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High performance electronically tunable log-domain current-mode PID controller

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ABSTRACT

This research proposes a log-domain P (proportional) I (integral) D (derivative) controller whereby the bias currents are arbitrarily applied to the P, I and D components for independent or simultaneous electronic tuning and the subsequent improved response. In the study, the initial P, I and D circuits were individually realized using 17, 13 and 21 bipolar transistors, and the final PID controller required 62 bipolar transistors including the biasing circuits and a multiple-output current buffer. The proposed PID controller was operational on a dual power supply of ±1.5 V, with the wide-range tunability up to three decades without the circuit topology alteration. Additionally, simulations were carried out with the individual P, I, D circuits and PID controller to verify the performance (i.e. tunability and the response time) and the simulation results compared with the existing PID schemes. Importantly, the simulation results of the PID controller are in good agreement with the theoretical PID functions.

1. Introduction

The Proportional-Integral-Derivative (PID) controller is a closed-loop controller that is commonly deployed in the industry sector, especially in the automatic process control applications, including the flow, temperature, pressure control [1,2]. The main advantage of the PID controller is the adjustability of the parameters to the specific plant [3,4].

In Ref. [5], the voltage-mode PID controller was realized using the operational amplifiers (OPAMPs) and passive elements. However, the OPAMP-based PID was limited in functionality and lacked the electronic tunability. More recently, several voltage-mode PID configurations were proposed based on the active building blocks (ABB), including the 2nd-generation current conveyors (CCIIs) [6–8], the operational transconductance amplifiers (OTAs) [9], and the current differencing buffered amplifiers (CDBAs) [10]. In Refs. [11,12], the voltage-mode PID circuits were realized using a single active element but the controllers lacked the tunable capability. In fact, the circuit construction with active building blocks necessitates numerous transistors, resulting in the bandwidth limitation. Furthermore, the PID circuits required the floating passive elements [6–8,10–12], giving rise to the integration challenges. Generally, the voltage-mode integrated circuits are plagued with the following drawbacks: high voltage, high power consumption, slow response and a large die area.

Specifically, the PID controllers based on CCIIs [6–8] were proposed, but they neither possessed the electronic tunable capability nor allowed for the independent controller-type selection (PID, PI, PD, P or I), in addition to the passive component-matching condition requirement. In Ref. [9], the OTA-based PID controller with two grounded capacitors and eight OTAs suffered from the multiple active components and limited bias-current tunability. In Refs. [13–17], the PID controllers were realized using the inverse band pass filters; however, the controllers lacked the electronic tunable capability and inhibited the independent controller-type selection. Moreover, the inverse filters required multiple active components. In Ref. [18], the cascode OTA-based PID was proposed using only 24 MOS transistors; however, the PID suffered from the PMOS and NMOS transistors mismatch, rendering it impractical to use. Moreover, the OTA contributed to the limited tunable range.

In Ref. [19], the log-domain companding concept was introduced for the filter applications whereby the linear signal was systematically compressed into the nonlinear-domain compressed signal which processed in very low amplitude but higher than the noise floor prior to re-expanding to the linear signal, using the translinear principle [20]. In Ref. [21], the arbitrary-order log-domain filters were synthesized based on a state-space approach [21]. Due to the minimal of compressed signal, the process of charge and discharge capacitors become faster than linear-domain. More importantly, in comparison with the linear-domain

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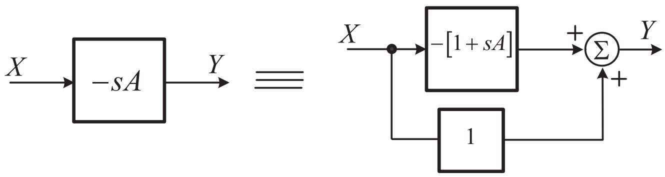

Fig. 1. Block diagram of the derivative (D) controller realized by the differentiator plus a unity gain.

concept, the log-domain concept offers the wider range tunability, wider dynamic range under low voltage and higher bandwidth [22].

In Ref. [23], the early version of the current-mode log-domain PID controller was proposed. However, the PID circuit was afflicted with certain small drawbacks in the feedback part and biasing circuits. Thus, this current research proposes an improved high-performance version of the current-mode log-domain PID controller. Specifically, the improved PID circuit inherits the beneficial properties of the log-domain principle and is integration-friendly thanks to the grounded capacitors [24,25]. In addition, the PID controller allows for the independent controller-type selection (PID, PI, PD, P, D or I controller) using the bias current. Importantly, the proposed PID controller could achieve the wide-range tunability, high output impedance and fast response without the circuit topology alteration. To verify, the simulations were carried out in the open-loop and closed-loop schemes in time and frequency domain. In short, the advantages of the log-domain PID controller render it applicable to the microelectromechanical systems (MEMS) [26].

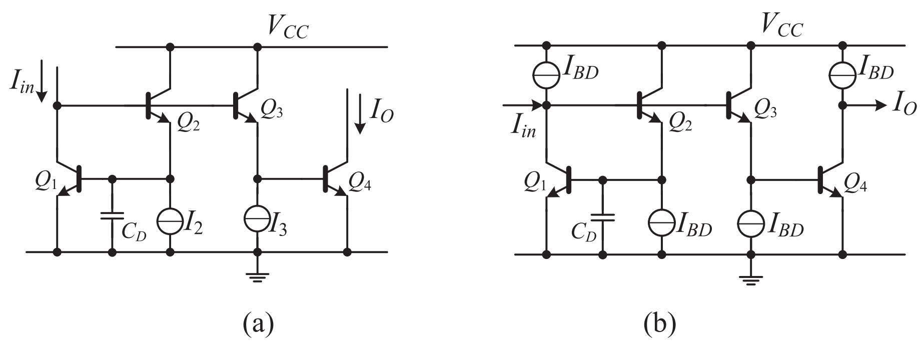

Fig. 2. The log-domain differentiator plus a unity gain: (a) the analytical stage (b) the realization stage.

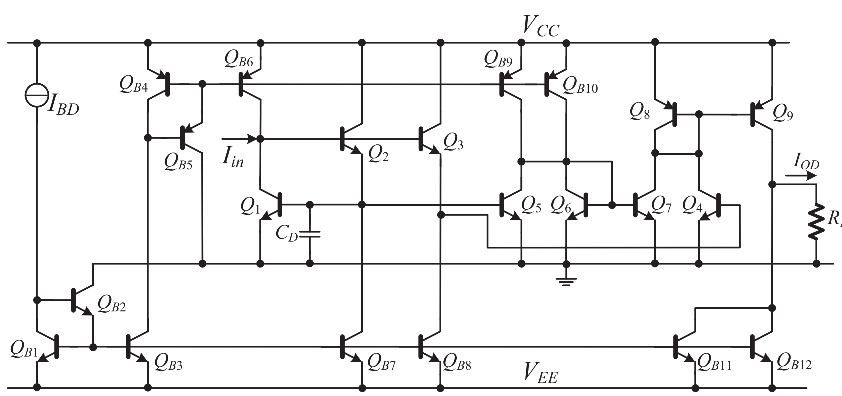

Fig. 3. The final log-domain derivative (D) controller.

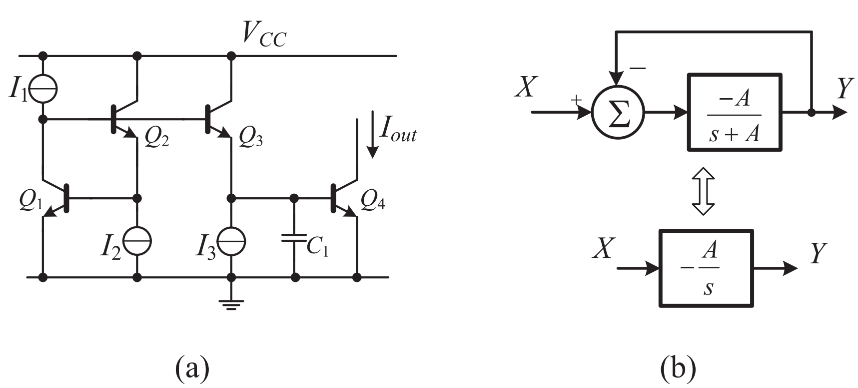

Fig. 4. (a) Lossy integrator (b) Lossless integrator realized by lossy integrator.