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Design of CMOS Analog Integrated Fractional-Order Circuits

Applications in Medicine and Biology

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Preface

It is known that many dynamic systems in our world can be better described by differential equations of a non-integer-order, i.e., they behave like non-integer-order (fractional-order) systems. Such systems can be found not only in electronics and signal processing, but also in thermodynamics, biology, chemistry, medicine, mechanics, control theory, nanotechnologies, finances, etc. Thus, fractional-order systems are an emerging area of multidisciplinary research labeled even as the "twenty-first century systems." Electronic engineers are very interested in applying the concept of fractional calculus. It is motivated mainly by the interdisciplinary nature of this research and possibility to obtain qualitatively new circuit solutions that can provide characteristics not available at integer-order systems. For example, the capability for stepless control of the slope of frequency characteristics in fractional-order filters in comparison with the corresponding integer-order filters is an attractive feature. Fractional-order impedance circuits are also very promising in modeling electrical properties of biological materials, tissues, or cells. Oscillators of fractional-order provide possibility of obtaining higher oscillation frequencies compared to the integer-order counterparts with the same values of passive element parameters offering arbitrary phase shift between output signals.

This book deals with the design and realization of analog fractional-order circuits, which offer the following benefits: (i) capability for on-chip implementation, (ii) capability for low-voltage operation, and (iii) electronic adjustment of their characteristics. Applications of fractional-order circuits, including: a preprocessing stage suitable for the implementation of the Pan-Tompkins algorithm for detecting the QRS complexes of an electrocardiogram (ECG), a fully tunable implementation of the Cole-Cole model used for the modeling of biological tissues, and a simple non-impedance based measuring technique for super-capacitors. A part of the material presented in this book, originates from the work done by Georgia

Tsirimokou for her Ph.D. at University of Patras, Greece. It includes details and measurement results for each research project, supported by Grant E.029 from the Research Committee of the University of Patras (Programme K. Karatheodori).

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Costas Psychalinos received his B.Sc. and Ph.D. degrees in Physics and Electronics from the University of Patras, Greece, in 1986 and 1991, respectively. From 1993 to 1995, he worked as Post-Doctoral Researcher in the VLSI Design Laboratory, University of Patras. From 1996 to 2000, he was an Adjunct Lecturer in the Department of Computer Engineering and Informatics, University of Patras. From 2000 to 2004 he served as Assistant Professor in the Electronics Laboratory, Department of Physics, Aristotle University of Thessaloniki, Greece. From 2004 he serves as faculty member in the Electronics Laboratory, Department of Physics, University of Patras, Greece and, currently, he is Full Professor. His research area is in the continuous and discrete-time analog filtering, including fractional-order circuits, companding filters, current amplifier filters, CCII and CFOA filters, and sampled-data filters, and in the development of ultra-low voltage building blocks for biomedical applications. He serves as Area Editor of the *International Journal of Electronics and Communications* (AEU) Journal, and Associate Editor of the *Circuits Systems and Signal Processing* Journal. He is member of the Editorial Board of the *Analog Integrated Circuits and Signal Processing* Journal, and *Microelectronics* Journal. He is also an IEEE Senior Member.

Ahmed Elwakil was born in Cairo, Egypt. He received the B.Sc. and M.Sc. degrees from the Department of Electronics and Communications at Cairo University, Cairo, Egypt, and the Ph.D. degree from the Department of Electrical and Electronic Engineering, National University of Ireland, University College

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Prof. Elwakil has been a member of the IEEE Technical Committee on Nonlinear Circuits and Systems (TCNCAS) since 2003 and was a Lead Guest Editor for the *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, special issue on fractional-order circuits and systems (Sep. 2013) and a Guest Editor for a special issue on Chaos-Fractals Theories and Applications published in the *Journal of Mathematical Problems in Engineering*, 2014. He is also the guest editor for a special issue on Fractional-Order Circuits (June 2016) in the *Journal of Circuits Systems and Signal Processing* (Springer). He received the Egyptian Government first class medal for achievements in Engineering Sciences in 2003, 2009, and 2015, respectively, and was a visiting Professor/Researcher at Istanbul Technical University (Istanbul, Turkey), University of Calgary (Alberta, Canada), Queens University (Belfast, UK), Technical University of Denmark (Lyngby, Denmark), Ohio State University (Columbus, Ohio), University College Cork (Cork, Ireland), King Abdullah University of Science and Technology (KAUST, Saudi Arabia), and Nile University (Cairo, Egypt). He is currently an Adjunct Prof. in the Nano-electronics Integrated Systems Center at Nile University, Egypt.