PRINCIPLES OF
ELECTRICAL ENGINEERING
SERIES

Applied Electronics

A FIRST COURSE IN ELECTRONICS, ELECTRON TUBES, AND ASSOCIATED CIRCUITS

SECOND EDITION

by

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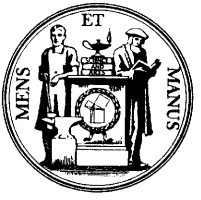

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Foreword

The staff of the Department of Electrical Engineering at the Massachusetts Institute of Technology has for some years been engaged in an extensive program of revising as a unit its entire presentation of the basic technological principles of electrical engineering. This new edition of *Applied Electronics* covers a part of that presentation.

The decision to undertake so comprehensive a plan rather than to add here and patch there came from the belief that the Department's large staff, with its varied interests in teaching and related research, could effect a new synthesis of educational material in the field of electrical engineering and evolve a set of textbooks with a breadth of view not easily approached by an author working individually.

Such a comprehensive revision, it was felt, should be free from the duplications, repetitions, and unbalances so often present in an unintegrated program. It should possess a unity and breadth arising from the organization of a subject as a whole. It should appeal to the student of ordinary preparation and also provide a depth and rigor challenging to the exceptional student and acceptable to the advanced scholar. It should comprise a basic course adequate for all students of electrical engineering regardless of their ultimate specialty. Restricted to material which is of fundamental importance to all branches of electrical engineering, the course should naturally lead into any one branch.

This book and the reorganized program of teaching out of which it has grown are thus products of a major research project to improve educational methods. The rapid development of electronics brought about by the impetus of the recent wars has made desirable revision of the original book to include new and improved devices, techniques, and methods of presentation. During these developments it has become clear that revision of this treatment and extension of it to new areas such as are included in this book should become more and more the responsibility of individual authorities who could relate their work to the over-all structure.

KARL T. COMPTON

Preface

During the years since the first edition of this book was published, electronics has truly come of age. We now rely on it for our comfort, our convenience, and even our lives in diverse fields such as energy conversion, communication, and control. We look to it with justified expectancy for new useful developments of benefit to mankind. The importance of electronics in science and engineering and, correspondingly, in technological education, has thus become even more clearly established than ever before. To facilitate such education, this book aims to lay a foundation for effective engineering application of the basic phenomena of electronics.

The extent of the use of electronics in the different branches of electrical engineering—power, communications, measurement, control, and others—precludes a complete treatment of the subject in a single volume. Hence, this book is not exhaustive; details of application are expected to follow in courses designed for specialization by students in the different branches. This book is for a first basic course. Rigor of thought and analysis, rather than extensiveness of scope, is its intended feature.

New devices, new principles, and new methods of analysis have extended the possibilities for application of electronics. The basic pattern of the field, and hence of this book, remains, however, essentially unchanged from that of the original edition. On the premise that proper application of electronic apparatus requires a working knowledge of the physical phenomena involved in the apparatus, the first part of the book is a discussion of those phenomena. The second part is an explanation of the way the phenomena combine to govern the characteristics, ratings, and limitations of electronic devices, and the third is a consideration of applications common to the several branches of electrical engineering. Finally, the fourth part is a treatment of semiconductor devices, primarily the transistor, in a manner parallel to the previous treatment of vacuum tubes. This arrangement makes practicable use of the book as a textbook in a number of different ways. In its entirety, it is intended to be suitable for a two-semester course. Assigning the early chapters and certain of the later chapters as reference material for reading only, with resultant emphasis upon the chapters that treat the circuit applications of electron tubes and semiconductor devices, makes possible use of the book for a one-semester course. To provide for addi-

tional study by particularly apt or advanced students, more material than is usually covered in a first course is presented; and to aid independent study outside the classroom, graphical data on typical electron tubes and answers to representative problems stated at the ends of the chapters are included in appendices.

Most of the functional methods by which electronics is employed in engineering are included. To make the book adequate as a point of departure into independent study and analysis of specialized applications of electronics, emphasis is placed on care in reasoning, with the thought that ease of understanding is synonymous with clarity of conception. Attempt is made to point out all links in the chain of reasoning in order to avoid those gaps that are so easily spanned intuitively by experienced engineers, but are so disturbing to the careful but inexperienced student. In addition to exact logic, this effort involves not advanced mathematics, but rather scrupulous attention both to aids to clearness of thought and to apparently minor details that are elementary but essential. One important aid is precise definitions of symbols and interpretation of them in terms of physical quantities. Among the elementary details requiring attention are the algebraic signs associated with the distinction between actual and reference directions of quantities, and avoidance of the common error of mixing complex numbers and time functions in the same equation. The three categories of mathematical quantities—scalars, complex numbers, and vectors—are distinguished by distinctive type, in accordance with the ASA American Standard Letter Symbols for Electrical Quantities. Since some of the rules for mathematical manipulation of quantities in each of these categories differ from the rules for quantities in the other two categories, such a distinction is essential for clarity. Symbols for the various component currents and voltages in electron-tube circuits are consistent with the recently revised standard for those quantities, and rationalized meter-kilogram-second units for physical quantities are used throughout the book, in accordance with almost universal present-day practice.

During preparation of this revision, it has been a pleasure to recall the contributions of colleagues who shared in supplying preliminary drafts of sections of the original edition. Many of them are now at other educational institutions or with industrial organizations; some, however, are still my close associates. The fact that many of the ideas and concepts in those early drafts continue to be regarded as fundamental and are hence retained in this revised book attests to the soundness of their judgment. I have been greatly aided by discussions with and suggestions from my present colleagues. In particular, I wish especially to thank Professor A. B. Van Rennes and Professor E. F. Buckley for their many

constructive suggestions throughout the book, and their able, generous, and untiring aid in reading all the manuscript and the proof. I am also indebted to Professor S. J. Mason and Professor R. E. Scott for their suggestions regarding circuit analysis, and to Professor R. B. Adler for his advice regarding the chapter on semiconductor devices. Dean F. G. Fassett, Jr., has been ever helpful with counsel on presentation and style, and Dean H. L. Hazen and Professor G. S. Brown have provided continual inspiration by their encouragement and support of this work. To all these individuals, and to my wife Isabel for her constant encouragement, assistance, and forbearance, I extend my thanks, with the hope that their helpfulness will be reflected in increased usefulness of the book to students.

TRUMAN S. GRAY

October 27, 1953

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APPENDICES

Table of Symbols

In this book a **boldface roman-type** or **script letter** is used to represent a space vector, and an ordinary *italic* or *script letter* to represent its magnitude, for example: $\mathbf{B}$, $\mathscr{E}$, B, $\mathscr{E}$. Similarly, a ***boldface italic letter*** is used to represent a complex number, and an *italic letter* its magnitude, for example: $\boldsymbol{E}$, E. Ordinary italic or script letters are used to represent the ordinary real scalar quantities. For voltage, current, and charge, capital letters generally represent fixed quantities, and lower-case letters represent variable quantities. For transistors, however, an exception is made, as is explained in Art. 4, Ch. XIII. In general, each letter stands for a quantity of a particular kind, and subscripts are used to distinguish several quantities of the same kind from one another. For example, i is used for instantaneous current, and i_b specifies the instantaneous plate current in an electron tube.

The notation used in this book conforms to that standardized by the Institute of Radio Engineers[1] for use with electron tubes and their circuits. In order to make this conformity possible no distinction is made between e and v, or E and V. Any one is used to represent a voltage whether it be that of a source or not.

In the table that follows are listed the more important symbols used in this book. Many of the special symbols obtained through adding subscripts to the letters listed are omitted from this list, but are defined in the text where used. The standardized symbols used to designate voltage and current components encountered in electron-tube circuits are omitted from the main list and appear instead in a table at the end of the list. This table is repeated in Art. 20, Ch. VIII.

Abbreviations used in this book are, in general, those approved by the American Standards Association.[2]

[1] *Standards on Abbreviations, Graphical Symbols, Letter Symbols, and Mathematical Signs, 1948* (New York: The Institute of Radio Engineers, 1948), 1–9.

[2] *American Standard Abbreviations for Scientific and Engineering Terms — ASA No. Z10.1* (New York: American Society of Mechanical Engineers, 1941).