Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 Vol II
IMECS 2009, March 18 - 20, 2009, Hong Kong

Current Limiters with Single Current Follower

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***Abstract*— A synthesis of current limiters (CLs) using single current follower (CF) is described. The breakpoint of the resulting transfer characteristic obtained from the proposed CF-based CLs is electronically adjustable through an external control current. To demonstrate feasibility of the proposed CL circuits, some nonlinear applications to programmable current-mode precision full-wave rectifiers are also presented. PSPICE simulation and experimental results are included to support the theoretical claims.**

***Index Terms*— Current Limiter (CL), Current Follower (CF), Current-mode circuits, Non-linear circuits**

I. INTRODUCTION

In general, the current limiter (CL) is an alternative way to handle nonlinear problems. In the area of analog signal processing applications, it can be widely found as the basic element in the design of nonlinear components and networks, such as nonlinear resistors, chaotic oscillators, precision rectifiers, and piecewise-linear function approximation generators [1]-[6]. Because of the advantages of wider bandwidth, low power consumption and simpler structures, the current follower (CF) is very useful building block in the design of current-mode signal processing systems. From the point of view of the active sensitivity, the problems caused by the voltage tracking error are not taken into consideration in the CF because of the property of its virtual ground input. Moreover, by appropriately designing the CF-based configurations, the resulting circuits would also be insensitive to the current tracking error of the CF's. For the above explanations, the CF has attracted considerable attention as alternative to other more complex building blocks in the implementation of amplifying, filtering, immittance simulating and oscillator circuits [7]-[13]. In addition, nonlinear applications based on CFs are also expected, in particular current limiters and current-mode precision rectifiers. However, few contributions with CFs are realized to synthesize current limiter circuits.

In this paper, we are presenting the applicability of CF's for implementing the simple CL building blocks. The breakpoint of the realized transfer curve can be electronically adjusted by an external DC control current. To demonstrate the performance of the proposed circuits, some application examples on the realization of the programmable positive and negative current-mode precision full-wave rectifiers are also presented. PSPICE simulation and experimental results using the commercially available integrated circuit chip AD844 from Analog Devices are included and discussed.

Manuscript received January 7, 2009.

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II. PROPOSED CURRENT FOLLOWER-BASED CURRENT LIMITERS

Ideally, the CF can be defined as an active building block with zero input resistance, infinite output resistance and unity-current gain. The circuit representation of the CF is symbolically represented in Fig.1, whose terminal characteristics can be expressed by the following matrix equation :

$$\begin{bmatrix} i_z \\ v_z \end{bmatrix} = \begin{bmatrix} \pm 1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} i_x \\ v_x \end{bmatrix} \qquad (1)$$

where the plus and minus signs of the current transfer ratio represent the positive CF (CF+) and the negative CF (CF-), respectively.

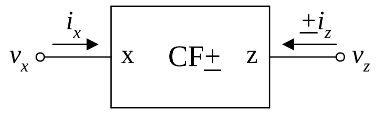
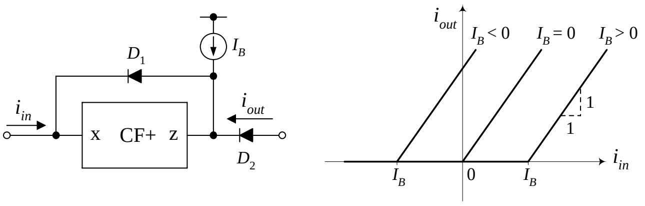


Fig.1 : Circuit symbol of the CF.

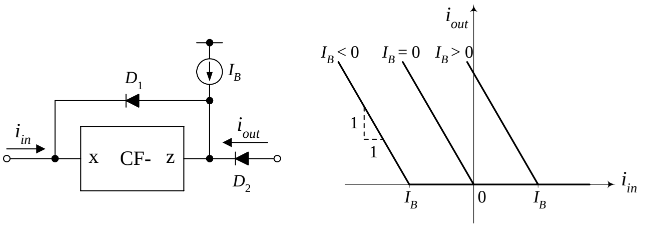
Fig.2 shows the block diagrams of the proposed CF-based CLs and their corresponding transfer characteristic curves. Consider the proposed circuit depicted in Fig.3(a), where i_{in} is an input current and I_B is the breakpoint current. If $i_{in} \le I_B$, the diode D_1 is turn on, while the diode D_2 is turn off. Since no current flows through the diode D_2 ($I_{D2} = 0$), the output current becomes zero ($i_{out} = 0$). For the case of $i_{in} > I_B$, the diode D_1 is turn off, the output current i_{out} will flow through the diode D_2. Therefore, the output current i_{out} of the circuit related to the breakpoint current I_B can be described as :

$$i_{out} = \begin{cases} 0 & \text{for } \; i_{in} \le I_B \\ i_{in} - I_B & \text{for } \; i_{in} > I_B \end{cases} \qquad (2)$$

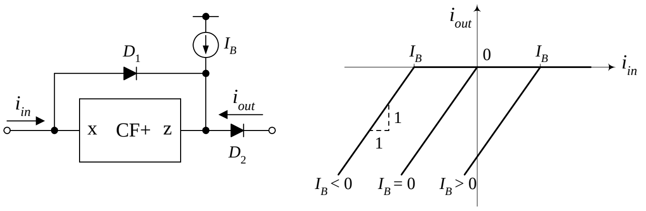
From equation (2), we will simply state that the breakpoint of the transfer characteristic curve can be electronically controlled by changing the values of the current I_B, which gives an additional flexibility in the nonlinear function approximation design problem. In addition, by the same principle, the remaining proposed circuits shown in Figs.2(b)-(d) will give similar transfer characteristics to equation (2), depending on the terminal connections of both diodes and appropriately selection of the CF's type.



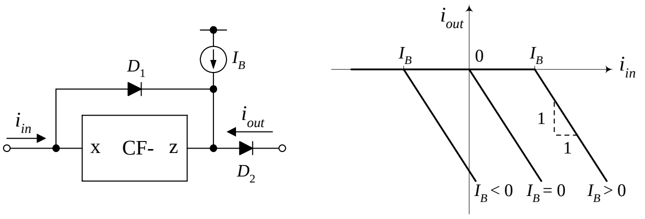
(a)



(b)



(c)



(d)

Fig.2 : Proposed CF-based CL building blocks.

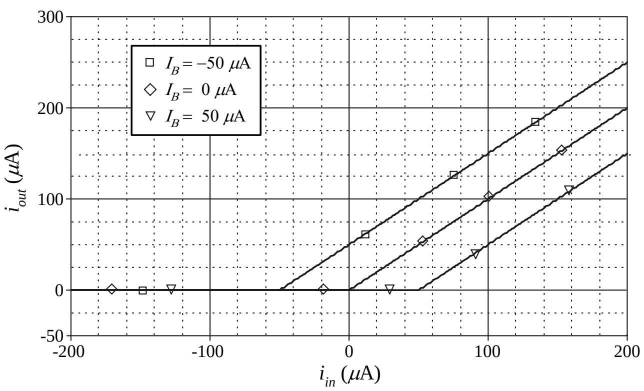
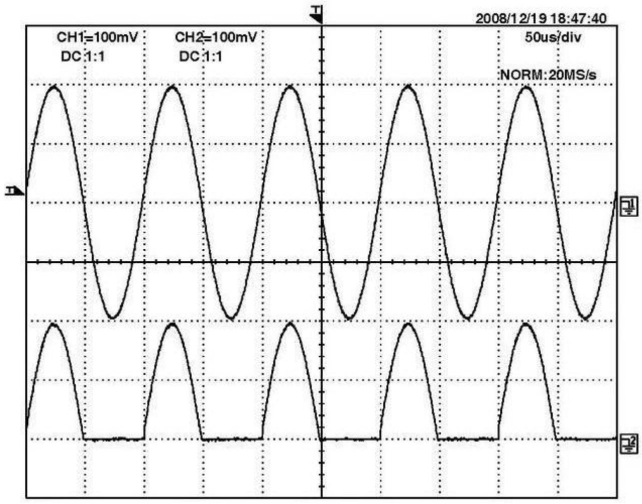


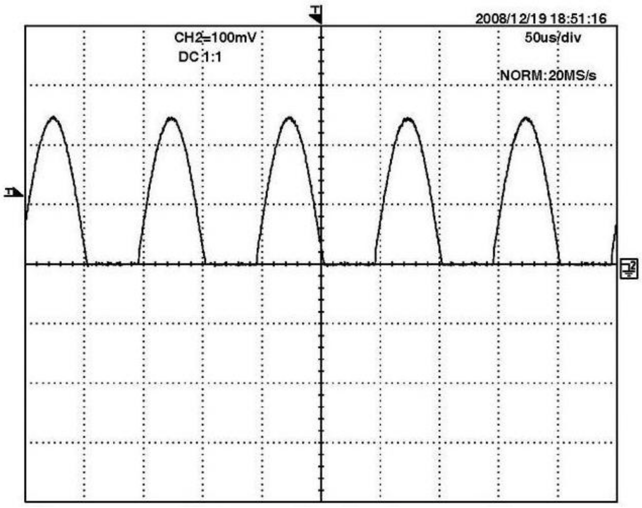
Fig.3 : Simulated current transfer characteristic of Fig.2(a)

III. Simulation and Experimental Results

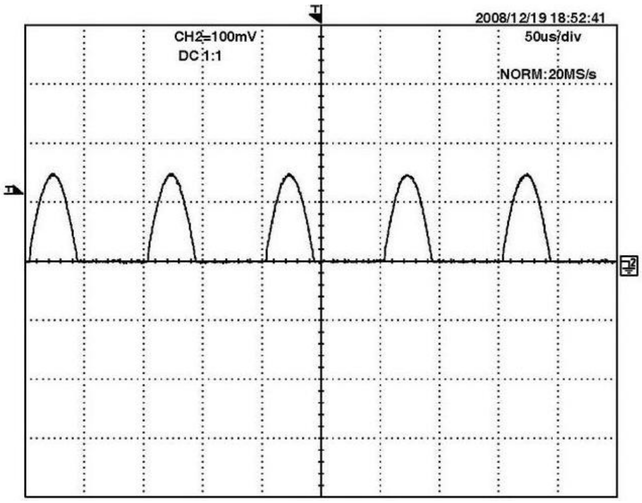
In order to confirm the theory given above, the proposed CF-based CL building blocks of Fig.2 have been simulated with PSPICE program and experimentally tested. For the CF implementation, we have used the commercially available current feedback amplifier AD844 from Analog Devices, biasing with ±12V power supplies. The diodes used were performed with 1N4148. In the simulations, the AD844 model parameters were taken from the built-in library (AD844/AD).



(a)



(b)



(c)

Fig.4 : Measured input and output waveforms of the experimental CL circuit of Fig.2(a), when
(a) I_B = 0 μA (b) I_B = -50 μA (c) I_B = 50 μA

Fig.3 shows the simulated current transfer characteristic of the proposed circuit given in Fig.2(a) when the input current i_{in} is varied from -200 μA to 200 μA for three different values of I_B, and the load resistor is 1 kΩ. From the simulations, it can be measured that the maximum error in i_{out} was less than 100 nA. This error directly results from the nonzero offset current of the CF and the non-ideal characteristic of the diode. Owing to similar transfer curves and performances between the circuit discussed above and the remaining circuits in Figs.2(b)-(d), the plots for those circuits will not be reported here.

To confirm the correct operation of the proposed circuit by experiment, the circuit in Fig.2(a) was also constructed in the laboratory with the same component values used in the simulations. In this case, a sinusoidal input with i_{in} = 200 μA peak and f = 10 kHz was applied to the circuit and the output current i_{out} was measured across a 1-kΩ load resistor. Fig.4 displays the measured input and output waveforms of the experimental circuit for three values of the external DC bias current (I_B = 0 μA, -50 μA and 50 μA), where the vertical scale is 100 μA/div while the horizontal scale is 50 μS/div. The measured data agree fairly well with the theoretical predictions.

IV. Application Examples

In this section, two illustrative application examples of the proposed CL circuits will be described. Based on the use of the proposed CF-based CLs of Fig.2, the configurations for realizing positive and negative current-mode full-wave rectifiers can be illustrated in Figs.5 and 6, respectively. For this purpose, the multiple-output current follower stage is the circuit that generates, from the input current (i_{in}), multiple output currents in the same direction. From the basic operation of the proposed CLs described above, the relations between the input and the output currents of the two new circuits can be expressed as follows.

For Fig.5 ;

$$i_{out} = |(i_{in} - I_B)| \tag{3}$$

and, inversely, for Fig.6 ;

$$-i_{out} = |(i_{in} - I_B)| \tag{4}$$

It should be noted from equations (3) and (4) that the circuits of Figs.5 and 6 operate as the positive and negative current-mode full-wave rectifiers, respectively.

The circuit of Fig.5(a) was also tested experimentally to verify the presented theory. In the experiment, a 200-μA peak sinusoidal waveform of 10 kHz was applied to the circuit. The measured results of the experimental circuit showing the input and output waveforms when I_B = 0 μA and R_L = 1 kΩ are shown in Fig.7. The results obtained thus agree with the theoretical analyses.

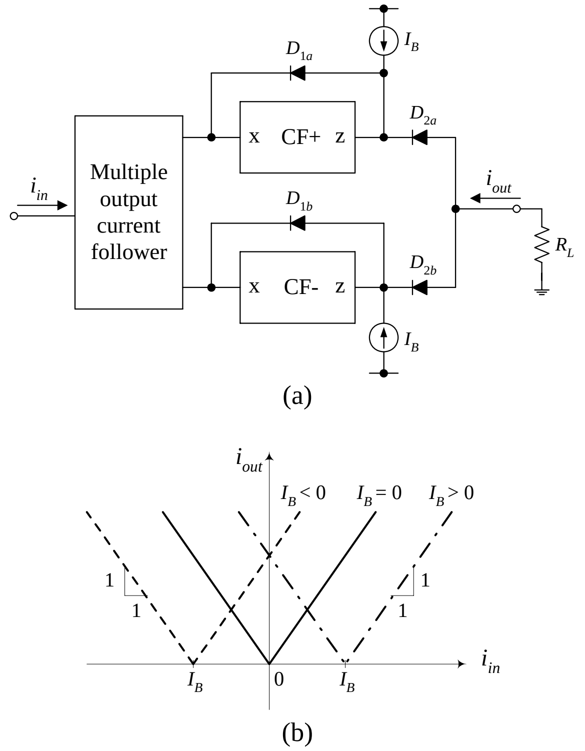


Fig.5 : Positive current-mode full-wave rectifier.
(a) circuit realization (b) transfer characteristic curve

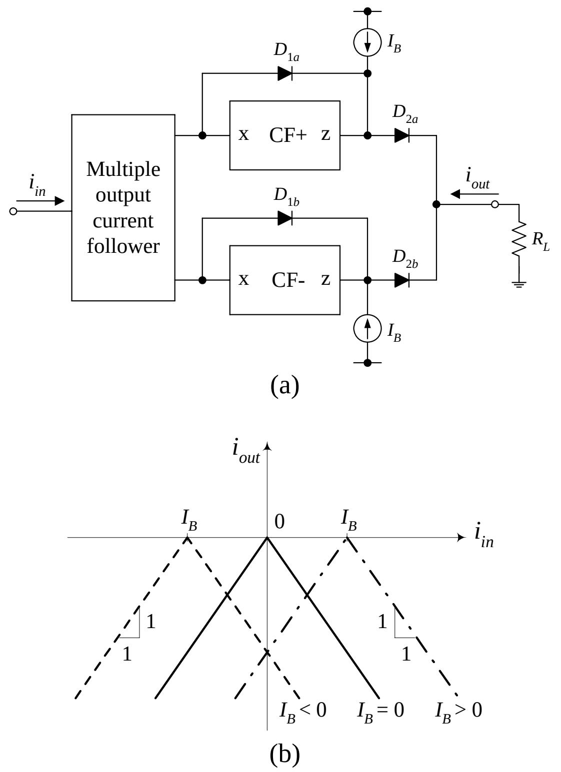


Fig.6 : Negative current-mode full-wave rectifier.
(a) circuit realization (b) transfer characteristic curve

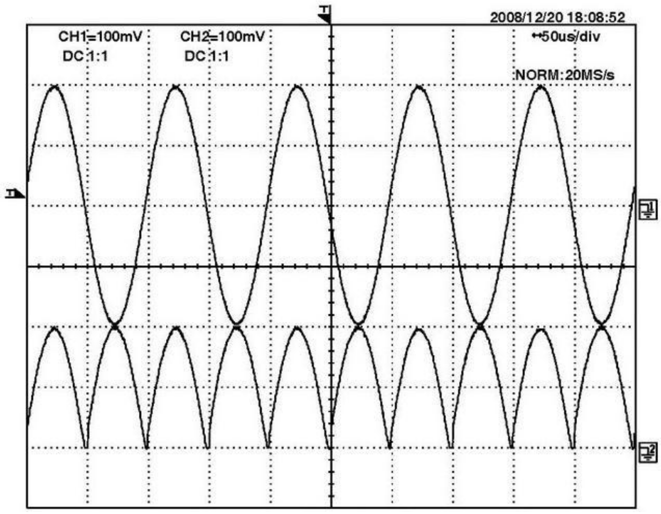


Fig.7 : Transient responses of the current-mode full-wave rectifier of Fig.5(a).
Vertical 100 μA/div; horizontal 50 μS/div.

V. CONCLUSION

An approach for the syntheses of the current limiters using the CF as an active element is proposed in this article. All the resulting synthetic building blocks provide desirable property in which the realized breakpoint of the linear segment can be electronically adjusted by controlling the external DC bias current. Because of this property, the proposed CF circuits are expected to find wide applications in non-linear analog function synthesis systems. The proposed CL circuits and their applications have been confirmed using SPICE simulation and experimentally demonstrated.

The influences of the non-ideal characteristics of the CF and diodes should be taken into consideration when high-precision operations are necessary. Further detailed analytical and experimental evaluations of the effect of these non-idealities on the accuracy of the proposed circuits are the subject of future investigations, and the results will be reported in a forth-coming paper.

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