High-Speed Electronics and Optoelectronics

This authoritative account of electronic and optoelectronic devices operating at frequencies greater than 1 GHz covers the concepts and fundamental principles of operation, and, uniquely, their circuit applications too.

Key features include:

- a comprehensive coverage of electron devices, such as MESFET, HEMT, RF MOSFET, BJT and HBT, and their models;
- discussions of semiconductor devices fabricated in a variety of material systems, such as Si, III–V compound semiconductors and SiGe;
- a description of light-emitting diodes, semiconductor lasers and photodetectors;
- an executive summary at the beginning of each chapter;
- plentiful real-world examples; and
- end-of-chapter problems to test understanding of the material covered.

From crystal structure to atomic bonding, recombination and radiation in semiconductors to p–n junctions and heterojunctions, a wide range of critical topics is covered. Moreover, a chapter on analogue circuit applications provides an introduction to scattering parameter theory, followed by descriptions of different types of amplifier and oscillator utilising HBTs and HEMTs. Optimisation algorithms, such as simulated annealing and neural network applications, and parameter extraction of electronic device equivalent circuit models are also discussed. Graduate students in electrical engineering, industry professionals and researchers will all find this a valuable resource.

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Contents

Preface

Starting from the development of transistor technology to laser technology, the field of solid state devices and their circuit applications has advanced rapidly. The silicon bipolar junction transistor was first applied to low frequency circuits. The subsequent advances in materials science made it possible to fabricate compound semiconductor transistors capable of operating at microwave frequencies and high speeds. This presented the capability of applications in both analogue and digital circuits. At the same time, the wide choice of high performance semiconductor materials also enabled the development of optoelectronic devices such as lasers and light-emitting diodes. The communications industry continues to grow and diversify, thus necessitating the design of circuits which will satisfy the requirements of mobile telephones which are becoming more and more sophisticated in their performance. Circuit design has applications in other areas such as optical communications.

This book focusses on high-speed electronics and optoelectronics where the devices operate at frequencies $\geq$1 GHz. It is presented in two parts with devices being discussed in the first part and the circuit applications in the second part. In Part One, semiconductor devices fabricated in a variety of material systems – Si, III–V compound semiconductors and SiGe – are presented. We discuss the concepts and the fundamental principles of operation. We do not attempt to present the latest results as they will already be obsolete by the time the book is published. It is assumed that the reader has had a course in fundamental solid state physics.

Chapter 1 reviews semiconductor materials and physics. For the reader who is familiar with the topics, this chapter will be a brief review. If not, the reader can go to the references section to get a detailed coverage of the topics. Semiconductor materials are described followed by brief discussions of crystal structure and bonding. The section on quantum mechanics is intended to present only the important concepts and is not a comprehensive treatment of the subject. Semiconductor properties are described followed by types of semiconductors. Semiconductor junctions are treated in detail as they are the basis of the devices to be treated in subsequent chapters.

Chapter 2 presents high-frequency/high-speed electronic devices starting with the MESFET, which was the first transistor to operate at microwave frequencies. The development of the high electron mobility transistor (HEMT) represented a major advance in technology and is presented here in detail. The recent application of MOSFETs to radio frequency has been successful and the properties are covered in detail. Finally, bipolar

and heterojunction bipolar transistors (HBTs) are described. Models for the transistors are presented and their method of implementation is described.

Chapter 3 presents the optimisation and parameter extraction of the circuit models of the electronic devices. The simulated annealing algorithm is discussed followed by the application of neural networks to circuit modelling. The genetic algorithm is defined and its application to optimisation is shown. Parameter extraction methods are given for circuit models using semi-analytical methods and basic expressions are derived.

Chapter 4 deals with various optical sources such as light-emitting diodes and lasers, giving details of their physical properties and their modes of operation. The discussion of emitters is followed by an extensive coverage of a variety of photodetectors.

In Part Two of the book, we discuss analogue circuits at the gate level. We will assume that the reader has a background (at the undergraduate level) in fundamental analogue circuit theory. Chapter 5 (Part Two of the book) deals with the components of high-speed analogue circuits. After a review of scattering parameter theory, the power and noise relations for two-port networks are discussed. Transistor amplifiers are covered in detail, showing the application of the devices described in Chapter 2. This is followed by a discussion of oscillators and mixers for high-speed circuits. Important passive components of high-speed circuits complete this chapter.

We have a layered approach to each chapter in the book. There is an executive summary at the beginning of each chapter. This will make the book valuable also for technical managers who may not want to go through the chapter content in detail. We have extensive problems at the end of each chapter, which will give the student applications of the theory. This book should be useful to research engineers and graduate students. Results from various research papers are presented, many of which are only available in journals which are referenced extensively. However, the reader need not go to the original papers as the results are given in sufficient detail to give a good understanding of the material.

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Sheila Prasad

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