

# A Digitally Programmable Voltage-mode Multifunction Biquad Filter with Single-Output

C. Ketviriyakit, W. Kongnun, C. Chanapromma, P. Silapan

**Abstract**—This article proposes a voltage-mode multifunction filter using differential voltage current controllable current conveyor transconductance amplifier (DV-CCCCTA). The features of the circuit are that: the quality factor and pole frequency can be tuned independently via the values of capacitors: the circuit description is very simple, consisting of merely 1 DV-CCCCTA, and 2 capacitors. Without any component matching conditions, the proposed circuit is very appropriate to further develop into an integrated circuit. Additionally, each function response can be selected by suitably selecting input signals with digital method. The PSpice simulation results are depicted. The given results agree well with the theoretical anticipation.

**Keywords**—DV-CCCCTA, Voltage-mode, Multifunction filter

## I. INTRODUCTION

IN analog signal processing applications it may be desirable to employ active filters. They can be found in many applications: e.g., communication, measurement and instrumentation and control systems [1-2]. One of most popular analog filters is a multi-function filter since it can provide several functions, depending on desired selections. The literature surveys show that the voltage-mode multifunction filter circuits [3-13] have been reported. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Excessive use of the active and/or passive elements [3, 5-6, 7, 9, 11, 13].
- Requirement for changing circuit topologies to achieve several functions [4, 9, 12].
- The pole frequency and quality factor can not be tuned independently [8-9].

In 2010, A reported active element, namely differential voltage current controllable current conveyor transconductance amplifier (DV-CCCCTA) [14], seems to be a versatile component in the realisation of a class of analog signal processing circuits. The fact is that the device can operate in both current and voltage-modes, provides flexibility and enables a variety of circuit designs. In addition, output current of DV-CCCCTA can be electronically adjusted.

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The aim of this paper is to propose a voltage-mode multifunction filter, emphasizing on use of the DV-CCCCTA. The features of proposed circuit are that: the proposed multifunction filter can provide completely standard functions (low-pass, high-pass, band-pass, band-reject and all-pass) without changing circuit topology: the circuit description is very simple, it uses 2 capacitors as passive elements, which is suitable for fabricating in monolithic chip or off-the-shelf implementation: quality factor and pole frequency can be independently adjusted. The performances of proposed circuit are illustrated by PSpice simulations, they show good agreement as mentioned.

## II. CIRCUIT CONFIGURATION

### A. Basic Concept of DV-CCCCTA

This section describes the principle of DV-CCCCTA, it was proposed by A. Jantakaun and M. Siriruchyanun in 2010. Figs 1(a) and (b) illustrate the schematic symbol and equivalent circuit of DV-CCCCTA, respectively. In ideal case, the relationship of voltage and current of DV-CCCCTA can be shown by (1)

$$\begin{bmatrix} V_x \\ I_{y1} \\ I_{y2} \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} R_x & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_{y1} \\ V_{y2} \\ V_z \\ V_o \end{bmatrix} \quad (1)$$

Since the DV-CCCCTA is design by BJT technology,  $R_x$  and  $g_m$  can be expressed as

$$\text{where } R_x = \frac{V_T}{2I_{B1}}, \quad (2)$$

$$\text{and } g_m = \frac{I_{B2}}{2V_T}, \quad (3)$$

$R_x$  and  $g_m$  are the parasitic resistance and transconductances of the DV-CCCCTA at x and o terminals, respectively. They can be adjusted via bias currents.  $V_T$  is the thermal voltage, its values is about 26mV at 27°C .

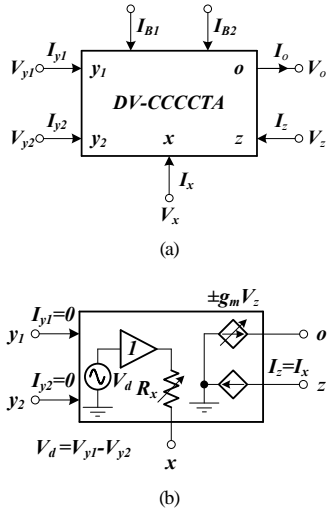


Fig. 1 DV-CCCCTA (a) schematic symbol, (b) equivalent circuit

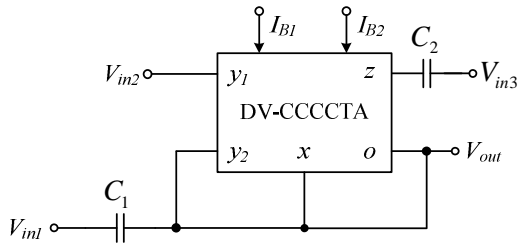


Fig. 2 Circuit diagram of voltage-mode filter.

**B. Proposed Multi-function Voltage-mode filter**

The proposed voltage-mode filter using DV-CCCCTA is shown in Fig. 2 where  $I_{B1}$  and  $I_{B2}$  are bias currents of the DV-CCCCTA. It comprises 1 DV-CCCCTA and 2 floating capacitors. By routine of analysis circuit in Fig. 2 and using the properties of DV-CCCCTA as explained in Section II.A, the output current and voltage at x terminal ( $I_x$  and  $V_x$ ) of DV-CCCCTA is obtained

$$I_x = (V_{in1} - V_{out})C_1s + I_o, \tag{3}$$

and

$$V_{out} = V_{in2} - V_{out} + I_x R_x. \tag{4}$$

From (4), the  $I_x$  can be expressed as

$$I_x = (2V_{out} - V_{in2})/R_x. \tag{5}$$

From the properties of DV-CCCCTA, the current at o terminal can be found to be

$$I_o = g_m V_z = [g_m (R_x C_2 s V_{in3} + V_{in2} - 2V_{out})]/R_x C_2 s. \tag{6}$$

From (5) and (6), the voltage output ( $V_{out}$ ) can be ultimately obtained

$$V_{out} = \frac{R_x C_1 C_2 s^2 V_{in1} + V_{in2} (C_2 s + g_m) + R_x g_m C_2 s V_{in3}}{R_x C_1 C_2 s^2 + C_2 s + 2g_m} \tag{7}$$

From (7), the amplitudes of input voltages  $V_{in1}$ ,  $V_{in2}$  and  $V_{in3}$  are selected as Table 1 by digital method to obtain a standard function of the 2<sup>nd</sup> order network. From (7), the pole frequency ( $\omega_0$ ) and quality factor ( $Q_0$ ) of each filter response can be expressed as

$$\omega_0 = \sqrt{\frac{2g_m}{R_x C_1 C_2}} = \frac{1}{V_T} \sqrt{\frac{2I_{B1} I_{B2}}{C_1 C_2}}, \tag{8}$$

And

$$Q_0 = \sqrt{\frac{2R_x C_1 g_m}{C_2}} = \sqrt{\frac{C_1 I_{B2}}{2C_2 I_{B1}}}, \tag{9}$$

In addition, bandwidth ( $BW$ ) of the system can be expressed by

$$BW = \frac{1}{R_x C_1} = \frac{2I_{B1}}{V_T C_1}, \tag{10}$$

For simple consideration, if we set  $C_1 = C_2 = C$ , then (8) and (9) are subsequently modified to

$$\omega_0 = \frac{1}{CV_T} \sqrt{2I_{B1} I_{B2}}, \tag{11}$$

and

$$Q_0 = \sqrt{\frac{I_{B2}}{2I_{B1}}}. \tag{12}$$

From (11) and (12), it can be clearly seen that the  $\omega_0$  and  $Q_0$  can be independently controlled by  $C$ .

TABLE I

THE  $V_{in1}$ ,  $V_{in2}$  AND  $V_{in3}$  VALUES FOR EACH FILTER FUNCTION RESPONSE

Filter Responses	Input		
$V_o$	$V_{in1}$	$V_{in2}$	$V_{in3}$
BP ( $R_x=1/g_m$ )	0	0	1
HP	1	0	0
LP ( $R_x=1/g_m$ )	0	2	-2
BR ( $R_x=1/g_m$ )	1	2	-2
AP ( $R_x=1/g_m$ )	1	2	-3

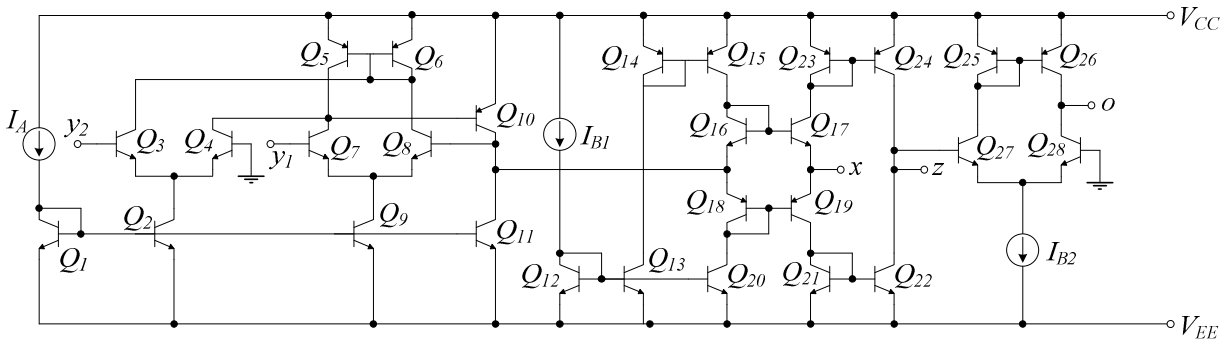


Fig. 3 Internal construction of DV-CCCCTA

III. SIMULATION RESULTS

The performances of the proposed voltage-mode filter have been tested by PSpice simulation. This work employed a DV-CCCCTA realized by a BJT technology. The PNP and NPN transistors employed in the proposed circuit as shown in Fig. 3 were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [15] with  $\pm 2V$  supply voltages,  $I_A = 100\mu A$ . Fig. 3 depicts the schematic description of DV-CCCCTA used in the simulations. Table I shows the parameters of BJT where it is used in the proposed circuit.

TABLE II  
PARAMETER OF BIPOLAR JUNCTION TRANSISTOR

NPN

.MODEL NR200N NPN(RB=262.5 IRB=0 RBM=12.5 RC=25 RE=0.5  
+IS=242E-18 EG=1.206 XTI=2 XTB=1.538 BF=137.5  
+IKF=13.94E-3 NF=1 VAF=159.4 ISE=72E-16 NE=1.713  
+BR=0.7258 IKR=4.396E-3 NR=1 VAR=10.73 ISC=0 NC=2  
+TF=0.425E-9 TR=0.425E-8 CJE=0.428E-12 VJE=0.5  
+MJE=0.28 CJC=1.97E-13 VJC=0.5 MJC=0.3 XCJC=0.065  
+CJS=1.17E-12 VJS=0.64 MJS=0.4 FC=0.5)

PNP

.MODEL PR200N PNP(RB=163.5 IRB=0 RBM=12.27 RC=25 RE=1.5  
+IS=147E-18 EG=1.206 XTI=1.7 XTB=1.866 BF=110  
+IKF=4.718E-3 NF=1 VAF=51.8 ISE=50.2E-16 NE=1.650  
+BR=0.4745 IKR=12.96E-3 NR=1 VAR=9.96 ISC=0 NC=2  
+TF=0.610E-9 TR=0.610E-8 CJE=0.36E-12 VJE=0.5  
+MJE=0.28 CJC=0.328E-12 VJC=0.8 MJC=0.4 XCJC=0.074  
+CJS=1.39E-12 VJS=0.55 MJS=0.35 FC=0.5)

The results shown in Fig. 4 are the gain and phase responses of the proposed biquad filter obtained from Fig. 2 with different functions as shown Table 1, where  $I_{B1}$ , and  $I_{B2}$  are equal  $20\mu A$  and  $80\mu A$ . There are clearly seen that the proposed biquad filter can provide low-pass, high-pass, band-pass, band-reject and all-pass functions dependent on selection as shown in Table I, without modifying major circuit topology.

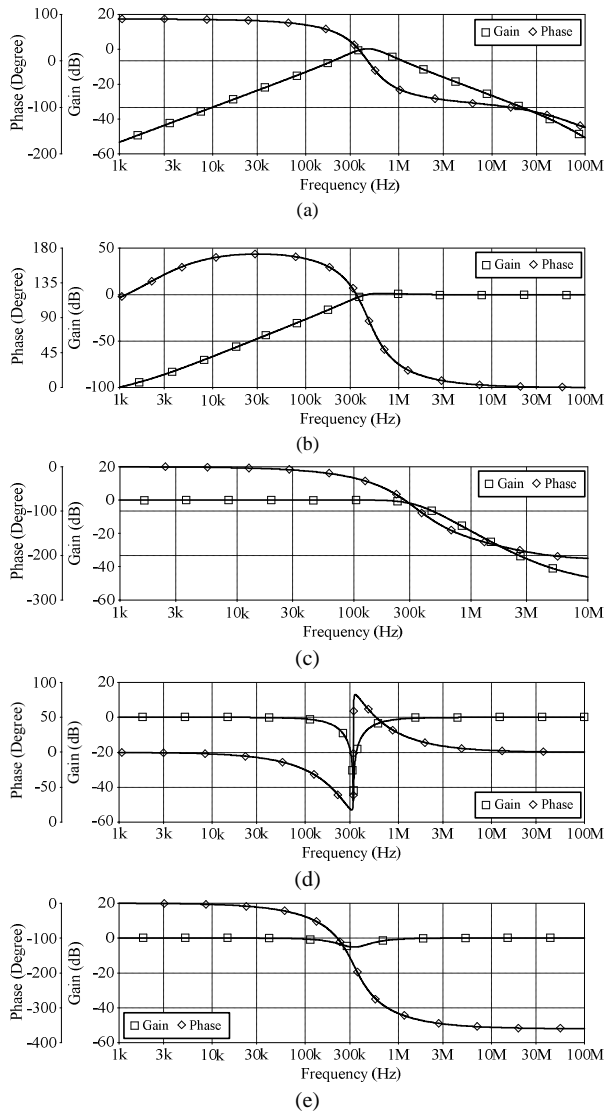


Fig. 4 Normalized magnitude and phase responses of the biquad filter (a) BP (b) HP (c) LP (d) BR (e) AP

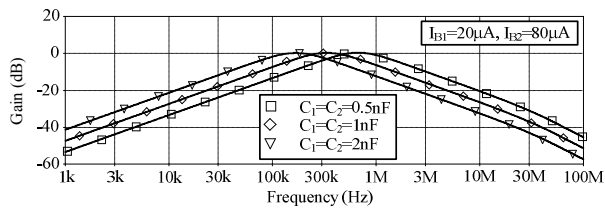


Fig. 5 Band-pass responses at different values of C

Fig. 5 displays the gain of Band-pass responses at different values of C. From this result, it can be found that if  $C_1 = C_2$ , the  $Q_0$  and  $\omega_0$  can be independently adjusted by C.

#### IV. CONCLUSION

The voltage-mode multifunction biquadratic filter base on DV-CCCCTA has been presented. The features of the proposed circuit are that: it performs low-pass, high-pass, band-pass, band-reject and all-pass functions with only single output depending on a digital selection method of input terminals as given in Table 1: the quality factor and the pole frequency can be independently controlled via values of capacitors. In addition, from simulation results, the proposed circuit can work at low supply voltages ( $\pm 2V$ ), low power consumption. The circuit description consists of only 1 DV-CCCCTA and 2 floating capacitors. By the way, from Table 1, the proposed voltage-mode biquad filter can be easily improved to achieve digital programmability, by adding digitally selective circuit [16]. With mentioned features, it is very suitable to realize the proposed circuits in monolithic chip for use in battery-powered, portable electronic equipments such as wireless communication system devices.

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