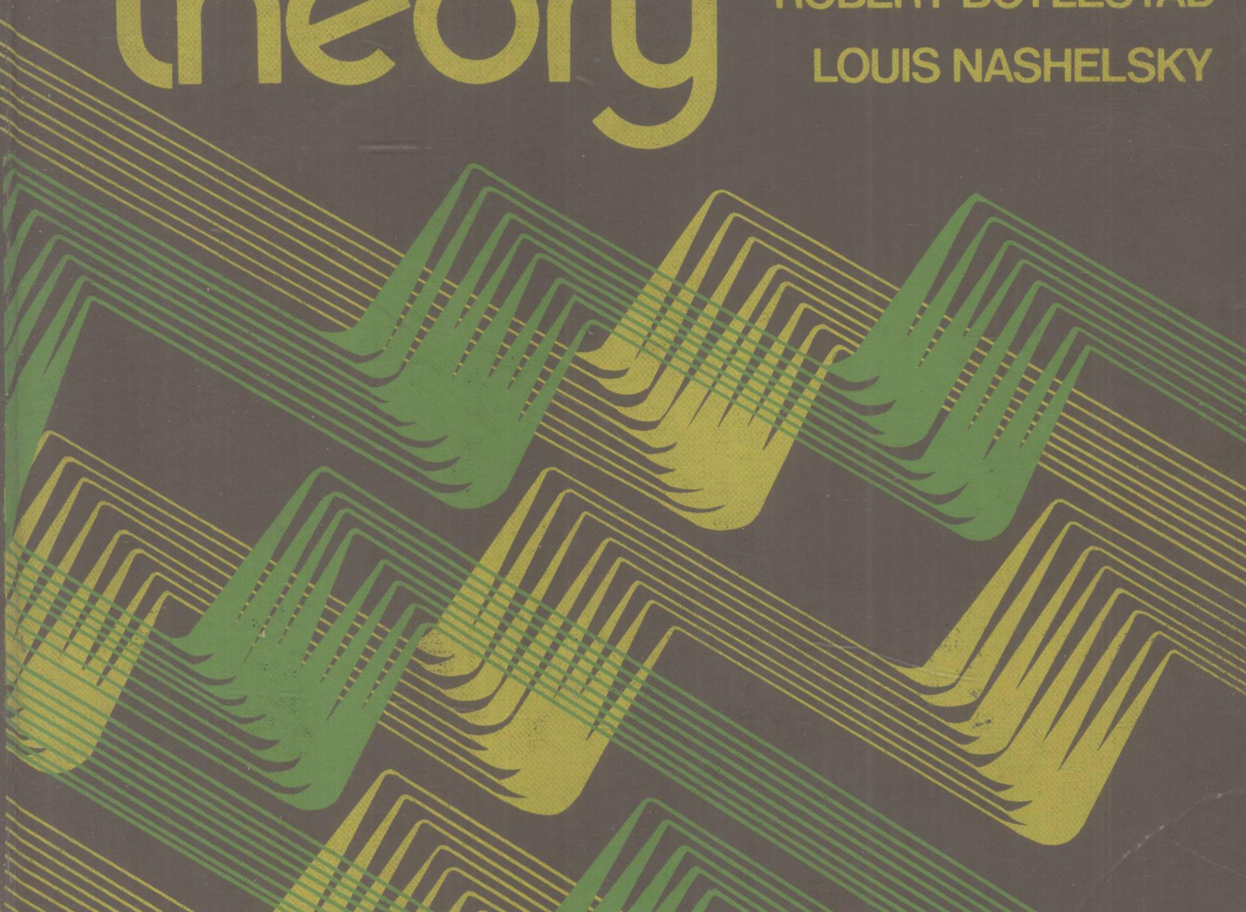
second edition

electronic devices and circuit theory

ROBERT BOYLESTAD

LOUIS NASHELSKY

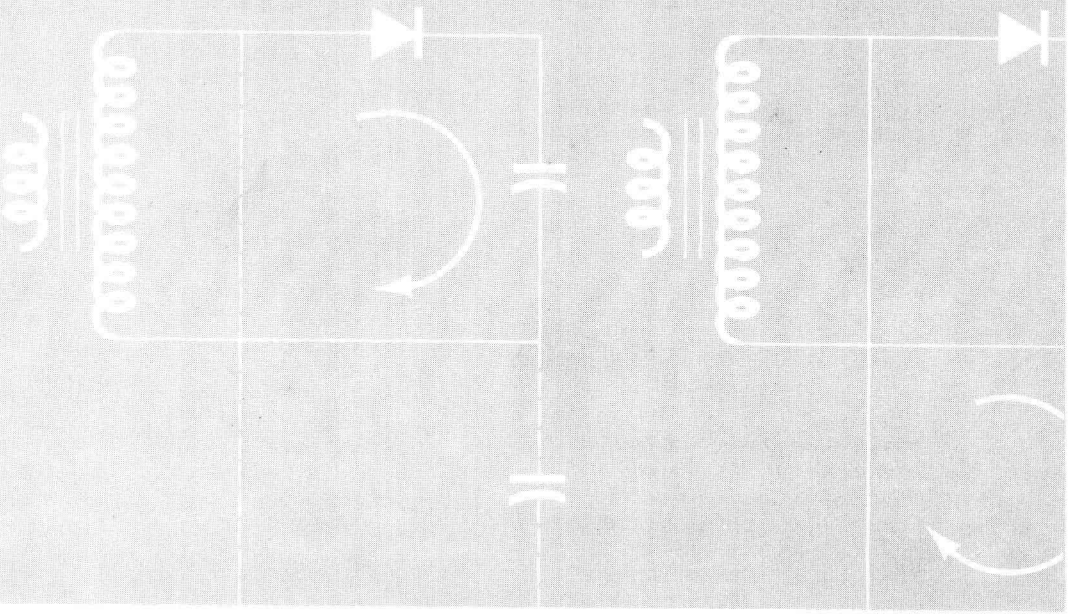


ROBERT BOYLESTAD

Professor
Queensborough College (City University of New York)

LOUIS NASHELSKY

Professor
Queensborough College (City University of New York)



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Robert Boylestad/Louis Nashelsky

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second edition

PRENTICE-HALL, INC. ENGLEWOOD CLIFFS, NEW JERSEY 07632

dedicated to:
ELSE MARIE, ERIC, ALISON, and STACEY
and to
KATRIN, KIRA, and LARREN

preface

This text is designed primarily for use in a two-semester or three-trimester sequence in the basic electronics area. It is expected that the student has taken a course in dc circuit analysis and has either taken or is taking a course in ac circuit analysis. This text requires only a mathematical background similar to that required for the ac circuit analysis course.

In an effort to aid the student, the text contains extensive examples that stress the main points of each chapter. There are also numerous illustrations to guide the student through the new concepts and techniques. Important conclusions are emphasized by boxed equations or boldface answers to make the student aware of the essential points covered.

The text is the result of a two-semester electronics course sequence which both authors were actively involved in teaching over a period of years. However, the fifteen chapters actually contain more material than can be covered in two fifteen-week semesters (or three ten-week trimesters). This preface will show how the authors feel the material can be organized.

This second edition was necessary to update material in a number of areas. The majority of the changes appear in the first seven chapters. The fundamental content of each chapter, however, remains the same. Techniques of analysis have been improved to provide a clearer, more meaningful development. Material on popular new devices has been added or expanded to maintain relevancy.

Essentially, the first six chapters provide the basic background to electronic devices—including construction, biasing, and operation as single stages. The material in these chapters can be included in the first semester with the option left to the teacher of stressing some areas more than others, or some not at all. The course would begin with the theory and operation of two-terminal devices, stressing semiconductor diodes. Since the theory course is usually taught in conjunction with a laboratory course the material has been organized with regard to providing practical circuit examples which can be operated in the lab. New material on LED, LCD, and solar cells have been added.

Chapter 2 (on diode rectifiers and filters) provides some practical examples of diode application to the basic electronic area of power supplies. Other texts generally place this material at the end of the text. Our own experience shows that this practical study serves as an interlude between the chapters on basic device theory and provides some valuable lab experiments. Material on the capacitor filter has been improved, while the emphasis on less popular filter circuits has been reduced.

Chapter 3 covers the BJT transistor device, its construction and theory of operation. As mentioned earlier it is possible to follow Chapter 1 with this chapter. The operation of the transistor is presented both mathematically and graphically; the amplifying action of the transistor is defined and demonstrated. Actual current directions are used in this introductory area, as teaching experience shows that students understand initial concepts best this way.

It is the authors' experience that the student can better comprehend the operation of the BJT transistor device if, initially, the dc bias and ac operation are treated separately. Thus, Chapter 4 deals only with the dc bias of the BJT transistor (and tube). This is done for common-emitter, common-base, and common-collector (emitter follower) configurations for a variety of bias circuit types. Numerous examples help to demonstrate the theory presented. Also, some design problems are included to provide a well-rounded treatment.

Chapter 5 is one of the most important in the basic coverage area and should be given sufficient time in any course. The development of the BJT transistor ac equivalent circuit model is covered in detail, followed by analysis of the ac operation of the full small-signal circuit. The treatment in this chapter (as in Chapter 4) is essentially mathematical. However, the mathematics are kept short and direct, with a generous number of examples provided so that students will be able to follow the ideas presented. The hybrid equivalent circuit of the transistor is presented, and then the usual engineering simplifications are included in ac analysis to provide a more practically meaningful treatment. This is followed by an introduction to a simplified model which has received increased interest in the analysis of BJT circuits.

If possible the material on the field effect transistor (FET) should also be covered in the first semester of electronics. After having presented and developed the concepts of dc bias and ac analysis of the BJT, Chapter 6 then covers a number of practical FET circuits. We had considered including the FET dc biasing in Chapter 4 and ac analysis in Chapter 5. It was our feeling from classroom experience that this would require spending too much time on each topic, and the FET would appear to be a minor device to the student. By covering the FET in a separate chapter, its significance is stressed and its operation can be properly presented. The chapter has been extensively revised to include graphical techniques which permit the student to directly obtain dc levels for any FET device.

Chapter 7 would be the first topic in the second semester and covers the operation of multistage BJT and FET transistor circuits. Stage loading, overall gain calculations, and use of decibels are all covered in this important chapter. A number of examples help emphasize the main points of the chapter. Increased emphasis has been placed on use of the approximate analysis techniques for multistage amplifiers. The material on frequency has been totally revised for increased clarity.

Chapter 8 covers the operation of power transistors in a few basic power amplifier circuits. Most important is the operation of the push-pull circuit. Transistor push-pull circuits containing a transformer as well as transformerless circuits are covered. Additional material on quasi-complementary push-pull amplifiers and on class-B power and efficiency is provided.

Chapter 9 is a "catch-all" of a number of *pnpn* devices—covering their construction, operation, and circuit applications. It can be covered quickly or even passed over, if desired, without loss of continuity. This edition includes an introduction to the modern VFET and its higher power capabilities.

Chapter 10 is a short treatment of the fabrication and construction of integrated circuits (IC) and can be assigned mainly as student reading.

Chapter 11 provides coverage of two very important topics and should be considered essential to the second semester coverage. Due to the popularity of linear IC units, both the differential and operation amplifier are now regarded as basic units. A comprehensive treatment is accordingly given each topic as well as examples and practical applications.

Chapter 12 on feedback amplifiers and oscillators should be covered at least partially in the second semester. The material can also be deferred to a third electronics course on communications if desired. The chapter is extensive and need not be fully covered if time is limited.

Chapter 13 on digital circuits provides a good survey. It is so important in the present electronics field to know this area well. If no course devoted exclusively to computer circuits and logic is taught in your curriculum, the material of this chapter should be closely covered.

Chapter 14 provides coverage of voltage regulators. The miscellaneous circuits provided are for the student's own practical study and can be used to stimulate or motivate his interest.

Chapter 15 can be integrated anywhere in the two semesters. Although this material may not be covered in classroom lectures, it is quite important to the student and can be used to supplement laboratory work on CRO theory and applications. The fundamental operation and use of the CRO is stressed in this chapter. Again, generous examples help emphasize the main points covered.

To improve the use of this text by both student and instructor there are numerous practical examples in most chapters. Problems at the end of these chapters are keyed to the particular section in which the problems are covered.

We wish to thank Professors Aidala and Katz of the Electrical Technology department at Queensborough Community College for their continued help and encouragement over the years. They have provided us with both courses and atmosphere conductive to the best in learning and teaching. We thank Mrs. Doris

Topel and Mrs. Helene Rosenberg, Electrical Technology department secretaries, for their assistance in preparing this revised edition. Finally, we wish to thank each other for a remarkably pleasant and rewarding collaboration.

Robert Boylestad / Louis Nashelsky
Hanover, N. H. *Great Neck, N. Y*

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two-terminal devices

1.1 INTRODUCTION

A major portion of the electronic devices in commercial use today have only two terminals. One of the most important is the diode, which is one of the fundamental building blocks of the wide variety of electronic circuits in use today. It is essential to the operation of such representative systems as rectifiers, doublers, limiters, clampers, clippers, modulators and demodulators, waveforming circuits, and frequency converters. The diode is available in many different sizes and shapes with varying modes of operation. The *vacuum* and *semiconductor* diodes will both be considered in detail in this chapter. Later sections will contain brief descriptions of the *Zener*, *varicap*, *tunnel*, *photoelectric*, *silicon power*, *and Schottky diodes*. Also to be covered is a temperature-sensitive resistor, the *thermistor*, various types of visual displays, such as the *LED* and *LCD*, and *solar* cells which have enjoyed a renewed interest as a result of energy considerations.

The first diode, called Fleming's valve, was developed by J. Ambrose Fleming in 1902. Its basic construction consisted of two elements, a filament and metallic plate in an evacuated glass envelope, similar in many respects to the modern high-vacuum diode. It was not until the early 1930s that a radically new type of diode became increasingly important: the semiconductor diode. This solid-state device, much smaller than the vacuum diode with characteristics closer to the ideal switching characteristics, led the way to the development of the transistor amplifier (a three-terminal device to be examined in Chapter 3) by J. Bardeen and W. Brattain of Bell Laboratories in 1948.

In recent years emphasis has been almost completely on the development of the semiconductor diode. Except for very high frequencies or high-power applica-