ENGINEERING ELECTRONICS

GEORGE E. HAPPELL
Associate Professor of Electrical Engineering
Purdue University

WILFRED M. HESSELBERTH
Associate Professor of Electrical Engineering
Purdue University

NEW YORK  TORONTO  LONDON
McGRAW-HILL BOOK COMPANY, INC.
1953
PREFACE

The authors present herewith a textbook for use in a beginning course in electronics for electrical-engineering students. Most of the material used was first published in pamphlet form and has been used as a text at Purdue University for the past two years. It has been revised and brought up to date as use in the classroom and the advice of critics have indicated that improvements could be made.

The usual course in technical schools consists of two or three class periods and one laboratory period each week throughout the school year. Sufficient material is included for such a program. It has been the authors' experience that the average student enrolling in such a course has the following status: He is a junior and has already had courses in general physics, mathematics through calculus, and direct-current circuits. He is starting courses in alternating-current circuits, electrical measurements, and possibly differential equations, as well as electronics. The student plans to enter one of various fields—communications, electronic control, automatic control, power machinery, power transmission, business, graduate study. What he will actually do after graduation is often something else. In any event, electronics will be useful knowledge for one engaged in nearly any branch of electrical engineering and in many allied fields. The material in this book presents the fundamental ideas of electronics in both a theoretical and a practical fashion to provide a good foundation for further study, as well as useful knowledge for a terminal course.

The first four chapters provide material for a brief study of the physics of vacuum tubes, not covered in the usual previous physics courses. They also serve to delay the study of circuits until the student has gained some knowledge of a-c circuits elsewhere. Chapter 5 presents a very elementary description of the circuits and actions of certain very common electronic devices. It also acquaints the student with some common electronic nomenclature. The authors have found it fills a very real need—to provide a background for those students who have not picked it up in their experience. Even with very rapid coverage it should be valuable. Chapter 6 presents the usual methods employed in electronic-circuit analyses, analytic and graphical. Great stress is laid on the use of the linear-equivalent-circuit theorem. Also considerable attention is paid to graphical methods with nonlinear circuits. Only elementary aspects of
this fascinating subject are presented because of the limitations of time and space.

Although in theory a student should have well in hand all the tools he has studied, as a practical matter the authors feel that a brief restatement or treatment of certain ideas often helps enough to pay for its inclusion in a volume designed principally as a textbook. Hence the short treatment of such subjects as network theorems and Fourier analysis are included. The practical use of this material begins at once in the following chapter, although for some of it the delay is great enough, as in the case of power-series expansion of plate current, so that the student will wish to refer back to the discussion again. At any rate he knows where to find the material.

The chapters following the sixth present a selection of the various aspects of electronics which can reasonably be included in a beginning course. No claim is made that all the interesting and useful developments in the field are discussed or even mentioned.

In the numerous cases in which a mathematical development is attempted, the authors have endeavored to provide, first, a facile word explanation for the behavior. Then follows the setting of current and voltage symbols, the writing of circuit equations, the solution of these, the simplifying assumptions and rearrangement needed to pace the solution in a usable form (which often involves the drawing of a simplified equivalent circuit), and the final interpretation of the results. Numerous worked-out examples are provided to help in understanding. The authors feel that much practice is needed in these matters for students who plan to continue in fields allied to electronics.

The authors have freely consulted periodicals and engineering texts by many writers. They wish to acknowledge the valuable criticism and encouragement given by their colleagues. Especially do they appreciate the assistance of their former colleague, Dr. K. J. Hummelbein. In addition, thanks are due the unknown critics engaged by the publisher. They have made many valuable suggestions.

George E. Happel
Wilfred M. Hesselberth
CONTENTS

Preface ........................................ v

1. ELECTRON BALLISTICS .................................. 1
   The electron. Other charged particles. Properties of charged bodies.
   The electric field. Potential. Potential gradient. The behavior of an
   electron in an electric field. Moving electrons in a magnetic field. Mag-
   netic focussing of an electron beam. The cathode-ray tube—electrostatic
   focussing. The deflection of the electron beam in a cathode-ray tube.

2. EMISSION ........................................... 30
   Structure of the atom. Free electrons in a metal. Electron escape from a
   metal. The work function. The electron-volt. Contact difference in
   potential. Thermionic emission. Thermionic emission from tungsten.
   Thoriated-tungsten filaments. Oxide-coated emitters. Schottky effect.
   High-field emission. Secondary emission. Photodetector emission.

3. THE HIGH-VACUUM DIODE .................................. 49
   Space charge. The diode. Experimental determination of the current in a
   diode. Potential distribution in a diode with parallel plane electrodes.
   Gauss's theorem. The space-charge equation. Experimental proof of the
   Characteristic curves for a diode.

4. THE VACUUM TRIODE AND OTHER MULTIELEMENT TUBES ................. 69
   De Forest’s triode. Triode construction. The function of the grid.
   Triode characteristics. Triode coefficients. Calculation of tube coef-
   ficients. Dynamic transfer characteristics. Shortcomings of the triode.
   The tetrode. Tetrode characteristics. Tube coefficients for the tetrode.
   Shortcomings of the tetrode. The pentode. The static characteristics of a
   pentode. Dynamic transfer characteristics for a pentode. Tube coefficients
   power tubes. Miscellaneous types of high-vacuum tubes.

5. SOME APPLICATIONS OF VACUUM TUBES ..................................... 101
   Radio communication. A-m transmitter system. An a-m receiver system.
   The diode rectifier. The diode detector. The triode current amplifier.
   The triode voltage amplifier. Two-stage voltage amplifier with resistive-
   capacitance coupling between stages. Two-stage a-c voltage amplifier with
   transformer coupling and cathode bias. The pentode voltage amplifier with
   resistance load. The pentode voltage amplifier with tuned load. The
10. FEEDBACK AMPLIFIERS. 299
Distortion and stability. Interference. How negative feedback helps.
Feedback and its effects on amplification. Effect on distortion and noise.
Feedback in amplifiers with low-level inputs. Voltage and current feedback.
Multistage feedback circuits. The effects of feedback in output impedances;
equivalent circuits. Some practical feedback amplifiers. Oscillators in
feedback amplifiers.

11. OSCILLATORS 321
Types of oscillators. The parallel LC circuit as a generator of oscillations.
Regenerative feedback oscillators. Practical feedback oscillators. The
analysis of a tuned-plate oscillator. Power oscillators and voltage oscil-
lators. Negative-resistance oscillators. LC oscillators. Phase-shift oscil-

12. MODULATION AND DETECTION 344
The meaning of modulation. Types of modulation. Amplitude modula-
tion. Method of amplitude modulation. Rate modulation of a class C
amplifier. Grid-bias modulation of a class C amplifier. Modulation of a
class A amplifier. The balanced modulated amplifier. Heterodyne fre-
quency conversion. Square-law demodulation. Linear diode detection.
Interference in radio reception. The frequency spectrum of an angular-
modulated wave. Preemphasis. Frequency modulation using a resistance
tube. Frequency modulation by means of phase modulation. FM
receivers. Limiters. Discriminators.

13. CONDUCTION THROUGH GASES 385
Types of gaseous discharges. Physical properties of the atom. The excited
atom. Ionization. Collision processes in gasses. Neutralization of nega-
tive gaseous charge by positive ions. Gaseous discharges. The Townsend
discharge. Breakdown. The normal glow. The abnormal glow. The
arc discharge. Gaseous diodes with cold cathodes. Gas diodes with ther-
monic cathodes. Thermionic cathodes used in gas tubes. Gas and vapor-
filled tubes. Effects of pressure on operating characteristics. Mercury-
Thyratrons. Shield-grid thyratrons. Ignition and demagnetization times.

14. RECTIFIERS 408
The ideal rectifier. The high-vacuum diode as a rectifier. The half-wave
high-vacuum rectifier with a resistance load. Full-wave high-vacuum recti-
fer with a resistance load. Half-wave gas-diode rectifier with a resistance
load. Half-wave rectifier with a capacitor filter. Full-wave rectifier using
a series-inductor filter. Full-wave rectifier with an 1-section filter. Recti-
fiers with a section filter. Applications of diode rectifiers. Grid-con-
trolled rectifiers. The control of thyatrons. Gas-cooled control. Phase-shift
control. Bias-phase control. The igniter as a controlled rectifier.
CONTENTS

15. PHOTOELECTRIC CELLS 448

16. SOLID-STATE ELECTRONICS AND REACTANCE AMPLIFIERS 461

APPENDIX A. CHARACTERISTIC CURVES FOR SEVERAL TUBES 487
APPENDIX B. R-C-COUPLED AMPLIFIER DESIGN CHARTS 494
APPENDIX C. A TABLE OF SYMBOLS 497
INDEX 499
Electronic engineering is a discipline that utilizes the behavior and effects of electrons for the production of electronic devices (such as electron tubes and transistors), systems, or equipment. In many parts of the world, electronic engineering is considered at the same level as electrical engineering, so that general programs are called electrical and electronic engineering. (Many UK and Turkish universities have departments of Electronic