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P.V. Ananda Mohan

VLSI Analog Filters

Active RC, OTA-C, and SC

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To
Radha Nirmala

Preface

The design of mixed signal integrated circuits is of continuing interest. The most important analog blocks in these are A/D converters, D/A converters, and filters. The art of analog filter design has been documented in several classic books used in academic institutions worldwide. Some books have focused completely on one particular topic, such as switched-capacitor filters, current-mode filters, or active RC filters (based on opamps). Some books have covered all or a few of these. To the author's knowledge the most recent book appeared in 2005.

More recent industry requirements in mixed signal chips include low-voltage operation, low power requirement, and high-frequency operation. Many specialized techniques will be needed to achieve these objectives. These interesting and innovative techniques are documented in reputable journals such the *IEEE Journal of Solid-State Circuits* and *IEEE Transactions on Circuits and Systems*, among others. Hence, introducing these into the curriculum is of utmost importance so that students may graduate with up-to-date knowledge to cater to the needs of industry. In addition, it has become important to teach most relevant information in the short space of one or two semesters while giving sufficiently broad coverage of the various topics.

This book is an effort in this direction. Contemporary designs of VLSI analog filters can be classified into active RC filters, OTA (operational transconductance amplifier)-C filters, SC (switched-capacitor) filters, log-domain filters, MOSFET-C filters, current-mode filters using devices such as current conveyors or current feedback amplifiers, and so on. Among these perhaps the most popular have been the first three because of the possible ease of design, implementation, and versatility; good high-frequency performance; and the ability to work at low power supply voltages and in an acceptable dynamic range. In this book, we focus on these three areas.

The structure of the book is as follows. In Chap. 1, a general introduction to the subject of VLSI analog filters is presented. Chapter 2 deals with active RC filters

starting from amplifiers and first-order filters and considers the effect of nonidealities of the opamp and techniques for compensation of these nonidealities. Second-order active RC filters using a single amplifier, two opamps, and more opamps are covered. Only popular structures are considered with analysis presented on sensitivity to passive components and effect of opamp bandwidth. Techniques of using the finite bandwidth of opamps in active filter realization to eliminate one or both capacitors needed in a biquad realization are also considered in detail. Active RC filter design based on component simulation and operational simulation of LC ladders as well as multiloop feedback filters are considered. Noise analysis and distortion analysis are also described. Designs that can take advantage of differential output amplifiers are also described.

In Chap. 3, active filter design using OTAs and capacitors is described in detail. First-order filters, second-order filters using grounded capacitors, and filters derived through component simulation are studied in detail. Filters using OTAs with dual current outputs and with current outputs are also studied in detail. High-order filter design using some recently described analytical synthesis techniques is considered as well. The effect of nonideal frequency response of OTA and noise of OTA-C filters is discussed for various filters.

Chapter 4 deals with SC filters. The concepts of switched capacitor filter and the method of analysis using Laker's equivalent circuit are described so as to enable the reader to derive digital transfer functions of various filters. Second-order stray-insensitive filters are considered in detail since they are the most popular in industry. The optimal design of these filters to reduce area/capacitor spread/sensitivity is considered. High-order SC filters based on operational simulation are described in detail. Recent designs extend the frequency of operation of SC filters by using a variety of interesting techniques such as *N*-path filters, double-sampling, and precision opamp gain (POG). All these techniques are described in detail. The analysis techniques for the nonidealities in SC filters such as opamp offset, switch clock feedthrough, charge injection, distortion, finite gain, and bandwidth of the opamp, foldover noise, and opamp 1/f noise are described in great detail together with compensation techniques. Due to the most popular application of SC circuits being in oversampled A/D converters, a section deals exclusively with the architectures and performance-related issues. The design of low-voltage SC filters is also considered for completeness.

Several innovative designs using the techniques considered in Chaps. 2, 3, 4, and 5 have been fruitfully employed in many contemporary integrated system-on-chip (SOC) designs. In Chap. 5, several recent application-specific designs have been surveyed in order to illustrate how the theory can be applied in practice.

The book has several illustrations to explain the concepts clearly and has an extensive bibliography. Several WINSPICE-based simulation examples have been provided in Chaps. 2, 3, 4, and 5 so that the performance of the various circuits can be analyzed. The book can be used for self-study or prescribed as a textbook. The only prerequisite is a basic course in circuit analysis, and a basic knowledge of DSP fundamentals.

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