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Design of fractional-order transitional filters of the Butterworth-Sync-Tuned, Butterworth-Chebyshev, and Chebyshev-Sync-Tuned types: optimization, simulation, and experimental verification

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ABSTRACT

This paper presents the optimal and generalized design of three different fractional-order (FO) transitional filters for the first time in the literature. The transitional filters considered are of the FO Butterworth-sync-tuned, the FO Butterworth-Chebyshev, and the FO Chebyshev-sync-tuned types. A metaheuristic swarm intelligence optimizer, namely the Crow Search Algorithm (CSA), helps to achieve the optimal FO filter model that minimizes the magnitude error with the theoretical function. The accuracy of the proposed approximants is examined for 19 different combinations of orders of the constituent filters for each of the three types of FO transitional filters. Comparisons with the modified stability boundary locus-based second-, third-, and fourth-order filter approximants demonstrate the compactness and superior accuracy of the proposed models. The average performance regarding the approximation accuracy, computational time, and convergence of CSA for solving the proposed filter design problems is investigated. Circuit simulations conducted on the OrCAD PSPICE platform for the proposed filter using the current feedback operational amplifier as an active element highlight good matching between the proposed model and theoretical filter function. Experimental validation is also carried out to justify the practical feasibility of the proposed filter with printed circuit board fabricated FO capacitor emulators.

1. Introduction

Analog filters are frequency-selective systems that find applications in the front-end of telecommunication systems, noise removal in sensing and instrumentation systems, etc. While traditional filters involved the use of integer-order models, the advent of fractional-order (FO) filters has opened up the possibility of achieving exact design orders and precise stopband attenuation profile [1–3]. The important feature of FO filters is the extra degree of freedom with regard to the slope of the stopband attenuation. This slope is continuously adjustable without limitation to integer multiples of 20 dB/decade (dB/dec), as is the case with the classical (integer-order) filters. Applications of FO filters can be found in the processing of biological signals [4], reduction of unnecessary oscillations in various dynamical systems [5], etc. The aforementioned advantage stems from the applicability of a domain of mathematics

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