Preface

CMOS spiral inductors have found a broad range of applications in high-speed analog signal processing and data communications. These applications include bandwidth enhancement, delay reduction, impedance matching, frequency selection, distributed amplifiers, RF phase shifters, low-noise amplifiers, and voltage-controlled oscillators, to name a few. The effectiveness of these inductors, however, is affected by a number of limitations intrinsic to the spiral layout of the inductors. These limitations include a low quality factor, a low self-resonant frequency, a small and non-tunable inductance, and the need for a prohibitively large silicon area. The use of CMOS spiral transformers in RF applications such as low-noise amplifiers, power amplifiers, and LC oscillators has emerged recently. These transformers are constructed by coupling two spiral inductors via a magnetic link. They offer the advantages of a reduced silicon consumption and increased inductances. The limitations of spiral inductors, however, are inherited by spiral transformers.

Inductors and transformers synthesized using active devices, known as active inductors and transformers, offer a number of unique advantages over their spiral counterparts including virtually no chip area requirement, large and tunable inductances with large inductance tuning ranges, large and tunable quality factors, high self-resonant frequencies, and full compatibility with digital oriented CMOS technologies. Active inductors and transformers have found increasing applications in high-speed analog signal processing and data communications where spiral inductors and transformers are usually employed. As compared with spiral inductors and transformers, the applications of CMOS active inductors and transformers are affected by a number of limitations intrinsic to synthesized devices. These limitations include a small dynamic range, poor noise performance, a high level of power consumption, and a high sensitivity to supply voltage fluctuation and process variation.

This book provides a comprehensive treatment of the principle, topologies, and characteristics of CMOS active inductors and transformers, and an in-depth examination of their emerging applications in high-speed analog signal processing and data communications. The materials presented in the book are based on the work of many researchers who contributed to the theory and design of CMOS active inductors and transformers. In recognition of their contributions, the active inductors and transformers presented in this text are named in the names of the researchers. For active inductors and transformers developed by more than two researchers, although due to the space constraint, only the name of the first author of the work is used to name the active inductors and transformers, the contributions of all other authors are equally recognized. This is reflected by the presentation of the full authorship of the work in the *References* of the book. The same approach is followed in the presentation of CMOS active inductor/transformer bandpass filters, oscillators, and other sub-systems.

This book consists of two parts : Part I - *Principle and Implementation of CMOS Active Inductors and Transformers*, and Part II -*Applications of CMOS Active Inductors and Transformers*.

Part I of the book deals with the topologies, characteristics and implementation of CMOS active inductors and transformers. This part consists of three chapters.

Chapter 1 starts with a brief investigation into why inductive characteristics are critically needed in high-speed applications. This is demonstrated with the applications of inductors and transformers in LC oscillators, impedance matching networks, RF phase shifters, RF power dividers, frequency selection networks, in particular, RF bandpass filters, and low-noise amplifiers. A detailed examination of the design constraints of monolithic inductors and transformers is followed. The advantages and design challenges of CMOS active inductors and transformers are examined in detail.

Chapter 2 presents the principles of the synthesis of inductors using gyrator-C networks. Both lossless and lossy single-ended and fully differential gyrator-C active inductors are studied. The important figure-of-merits that quantify the performance of active inductors including frequency operation range, inductance tunability, quality factor, noise, linearity, stability, supply voltage sensitivity, parameter sensitivity, signal sensitivity, and power consumption are examined in detailed. The details of the CMOS implementation and analysis of single-ended and fully differential active inductors are presented. The circuit implementation and characteristics of published CMOS active inductors are examined in detail.

Chapter 3 focuses on the principles of the synthesis of CMOS active transformers. Both lossless and lossy gyrator-C active transformers are studied. The characterization of active transformers including stability, frequency operation range, the tunability of self and mutual inductances, turn ratios, coupling factors, voltage and current transfer characteristics, impedance transformation, noise, quality factors, linearity, supply voltage sensitivity, parameter sensitivity, and power consumption is examined in detail. The CMOS implementation of several published CMOS active transformers is presented and their characteristics are analyzed.

Part II of the book focuses upon the emerging applications of CMOS active inductors and transformers in high-speed analog signal processing and data communications. This part consists of four chapters.

Chapter 4 investigates the implementation and characteristics of RF bandpass filters using CMOS active inductors. The chapter starts with a detailed investigation of the characterization of bandpass filters. Bandwidth, 1-dB compression points, third-order intercept points, noise figure, noise bandwidth, spurious-free-dynamic range, frequency selectivity, and passband center frequency tuning are examined. It is followed by a detailed examination of the configurations of RF bandpass filters with active inductors. Wu bandpass filters, Thanachayanont bandpass filters, Xiao-Schaumann bandpass filters, Thanachayanont-Payne bandpass filter, and Weng-Kuo bandpass filters are studied and their performance is compared.

Chapter 5 looks into the realization of the building blocks of high-speed transceivers using CMOS active inductors and transformers. The use of CMOS active inductors in low-noise amplifiers, optical front-ends, RF phase shifters, RF modulators, RF power dividers, and Gb/s serial-link transceivers is examined in detail.

Chapter 6 starts with a brief review of the fundamentals of electrical oscillators. Both ring and LC oscillators are investigated. The use of CMOS active inductors in improving the performance of ring oscillators is investigated. The presentation continues with a close examination of the use of CMOS active inductors in LC oscillators. A special attention is given to the comparison of the phase noise of these oscillators. LC oscillators and LC quadrature oscillators using CMOS active transformers are also studied.

Chapter 7 presents the theory of current-mode phase-locked loops (PLLs) and examines the intrinsic differences between voltage-mode and current-mode PLLs. The chapter starts with an in-depth study of the configurations and characteristics of voltage-mode PLLs. Both type I and type II voltage-mode PLLs are studied. It then moves on to investigate current-mode PLLs with CMOS active inductors and transformers. The loop dynamics of these PLLs are investigated in detailed. Three design examples are utilized to demonstrate the performance of current-mode PLLs with active inductors and active transformers.

The materials of the book are presented with an emphasis on both the evolution of each class of circuits and a close comparison of their advantages and limitations. The examples given in the book were implemented in TSMC-

0.18μm 1.8V and UMC-0.13μm 1.2V CMOS technologies, and analyzed using SpectreRF from Cadence Design Systems with BSIM3v3RF device models that account for both the parasitics and high-order effects of MOS devices at high frequencies. Readers are assumed to be familiar with the fundamentals of electrical networks, microelectronic devices and circuits, signals and systems, and basic RF circuits.

This book is the first text that provides a comprehensive treatment of the principle, implementation, and applications of CMOS active inductors and transformers. It is a valuable resource for senior undergraduate / graduate students and an important reference for IC design engineers.

Although an immense amount of effort has been made in preparation of the manuscript, flaws and errors will still exist due to erring human nature. Suggestions and corrections will be gratefully appreciated by the author.

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