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Pathological realizations of the DCVC (CDBA) and applications to oscillators and filters

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ABSTRACT

The historical origin of the introduction of the differential current voltage conveyor (DCVC) also known as the current differencing buffered amplifier (CDBA) is reviewed. Pathological realizations of the modified differential current conveyor (MDCC) and of the DCVC are given. Generation of alternative equivalent oscillator and filter circuits using voltage followers (VF), current followers (CF), voltage inverters (VI) and current inverters (CI) from known CDBA oscillators and filters is demonstrated by several examples. It is found that there is duplication in some of the recently published circuits and new simplified oscillator and filter circuits are reported.

1. Introduction

The differential current conveyor (DCC) was introduced in [1] as a five terminal analog building block with the symbolic representation shown in Fig. 1(a). A CMOS circuit was also introduced in [1] and simplified to realize the current mode building block defined as MDCC. Applications of the MDCC in realizing four quadrant multiplier cell and a universal current mode filter have also been introduced in [1]. The idea of current subtraction was known before and the active building block known as current differencing operational amplifier (CDOA) was used in the realization of a second order notch filter in [2]. The CDOA used in [2] is the commercially available LM 3900 (National Semiconductor) using bipolar transistors and biased by a single power supply. The CDOA also known as the Norton Operational Amplifier (Norton-OA) could not achieve the desirable zero input impedance required by an ideal current driven active building block due to the finite V_{BE} of the input bipolar transistors. The Norton-OA was redefined as the operational transresistance amplifier (OTRA) and realized using CMOS transistors and used in several applications in [3]. The main advantage of the OTRA circuits is that the input voltages at the two-input terminals are zero thus providing parasitic capacitance insensitive current mode circuits as demonstrated in [3].

2. Pathological realizations of the MDCC and DCVC

The DCC is a five terminal analog building block introduced in [1] and shown symbolically in Fig. 1(a) and is defined by the following matrix equation:

$$\begin{bmatrix} V_{X_1} \\ V_{X_2} \\ I_Y \\ I_Z \\ I_{Z+} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{X_1} \\ I_{X_2} \\ V_Y \\ V_Z \\ V_{Z+} \end{bmatrix} \tag{1}$$

In order to achieve the desirable very low input impedance at the two input terminals the DCC is modified to a four terminal building block called MDCC defined by the following matrix equation:

$$\begin{bmatrix} V_{X_1} \\ V_{X_2} \\ I_Z \\ I_{Z+} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{X_1} \\ I_{X_2} \\ V_Z \\ V_{Z+} \end{bmatrix} \tag{2}$$

Fig. 1(b) represents the symbol of the MDCC with single Z output, and its pathological realization using two nullator, one norator and one current mirror (CM) [4] is given in Fig. 1(c). Fig. 2(a) represents the symbol of the MDCC with single $Z+$ output, and its pathological realization using two nullator, one norator and one CM is given in Fig. 2(b). Fig. 3(a) represents the symbol of the balanced output MDCC, and its pathological realization using four nullator, one norator and three CM is given in Fig. 3(b). It should be noted that the two nullator at the right side are dummy and are added to achieve the desirable equality between number of norator plus number of CM equal to number of nullator [5].

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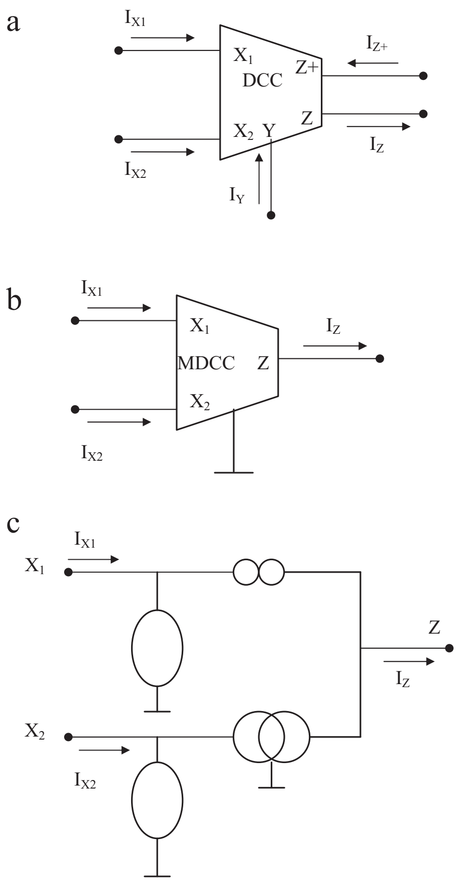

Fig. 1. (a) Symbol of the differential current conveyor [1], (b) symbol of the modified differential current conveyor [1] (c) Pathological realization of the single Z output MDCC.

The DCVC was introduced in [6] as a four terminal analog building block shown symbolically in Fig. 4(a) and defined by:

$$\begin{bmatrix} V_{X_1} \\ V_{X_2} \\ I_Z \\ V_O \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} I_{X_1} \\ I_{X_2} \\ V_Z \\ I_O \end{bmatrix} \quad (3)$$

The voltage V_Z at node Z is determined by the external load Z_L at node Z and the current I_Z. A new CMOS realization of the DCVC was also given in [6] and used in the realization of a MOS-C quadrature oscillator. Additional applications of the DCVC in the realization of MOS-C Tow Thomas filter have been introduced in [7].

New pathological realization of the DCVC using; three nullators, one CM and two norators is given in Fig. 4(b). The pathological realizations are useful in obtaining alternative active building blocks realizations of the MDCC and the DCVC that are all equivalent in the ideal case. Table 1 includes a summary of the numbers of each of the four pathological elements used in the realizations of the MDCC and the DCVC.

The realization of the DCVC can be achieved using three current conveyors (CCII) as shown in Fig. 4(c) [7]. This realization is equivalent to the unity gain cells based realization shown in Fig. 4(d). A two CI one VF realization of the DCVC is shown in Fig. 4(e), which can be practically realized using two current feedback operational amplifiers (CFOA) as shown in Fig. 4(f) [7].

The DCVC was independently introduced and defined as a CDBA in [8] and used in several applications in [8–11].

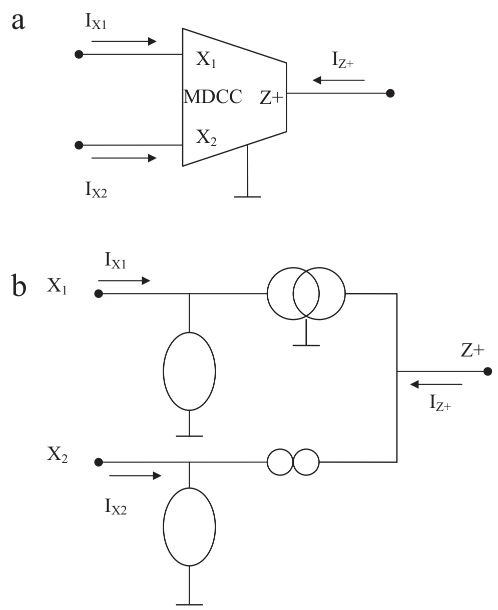

Fig. 2. (a) Symbol of the MDCC with Z+ output, (b) pathological realization of the MDCC with Z+ output.

3. Applications of the DCVC in oscillator circuits

Several oscillator examples using DCVC are available in the literature. Two examples are taken in this section to demonstrate that most of the DCVC oscillators are related to unity gain cells based oscillators and additional new oscillators are introduced in this paper.

The first oscillator circuit considered in this section is shown in Fig. 5(a) which uses two DCVC, two grounded capacitors and four virtually grounded resistors and was introduced in [12]. The same circuit was republished as Fig. 4 in [13] with the two DCVC being interchanged in the position. The state matrix equation is given by:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} G_3 - G_1 & G_4 \\ -G_2 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad (4)$$

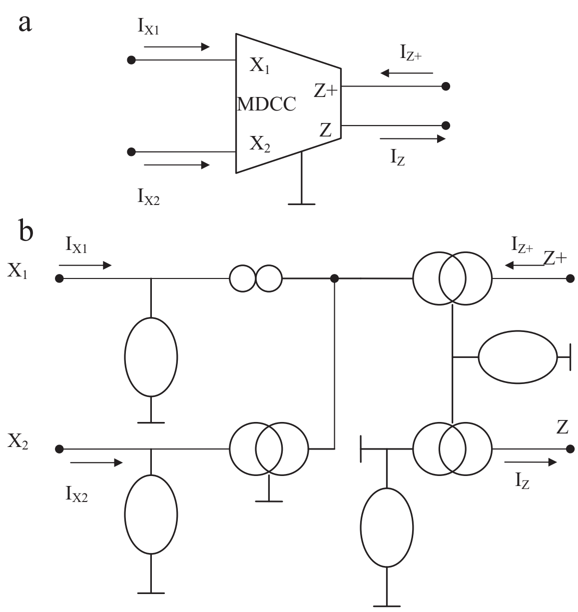

Fig. 3. (a) Symbol of the MDCC with balanced output [1], (b) pathological realization of the balanced output MDCC.

Table 1
Pathological elements realizing MDCC and DCVC.

Active element	Figure number	Nullator	Norator	VM	CM
MDCC	1(c)	2	1	0	1
MDCC	2(b)	2	1	0	1
MDCC	3(b)	4	1	0	3
DCVC	4(b)	3	2	0	1

The condition of oscillation and the radian frequency of oscillation are given by:

$$G_3 = G_1 \quad \text{and} \quad \omega_O = \sqrt{\frac{G_2 G_4}{C_1 C_2}} \tag{5}$$

An equivalent oscillator circuit using two VF, one CF and two CI is shown in Fig. 5(b). This new unity gain cells oscillator can be simplified as shown in Fig. 5(c) using one CI less. An equivalent oscillator is shown in Fig. 5(d), which also has the same matrix Eq. (4). There are two more oscillator circuit members that belong to this unity gain cells oscillators topology and they have the following state matrix equation:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} G_3 - G_1 & -G_4 \\ G_2 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{6}$$

Eq. (5) applies to these two additional unity gain cells oscillators.

This example demonstrates that there are four unity gain cells oscillators that are equivalent to the circuit of Fig. 5(a) but originally have been generated from the two integrator loop oscillator using Op Amps is demonstrated in [14].

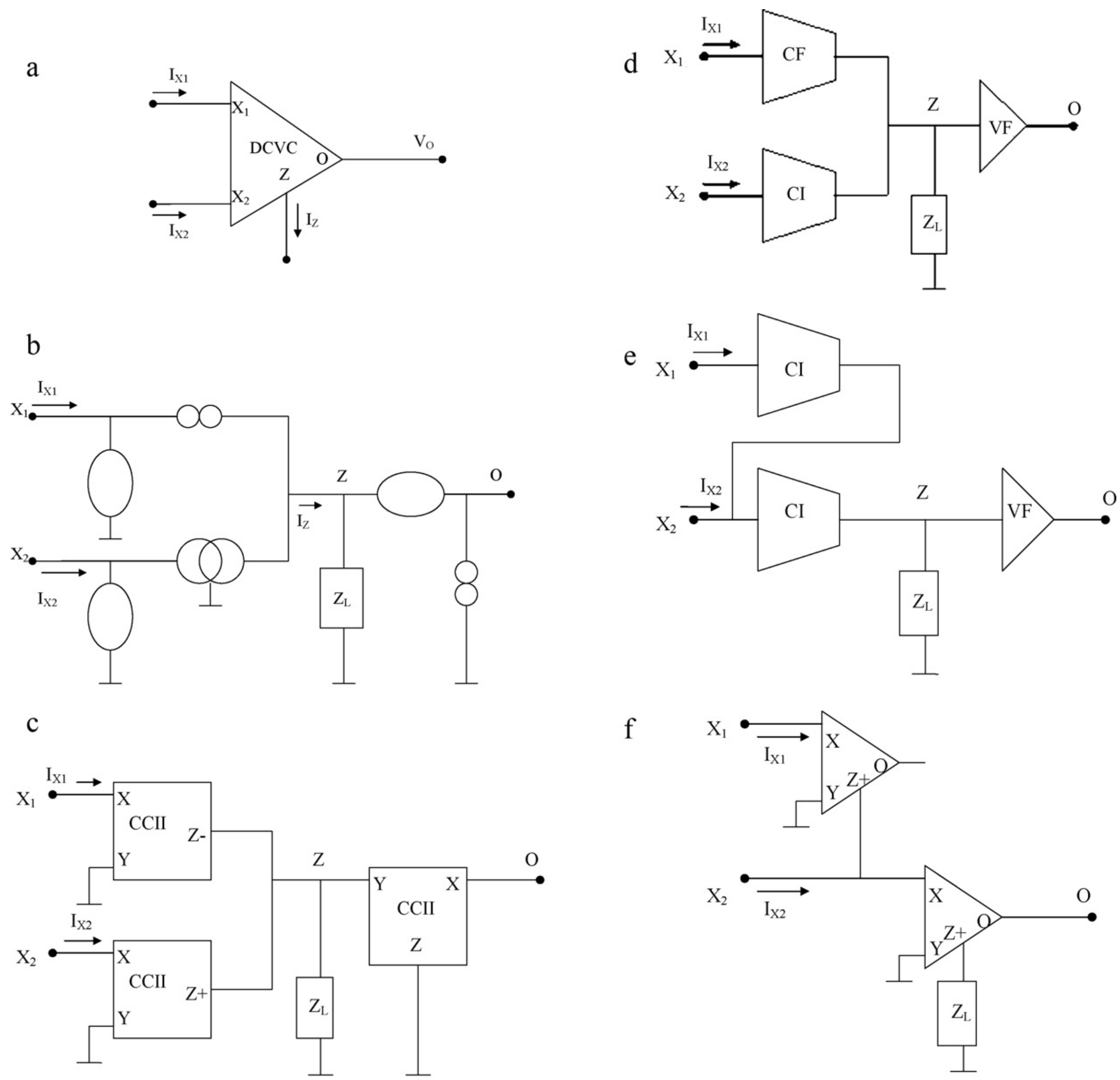

Fig. 4. (a) Symbol of the differential current voltage conveyor [6–7], (b) pathological realization of the DCVC or CDBA, (c) three CCII based realization of the DCVC or CDBA, (d) unity gain cells realization equivalent to (c), (e) alternative unity gain cells realization of the DCVC, (f) two CFOA realization of the DCVC.

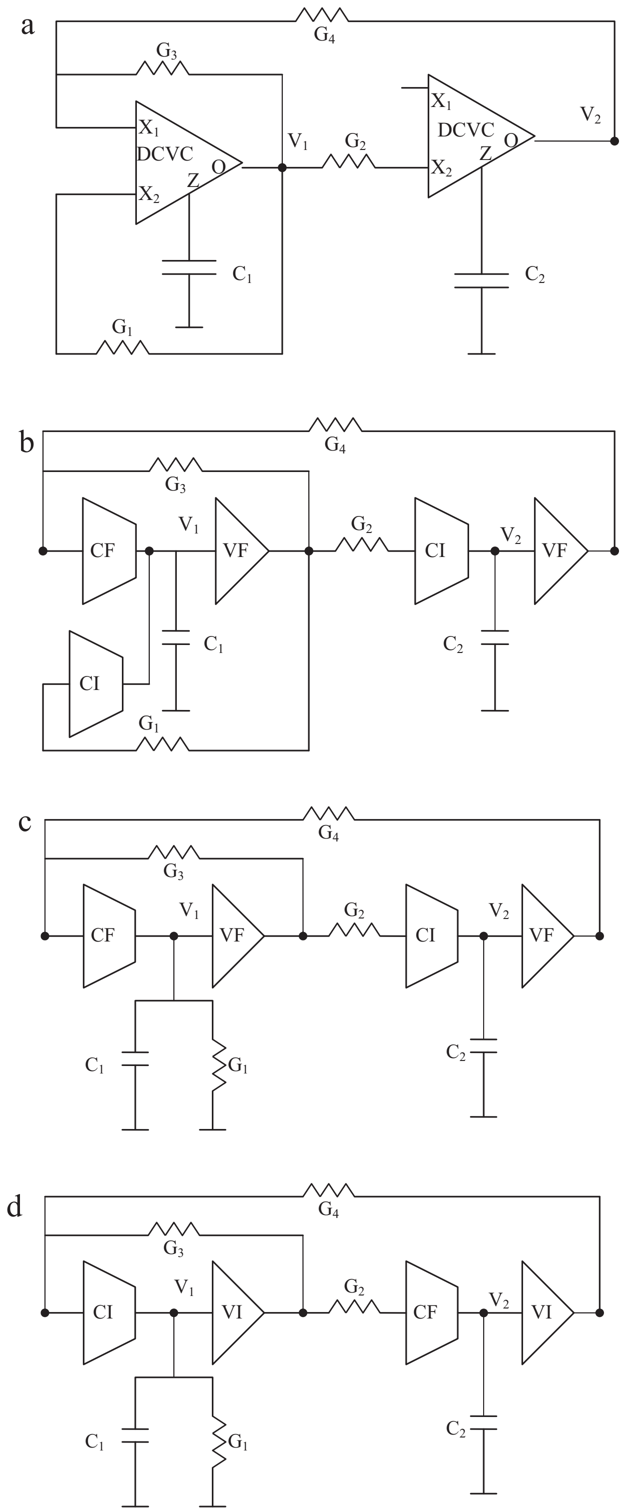

Fig. 5. (a) Quadrature oscillator using two DCVC and four resistors [12], (b) unity gain cells based oscillator equivalent to (a), (c) simplified unity gain cells based oscillator to (b) [14], (d) equivalent unity gain cells based oscillator to (b) [14].

The second oscillator circuit considered in this section is shown in Fig. 6(a) which uses two DCVC, two grounded capacitors and three virtually grounded resistors and was introduced in [15]. The state matrix equation is given by:

$$\begin{bmatrix} sC_1V_1 \\ sC_2V_2 \end{bmatrix} = \begin{bmatrix} G_1 - G_2 & -G_3 \\ G_2 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad (7)$$

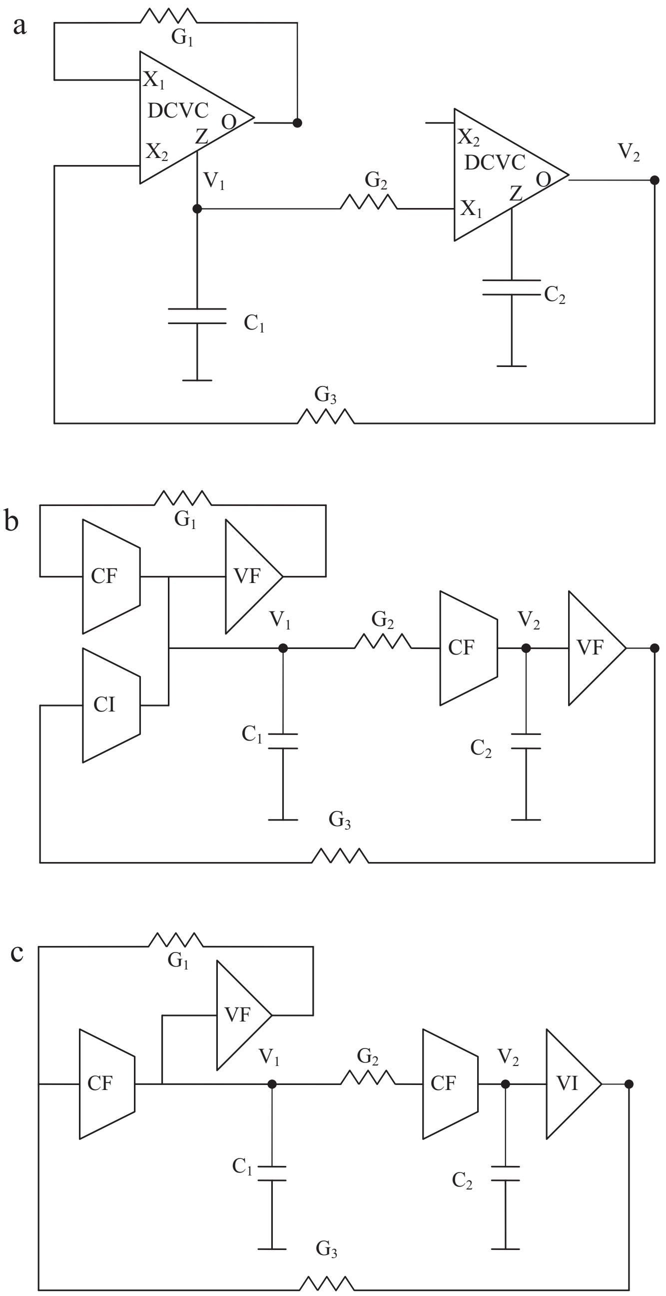

Fig. 6. (a) Quadrature oscillator using two DCVC and three resistors [15], (b) unity gain cells based oscillator equivalent to (a), (c) simplified unity gain cells based oscillator equivalent to (b).

The condition of oscillation and the radian frequency of oscillation are given by:

$$G_2 = G_1 \quad \text{and} \quad \omega_O = \sqrt{\frac{G_2G_3}{C_1C_2}} \quad (8)$$

An equivalent new oscillator circuit using two VF, two CF and one CI is shown in Fig. 6(b). A simplified equivalent new oscillator circuit using one VF, two CF and one VI is shown in Fig. 6(c). Table 2 includes a summary of the numbers of the passive and active circuit elements realizing the oscillator circuits of Figs 5 and 6.

4. Applications of the DCVC in filter circuits

Two filter examples are taken in this section to demonstrate that most of the DCVC filters are related to unity gain cells based filters.

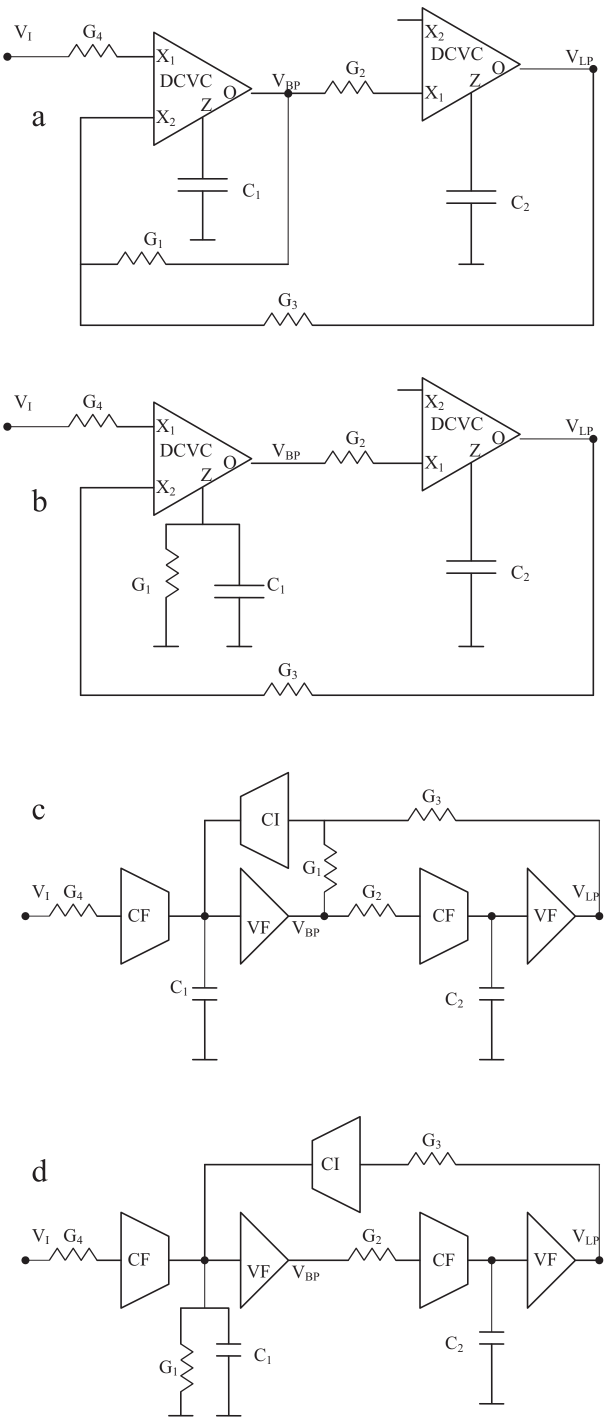

Fig. 7. (a) Band-pass low-pass filter using two DCVC and four resistors [16], (b) equivalent band-pass low-pass filter to (a), (c) unity gain cells based band-pass low-pass filter equivalent to (a), (d) unity gain cells based band-pass low-pass filter equivalent to (c).

The first filter circuit considered in this section is shown in Fig. 7(a) which is the equivalent Tow Thomas filter using two DCVC, two grounded capacitors and four virtually grounded resistors as given in [16].

The transfer functions at the band-pass and low-pass outputs are given by:

$$\frac{V_{BP}}{V_I} = \frac{sC_2G_4}{s^2C_1C_2 + sC_2G_1 + G_2G_3} \tag{9}$$

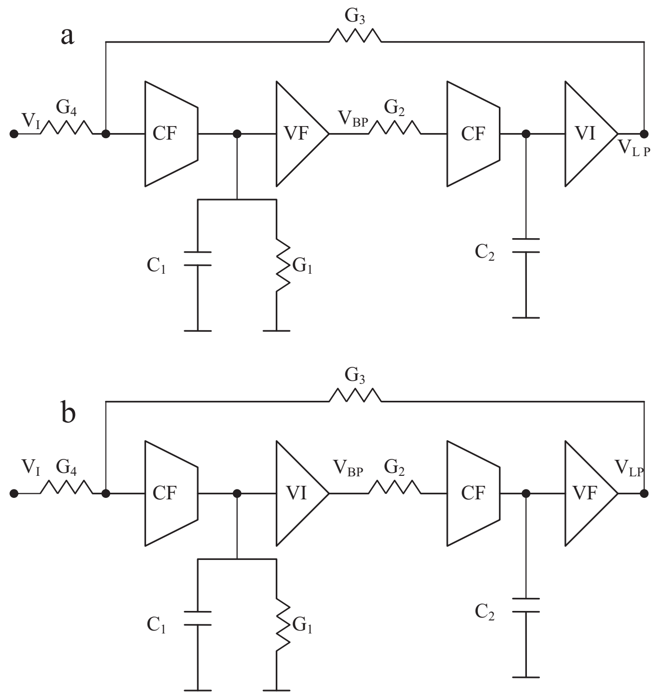

Fig. 8. (a) Unity gain cells based band-pass low-pass filter [17], (b) alternative unity gain cells based band-pass low-pass filter [17].

$$\frac{V_{LP}}{V_I} = \frac{G_2G_4}{s^2C_1C_2 + sC_2G_1 + G_2G_3} \tag{10}$$

The selectivity factor Q and the radian frequency are given by:

$$Q = \frac{1}{G_1}\sqrt{\frac{C_1G_2G_3}{C_2}}, \qquad \omega_o = \sqrt{\frac{G_2G_3}{C_1C_2}} \tag{11}$$

$$\text{LP gain}(0) = \frac{G_4}{G_3}, \qquad \text{BP gain}(\omega_o) = \frac{G_4}{G_1} \tag{12}$$

Fig. 7(b) represents a modified form of Tow Thomas circuit using two DCVC using one grounded resistor and three virtually grounded resistors.

Fig. 7(c) represents a unity gain cells equivalent circuit, which can be simplified resulting in the new unity gain cells circuit shown in Fig. 7(d). The polarities at the two outputs are non-inverting as in the circuit of Fig. 7(a).

The circuits shown in Fig. 8(a and b) was introduced in [17] realizing inverting low-pass polarity in both circuits and inverting band-pass polarity in the circuit shown in Fig. 8(b). These two circuits belong to a family of eight circuits as given in [17]. Table 3 includes a summary of the numbers of the passive and active circuit elements realizing the Tow Thomas filters of Figs. 7 and 8.

The second filter circuit considered in this section is shown in Fig. 9(a) which uses two DCVC, two grounded capacitors and four virtually grounded resistors and is a special case from the three input filter that was introduced in [13].

The voltage transfer function at the low-pass output is given by:

$$\frac{V_{LP}}{V_I} = \frac{G_1G_2}{s^2C_1C_2 + sC_1G_4 + G_2G_3} \tag{13}$$

The selectivity factor Q and the radian frequency are given by:

$$Q = \frac{1}{G_4}\sqrt{\frac{C_2G_2G_3}{C_1}}, \qquad \omega_O = \sqrt{\frac{G_2G_3}{C_1C_2}} \tag{14}$$

An equivalent two DCVC circuit with G_4 grounded is shown in Fig. 9(b). A two VF, two CF and two CI equivalent low-pass filter is shown in Fig. 9(c). A simplified equivalent realization using one CI

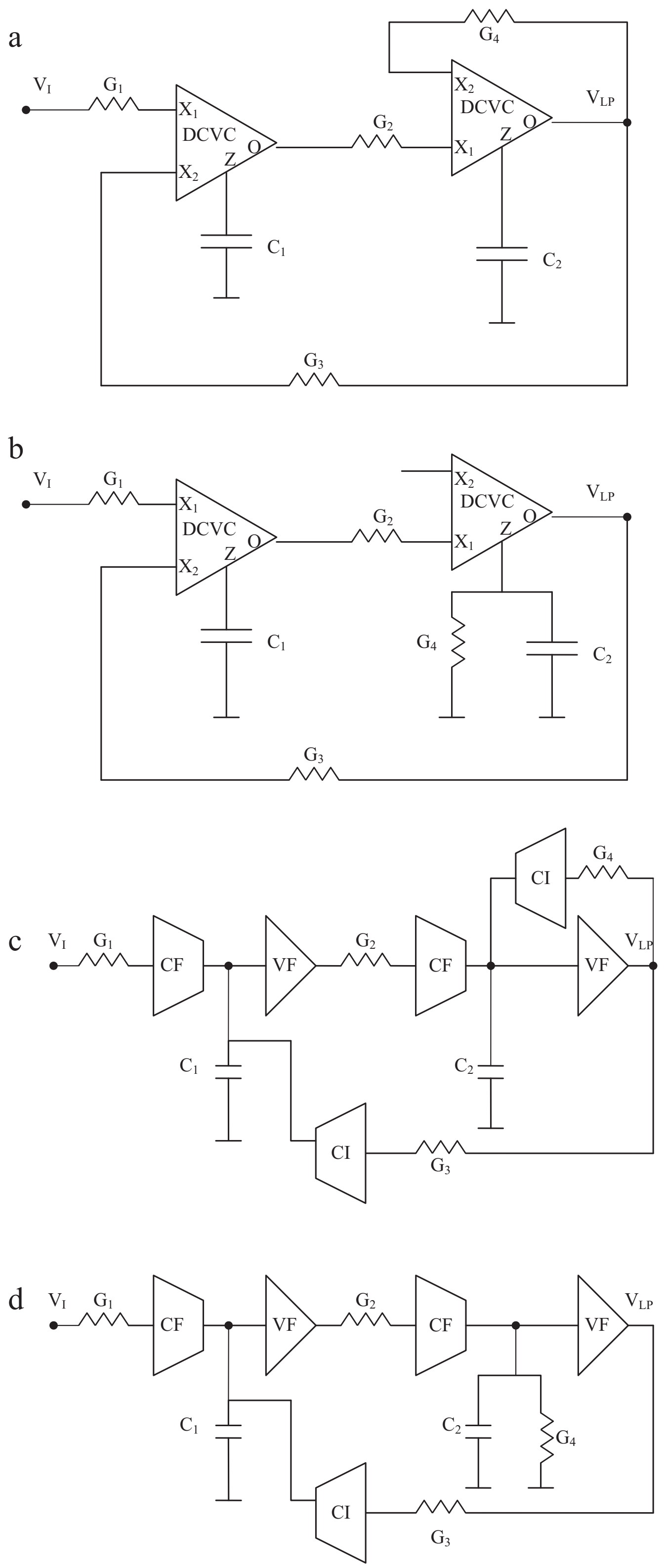

Fig. 9. (a) Low-pass filter using two DCVC and four resistors [13], (b) equivalent low-pass filter to (a), (c) unity gain cells based equivalent circuit to (a), (d) unity gain cells based equivalent circuit to (c).

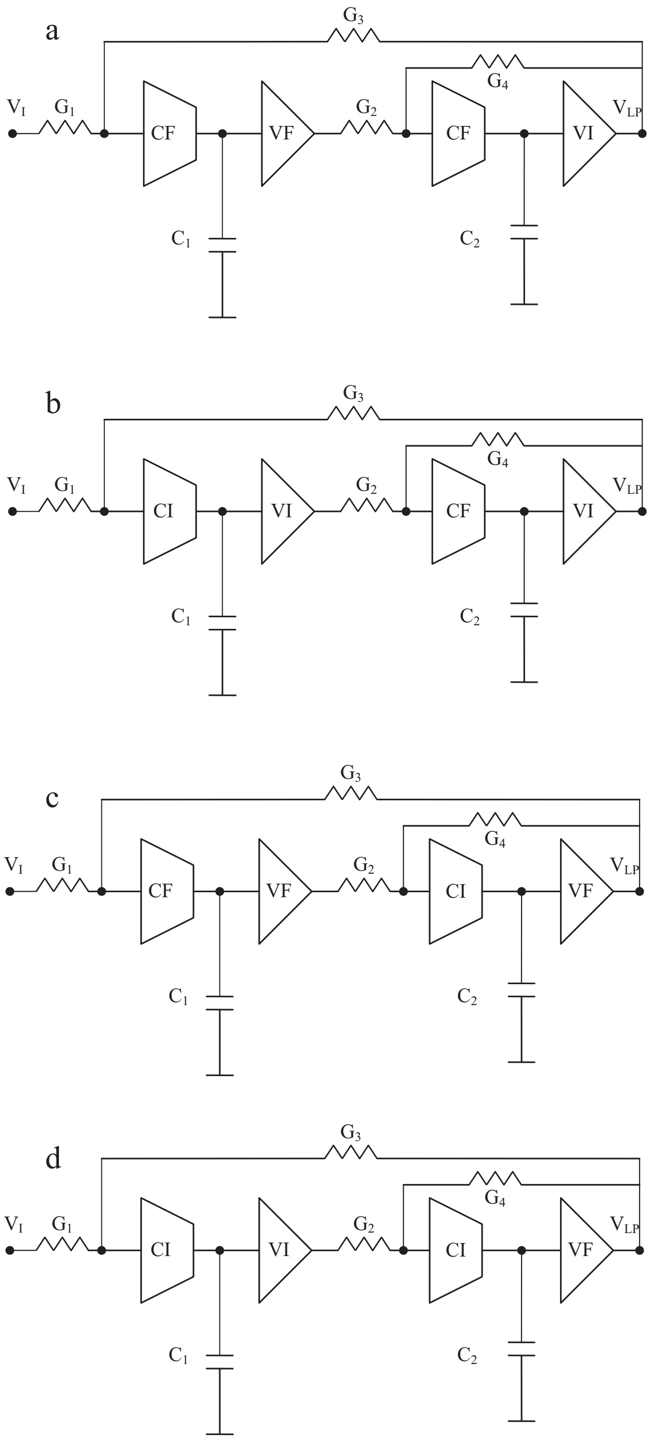

Fig. 10. (a) Simplified unity gain cells based inverting low-pass filter, (b) alternative unity gain cells based inverting low-pass filter, (c) alternative unity gain cells based inverting low-pass filter, (d) alternative unity gain cells based inverting low-pass filter.

less and with G_4 grounded is shown in Fig. 9(d). Fig. 10 includes four equivalent new unity gain cells realizing the low-pass transfer function given by Eq. (16) except with a negative sign and with G_4 virtually grounded. It should be noted that all the four circuits of Fig. 10 can be modified to move G_4 to be grounded and in parallel with C_2. In this case there will be an additional four equivalent circuits as shown in Fig. 11. That is there is a total of eight equivalent circuits with G_4 grounded; family of Fig. 11,and only four

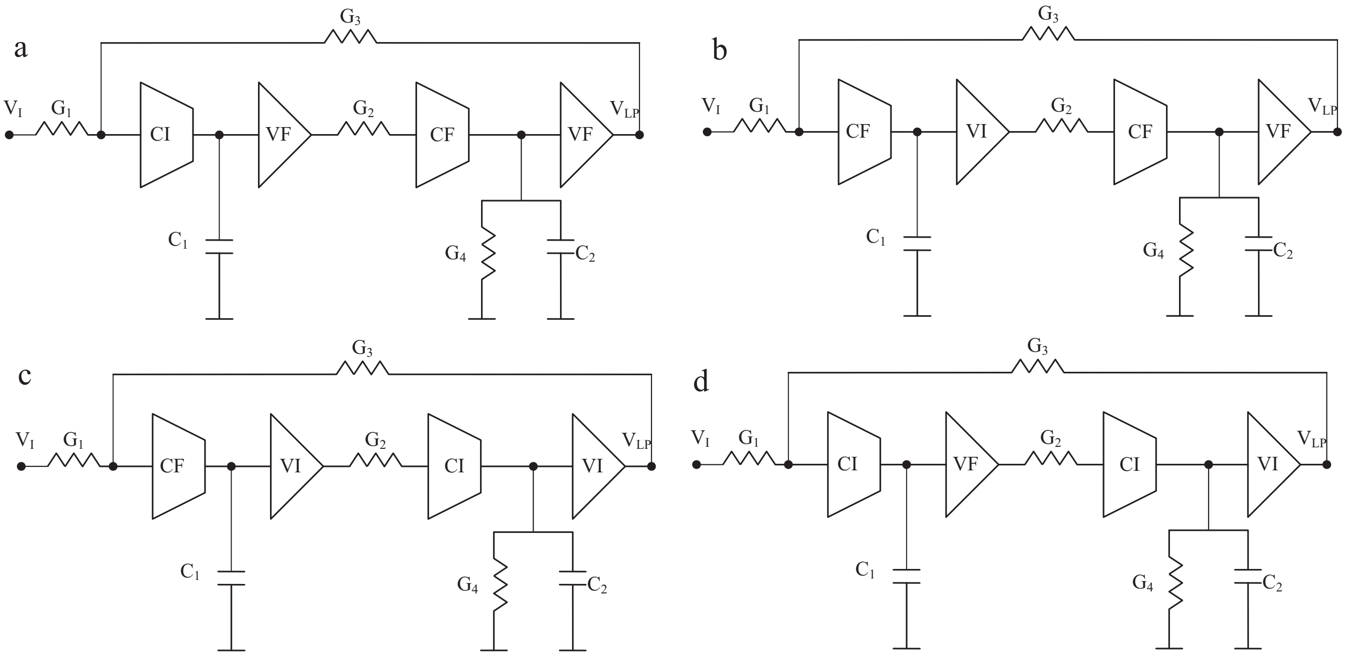

Fig. 11. (a) Simplified unity gain cells based low-pass filter to Fig. 10(a), (b) alternative unity gain cells based inverting low-pass filter, (c) alternative unity gain cells based inverting low-pass filter, (d) alternative unity gain cells based inverting low-pass filter.

Table 2
Elements realizing oscillator circuits of Figs. 5 and 6.

Figure number	Grounded resistor	Floating resistor	Grounded capacitor	DCVC	VF	VI	CF	CI
5(a)	0	4	2	2	0	0	0	0
5(b)	0	4	2	0	2	0	1	2
5(c)	1	3	2	0	2	0	1	1
5(d)	1	3	2	0	0	2	1	1
6(a)	0	3	2	2	0	0	0	0
6(b)	0	3	2	0	2	0	2	1
6(c)	0	3	2	0	1	1	2	0

Table 3
Elements realizing band-pass and low-pass filters of Figs. 7 and 8.

Figure number	Grounded resistor	Floating resistor	Grounded capacitor	DCVC	VF	VI	CF	CI	BP sign	LP sign
7(a)	0	4	2	2	0	0	0	0	+	+
7(b)	1	3	2	2	0	0	0	0	+	+
7(c)	0	4	2	0	2	0	2	1	+	+
7(d)	1	3	2	0	2	0	2	1	+	+
8(a)	1	3	2	0	1	1	2	0	+	–
8(b)	1	3	2	0	1	1	2	0	–	–

Table 4
Elements realizing low-pass filters of Figs. 9–11.

Figure number	Grounded resistor	Floating resistor	Grounded capacitor	DCVC	VF	VI	CF	CI	LP sign
9(a)	0	4	2	2	0	0	0	0	+
9(b)	1	3	2	2	0	0	0	0	+
9(c)	0	4	2	0	2	0	2	2	+
9(d)	1	3	2	0	2	0	2	1	+
10(a)	0	4	2	0	1	1	2	0	–
10(b)	0	4	2	0	0	2	1	1	–
10(c)	0	4	2	0	2	0	1	1	–
10(d)	0	4	2	0	1	1	0	2	–
11(a)	1	3	2	0	2	0	1	1	–
11(b)	1	3	2	0	1	1	2	0	–
11(c)	1	3	2	0	0	2	1	1	–
11(d)	1	3	2	0	1	1	0	2	–

equivalent circuits with G_4 virtually grounded; family of Fig. 10. For each of the twelve equivalent circuits the low-pass polarity is inverting. Table 4 includes a summary of the numbers of the passive and active circuit elements realizing the low-pass filters of Figs. 9–11.

5. Conclusions

The historical origin of the DCVC also known as the CDBA is reviewed. Pathological realizations of the MDCC and the DCVC are given. The pathological realizations are useful in obtaining alternative active building blocks realizations of the MDCC and the DCVC that are all equivalent in the ideal case. The generation of alternative equivalent oscillator and filter circuits using unity gain cells from known CDBA oscillators and filters is demonstrated by several examples. It is found that there is duplication in some of the recently published circuits and new simplified oscillator and filter circuits are reported. Several other publications on the CDBA have appeared in the literature [18–24] and are not considered in details in this paper due to the limited space. It is hoped that the duplication of the names of the Norton Op Amp [25] and the OTRA and of the DCVC and the CDBA is clearly explained and will serve in avoiding duplication of names of the same active block in the future.

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