Floating Positive/Negative Resistance Simulators Employing Single Dual-output OTA

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***Abstract*— This article reviews floating positive and negative resistance simulators, based on dual-output operational transconductance amplifier (DO-OTA). The features of proposed circuit are that: the resistance value can be controlled electronically by adjusting the input bias current of OTA, the schemes are very simple; they comprise only single DO-OTA without any passive element requirements, trey are suitable for further fabricating in IC form. In addition, it can be used for sensing temperature. Simulation results obtained from PSPICE are in accordance with the theoretical predictions. The maximum bandwidth is 82.7MHz and their resistances can be tuned by bias current over 300nA-3mA. Resistance increasing and some applications are included.**

Keywords: **OTA, Resistance Simulator.**

I. INTRODUCTION

As well accepted, to design the precision integrated circuits (ICs), it is not suitable to use the passive resistors [1]. It is possible to achieve floating resistors in silicon technology by using polysilicon or diffusion areas in a monolithic integrated circuit. However, these resistors occupy large silicon chip areas and it is difficult to achieve precise values. Moreover, the resistance values can not be tuned [2]. The resistance simulator can be implemented both floating and grounded resistors but the floating resistor is more convenient to use than the grounded resistor one. The positive resistance simulator is required in the instrumentation systems, programmable amplifiers, filters, oscillators and etc. While the negative resistance simulator is very useful in various applications such as impedance matching, instrumentation system, cancelling resistance circuit, improving the quality factor in resonant circuit [3]. In general, the resistance simulator is realized as the passive resistor in order to achieve low power consumption, easy to fabrication and can be electronically controlled so it is very suitable to use in the automatic control system. The resistance simulators in CMOS technologies have been proposed [4-5], unfortunately their supply voltages are quite high and they are only able to operate at low frequencies. Recently, a floating resistance simulator using CCCIIs was proposed [6]. Though, it had advantage in providing floating resistor, but it is not convenient to further fabricate in IC due to complexity of circuit description.

In this paper, we present positive and negative floating resistance simulators using only single DO-OTA. Proposed circuits comprise only single DO-OTA without any passive elements. They are, therefore, convenient to realize in IC. Resistance values can be controlled via bias current of the OTA. The performances of the proposed circuits are illustrated by PSPICE simulations, which are in accordance with theoretical predictions. Some applications of positive and negative resistance simulators are given here to display the usefulness of the proposed circuits. Resistance increasing for the proposed circuit with the use of current dividers is also included.

II. PRINCIPLE OF OPERATION

A. *Dual-Output Operational Transconductance Amplifier (DO-OTA)*

Since the proposed circuits are based on DO-OTA, a brief review of DO-OTA is given in this section. An ideal DO-OTA has infinite input and output impedances. Output current of DO-OTA is given by

$$I_{O+} = -I_{O-} = g_m(V_2 - V_1). \qquad (1)$$

Where g_m is the transconductance parameter of DO-OTA. For a bipolar DO-OTA, the transconductance can be expressed by

$$g_m = \frac{I_B}{2V_T}. \qquad (2)$$

Where I_B and V_T are bias current and thermal voltage, respectively. The symbol and the equivalent circuit of the OTA are illustrated in Fig. 1(a) and (b), respectively.

B. Proposed Floating Positive Resistance Simulator

The proposed circuit of the floating positive resistance simulator is shown in Fig. 2, where I_B is the bias current of the OTA. Considering the circuit in Fig. 2 and using the properties of the OTA described in section II. A, we will get

$$R_{eq} = \frac{V_1 - V_2}{I_R} = \frac{1}{g_m}. \tag{3}$$

From Eq. (3), it is obvious that the circuit shown in Fig. 2 performs a floating positive resistance with a value

$$R_{eq} = \frac{2V_T}{I_B}. \tag{4}$$

It can be seen from Eq. (4) that the resistance value can be easily adjusted electronically by the bias current I_B. In addition, the resistance value in Eq. (4) linearly depends on the thermal voltage, so the proposed resistance simulator in Fig. 2 can be used for sensing temperature.

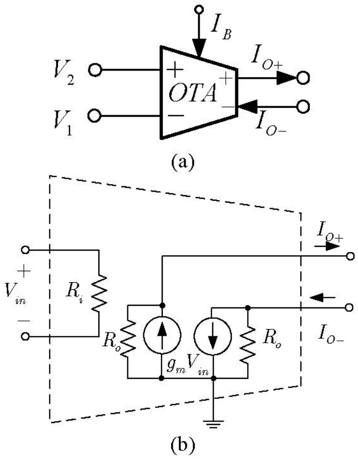


Fig. 1. DO-OTA (a) Symbol (b) Equivalent circuit

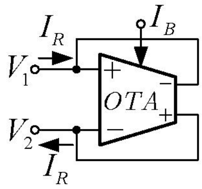


Fig. 2. Proposed floating positive resistance simulator

C. Proposed Floating Negative Resistance Simulator

Fig. 3 depicts the proposed negative floating resistance simulator. Similarly, it can be seen from Fig. 3 that the equivalent resistance of the simulator is

$$R_{eq} = \frac{V_1 - V_2}{I_R} = -\frac{1}{g_m} = -\frac{2V_T}{I_B}. \tag{5}$$

From Eq. (5), it is evident that the negative resistance can be tuned electronically by controlling the bias current I_B. Similarly, from Eq. (5), the resistance value linearly depends from thermal voltage so the circuit in Fig.2 can be used for sensing temperature.

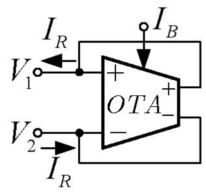


Fig. 3. Proposed floating negative resistance simulator

D. Principle for Resistance Increasing

To achieve more sensitivity of the provided resistance, a technique to increase the resistance value is also presented in this paper. Fig. 4 gives the theoretical implementation of resistance increasing circuit with current dividers for positive resistance simulator [6]. From the scheme in Fig. 4, we can see that $I_R = I_O / n$. Considering the properties of the OTA described in section II.A and Eq. (1), we will receive

$$R_{eq} = \frac{V_1 - V_2}{I_R} = \frac{n}{g_m} = n\frac{2V_T}{I_B}. \tag{6}$$

The design of the resistance increasing circuit for the negative resistance simulator and the relationships would be analogical. The internal construction of the resistance increasing circuit using OTA with current dividers according to the Fig. 4 is depicted in Fig. 6.

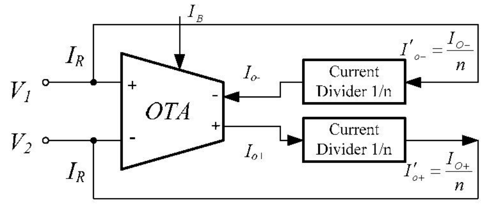


Fig. 4. Symbolic implementation of the resistance increasing circuit

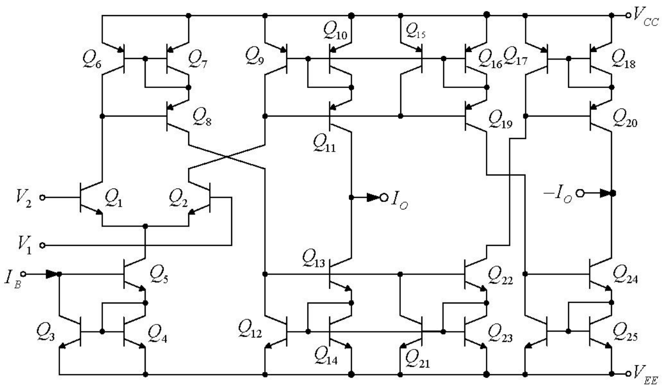


Fig. 5. Internal construction of dual-output OTA

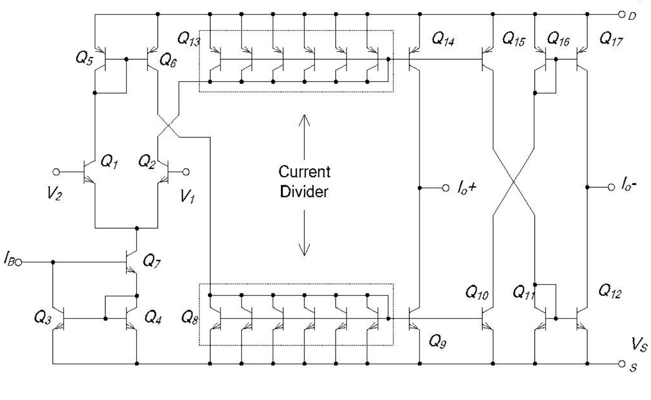


Fig. 6. Internal construction of the resistance increasing circuit

III. Simulation Results And Discussions

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examinations. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [7] with ±1.5V supply voltages. Fig. 5 depicts schematic description of the DO-OTA used in the simulations.

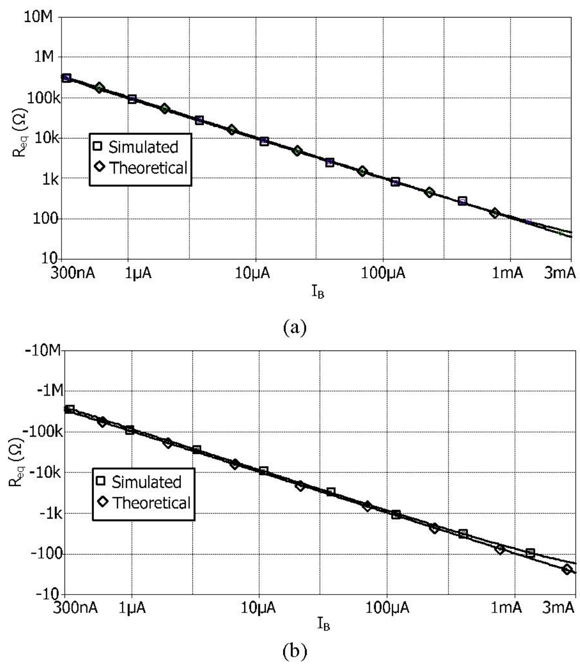


Fig. 7. Resistance values relative to frequency compared to theoretically calculated values (a) for positive value (b) for negative value

Fig. 7 shows the simulated magnitudes of the positive and negative resistances between ports V_1 and V_2 as a function of the bias current I_B, which are compared to the theoretical resistances calculated from Eq. (4) and Eq. (5).

Current gain relative to frequencies of the positive and negative floating resistance simulator is shown in Fig. 8 for $I_B = 250\mu A$. It can be seen that the bandwidth of the proposed positive resistance simulator is 82.7MHz, while the bandwidth of the proposed negative simulator is 71.1MHz.

Simulated I-V characteristics of the positive and negative resistance simulators are shown in Fig. 9. The characteristics show good linearity in the range of about $\pm 40mV$.

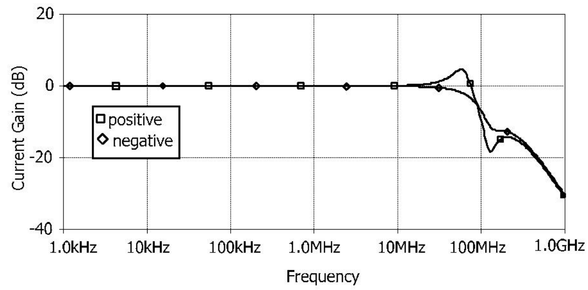


Fig. 8. Bandwidth of the proposed positive and negative resistance simulator

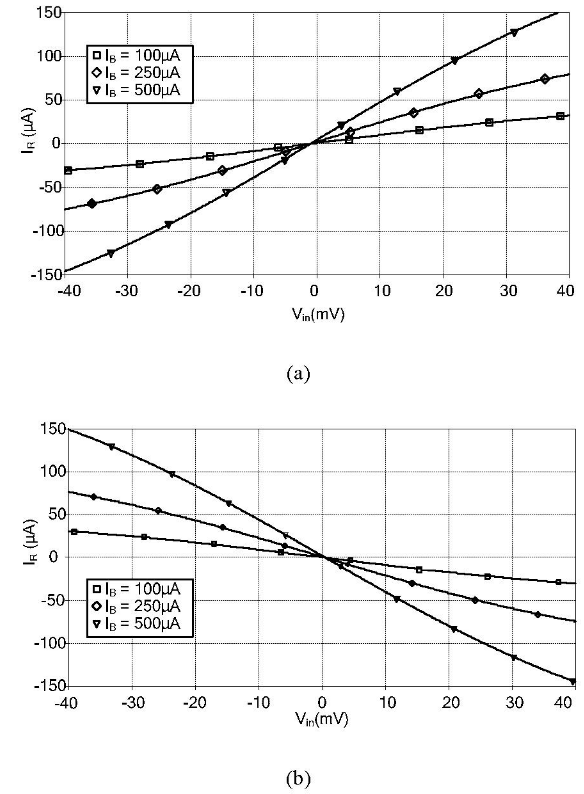


Fig. 9. I-V characteristics for various bias currents I_B (a) positive (b) negative resistance simulator

To demonstrate applicability of the proposed positive floating resistance simulators, it is employed in an RLC series-resonant circuit shown in Fig. 10, where $V_{in} = 10mV$. The frequency responses of the output current I_o for different bias currents I_B=100µA, 200µA, and 1mA are shown in Fig. 11. To illustrate an application of the negative resistance simulator, it is employed in RLC series-resonant circuit in Fig.12 to cancel the serial resistance R. The frequency responses of the output current I_o for different bias currents I_B=200µA, 300µA, and 400µA are shown in Fig.13.

Fig. 14 depicts resistance values relative to frequency of the resistance increasing circuit from Fig. 4 for various divider coefficients n=1, n=6, and n=10. In addition, Fig. 15 depicts resistance values relative to variations of the temperature, it is evident that the provided resistors can be used as a temperature sensor.

IV. Conclusion

The floating positive and negative resistance simulators have been presented through this paper. The both proposed resistors enjoy several features; for instance, circuit simplicity and convenience to fabricate in IC form, electronic controllability, free from component matching. The PSPICE results confirm the mentioned benefits. The power consumptions are approximately 1.31mW and both floating resistance simulators, respectively at ±1.5V supply voltages.

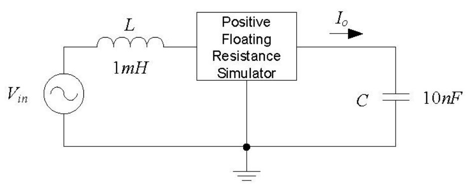


Fig. 10. Series RLC resonant circuit with positive resistance simulator

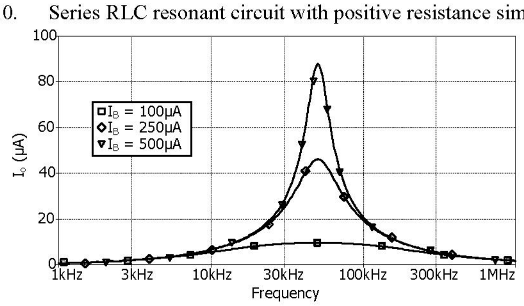


Fig. 11. Simulated current characteristics of the series RLC resonant circuit from Fig. 10 when I_b is varied.

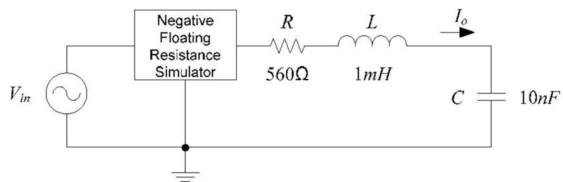


Fig. 12. Series RLC resonant circuit with negative resistance simulator canceling the serial resistance R.

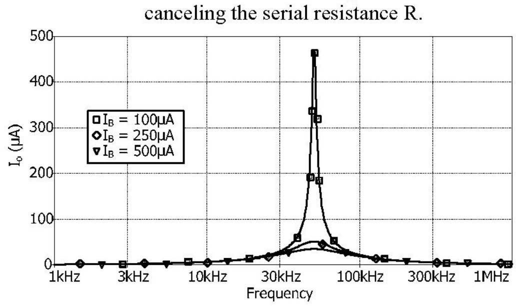


Fig. 13. Current characteristics of the RLC circuit from Fig.11 for various bias currents I_B.

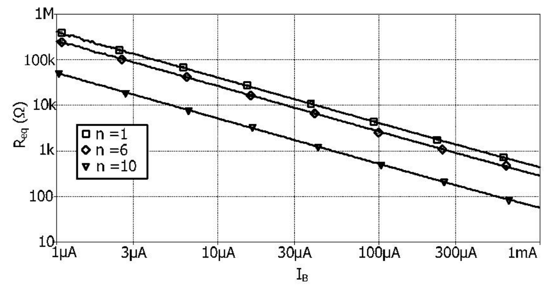
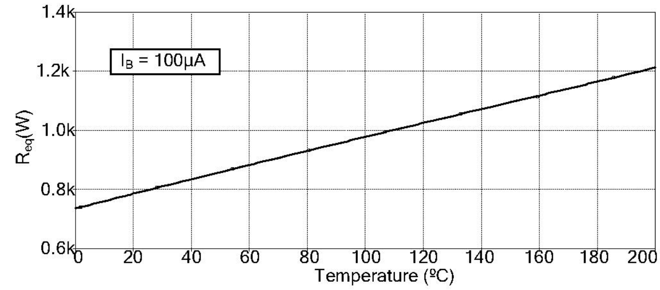
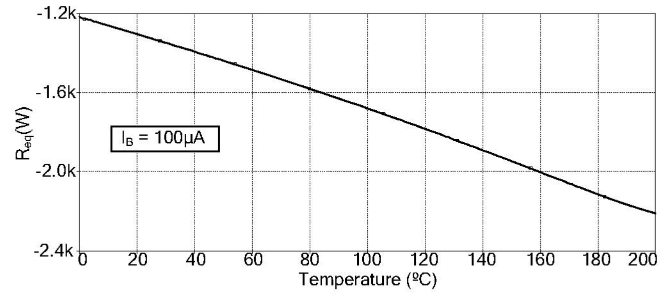


Fig. 14. Variation of the resistance values as a function of the bias current I_B for different dividing coefficient n



(a)



(b)

Fig. 15. Resistance values where temperature is varied (a) for positive value (b) for negative value

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