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CURRENT LIMITERS USING SINGLE CDTA AND APPLICATIONS

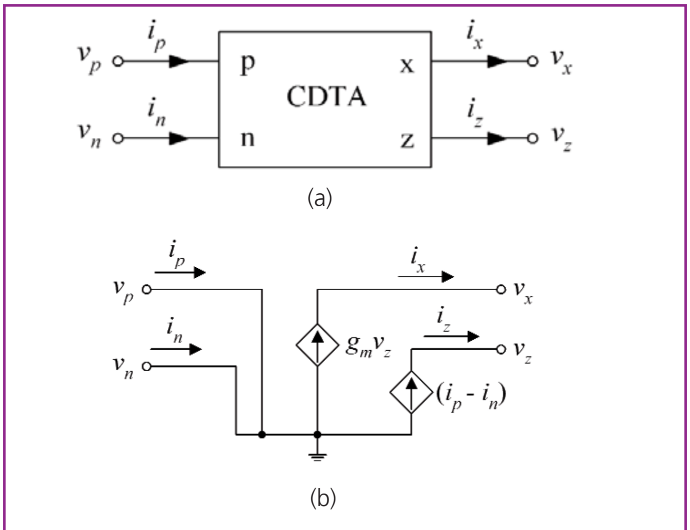

***Figure 1**: CDTA (a) circuit symbol (b) equivalent circuit*

Generally, the current limiter (CL) is an alternative way to handle non-linear problems. In the area of analogue signal processing applications, it can be widely found as the basic element in the design of non-linear components and networks, such as non-linear resistors, chaotic oscillators, precision rectifiers and piecewise-linear function approximation generators.

Recently, a new current-mode active element with two current inputs and two kinds of current output, which is called a Current Differencing Transconductance Amplifier (CDTA), has been introduced (see D. Biolek's ***"CDTA-Building block for current-mode analogue signal processing",*** Proceeding of the ECCTD'03, vol. III, Krakow, Poland; pp.397-400, 2003). This device is synthesised using the current differencing nature of the modified differential current conveyor (MDCC) and a multiple-output transconductance amplifier to facilitate the implementation of current-mode analogue signal processing. As a result, several implementations have emerged, such as active filters, oscillator and amplifiers using CDTAs as active components.

Non-linear CDTA applications are also expected, in particular precision rectifiers, current-mode Schmitt triggers and current-mode multipliers. Unfortunately, not much is being reported in literature on the use of CDTAs for synthesising current limiter circuits.

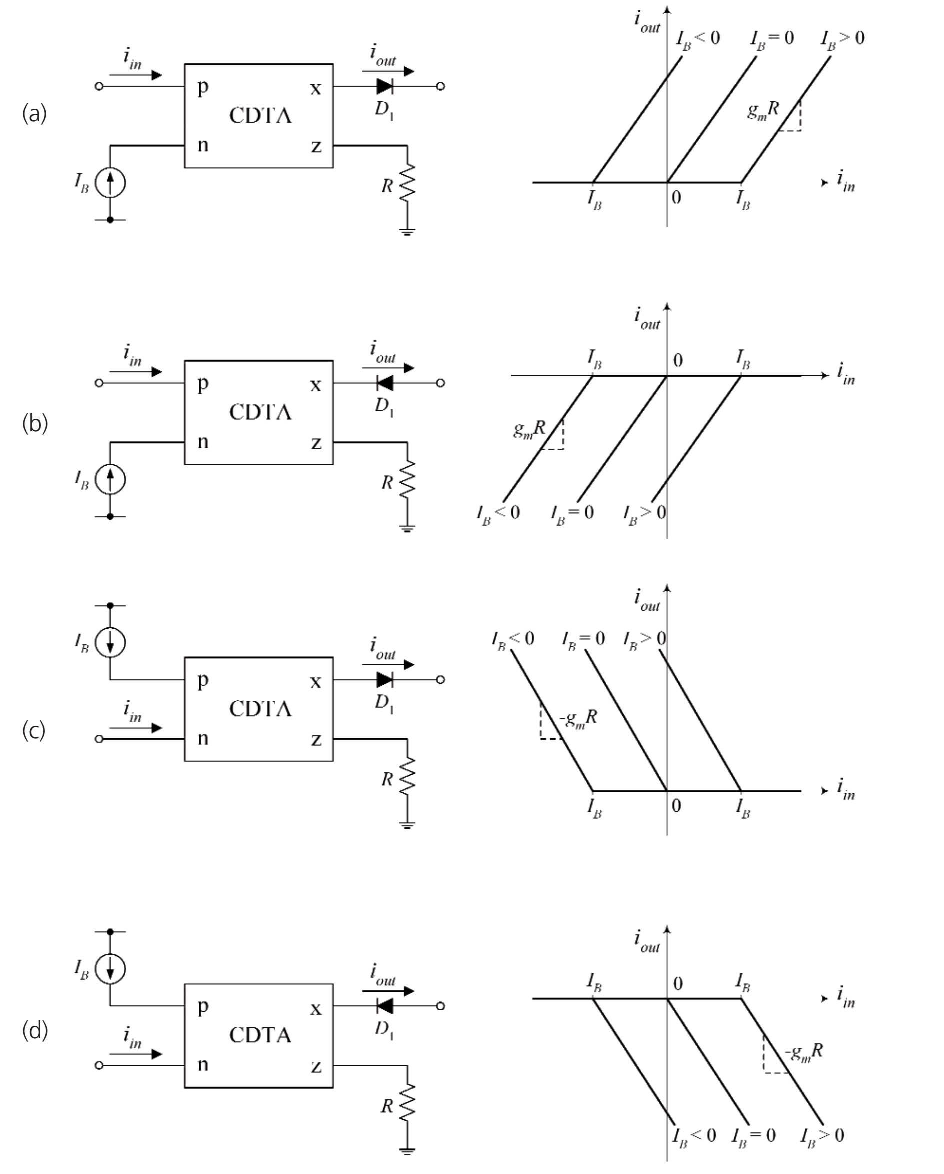

***Figure 2**: Proposed CDTA-based current limiter building blocks*

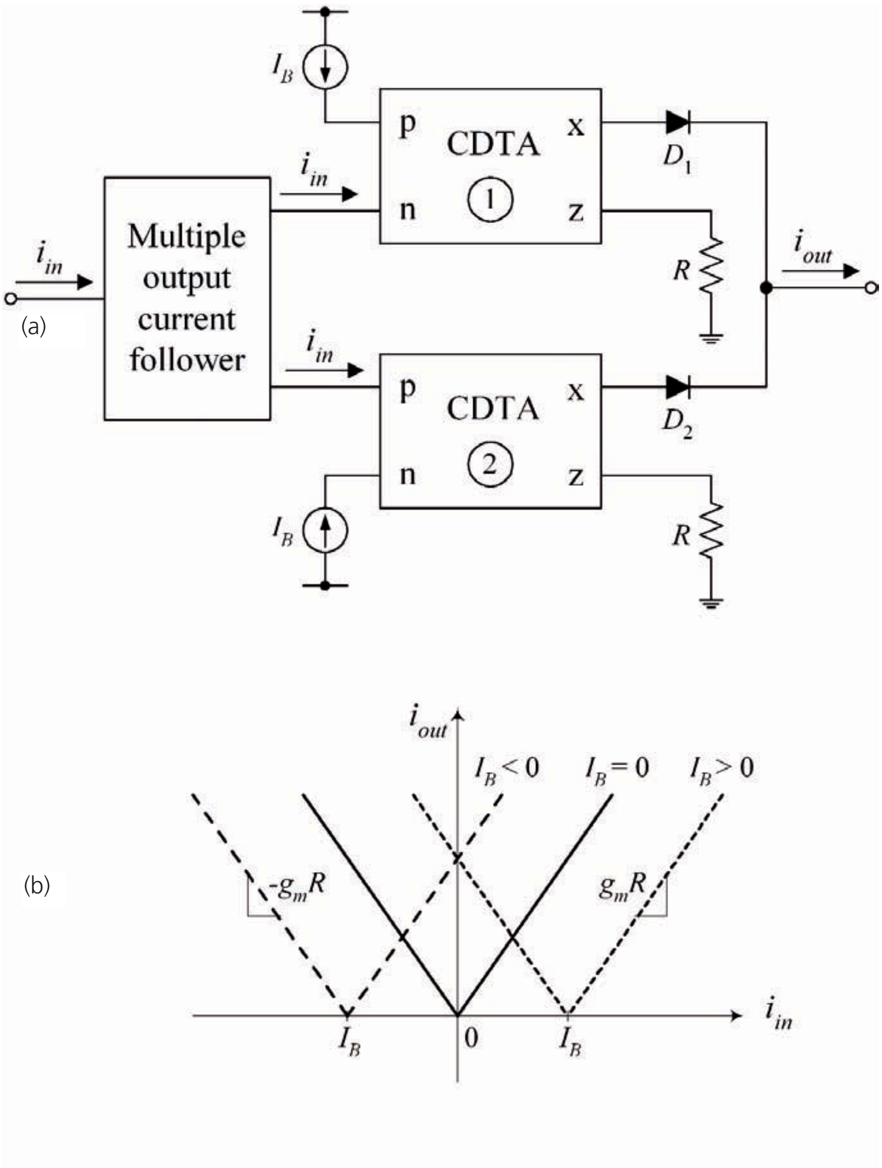

***Figure 3**: Positive current-mode full-wave rectifier (a) circuit implementation (b) transfer characteristic curve*

Here, we propose the applicability of CDTAs as the fundamental active elements for designing the simple CL building blocks. The breakpoints and slopes of the realised transfer curves can be electronically programmed by the transconductance gain (g_m) of the CDTA. To demonstrate versatility of the proposed electronically tunable CLs, some non-linear applications to programmable current-mode precision full-wave rectifiers and piecewise-linear function approximation generator are also presented.

Circuit Description and Operation

The circuit representation and the equivalent circuit of the CDTA are shown in **Figure 1**. The terminal relation of the CDTA can be characterised by the following set of equations:

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

where Z_z is an external impedance connected at the terminal z. In general, the g_m value is linearly adjustable over several decades by a supplied bias current/voltage, which lends electronic controllability to design circuit parameters. It may also be emphasised that the electronic controllability becomes very important when the circuit is in a variety of design specifications and in the integrated circuit (IC) form.

Figure 2 shows the basic building blocks of the proposed CDTA-based CLs and their corresponding transfer characteristic curves. First, consider the proposed circuit depicted in Figure 2a, where i_{in} is an input current and I_B is the breakpoint current. If $i_{in} \leq I_B$, the diode is cut-off. Since no current flows through the diode D_1 ($I_{D1} = 0$), the output current becomes zero ($i_{out} = 0$). For the case of $i_{in} > I_B$, the output current i_{out} will flow through the diode D_1. Therefore, the output current i_{out} of the circuit related to the breakpoint current I_B and the gain g_m can be given as :

$$i_{out} = \begin{cases} 0 & \text{for } i_{in} \leq I_B \\ g_m R(i_{in} - I_B) & \text{for } i_{in} > I_B \end{cases} \quad (2)$$

From **Equation 2**, we will simply state that both breakpoint and slope of the transfer characteristic curve can be electronically controlled by tuning the values of the current I_B and the gain g_m, which gives an additional flexibility in the non-linear function approximation design problem. In addition, by the same principle, the remaining proposed circuits shown in Figures 2b-d will give similar transfer characteristics to Equation 2, depending on the terminal connection of the CDTA and the diode.

Applications

The proposed CLs of Figure 2 can be effectively used to implement current-

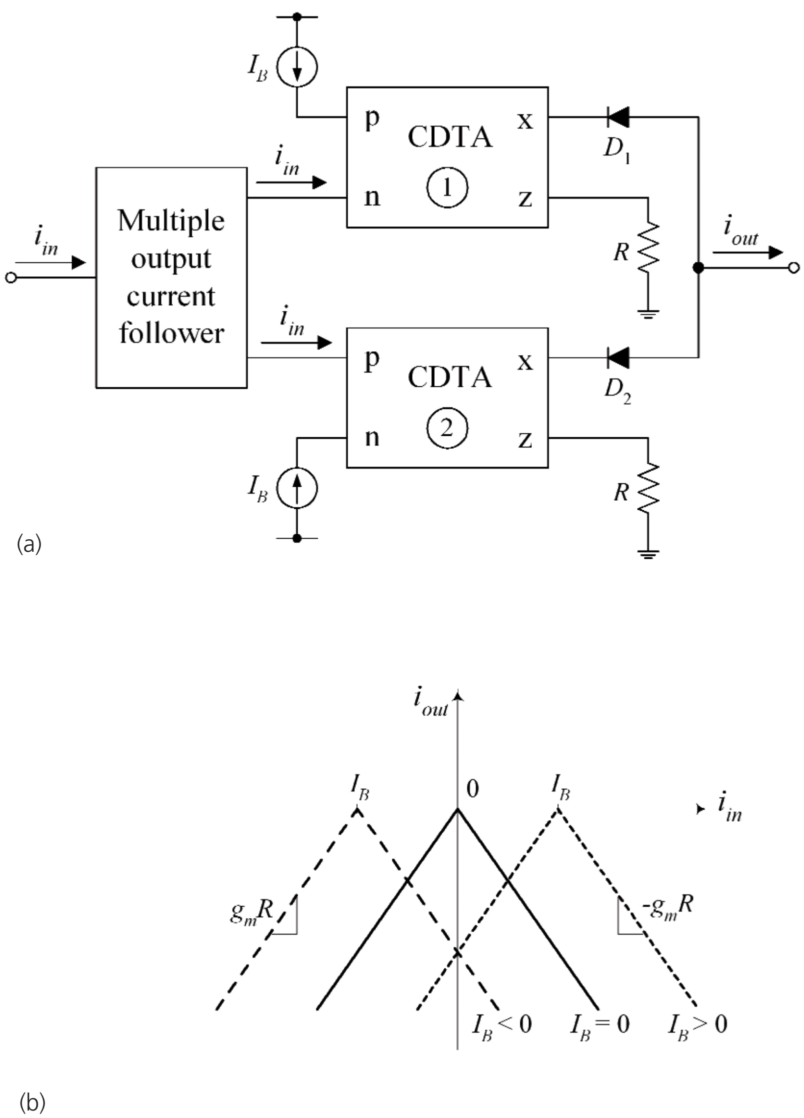

***Figure 4**: Negative current-mode full-wave rectifier (a) circuit implementation (b) transfer characteristic curve*

mode precision full-wave rectifiers as shown in **Figures 3** and **4**. The multiple-output current follower stage is the circuit that generates, from the input current (i_{in}), multiple output currents in the same direction. It can be realised by using the basic current mirror with multi-output terminals. From the operation of the proposed CDTA-based CLs described above and by setting $g_{m1} = g_{m2} = g_m$, the relations between the input and the output currents of the two new circuits can be expressed as follows.

$$i_{out} = |g_m R(i_{in} - I_B)| \quad (3)$$

$$-i_{out} = |g_m R(i_{in} - I_B)| \quad (4)$$

This means that the circuits of Figures 3 and 4 operate as the positive and negative current-mode full-wave rectifiers, respectively. It is worth nothing that the slopes of the transfer curves can still be continuously controlled by tuning g_{m1} of the CDTA1 for the negative slope and by tuning g_{m2} of the CDTA2 for the positive slope.

The applications of the proposed CLs for implementing the piecewise-linear (PWL) function approximation circuits can also be realised. As an example, the desired transfer characteristic is shown in **Figure 5a** (see next page) which is composed of three linear segments. The required individual slopes due to each CDTA-based CL of Figure 2 are indicated in the lower part of Figure 5a, and the actual circuit implementation can be shown in **Figure 5b.**

It should be noted that the slopes S_0, S_1 and S_2 of the composed resulting transfer characteristics can be easily determined by adjusting the values of $g_{m1}R_1$, $g_{m2}R_2$ and $g_{m3}R_3$, respectively. From the above discussions, it is further apparent that a class of arbitrary non-linear current generators can be synthesised.

Conclusion

A simple approach for the syntheses of the current limiters using the CDTA as an active element is proposed. The proposed CDTA-based CLs were then used as fundamental circuit building blocks to implement integrable non-linear function circuits, such as current-mode precision full-wave rectifiers and a piecewise-linear function approximation circuit. All the resulting synthetic building blocks will also posses several desirable properties, namely, the positive and negative slopes of the linear segments and breakpoints can be electronically tunable through the g_m-value of the CDTA.

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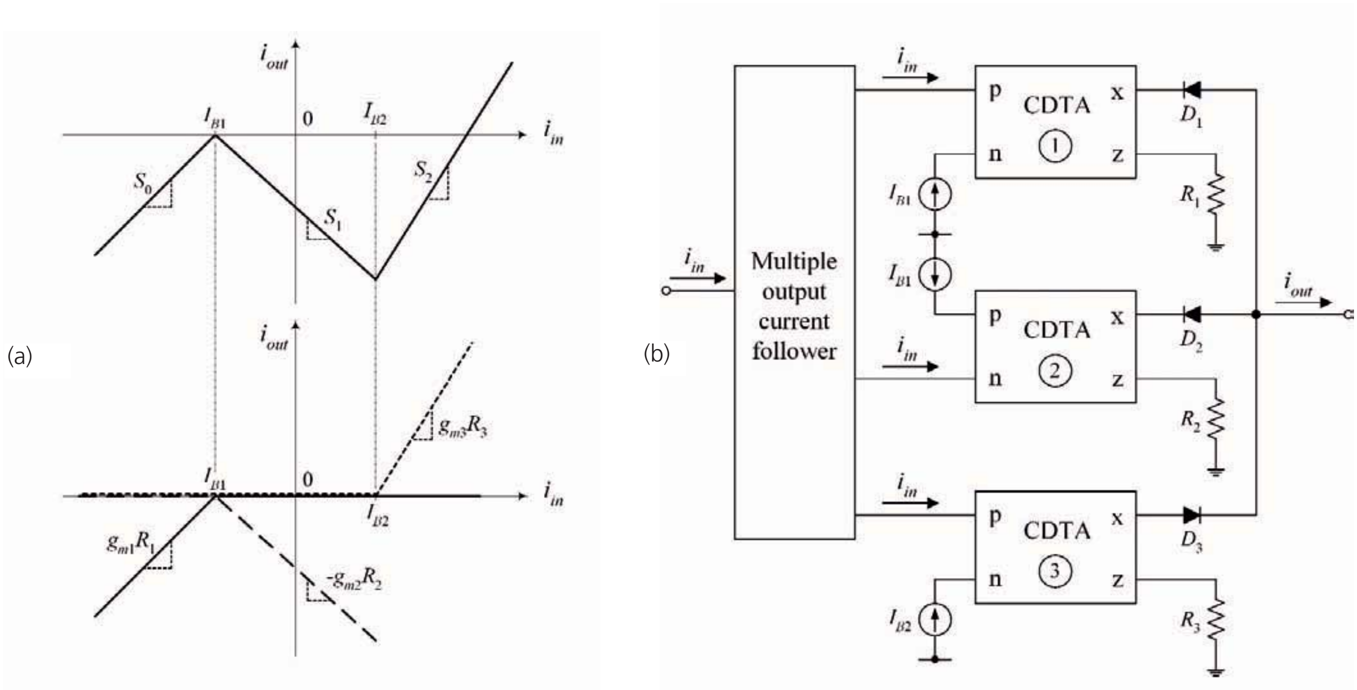

***Figure 5**: Piecewise-linear (PWL) function approximation function (a) desired transfer characteristic curve (b) circuit implementation*