approximately  $90^\circ$ . The total power consumption is found as : 0.89 mW.

The simulated frequency characteristics for the input impedance  $Z_{in}$  of the proposed tunable capacitance multiplier circuit of Fig.2 comparing with the theoretical responses are shown in Fig.5. The following passive component values :  $R_1 = 10 \text{ k}\Omega$  and  $C_1 = 0.1 \text{ nF}$  are selected, and the external DC bias current ( $I_Q$ ) of the VDBA is varied from  $20 \mu A$ ,  $50 \mu A$ ,  $250 \mu A$  to  $520 \mu A$ , which result in  $g_m = 0.4 \text{ mA/V}$ ,  $1 \text{ mA/V}$ ,  $5 \text{ mA/V}$  and  $10 \text{ mA/V}$ , respectively. By setting these parameters, the realized equivalent capacitance  $C_{eq}$  can be obtained as : 0.5 nF, 1 nF, 5 nF and 10 nF. The resulting characteristics show that the proposed circuit works pretty well between 100 Hz and 100 kHz approximately. Also from Fig.5, it is proven that the circuit can exhibit an electronically tunable capacitance over a wide range by adjusting the  $g_m$ -value of the VDBA.

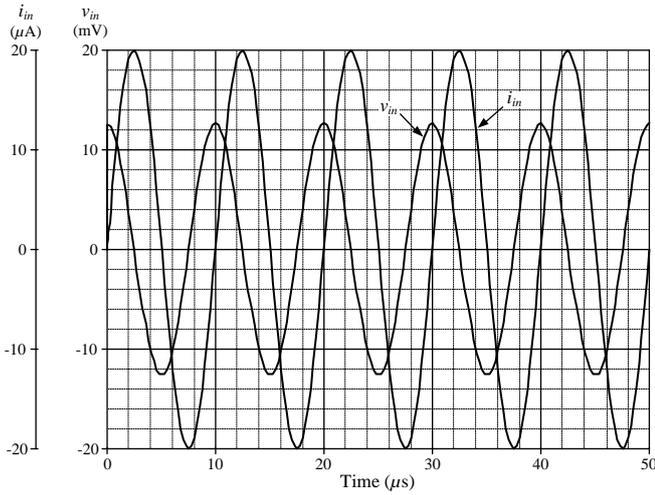


Fig. 4. Simulated time-domain responses for  $v_{in}$  and  $i_{in}$  of the proposed capacitance multiplier in Fig.2.

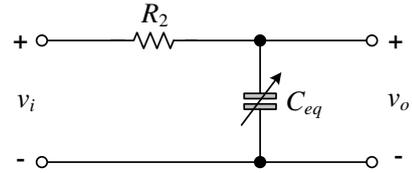


Fig. 6. Active RC first-order lowpass filter.

As an application example, the proposed capacitance simulator in Fig.2 is utilized in the implementation of an active RC lowpass filter shown in Fig.6. The cut-off frequency ( $f_c = \omega_c/2\pi$ ) of the circuit can be obtained as :

$$\omega_c = \frac{1}{R_2 C_{eq}} \quad (7)$$

Since the value of  $C_{eq}$  can be controlled with the external biasing current, the cut-off frequency ( $f_c$ ) is electronically tunable. In addition to take the effect of the VDBA non-idealities into account, eq.(7) turns to

$$\omega_c = \frac{1}{(1 + \alpha\beta g_m R_1) R_2 C_1} \quad (8)$$

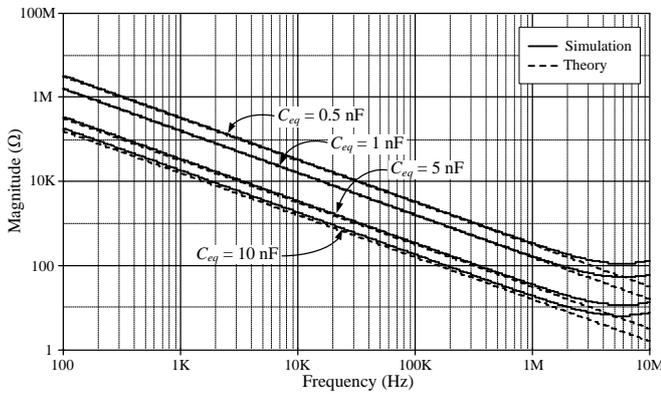
The sensitivities of  $\omega_c$  with respect to the active and passive components can be found as :

$$S_{\alpha}^{\omega_c} = S_{\beta}^{\omega_c} = S_{g_m}^{\omega_c} = S_{R_1}^{\omega_c} = -\frac{\alpha\beta g_m R_1}{1 + \alpha\beta g_m R_1} \quad (9)$$

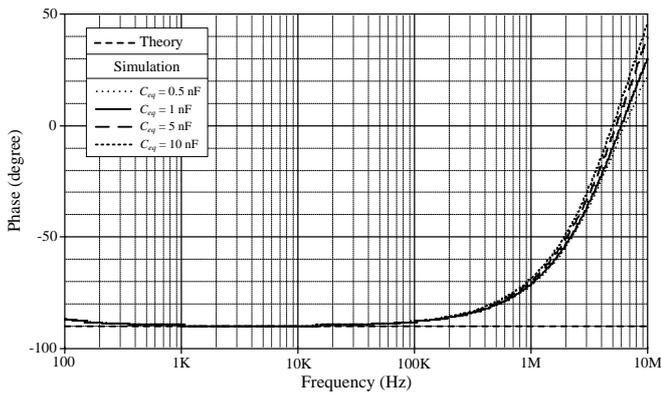
and 
$$S_{R_2}^{\omega_c} = S_{C_1}^{\omega_c} = -1 \quad (10)$$

From the above expressions, the circuit sensitivities are very small, since all of which are less than unity in absolute value.

To demonstrate the performance of an illustrative lowpass filter in Fig.6, the component values are selected as follows :  $R_1 = 10 \text{ k}\Omega$ ,  $C_1 = 0.1 \text{ nF}$ ,  $R_2 = 1 \text{ k}\Omega$  and  $C_{eq} = 10 \text{ nF}$ ,  $5 \text{ nF}$ ,  $1 \text{ nF}$  and  $0.5 \text{ nF}$ , respectively. This results in  $f_c = 15.9 \text{ kHz}$ ,  $31.8 \text{ kHz}$ ,  $159 \text{ kHz}$  and  $318 \text{ kHz}$ , respectively. Fig.7 shows the theory and simulated frequency responses of the active RC lowpass filter in Fig.6 with the proposed electronically tunable  $C_{eq}$ . The corresponding  $f_c$  obtained from the simulated results are approximated to :  $18.4 \text{ kHz}$ ,  $34.1 \text{ kHz}$ ,  $154 \text{ kHz}$  and  $294 \text{ kHz}$ , respectively. As a result, the corresponding errors for  $f_c$  are  $-15.69\%$ ,  $-8.01\%$ ,  $2.91\%$  and  $7.37\%$ . The results of the circuit simulations are close to the theoretical one as expected.



(a)



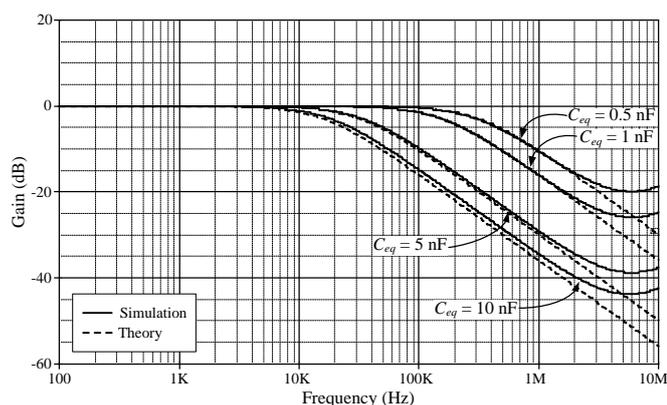
(b)

Fig. 5. Simulated frequency characteristics for  $Z_{in}$  of the proposed capacitance multiplier in Fig.2.

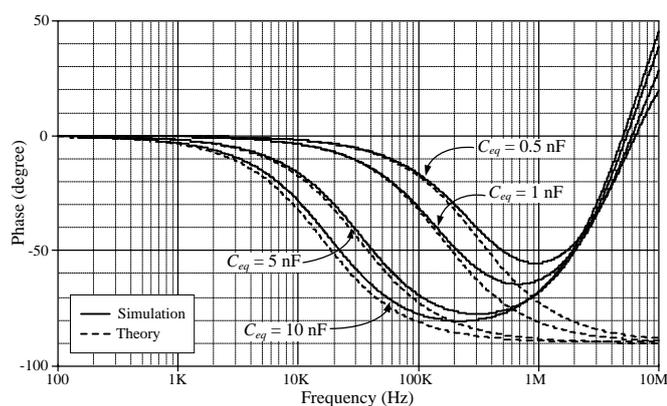
(a) magnitude responses (b) phase responses

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(a)



(b)

Fig. 7. Simulated frequency responses of the active first-order RC lowpass filter of Fig.6.

(a) gain responses (b) phase responses

## VI. CONCLUSION

In this study, an electronically tunable capacitance multiplier based on using VDBA is proposed. The proposed capacitance simulator is designed with a single VDBA and only two passive components. The equivalent capacitance of the realized simulator can be tuned electronically by adjusting the transconductance parameter  $g_m$  of the VDBA. The proposed capacitance simulator contains a minimum number of components and exhibits very low various sensitivities. The proposed circuit is used to construct the active RC lowpass filter example and the simulation results are used to display the workability of the circuits.