DESIGN AND APPLICATIONS OF ANALOG INTEGRATED CIRCUITS

Sidney Soclof

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Preface

This book is a comprehensive treatment of the analysis, design, applications, and fabrication of analog integrated circuits. There is enough material in this book for a three- or four-semester senior- or graduate-level sequence of courses. The various chapters in this book are designed to be relatively self-sufficient, in that they may be used without much reference to or study of the other chapters. Therefore, a one-semester course covering a particular aspect of analog integrated circuits can be taught by selection of the appropriate chapters. For example, a one-semester course with primary emphasis on operational amplifiers can be built out of Chapters 5 through 9, and selected parts of Chapters 3 and 4 can also be included. A course with principal emphasis on integrated-circuit fabrication, devices, and the internal circuit design can be designed by using Chapters 1 through 3, with selections made from various other chapters. A one- or two-semester course with primary emphasis on applications of analog integrated circuits other than operational amplifiers can be constructed by choosing from Chapters 10 through 17. Thus there is enough material in this book for any advanced analog electronics course or sequence of courses.

Homework problems and references for further reading are given at the end of each chapter.

The material in this book is of an advanced nature and the reader should have the background of a two-semester introductory electronics course sequence.

Chapter 1 presents the basic processes that are used to manufacture various semiconductor devices, with particular emphasis on the processes used for integrated circuits. This chapter includes material on crystal growth, wafer preparation, diffusion, ion implantation, oxidation, photolithography, metallization, and chemical-vapor deposition processes, including epitaxy.

In Chapter 2, the basic processes described in Chapter 1 are combined to produce various semiconductor devices and, in particular, devices for integrated circuits. This chapter discusses the basic characteristics of PN junctions and the advantages of the use of epitaxial layers. The processing sequences used for diodes, bipolar transistors, junction field-effect transistors, and MOSFETs are described, followed by the various techniques used for the isolation of devices on an integrated-circuit circuit chip. The fabrication and characteristics of various integrated-circuit devices are presented, including NPN and PNP bipolar transistors, JFETs and MOSFETs, diodes, resistors, and capacitors. Other material in Chapter 2 deals with considerations of chip size, circuit complexity, and thermal design.

Chapters 3 and 4 present various electronic circuit configurations common to many types of analog integrated circuits. The first part of Chapter 3 deals with the various types of constant-current source circuits that are an important part of many integrated circuits. The second part of this chapter is concerned with low-impedance voltage source circuits, and the last part is a study of temperature-compensated voltage reference circuits.

The subject matter of Chapter 4 is differential amplifiers. In the first part of this chapter, the design and characteristics of bipolar transistor differential amplifiers are considered. This is followed by a presentation of JFET and MOSFET differential amplifiers. Closely associated with the subject of differential amplifiers is that of active-load circuits, which is discussed in the last part of the chapter, along with bipolar transistor and FET active loads.

The most widely used type of analog integrated circuit is the operational amplifier, and this is the subject matter of Chapters 5 through 9. The discussion commences in Chapter 5 with an analysis of closed-loop operational amplifier circuits based on the case of an ideal device. The various nonideal characteristics of operational amplifiers are discussed, including the effects of the input offset voltage, input bias current, input and output impedances, common-mode gain, and the noise generated both within the operational amplifier and the external resistances. As in any feedback system, the question of system stability is an important one. This is considered in Chapter 5, and the various compensation techniques to ensure an adequate margin of stability are also discussed. Later in the chapter, examples of a large number of applications of operational amplifiers are presented. An important category of operational amplifier applications is that of active filters. These applications are discussed in Chapter 6, together with material on switched-capacitor filters.

Whereas Chapters 5 and 6 deal mostly with the external circuitry and applications of operational amplifiers, attention in Chapter 7 is turned principally to the internal circuit design of operational amplifiers. The chapter begins with a discussion of the basic configuration of operational amplifiers and a general analysis of the open-loop frequency response, including a discussion of the unity gain frequency. This is followed by a discussion of large-signal response characteristics, including the slewing rate and the full-power bandwidth. A representative example of an operational amplifier circuit is then presented and analyzed. This analysis includes evaluation of dc biasing, the ac small-signal voltage gain of each stage and the entire amplifier, and various other amplifier characteristics, including the common-mode rejection ratio, the power supply rejection ratio, the open-loop frequency response, and the equivalent input noise voltage and current. Operational amplifiers that use field-effect transistors in just the input stage or throughout the entire amplifier are important devices and are considered in Chapter 8. A number of representative JFET and MOSFET operational-amplifier circuits are presented. In Chapter 9, current-feedback operational amplifiers, Norton operational amplifiers, and transconductance operational amplifiers are discussed. The current-feedback operational amplifiers are of particular interest due to their very wide bandwidth and fast slewing rate characteristics.

The voltage comparator is a device closely related to the operational amplifier, and a full discussion of this type of integrated circuit is given in Chapter 10. A consideration of some of the basic characteristics of voltage comparators and how these devices compare to operational amplifiers are thoroughly discussed. Examples of voltage comparators are then presented. One of the most important characteristics of the voltage comparator is its response time, and this is considered in detail. Various techniques that are used to reduce the response time are also presented. Complementary-symmetry MOSFETs can be used for comparators, especially for high-density, low-power applications. The CMOS inverter and CMOS voltage comparators are presented at the end of this chapter.

Integrated-circuit voltage regulators are presented in Chapter 11. In addition to a presentation of the basic theory, characteristics, and the protective circuitry of voltage regulators, examples of various types of voltage regulators are given, including adjustable positive and negative regulators, three-terminal fixed regulators, and switching-mode regulators.

In Chapter 12, integrated-circuit power amplifiers are investigated. Power conversion efficiency and distortion of power amplifiers are considered, and examples are given of integrated-circuit audio power amplifiers. Examples of power operational amplifiers are also presented.

In Chapter 13, attention is turned to the high-frequency performance of integrated circuits with a discussion of wide-bandwidth or video amplifiers. First, the performance of common-emitter, cascode, emitter-follower, and FET circuits at high frequencies is discussed. This is followed by a presentation of examples of video amplifier integrated cicuits. Then examples of operational amplifiers that have very wide bandwidths and high slewing rates are given.

Modulators, demodulators, and phase detector integrated circuits are discussed in Chapter 14. These are very closely related topics since the same basic circuit can be used for all three functions. The chapter opens with an analysis of the basic circuit configuration that is used for these three functions. Then application examples are given, including amplitude modulation and demodulation, frequency modulation and FM detection, frequency doubling, and phase detection.

Integrated circuits that are used to generate various types of waveforms are presented in Chapter 15. Examples of voltage-controlled oscillators in which the frequency can be varied by an input voltage are considered first, followed by a discussion of waveform generators for the production of square, triangular, pulse, and sinusoidal waveforms.

The phase-locked loops of Chapter 16 are an important element of many communications and signal-processing systems. The basic operation of these devices is discussed first, followed by examples of various applications, such as AM and FM detection, frequency synthesis, and stereo demodulation.

Analog-to-digital and digital-to-analog converters are essential elements for communication between analog and digital systems. These integrated circuits are discussed in Chapter 17 and various examples are given.

This book is intended to be of a practical nature, and the emphasis on the integrated circuits is mainly on what is, rather than what has been, or what might be. That is, the emphasis is on devices that are currently being used and are commercially available. Many circuits and devices presently being reported on in the research and development stage are not treated in this book because of size limitations.

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