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# ELECTRONIC CIRCUITS AND TUBES

*BY THE*  
ELECTRONICS TRAINING STAFF  
OF THE  
CRUFT LABORATORY  
*Harvard University*

(WITH PROBLEMS ADDED)

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ELECTRONIC CIRCUITS AND TUBES

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## FOREWORD

This book has developed from the lecture notes of a special wartime training course given in the Graduate School of Engineering, Harvard University.

The need for highly trained officers in the new uses of electronics was definitely appreciated even in 1941. In July of that year a course for officers of the Signal Corps who were graduate electrical engineers was established at Harvard University in the Graduate School of Engineering to give intensive training in the fundamentals of electronics and high-frequency circuits. Immediately after the United States declared war, the Navy also sent officers to the pre-radar course.

The rapid expansion of the course necessitated a greatly increased instructional staff. Professors and instructors from many educational institutions were invited to Cambridge to aid the regular staff at Harvard in the field of communication engineering.

Although the war training course was distinct from the regular graduate courses in communication engineering that have been given for more than two decades in the Cruft Laboratory, it was planned originally and patterned to a considerable degree on the lines of some of the Cruft Laboratory courses. Since the scope and the method of presentation of the material in this volume are not on a graduate level, they differ somewhat from corresponding course work in the Cruft Laboratory.

The members of the wartime staff have brought to the work many excellent ideas from their teaching experience. More than thirty repetitions of the course gave opportunity to improve its character both as to lecture presentations and laboratory experiments. Considerable new material was injected into the course content. In short, this war training program presented a rare opportunity to develop and improve teaching methods in electronics.

During the progress of the course, lecture notes were prepared mainly by twelve members of the lecturing staff. It was the original intention to publish the entire lecture material in a single volume. Because the single volume would be inconveniently large and also since a portion of the manuscript was completed early, that portion has been published in a separate volume "Transmission Lines, Antennas, and Wave Guides" by Associate Profs. R. W. P. King and H. R. Mimno and Dr. A. H. Wing. The remaining and larger por-

tion of the lecture material comprises the subject matter of the present book. Logically the material of this book precedes that of the book already published; thus, the present book is Volume I of a two-volume text. Eleven of the original twelve members of the wartime lecturing staff are authors of the present book.

The text presented in this book has developed out of the intensive devotion, during a war emergency, of a group of men to a single purpose, that of imparting to the student officers in the most efficient manner a comprehensive and practical knowledge of electronics. The material of the course was, however, fundamental in nature and not exclusively applicable to wartime training. For this reason, it is hoped that the text will be as valuable for peacetime courses as it was successful in its intended purpose.

The treatment of the subject matter of this book is suitable for juniors or seniors of colleges and engineering schools, who are specializing in the study of communication engineering or in electronics. A knowledge of mathematics through calculus, and of electricity and magnetism is assumed. The book may also be found to be of value as a reference for others.

E. L. CHAFFEE

## PREFACE

This book presents the basic theory of electronic tubes and electric circuits employed in conjunction with these tubes. The emphasis is on the applications in the fields of communication and electronic control. Supplementary material on mathematics and electricity and magnetism is given in the appendixes, making the book useful to those needing preparation in these subjects.

As stated in the foreword, the book has developed from the lecture notes of a special wartime training course. Many chapters of the book contain more material than was given in the course. In the preparation of the notes and the book, there was much collaboration among the authors. In this work, each chapter has been the responsibility of one or two of the authors. Chapters I, II, III, IV, XXII and Appendix C were written by L. W. Morris; Chaps. V and VI by S. P. Cooke; Chaps. VII, XIV, and part of Chap. XIX by E. L. Chaffee; Chaps. VIII, IX, XVIII and Appendix A by P. E. LeCorbeiller; Chaps. X and XI by R. O. Cornett; Chaps. XII, XV, and XXIV by H. R. Mimno; Chap. XIII mostly by G. R. Tatum, in part by H. Stockman; Chaps. XVI and XVII by J. D. Cobine; Chaps. XIX and XX by S. Githens, Jr. and A. H. Wing; Chap. XXIII by H. Stockman with the assistance of S. Githens, Jr.; Appendix B by P. E. LeCorbeiller and S. Githens, Jr.; Chap. XXI and Appendix D by A. H. Wing. This is not to be construed as a list of exclusive authorship in all cases, as there were many interchanges of ideas. There were also some modifications made in original versions in order to fit them into the general plan of the book.

The book teaches fundamental principles clearly and rigorously and contains much new material and new methods of presentation. In the treatment of a-c circuits the behavior of circuit elements with respect to nonsinusoidal waveforms is described in such a way as to develop correct concepts of resistance, inductance, and capacitance. For sinusoidal waveforms the emphasis is more on the magnitude and angle of the impedance rather than on resistance and reactance. Curves or loci are used extensively to describe circuit behavior. The treatment of resonance is rigorous and more complete than usual. There is a new presentation of the bridged-T and parallel-T networks.

In the chapter on networks and impedance matching, the subject

of equivalent four-terminal networks is discussed quite fully. Network theorems are presented, with more emphasis on Thévenin's theorem than on any of the others. The action of the tank circuit as an impedance transformer is clearly explained. The chapter on transients is fully illustrated with diagrams. The effect of the time constant in  $LR$  and  $CR$  circuits is stressed. The analysis of initial and final conditions is explained effectively.

Much hitherto unpublished material is given in Chap. VII. The method of correlating response curves of coupled circuits by means of space models and contour diagrams is unique and results in an understanding of these circuits surpassing that conveyed by the ordinary response-curve type of presentation. There is new material on the band widths of magnetically coupled circuits.

A new approach to filters is given in Chap. VIII, with added material on delay networks. A rigorous yet simplified presentation of Fourier analysis is given in Chap. IX; the effect of waveform discontinuities on the magnitude of the harmonic components is explained. The analysis of periodic phenomena is extended in Chap. XVIII to nonperiodic pulses, again by a simplified method. In view of the increased use of pulses, this material should be of considerable value to the undergraduate student.

In Chaps. X and XI the action of the vacuum tube as a device is emphasized, rather than the quantitative theory of electron emission. The explanations are given both graphically and analytically. Chapter XII contains a very complete but qualitative description of the cathode-ray tube. The effects of various combinations of magnetic and electrostatic focusing and deflection are discussed. There is an unusually clear and complete description of the modern cathode-ray oscillograph.

Chapter XIII is the longest in the book and includes a complete discussion of wide-band amplifiers. The effect of feedback on the response characteristics and the output impedance is derived. The cathode follower is treated very fully.

Extensive new material on power tubes is to be found in Chap. XIV. Contour diagrams are used to describe the behavior of the Class  $C$  stage. Many forms of coupling the load to the tube are analyzed. There is new material on methods of tuning and methods of neutralization.

Oscillators are given comprehensive but qualitative treatment in Chap. XV. The drag loop, a phenomenon commonly neglected but

of considerable importance where tuned systems are connected to oscillator tubes, is adequately explained here and in Chap. XIV. The newer types of oscillator circuits are also described.

The chapter on gas-filled tubes covers the use of these tubes as rectifiers and control elements. A complete example of a rectifier design is worked out in Chap. XVII. Voltage-regulated power supplies are covered more fully than usual.

The treatment of modulation is divided into two parts, one on principles and the other on methods. The principles are thoroughly discussed to facilitate the understanding of methods or devices, which in practice are being continually improved. The treatment of angle modulation will, it is hoped, save the student from pitfalls which have caught many in the discussion of this subject.

Linear and square-law detection are treated qualitatively and quantitatively in Chap. XXI. Oscillograms are used to show clipping in the diode detector. Rectification diagrams are given for all the important large-signal detectors. The more common discriminator circuits are qualitatively treated. This material ties in with Chap. XXIII in which radio receivers are classified by type and their operation described. The operation of mixer and converter tubes is explained with a new terminology. Receivers are not presented in this organized fashion in most text books, and this chapter fills a need for showing how circuits previously discussed separately are joined together to make a complete piece of equipment.

Chapter XXII on test instruments supplies needed and practical information. Too often the user does not appreciate just what an indicating instrument measures. New material on the behavior of vacuum-tube voltmeters is included.

A complete description of control and timing circuits is given in the last chapter. Synchronization of relaxation oscillators is discussed more clearly than usual. A new and accurate description of the blocking oscillator is given. The assembly of complete waveforming circuits from their simple elements is featured, and several circuits are worked out as examples or exercises.

Great credit is due to the members of the armed forces who were students and instructors in the Cruft courses. Their constructive criticism and hard work has been of immeasurable aid to the authors in making their work more effective. Many of the

Cruft electronics staff contributed time and effort toward the preparation of the course notes and the present book. In the preparation of the book manuscript the authors are deeply indebted to Prof. Harry E. Clifford for his valuable assistance and his helpful editing.

ALEXANDER H. WING

*September, 1947.*



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