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A New Proportional-integral-derivative (PID) Controller Realization by Using Current Conveyor

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Abstract: In process control industry, the proportional-integral-derivative (PID) controllers are one of the most important control elements. In practice, operational amplifiers are generally used in analog controllers. On the other hand, current-mode (CM) circuits such as second-generation current conveyors (CCII) have considerable attention due to their wider frequency band, lower power consumption, better linearity and stability properties compared to their voltage-mode counterparts, operational amplifiers. The purpose of this study is to present a synthesis procedure for the realization of analog PID controller by the use of CCIIs. All the PID controller circuits realizations employ only grounded passive components, and do not require passive element matching so the circuits are suitable for integration.

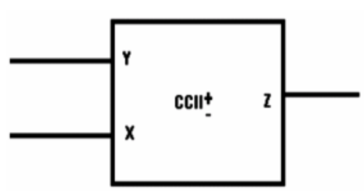
Keywords: PID controller, current conveyor (CCII).

1. INTRODUCTION

In IC technology during the last some decade, designers used current mode technique to solve the several circuit design problem. The current-mode approach to signal processing has often been claimed to provide one or more of the following advantages: higher frequency range of operation, lower power consumption, higher slew rates, improved linearity, and better accuracy. In this thesis, some current mode and voltage mode analog circuits, which include amplifier, differentiator, integrator etc. have been studied. These circuits are used to construct proportional integral (PI), proportional derivative (PD) and proportional integral derivative controller (PID). To realize these circuits active elements such as Current Conveyor (CC), Differential Voltage Current Conveyor (DVCC) and Current Differencing Buffered Amplifier (CDBA) have been used. These controllers based on the above mentioned active elements use reduced number of active and passive components as compared to the traditional op-amp based controllers. However, here most important proportional integral derivative controller have been simulated with SPICE using CMOS version of active elements as CCII. Proportional-integral-derivative (PID) controllers are extensively used in the many industrial control systems. It is estimated that more than 90% of all control loops involve PID controllers [4] because of their simplicity in design, easiness in parameter tuning, and cheap in cost [2]. A PID controller is composed of three terms. They are: (1) proportional, (2) integral, and (3) derivative. The proportional term adjusts the speed of 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 proportional-integral-derivative (PID) controllers with adjustable parameters are widely used in many industrial control systems.

2. CURRENT CONVEYOR (CCII)

The current conveyor (CC) is the basic building block of a number of applications both in the current and voltage and the mixed modes. The principle of the current conveyor of the first generation was published in 1968 by K. C. Smith and A. S. Sedra [6]. Two years later, today's widely used second-generation CCII was described in [7], and in 1995 the third-generation CCIII [8].



$$\begin{bmatrix} V_x \\ I_y \\ I_z \end{bmatrix} = \begin{bmatrix} \beta & 0 & 0 \\ 0 & 0 & 0 \\ 0 & \pm\alpha & 0 \end{bmatrix} \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix}$$

Figure 1: Block Diagram of CCII and Terminal Relations

2.1. CMOS Realization of DO-CCII+

The Dual ouput CCII (DO-CCII) has been simulated using the CMOS structure of Figure 2 with DC supply voltage equal to ± 1.5V and bias voltage equal to V_B = .5V.All MOS transistors are operated in saturation region and all of the bulks are connected to power supply voltage (bulks of PMOS are connected to + 1.5V, and bulks of NMOS are connected -1.5V). The simulations are based on .35um TSMC CMOS technology.

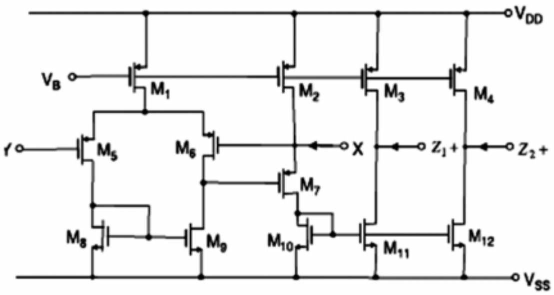
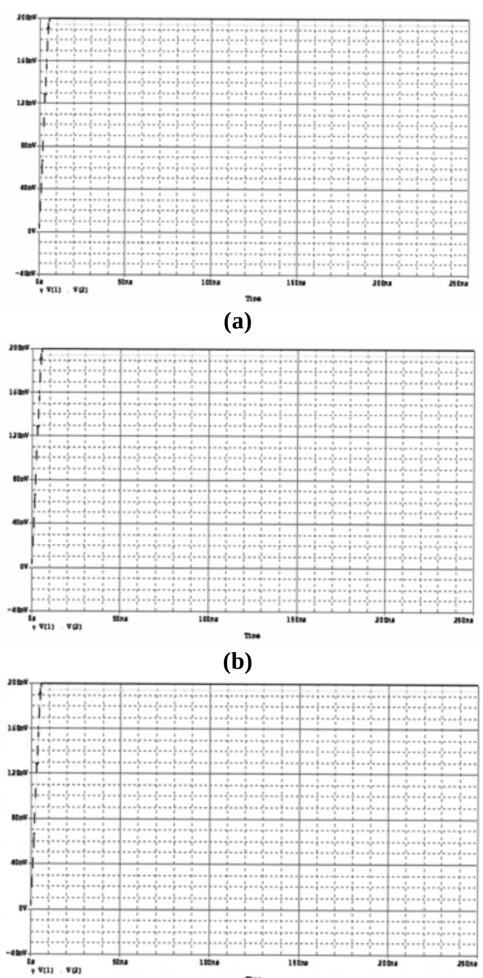


Figure 2: CMOS Structure of DO-CCII+

In order to demonstrate the port relations of the current conveyor, computer simulations are performed using CMOS based CCII schematic given in Figure 3, a pulse input of 200mv connected to Y port and other ports e. g. X, Z_1, Z_2 are terminated by resistances R_1, R_2 and R_3 each having a value of 1KΩ. The simulation results for $V_x = V_y$, $I_z = I_x$ and $I_z = -I_x$ are shown in Figure 4.



(a)

(b)

(c)

Figure 3: Simulated Port Relationship of CCII (a) $V_x = V_y$, (b) $I_z = I_x$ and (c) $I_z = -I_x$

3. PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER

This chapter presents proportional integral derivative controllers. In the first section we discussed about proportional (P), integral (I) and derivative (D) and proportional integral derivative (PID) controller. Then in next sections, we realized the PID controllers by using current conveyor, differential voltage current conveyor and current differential buffered amplifier in both current and voltage mode. In these sections, we simulate PID controllers by using PSpice and show the simulation results.

PID controllers designed by the current conveyors provide good results, such as greater linearity, wider bandwidth, better dynamic range, less chip area, less power dissipation and easy realization, etc. [1,2]. The second-generation current conveyor (CCII) has proved to be a versatile analog building block that can be used to implement numerous high frequency analog signal applications.

However, when it comes to applications demanding differential or floating inputs like impedance converter circuits and current mode instrumentation amplifiers, which also require two high input impedance terminals, a single CCII block is no more sufficient. In addition, most of these applications employ floating elements in order to minimize the number of used CCII blocks. For this reason and in order to provide two high input impedance terminals, two active building blocks, namely, the differential voltage current conveyor (DVCC) have been proposed in the late 90s. Although this building blocks has been used in a variety of applications, their CMOS circuit realizations exhibited mainly low input and output dynamic ranges. CDBA is a universal element for filter design, primarily for voltage-mode operation. Some of the applications from the basic CDBA feature, i.e. the non-problematic implementation of both non inverting and inverting integrator as a building block of filters of arbitrary order.

Proportional controller output; $c(t) = K_c * e(t) + c_s$

Integral Controller output = *(1/Ti) * int(error)*

$$I_{out} = K_i \int_0^t e(\tau)\, d\tau$$

Derivative controller output = *Td*d(error)/dt= Td*d (SP-PV)/dt*

$$D_{out} = K_d \frac{d_e}{dt}(t)$$

4. PID CONTROLLER USING CCII

A PID controller is composed of a proportional, Integral and derivative terms. The PID controller is sufficient when the process dynamics is essentially first-order. Both current-mode and voltage mode PID controllers employing reduced number of active element, that are composed of two second generation current conveyors with five grounded passive elements. Both of the PID controllers do not require passive component matching. In other words, each of the passive elements can be selected arbitrarily. are shown in Figures 4.

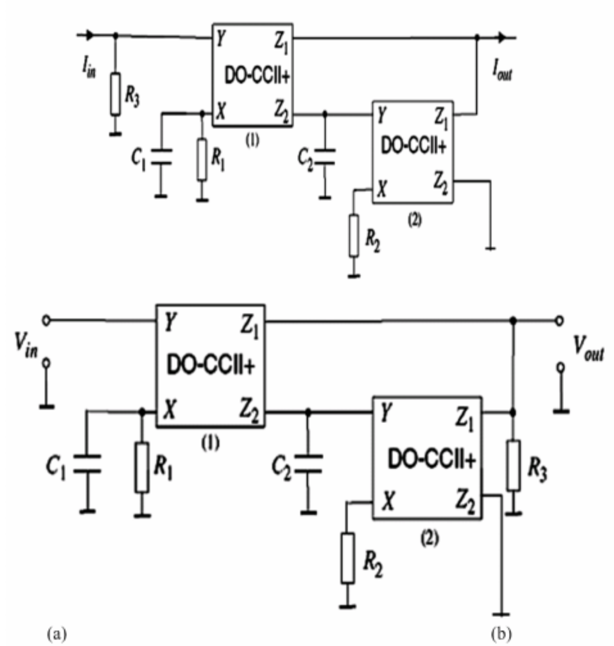


Figure 4: PID Controller (a) Current Mode (b) Voltage Mode

The analysis of the PID controller circuits in Figure 5 gives the following current transfer functions:

$$H_v(s) = \frac{V_{out}(s)}{V_{in}(s)} = K_{pv} + \frac{1}{sT_{iv}} + sT_{dv},$$

$$H_i(s) = \frac{I_{out}(s)}{I_{in}(s)} = K_{pi} + \frac{1}{sT_{ii}} + sT_{di}.$$

The proportional gain ($K_p = K_{pi} = K_{pv}$), the integral time constant ($T_i = T_{ii} = T_{iv}$) and the derivative time constant ($T_d = T_{di} = T_{dv}$) parameters of both PID controllers are as:

$$K_p = \alpha_1\beta_1 \frac{R_3}{R_7} + \alpha_2\beta_1\beta_2\gamma_1 \frac{C_1R_3}{C_2R_2},$$

$$T_i = \frac{C_2R_1R_2}{a_2\beta_1\beta_2\gamma_1R_3},$$

$$T_d = \alpha_1\beta_1C_1R_3.$$

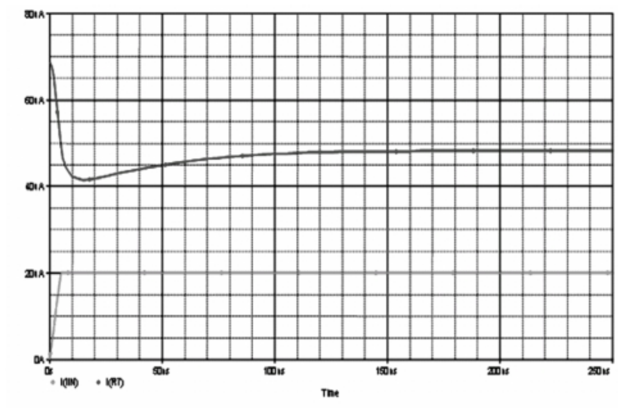
where, α_1, α_2, β_1, β_2 and γ_1 are in form of multiplier constants for the parameters.

It should be noted that the traditional PID controller circuit, which consists of simple op-amp circuits (integral circuit, proportional circuit and a summer circuit) [5], uses totally four op-amps and ten floating passive elements. However, this PID controller employs two CCII+ and five passive elements (two capacitors and three resistor), which are all grounded.

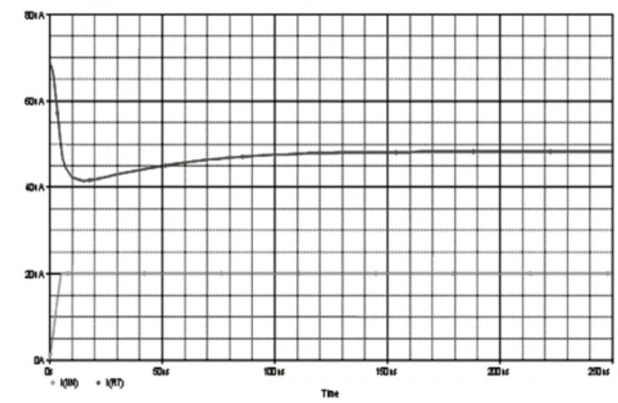
5. SIMULATION RESULT

5.1. Current Mode PID

In order to demonstrate the performance of the proposed PID controllers, computer simulations are done with R_1= 0.5k, $R_2 = R_3$ = 1k and $C_1 = C_2$= 100pF for circuit in Figure 5. PID controller has the parameters that are calculated as $K_{pi} = 3$, T_{ii} = 50ns, and $T_{di} = 10^{-7}$ s.



(a)



(b)

Figure 5: Simulated Result of (a) Current Mode PID (b) Voltage Mode Using CCII

5.2. Voltage Mode PID

In order to demonstrate the performance of the proposed PID controllers, computer simulations are done with R_1 = .5k, $R_2 = R_3$ = 1k and $C_1 = C_2$ = 100pF for circuit in Figure 5 PID controller has the parameters that are calculated as = 1.001, = 50ns, and = 10^{-7}s.

6. CONCLUSION

The current mode and voltage mode Proportional Integral Derivative controllers are realized using Dual output second generation current conveyor (DO-CCII+). All PID controllers employ reduced number of active and passive elements with respect to the traditional op-amp based controllers. So, these controllers need small chip area and less power dissipation and also employ grounded passive element in the circuits which is advantageous from the integrated circuit implementation point of view. All of the controller's parameters can be taken studied independently.

The proportional integral, proportional derivative and proportional integral derivative controllers have been simulated with SPICE using CMOS version of active elements.

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