VACUUM TUBE AMPLIFIERS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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NEW YORK · TORONTO · LONDON
McGRAW-HILL BOOK COMPANY, INC.
1948

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THE MAPLE PRESS COMPANY, YORK, PA.

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Foreword

THE tremendous research and development effort that went into the development of radar and related techniques during World War II resulted not only in hundreds of radar sets for military (and some for possible peacetime) use but also in a great body of information and new techniques in the electronics and high-frequency fields. Because this basic material may be of great value to science and engineering, it seemed most important to publish it as soon as security permitted.

The Radiation Laboratory of MIT, which operated under the supervision of the National Defense Research Committee, undertook the great task of preparing these volumes. The work described herein, however, is the collective result of work done at many laboratories, Army, Navy, university, and industrial, both in this country and in England, Canada, and other Dominions.

The Radiation Laboratory, once its proposals were approved and finances provided by the Office of Scientific Research and Development, chose Louis N. Ridenour as Editor-in-Chief to lead and direct the entire project. An editorial staff was then selected of those best qualified for this type of task. Finally the authors for the various volumes or chapters or sections were chosen from among those experts who were intimately familiar with the various fields, and who were able and willing to write the summaries of them. This entire staff agreed to remain at work at MIT for six months or more after the work of the Radiation Laboratory was complete. These volumes stand as a monument to this group.

These volumes serve as a memorial to the unnamed hundreds and thousands of other scientists, engineers, and others who actually carried on the research, development, and engineering work the results of which are herein described. There were so many involved in this work and they worked so closely together even though often in widely separated laboratories that it is impossible to name or even to know those who contributed to a particular idea or development. Only certain ones who wrote reports or articles have even been mentioned. But to all those who contributed in any way to this great cooperative development enterprise, both in this country and in England, these volumes are dedicated.

L. A. DUBRIDGE.

Preface

Soon after Drs. I. I. Rabi and L. A. DuBridge decided that the technical knowledge of the Radiation Laboratory staff should be preserved, it was evident that at least one complete book would be required on lumped-parameter circuits. The early planning for that book was done during a series of conferences called by L. J. Hawworth, and attended by B. Chance and G. E. Valley, Jr.

It was difficult to arrange all the subject matter in a way that would be easy to read and economical of space. It would have been possible to describe the various electrical devices in order, but to describe each instrument completely would have involved an intolerable amount of repetition concerning basic circuits, such as multivibrators and amplifiers. It would also have required an intolerable amount of cross-indexing if the work were to be usable by those interested, not in the particular instruments described, but in the application of their design principles to completely different problems. It was apparent, too, that the work should not stress radar.

The material was therefore divided into two parts: the first part to include the basic principles of circuit design, the second to pertain to the assembly of basic circuits into functional instruments such as receivers and data display systems. These decisions were made in the interests of clarity and brevity. Even so, upon completion of the consequent outline, it was evident that several volumes would be required. Accordingly new outlines were prepared for each of these and were then revised separately for each volume by committees composed of the editors and authors concerned.

The first of these books, *Components Handbook*, discusses the physical embodiments of the lumped-parameters themselves: resistors, cables, motors, vacuum tubes, etc. Next, *Vacuum Tube Amplifiers* and *Waveforms* discuss the principles of circuit design, respectively, for circuits that are essentially linear (amplifiers) and for circuits that are essentially nonlinear (oscillators, electronic switches, and the like). The four following volumes concern themselves with the design of complex functional devices. They are *Electronic Time Measurements*, *Electronic Instruments*, *Cathode Ray Tube Displays*, and *Microwave Receivers*.

The amplifiers discussed in this volume are designed to have extreme

values in one of several of the pertinent characteristics: bandwidth, sensitivity, linearity, constancy of gain over long periods of time, etc. In most cases the design of such amplifiers, in which the ultimate performance is obtained from available types of components, cannot be carried out by simple rules of thumb.

The volume therefore begins with a chapter on "Linear Analysis and Transient Response" which lays the theoretical basis for the high-fidelity reproduction of transient signals, such as rectangular pulses. Although the chapter is rather theoretical, a summary is contained in Sec. 1·10 of the precise steps needed to determine the transient response of a given network. The practical application of these principles is examined in the next chapter, "High-fidelity Pulse Amplifiers," for direct, or "video," pulses. The resemblance of this material to that contained in Chap. 3 is only superficial; "Pulse Amplifiers of Large Dynamic Range" is about the design of amplifiers intended to deal with pulses of widely varying magnitude, all other characteristics being secondary. Chapters 4 through 7 deal with the theoretical and practical aspects of several methods of amplifying, with varying degrees of fidelity, pulse-modulated carrier frequencies as high as 200 Mc/sec. Although the design principles are examined in these chapters chiefly from the standpoint of relatively high frequencies, they are perfectly general in their application. That this is true is exemplified by Chap. 10, "Low-frequency Feedback Amplifiers," wherein some of the results of Chap. 4 are applied to filter amplifiers operating at frequencies as low as 50 cps.

Chapter 8 deals with the examination and adjustment of the amplifiers previously described, especially when they are employed as intermediate frequency amplifiers in superheterodyne receivers. Chapter 9 discusses some of the innumerable ways in which inverse feedback can be employed to stabilize the gain of an amplifier. The well-known principles of Nyquist, Bode, and others are applied particularly to circuits in which inductances do not appear, and use is made of this fact to simplify the analysis; in addition the chapter describes the successively less approximate phases through which the design of such an amplifier can proceed. Chapter 11 recounts the experience at the Radiation Laboratory concerning the design of rugged and reliable direct-coupled amplifiers, no particular emphasis being placed upon extreme sensitivity.

Chapter 12, "Amplifier Sensitivity," examines the subject of noise in a rigorous and very theoretical manner. The design of amplifiers for best signal-to-noise ratio is discussed in Chap. 13, "Minimal-noise Input Circuits," and in Chap. 14 the experimental measurement of amplifier sensitivity is explained.

Appendix A contains an existence theorem on the physical realizability of filter amplitude characteristics.

In addition to the material contained in this volume, information concerning the application of amplifiers to specific purposes will be found in other volumes. In particular the use of amplifiers in computers and servomechanisms is discussed in *Electronic Instruments.* In *Cathode Ray Tube Displays* is included a chapter devoted to amplifiers specifically designed to drive inductive loads (i.e., cathode-ray tube deflection coils). *Microwave Receivers* contains a good deal of information on the use in microwave receivers of the types of amplifier described in Chaps. 3 through 7. It also contains a discussion of the noise problem as it affects superheterodyne receiving systems.

The editors wish to acknowledge the inspiration and guidance of the Editor-in-Chief, L. N. Ridenour, and of his editorial board. This book is the product of a large organization, much of the credit for whose successful operation goes to Charles Newton and his able assistants Dr. V. Josephson, M. Dolbeare, and M. Phillips. Whatever uniformity of style and format the book may present is largely due to the Technical Coordination Group operating under the direction of Drs. L. B. Linford and A. M. Stone. To the authors, the editors extend their thanks for a task conscientiously performed and their congratulations upon its completion. The assistance of Mr. J. H. Irving in furnishing important background material for Chap. 1 is gratefully acknowledged. It is due to the generosity of the British Air Commission that Mr. R. Q. Twiss was able to work on the several important chapters that bear his name.

The preparation of the illustrations for the volume was ably supervised by Martha Murrell. The timely assistance of Margot Cheney and Beka Hepner resulted in the volume's being prepared within the allotted time. It was the task of Doris Williams to type over the most illegible of the original manuscript.

THE EDITORS.

CAMBRIDGE, MASS.,
July, 1946.

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