Chapter 1

Introduction

1.1 Introduction

Growth in the integrated circuit industry is now expanding beyond the traditional emphasis on digital computation. With increasing interest in employing integrated circuits in a growing number of "real world" applications, analog circuits are becoming a key part of just about every design.

While many types of signal processing have indeed moved to the digital domain; analog circuits have proved fundamentally necessary in many of today's complex, high performance systems. There exist numerous applications where it is very difficult or even impossible to replace analog functions with their digital counterparts regardless of advances in technology, for example, design of analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) for high speed, high precision, and low power; design of high-performance analog amplifiers and filters to boost and suppress the out-of-band components; optical receivers to process a low-level signal at a very high-speed requiring low-noise, broadband circuit design; electrical and optical sensors which employ amplifiers, filters and converters (ADC and DAC); high-speed sense amplifiers for semiconductor memories; *etc*. Furthermore, many issues related to the distribution and timing of high-speed signals, non-idealities in signal and power interconnects, package parasitics, *etc*. of even digital chips require a solid understanding of analog design. These examples clearly demonstrate the wide and inevitable spread of analog circuits in modern industry.

But, the difficulty level of analog design is much higher than that of the digital design for the following reasons:

- With the speed and precision required in processing analog signals, analog signals are much more sensitive to noise, crosstalk, and other interferers than are digital signals.
- Second-order effects in devices influence the performance of analog circuits much more heavily than that of digital circuits.
- Despite tremendous progress, modeling and simulation of many effects in analog circuits continue to pose difficulties, forcing the designers to draw upon experience and intuition when analyzing the results of a simulation.
- An important thrust in today's semiconductor industry is to design analog circuits in mainstream IC technologies which are developed and characterized to fabricate digital products and do not easily lend themselves to analog design, requiring novel circuits and architectures to achieve high performance.
- The design of high-performance analog circuits can rarely be automated, usually requiring that every device be "hand-crafted". By contrast, many digital circuits are automatically synthesized and laid out.

In recent years, complete systems that earlier occupied one or more boards are increasingly being integrated on a few chips or even one single chip. Although most functions in such integrated systems are implemented with digital or digital signal processing (DSP) circuitry, the analog circuits needed at the interface between the electronic system and the real world, are also being integrated on the same die for reasons of cost and performance. The analog sections of such mixed-signal IC designs are generally small; however, demands for low power and increased system integration increase analog design complexity. At the same time, many present ASIC application markets are characterized by shortening product life cycles and time-to-market constraints. These constraints can only be met by using advanced Computer-Aided Design (CAD) tools. In the digital world, logic synthesis and semi-custom layout have emerged as the de facto strategies for managing the front-end (specifications to gate-level netlist steps) and the back-end (netlist to mask steps) of the design process. Unfortunately, we do not yet have robust circuit synthesis and layout tools in the analog domain. The design cycle for analog and mixed-signal ICs remain long and error-prone [Gray87].

In order to reduce analog IC design time, and thereby the time-to-market for most products, the development of analog IC design synthesis tools has been going on since the early 1970's [Nagel71, Nagle75, Kuhn87, DeGrauwe87, Nye88, Harjani89, Koh90, Rutenbar93, Carley96] and continues to occupy the attention of contemporary researchers [Aldana99, Ray02, Gielen05, Lee06, Unno06, Unno07]. The present thesis work also addresses the subject of analog circuit synthesis.

1.2 Thesis Organization

Chapter 2 introduces the available CAD tools and methodologies (available in the literature) and discusses the background and motivation that led to the present work.

Chapter 3 describes the concept of figure of merit based on small signal parameters, for the design of differential input stage amplifier for low frequency applications under the constraints of area. It outlines the analytical expressions developed for the figure of merit and its maximization under the constraints of area. It then compares the analytical results obtained with the SPICE simulated results.

In chapter 4 the proposed approach of figure of merit based design-synthesis of differential input stage amplifier has been applied at mid/moderate frequencies, where thermal noise dominates the flicker noise. Again the analytical results have been compared with SPICE simulation results.

Chapter 5 discusses the figure of merit based design of second stage of the operational amplifier, where noise does not play a dominant role.

Chapter 6 describes the CAD tool developed for the optimal synthesis of differential input stage amplifier under the constraints of maximum power and input-referred noise, and minimum differential dc gain and unity-gain bandwidth. The chapter includes the results of 2400 designs, which were synthesized using the tool. Layouts of the ten prototype circuits have been built in a 1.25 micron CMOS technology, and the performance predicted by the developed CAD tool and by SPICE simulations on extracted circuits is compared.

Chapter 7 is the concluding chapter of the thesis. It summarizes results, and discusses the application of the proposed figure of merit based methodology in CAD tools for the circuit synthesis of analog circuits. The chapter also highlights the future scope of work in this direction.