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Single active element implementation of fractional-order differentiators and integrators

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Abstract

A novel topology for implementing fractional-order differentiator and integrator transfer functions is presented in this paper. This topology is based on the employment of second generation Current Conveyor with EXtra inputs (EX-CCII), passive resistors, and fractional-order capacitors. The main benefit offered by this implementation is that both fractional-order differentiator and integrator transfer functions are simultaneously available at different output terminals, and that their frequency characteristics can be orthogonally adjusted without disturbing each other. With only one EX-CCII device needed, the proposed design is attractive from the active component count point of view. As an application example, a fractional-order controller is designed in order to control the velocity of a small scale submersible equipped with one propeller. Evaluation of the performance of the presented topology is performed using Cadence and the Design Kit provided by the Austria Mikro Systeme (AMS) $0.35\mu m$ CMOS process.

Keywords: Fractional-order circuits, fractional-order differentiators/integrators, fractional-order controllers, Current Conveyors.

1. Introduction

Fractional-order differentiators/integrators are fundamental building blocks for performing signal processing through the utilization of fractional-order calculus [1]. They are used in filter design [2, 3, 4], in biology and bio-medicine [5, 6, 7], and in control theory [8, 9]. Their transfer function is given by the general expression in (1)

$$H(s) = (\tau s)^r \quad r = \alpha, -\beta, \tag{1}$$

with $0 < \alpha, \beta < 1$, being the order of the differentiator/integrator, respectively. The time-constant (τ) is associated with the unity-gain frequency (ω_0) according to the formula: $\tau = 1/\omega_0$. The magnitude response is given by the expression: $H(\omega) = (\omega/\omega_0)^r$, while the phase response is constant over the entire bandwidth and equal to $r\pi/2$.

The most straight-forward method for implementing fractional-order differentiators/integrators is the replacement of the integer-order capacitors by their fractional-order counterparts, known also as constant phase elements-CPEs, in the corresponding integer-order stages. The development of single two-terminal fractional-order capacitors is still in progress and therefore they are not yet commercially available [10, 11]. Their behavior is usually emulated by appropriately configured RC-tree networks instead [12, 13], offering a quick way for implementing these stages without increasing the number of the active elements. The number of the employed passive resistors and capacitors used in the RC networks depends on the order of the performed approximation, which determines the bandwidth within which the approximation of the

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