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A Synthesis of Low Component Count for Current-mode PID, PI and PD Controllers Employing Single CCTA and Grounded Elements

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Abstract—**This paper presents a synthesis of current-mode PI, PD and PID controllers employing current conveyor transconductance amplifier (CCTA). The features of these controllers are that: the output parameters can be an electronically controlled by adjusting corresponding bias currents, circuit description of the PID controller is simply formulated, it consists of only one CCTA cooperating with 2 grounded resistors and 2 grounded capacitors, PI and PD controllers are composed of single CCTA, 2 grounded resistors, 2 grounded capacitors and 3 grounded resistors, a grounded capacitor, respectively. This proposed circuit is very suitable to develop into an integrated circuit. The given results of the PSpice simulation agree well with the theoretical anticipation. The maximum power consumption in a closed-loop control system obtained from the PID controller and current-mode low-pass filter are approximately 0.393mW and PI and PD controllers are 0.379mW and 0.367mW, respectively at ±1.5V supply voltages.**

Keywords—**PID controller, PI controller, PD controller, CCTA, Current-mode, Low component.**

I. Introduction

THE PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) controllers are the most important control devices employed in industrial process control. They consist of three-terms, which are P for the proportional term, I for the integral term and D for the derivative term. Proportional-integral (PI) controllers, proportional-derivative (PD) controllers and PID controllers are implemented in various pieces of work together controllers with adjustable parameters. These controllers are used in many applications, for example, motor speed control, temperature control, fluid control and etc [1].

In the last two decades, the attention is subsequently focused on the PID controllers using different high-performance active building blocks such as, operational transconductance amplifiers (OTAs) [2]-[3], current feedback op-amp (CFAs) [4]-[6], second generation current conveyors (CCIIs) [7]-[9], second generation current controlled current conveyors (CCCIIs) [10]-[11], current differencing buffered amplifiers (CDBAs) [12]-[13], and etc. The literature surveys show that a large number of circuit realizations for PI, PD and PID controllers simulators have been reported [2]-[13]. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Excessive use of the active and/or passive elements [2]-[13].
- Lack of electronic tunability [4]-[9], [12].
- Use of floating capacitors which are not desirable for IC implementation [4]-[5], [7].
- Complicated circuit [5], [7], [10].

Recently, a reported 5-terminals active element, namely the current conveyor transconductance amplifier (CCTA) [14], seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters. It is supposed for usage mostly in current-mode circuits, but it is also a choice in case of the voltage mode and/or hybrid (voltage-current) circuits (e.g. V/I converters) [14]-[16].

Presently, a current-mode technique has been more popular than the voltage-mode one. This is due to operating in the low-voltage environment as in portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current–mode technique is ideally suited for this purpose than the voltage-mode one. There is a growing interest in synthesizing the current-mode circuits because of their more potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry and lower power consumption [17].

The purpose of this paper is to introduce low component number of the current-mode PI, PD and PID controllers employing single CCTA. The features of proposed controllers are that: the PI, PD and PID circuits are use only single active element and all grounded passive elements, the circuit description of PI, PD and PID controllers are very simple, it consists of only one CCTA cooperating with two grounded resistors and two grounded capacitors, the output parameters can be electronically controlled by adjusting bias current I_B. The simulations are performed by PSpice to exhibit the performance of the developed automatic controllers. They show good agreement as mentioned.

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II. Circuit Configuration

A. Basic concept of CCTA

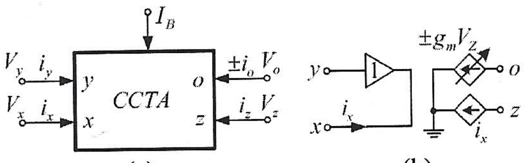
The characteristics of ideal CCTA are represented by the current conveyor (CCII) that is followed by dual output operational transconductance amplifier (OTA). The voltage and current relationships of the CCTA are shown in (1).

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix}, \qquad (1)$$

where g_m is the transconductance of a CCTA. For a bipolar CCTA, the transconductance gain can be respectively expressed by

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

where I_B and V_T are bias current and thermal voltage (it equals 26mV at a room temperature), respectively. The symbol and the equivalent circuit of the CCTA are illustrated in Fig. 1 (a) and (b), respectively.



(a) (b)

Fig. 1. The CCTA (a) symbol (b) equivalent circuit.

B. Synthesis of proposed controllers employing CCTA

PI Controller

A PI controller is composed of a proportional and an integral term. The PI controller is sufficient when the process dynamic is essentially first-order system. The proposed PI controller employs only single CCTA and two grounded capacitors with two grounded resistors as shown in Fig. 2. Transfer function of general PI controller can be written as shown in (3)-(4).

$$H_{PI}(s) = \frac{I_O}{I_{in}} = K_{Pi} + \frac{1}{T_i s}, \qquad (3)$$

and

$$H_{PI}(s) = \frac{I_O}{I_{in}} = g_m \left(\frac{R_y C_x}{C_z} + \frac{R_x s C_z}{R_y} \right). \qquad (4)$$

Substituting $g_m = I_B/2V_T$ into (5), it yields

$$H_{PI}(s) = \frac{I_O}{I_{in}} = \frac{I_B R_y C_x}{2V_T C_z} + \frac{I_B R_x s C_z}{2V_T R_y}. \qquad (5)$$

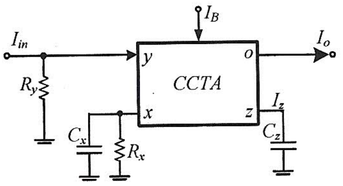


Fig. 2. The PI controller.

PD controller

The PD controller is the most widely used in strategy for robot manipulators, motor control, etc. Additionally, more advanced controllers often incorporate to PD algorithms in their control-loop to reach the desired configuration. The derivative term of the PD controller deals with slope of error, and it is effective in the transient-response. The derivative term has no effect if the steady-state error is constant in corresponding time. The proposed PD controller employs merely single CCTA and one grounded capacitor and three grounded resistors as shown in Fig. 3. Transfer function of general PD controller can be written in (6)

$$H_{PD}(s) = \frac{I_O}{I_{in}} = K_P + T_D s, \qquad (6)$$

The CCTA based PD controller shown in Fig. 3 has the transfer function as shown in (7)

$$H_{PD}(s) = \frac{I_O}{I_{in}} = g_m \left(\frac{R_y R_z}{R_x} + R_y s C_x \right), \qquad (7)$$

substituting $g_m = I_B/2V_T$ into (7), it yields

$$H_{PD}(s) = \frac{I_O}{I_{in}} = \frac{I_B R_y R_z}{2V_T R_x} + \frac{I_B R_y s C_x}{2V_T}. \qquad (8)$$

From (8), it can be seen that the proportional or gain (Kp) and derivative time (T_D) can be controlled by I_B.

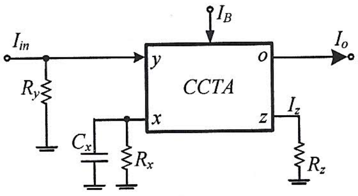


Fig. 3. The PD controller.

PID Controller

Proportional-integral-derivative (PID) controllers are extensively used in industry. It is estimated that more than 90% of all control loops involve PID controllers, where the proportional term adjusts the speed response of the system, the integral term adjusts the steady-state error of the system and the derivative term adjusts the degree of stability of the system.

The proposed PID controller in current-mode is shown in Fig. 4. It consists of only one CCTA and 4 grounded passive elements which are 2 grounded capacitors and 2 grounded resistors. It is suited for integrated circuit (IC) implementation. The transfer function of general analog PID controllers can be written as depicted in (9),

$$T(s) = \frac{I_{out}(s)}{I_{in}(s)} = K_p + \frac{K_I}{s} + sK_D, \qquad (9)$$