A CURRENT CONTROLLED CONVEYOR BASED PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) CONTROLLER

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ABSTRACT

A new PID controller realized with positive type, second generation current controlled conveyers (CCCII++) and passive components is presented. The outputs of SPICE simulations of the proposed circuit are verified with the theoretical expectations.

1. INTRODUCTION

Current controlled conveyors (CCCII) have recently considerable attention due to their wider and adjustable frequency band, lower power consumption, better linearity and stability properties and also providing electronically controllable characteristics to electronic circuits [1-6]. On the other hand, no other work has been carried out for the generation analog controllers in process control industry using CCCIIs at present except the ones by Erdal and Kuntman [1], although there are a vast number of electronic circuits realized with current controlled conveyors.

The purpose of this study is to present a synthesis procedure for the realization of analog PID controller by the use of CCCIIs. This procedure is based on signal-flow graphs, which are very useful to design active electronic circuits. The circuit obtained satisfies the general transfer function of a PID controller and contained minimum number of CCCIIs. The SPICE simulations of the proposed circuit are fulfilled to verify the theoretical predictions.

2. CURRENT CONTROLLED CONVEYOR

The circuit diagram of a current controlled conveyor (CCCII) is shown in Figure 1 [1-7].
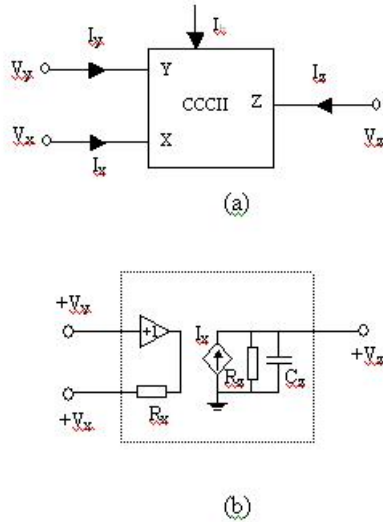
(a)

(b)

Figure 1. a) Electrical symbol of the current controlled conveyor (CCCII) b) Equivalent circuit of CCCII

The ideal current controlled conveyor can be described by the following equations:

$$I_y = 0 \ , \ V_x = V_y + R_x I_x \ , \ I_z = \pm k I_x \qquad (1)$$

Where V_y, V_x, I_y, and I_x are the voltages and currents of the positive and negative inputs, respectively. V_z and I_z are the output voltage and current, respectively. The positive k denotes a positive current controlled conveyor (CCCII+) and the negative sign denotes a negative current controlled conveyor (CCCII-), and k=1-ε, $|\varepsilon|$<<1 represents the current tracking error. R_x is the input resistance at port X and can be calculated as,

$$R_x = V_T / 2I_b \qquad (2)$$

where V_T is the thermal voltage (27 °C de 25,8 mV) and I_b is the bias current of the CCCII [3].
The equivalent circuit of CCCII is shown in Figure 1b where R_x is the output resistance of the equivalent Thevenin generator seen from port X. R_z and C_z are the resistance and the capacitance of z-output, respectively.

If the non-ideality properties are taken into account the describing equations of CCCII can be given as follows:

$$I_y(t) = Y_y(s)V_y , \qquad (3a)$$

$$V_x(t) = \beta V_y(t) + I_x R_x , \qquad (3b)$$

$$I_z(t) = \pm \alpha I_x(t) + Y_z V_z \qquad (3c)$$

where Y_y and Y_z are the parasitic admittances between each port Y and Z and the ground, respectively. $\alpha(s)$ and $\beta(s)$ are the current and voltage transfer gains of the conveyor, respectively.

3. SYNTHESIS PROCEDURE

Consider the current conveyor circuits shown in Fig. 2. Using the defining equation of the active element the signal-flow graph of these circuits can easily be drawn [8].

In Fig. 2(a), an amplifier circuit and its signal-flow graph are shown. The gain of the amplifier is R_I/R_x as it can be easily seen from the signal graph. In Fig. 2(b), an integration circuit and its signal-flow graph are shown. The integration time constant of this circuit is $1/R_xC_I$ as it can be easily seen from the signal graph.

In Fig. 2(c), a derivative circuit and its signal-flow graph are shown. The derivative time constant of this circuit is L/R_x. The problem in this circuit is to realize the required ideal inductance element. Because of the difficulty of the realization and the direct implementation, the inductance element has been simulated synthetically such as in Fig. 2(d). Routine analysis shows that the input impedance of this L simulation circuit can be calculated as follows:

$$Z_i = sR_{x1}R_{x2}C_D \qquad (4)$$

Since Z_i is proportional by s, this circuit behaves as an inductor.

The proposed three mathematical functions, i.e. multiplication, integration, and derivation, will be transmitted to the output by the CCCII-based summing circuit shown in Fig. 2(e) to obtain a PID circuit.

That means if a given transfer function is represented by a signal-flow graph composed of subgraphs shown in Fig. 2, then the circuit corresponding to the signal-flow graph can be realized by interconnecting the building blocks of Fig. 2 [8].

The transfer function of a general analog PID controller can be written as follow [9]:

$$T(s) = \frac{V_O(s)}{V_i(s)} = K_P + \frac{K_I}{s} + sK_D \qquad (5)$$

where $v_o(t)$ is the output voltage; $v_i(t)$ is the input voltage; K_P is the proportional gain; K_I is the integral gain; and K_D is the derivative gain.

A signal-flow graph of the transfer function of an analog PID controller given such as in Eq. 4 can be drawn such as in Fig. 3 [9,10].

The realization of the analog current controlled conveyor (CCCII) based PID controller circuit corresponding to the signal-flow graph in Fig. 3, which is realized by the subcircuits in Fig. 2, is shown in Fig. 4.

In Fig. 4, the CCCII numbered 1, together with the resistance R_1 describe the proportional gain. The CCCII numbered 2, together with the capacitor C_1 form the integration circuit. The CCCIIs numbered 4 and 5, together with the capacitor C_2, simulates an inductance with the value of $L=R_{x1}R_{x2}C_2$. This inductance and the CCCII numbered 3 configure the derivative circuit The CCCIIs numbered 6,7 and 8 form the weighted summing circuit.

In Fig. 4, a CCCII-based PI controller circuit and a CCCII-based PD controller circuit can be obtained by removing path III and path II, respectively, between input and output.

If the circuit in Fig. 4 is analyzed without taking the non-idealities into account, the controller gains K_P, K_I and K_D will be obtained as follows:

$$K_P = \frac{R_oR_1}{R_{x1}R_{x6}}, \tag{6a}$$

$$K_I = \frac{R_o}{R_{x2}R_{x7}C_1}, \tag{6b}$$

$$K_D = \frac{R_{x4}R_{x5}R_oC_2}{R_{x3}R_{x8}} \tag{6c}$$

As easily seen, the controller gains be can be assigned to the required values by adjusting the control current, I_{bi} of a selected CCCII since they depend mostly on X input resistances of CCCIIs, controller output resistance and the values of the capacitances.
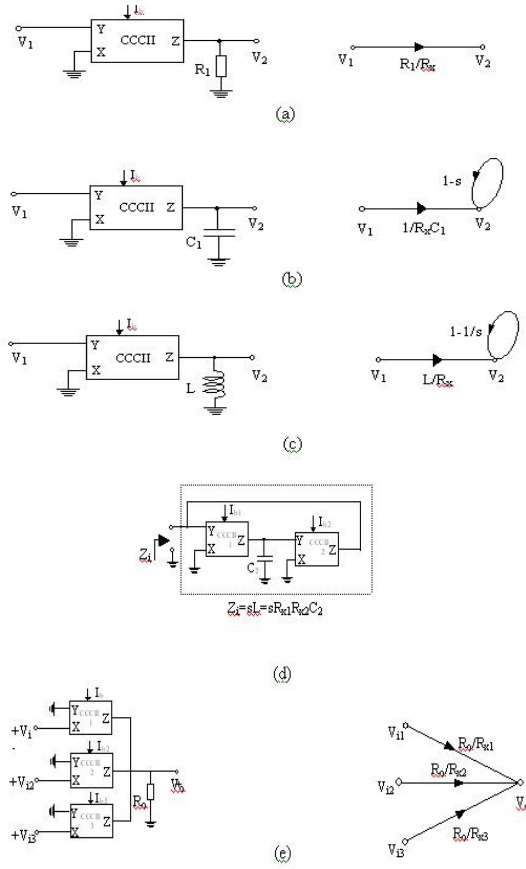

(a)

(b)

(c)

(d)

(e)

Figure 2. Sub-graphs and corresponding active sub-circuits involve CCCII
(a) Amplifier, (b) integrator, (c) derivative circuit, (d) inductance simulation (e) summing circuit

4. THE RESULTS OF SIMULATION

The performance of the proposed CCCII-based PID circuit given in Fig. 4 has been simulated using the SPICE circuit simulation program In this simulation, the bipolar CCCII+ circuit given in Fig. 5a is characterized by the model parameters NR100N and PR100N [11-15], then the CCCII macromodel obtained from this characterization has been used in SPICE simulation of the controller [16]. The variation of the input resistance at port X, R_x of CCCII with respect to the bias current in the circuit given in Fig. 5a is shown in Fig. 5b. The resistances seen from the Y and Z ports are determined respectively as $R_Y = 320k$ and $R_Z = 587k$ for a selected operational point. It is shown that K_P, K_D and K_I can be controlled independent from each other since the resistances R_{x1}, R_{x2} and R_{x3} can be varied with the bias currents of CCCIIs.

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This property gives a great comfort to the designer. One of the output characteristics is given in Fig. 5c as an example. The frequency response obtained by using real element is agreed very well with the ideal response in a wide range of frequency. The differences in lower and higher frequencies have been occurred from the nonidealities of CCCII, especially the limited port resistances R_Y and R_Z. The resistance R_{x1} has been varied by the bias current between the values of 100Ohm-250Ohm and there upon gain- frequency characteristic is changed. The value of K_P is decreased as R_{x1} increased, as expected.
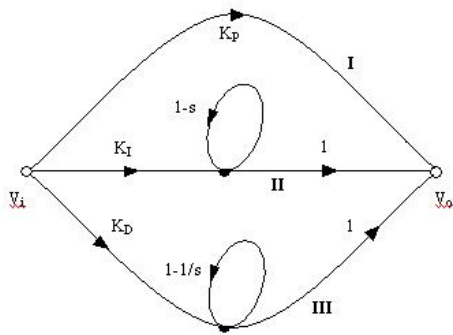

Figure 3. A signal flow graph corresponding to the general transfer function of the proportional-integral-derivative (PID) controller
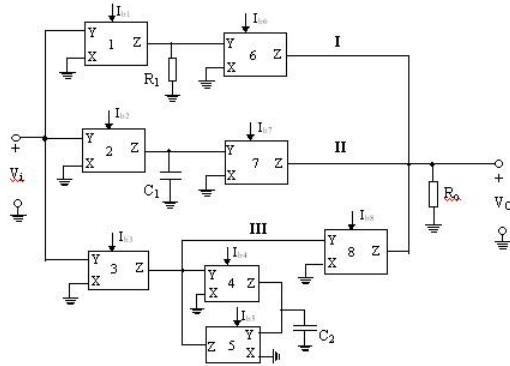

Figure 4. Proposed CCCII-based PID controller realization corresponding to the signal-flow graph shown in Fig.3.
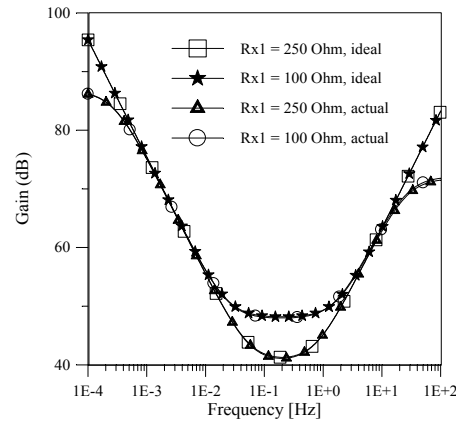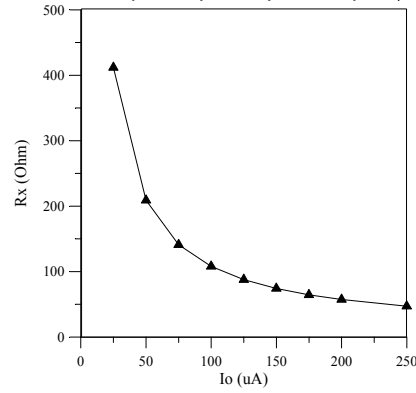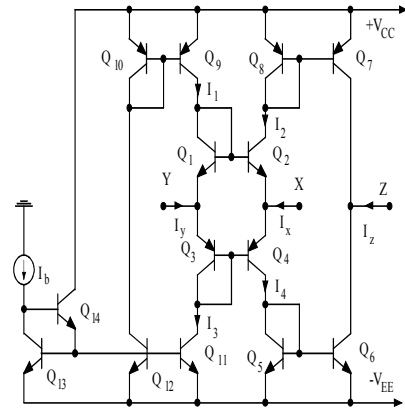

Figure-5 a) Bipolar CCCII+ circuit used in simulation
b) The dependency of the resistance Rx to the bias current in the CCCII+ circuit
c) The gain-frequency curve obtained for ideal and real element for Rx1= 100 Ohm and 250 Ohm

If the following values are given for the controller gains

K_P=67,6, K_I=38462 s^{-1}, and K_D=0,00005 s

$$(7)$$

the parameter values will be calculated as follows:

C_1=1uF, C_2=100nF, R_1=1kΩ, R_o=0.5kΩ,   (8a)

i_{b1}=150uA➔ R_{x1}=86Ω, i_{b2}=260uA➔ R_{x2}=50Ω,
$$(8b)$$

i_{b3}=260uA➔ R_{x3}=50Ω,   (8c)

i_{b4}=260uA➔ R_{x4}=50Ω, i_{b5}=260uA➔ R_{x5}=50Ω,

,

$$(8d)$$

i_{b6}=150uA➔ R_{x6}=86Ω,   (8e)

i_{b7}=50uA➔ R_{x7}=260Ω, i_{b8}=260uA➔ R_{x8}=50Ω.
$$(8f)$$

With the values in (8), the frequency response of PID given in Fig. 6 is obtained by changing the frequency of the input signal. As seen from Fig. 6, the bandwidth of the proposed PID circuit is almost 1MHz and the frequency response obtained by using real element is agreed very well with the ideal response in a wide range of frequency.
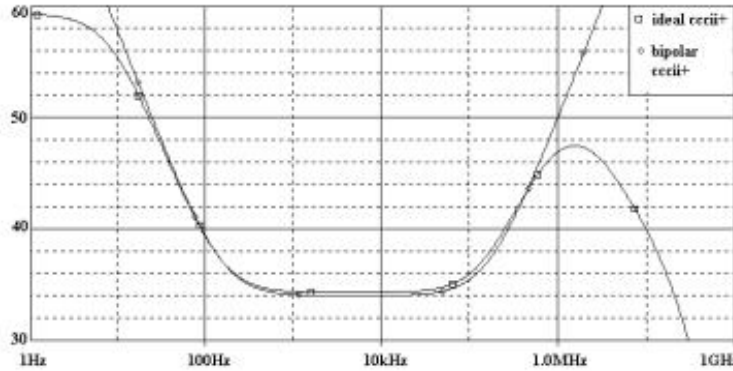

Figure 6. The frequency response of the proposed circuit for selected controller gains.

5. CONCLUSIONS

In this study, first a method to design a CCCII-based proportional-integral-derivative (PID) controller is given then a new CCCII-based PID controller circuit is presented. The method presented here is straightforward and simple, as it provides not only the configuration but also the element values directly from the coefficients of the PID controller voltage transfer function. The proposed circuit contains eight CCCIIs; two grounded capacitors, two resistors and is very convenient to implement in one integrated chip. The proposed PID circuit is very useful required for a stable control, very wide frequency band, which is almost 1MHz by choosing the appropriate parameter values, there upon to control rapidly changing signals since CCCIIs have wider and adjustable frequency band, lower power consumption, better linearity and stability

properties compare to the operational amplifiers and also providing electronically controllable characteristics to electronic circuits. Another advantage of the propose PID circuit is that the controller gains K_P, K_I and K_D are proportional with the ratios of the resistances and can be adjusted to any desired values by only bias current of a selected CCCII.

Finally, another CCCII-based PID controller configuration different from that proposed in this paper can be derived in a similar way using a different signal-flow graph model.

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