

ELECTRONICS

Experimental Techniques

by

WILLIAM C. ELMORE

Associate Professor of Physics
Swarthmore College

MATTHEW SANDS

Assistant Professor of Physics
Massachusetts Institute of Technology

New York · Toronto · London
McGRAW-HILL BOOK COMPANY, INC.

1949

NATIONAL NUCLEAR ENERGY SERIES
Manhattan Project Technical Section

Division V—Volume 1

ELECTRONICS
Experimental Techniques

FOREWORD

The United States program of development of atomic energy has been described by Major General L. R. Groves, who, as Commanding General of the War Department's Manhattan Project, directed the program from mid-1942 until December 31, 1946, as "a generation of scientific development compressed into three years." The tremendous scope of the Manhattan Project Technical Section of the National Nuclear Energy Series, which has been in preparation since 1944, is a tribute to the unprecedented accomplishments of science, industry, government, labor, and the Army and Navy, working together as a team. These volumes can be a firm foundation for the United States atomic energy program which, in the words of the Atomic Energy Act of 1946, is " . . . directed toward improving the public welfare, increasing the standard of living, strengthening free competition in private enterprise, and promoting world peace."

David E. Lilienthal, Chairman
U. S. Atomic Energy Commission

ACKNOWLEDGMENT

The Manhattan Project Technical Section of the National Nuclear Energy Series embodies results of work done in the nation's wartime atomic energy program by numerous contractors, including Columbia University. The arrangements for publication of the series volumes were effected by Columbia University, under a contract with the United States Atomic Energy Commission. The Commission, for itself and for the other contractors who contributed to this series, wishes to record here its appreciation of this service of Columbia University in support of the national nuclear energy program.

PREFACE

This volume is one of a series which has been prepared as a record of the research work done under the Manhattan Project and the Atomic Energy Commission. The name Manhattan Project was assigned by the Corps of Engineers, War Department, to the far-flung scientific and engineering activities which had as their objective the utilization of atomic energy for military purposes. In the attainment of this objective, there were many developments in scientific and technical fields which are of general interest. The National Nuclear Energy Series (Manhattan Project Technical Section) is a record of these scientific and technical contributions, as well as of the developments in these fields which are being sponsored by the Atomic Energy Commission.

The declassified portion of the National Nuclear Energy Series, when completed, is expected to consist of some 60 volumes. These will be grouped into eight divisions, as follows:

- Division I — Electromagnetic Separation Project
- Division II — Gaseous Diffusion Project
- Division III — Special Separations Project
- Division IV — Plutonium Project
- Division V — Los Alamos Project
- Division VI — University of Rochester Project
- Division VII — Materials Procurement Project
- Division VIII — Manhattan Project

Soon after the close of the war the Manhattan Project was able to give its attention to the preparation of a complete record of the research work accomplished under Project contracts. Writing programs were authorized at all laboratories, with the object of obtaining complete coverage of Project results. Each major installation was requested to designate one or more representatives to make up a committee, which was first called the Manhattan Project Editorial Advisory Board, and later, after the sponsorship of the Series was assumed by the Atomic Energy Commission, the Project Editorial Advisory Board. This group made plans to coordinate the writing programs at all the installations, and acted as an advisory group in all matters affecting the Project-wide writing program. Its last meeting was held on Feb. 9, 1948, when it recommended the publisher for the Series.

The names of the Board members and of the installations which they represented are given below.

Atomic Energy Commission Public and Technical Information Service	Alberto F. Thompson
Technical Information Branch, Oak Ridge Extension	Brewer F. Boardman
Office of New York Operations	Charles Slessor, J. H. Hayner, W. M. Hearon *
Brookhaven National Laboratory	Richard W. Dodson
Carbide & Carbon Chemicals Corporation (K-25)	R. B. Korsmeyer, W. L. Harwell, D. E. Hull, Ezra Staple
Carbide & Carbon Chemicals Corporation (Y-12) †	Russell Baldock
Clinton Laboratories ‡	J. R. Coe
General Electric Company, Hanford	T. W. Hauff
General Electric Company, Knolls Atomic Power Laboratory	John P. Howe
Kellex Corporation	John F. Hogerton, Jerome Simson, M. Benedict
Los Alamos	R. R. Davis, Ralph Carlisle Smith
National Bureau of Standards	C. J. Rodden
Plutonium Project Argonne National Laboratory	R. S. Mulliken, H. D. Young
Iowa State College	F. H. Spedding
Medical Group	R. E. Zirkle
SAM Laboratories §	G. M. Murphy
Stone & Webster Engineering Corporation	B. W. Whitehurst
University of California	R. K. Wakerling, A. Guthrie
University of Rochester	D. R. Charles, M. J. Wantman

* Represented Madison Square Area of the Manhattan District.

† The Y-12 plant at Oak Ridge was operated by Tennessee Eastman Corporation until May 4, 1947, at which time operations were taken over by Carbide & Carbon Chemicals Corporation.

‡ Clinton Laboratories was the former name of the Oak Ridge National Laboratory.

§ SAM (Substitute Alloy Materials) was the code name for the laboratories operated by Columbia University in New York under the direction of Dr. H. C. Urey, where much of the experimental work on isotope separation was done. On Feb. 1, 1945, the administration of these laboratories became the responsibility of Carbide & Carbon Chemicals Corporation. Research in progress there was transferred to the K-25 plant at Oak Ridge in June, 1946, and the New York laboratories were then closed.

Many difficulties were encountered in preparing a unified account of Atomic Energy Project work. For example, the Project Editorial Advisory Board was the first committee ever organized with representatives from every major installation of the Atomic Energy Project. Compartmentation for security was so rigorous during the war that it had been considered necessary to allow a certain amount of duplication of effort rather than to permit unrestricted circulation of research information between certain installations. As a result, the writing programs of different installations inevitably overlap markedly in many scientific fields. The Editorial Advisory Board has exerted itself to reduce duplication in so far as possible and to eliminate discrepancies in factual data included in the volumes of the NNEs. In particular, unified Project-wide volumes have been prepared on Uranium Chemistry and on the Analysis of Project Materials. Nevertheless, the reader will find many instances of differences in results or conclusions on similar subject matter prepared by different authors. This has not seemed wholly undesirable for several reasons. First of all, such divergencies are not unnatural and stimulate investigation. Second, promptness of publication has seemed more important than the removal of all discrepancies. Finally, many Project scientists completed their contributions some time ago and have become engrossed in other activities so that their time has not been available for a detailed review of their work in relation to similar work done at other installations.

The completion of the various individual volumes of the Series has also been beset with difficulties. Many of the key authors and editors have had important responsibilities in planning the future of atomic energy research. Under these circumstances, the completion of this technical series has been delayed longer than its editors wished. The volumes are being released in their present form in the interest of presenting the material as promptly as possible to those who can make use of it.

The Editorial Advisory Board

The Manhattan Project Technical Section of the National Nuclear Energy Series is intended to be a comprehensive account of the scientific and technical achievements of the United States program for the development of atomic energy. It is not intended to be a detailed documentary record of the making of any inventions that happen to be mentioned in it. Therefore, the dates used in the Series should be regarded as a general temporal frame of reference, rather than as establishing dates of conception of inventions, of their reduction to practice, or of occasions of first use. While a reasonable effort has been made to assign credit fairly in the NNEs volumes, this may, in many cases, be given to a group identified by the name of its leader rather than to an individual who was an actual inventor.

LOS ALAMOS PROJECT FOREWORD

The volumes comprising the Los Alamos Division of the National Nuclear Energy Series represent only a fraction of the total documentation of the activities of the Los Alamos Scientific Laboratory since its establishment early in 1943. They were prepared originally as part of the Los Alamos Technical Series, a group of books intended as a comprehensive survey of the accomplishments of the Atomic Bomb Project. However, the necessary restrictions imposed on the dissemination of technical information affecting the nation's security have permitted the inclusion in the National Nuclear Energy Series of only that portion of the Los Alamos work which does not deal specifically with the nuclear weapon program.

Most of the volumes of the Los Alamos Technical Series were prepared late in 1945 and early in 1946, and because of the impossibility at that time of predicting the precise nature of a declassification policy that had not yet been formulated, they were written primarily as laboratory manuals intended for use by authorized staff members of the Laboratory and the Manhattan Project, rather than as books that might conceivably be made available to the general public at some unknown time in an obscure future. Despite the fact that a considerable portion of the work contained information of quite general scientific interest and had no obviously close connection with the design and construction of weapons, it has been a difficult, tedious, and unfinished task to extract such material from the existing volumes in order to create books of a publishable nature. In most cases, the Technical Series volumes were so written that the separation of unclassified from classified information requires a major rewriting and editing program, which is even further complicated because a number of the original authors and editors are no longer directly associated with the program of the Atomic Energy Commission.

Only one of the original volumes was written in such a manner that a substantial proportion might be declassified with minor deletions and revision. It bore the title "Experimental Techniques," and was divided into three main parts, each of which seemed of sufficient length to justify being made into a separate volume for inclusion in the National Nuclear Energy Series. These were (1) "Electronics" by William C. Elmore and Matthew Sands, (2) "Ionization Chambers and Counters" by Bruno B. Rossi and Hans H. Staub, and (3)

"Miscellaneous Physical and Chemical Techniques" by Alvin C. Graves et al. These now will appear as the first published volumes of the Los Alamos part of the National Nuclear Energy Series. Darol K. Froman, one of the originators of the Los Alamos Technical Series and editor of the original volume on "Experimental Techniques," has served as volume editor for each of these three divisional books.

Robert R. Davis
Ralph Carlisle Smith

June, 1949

PREFACE TO THE "EXPERIMENTAL TECHNIQUES" VOLUMES OF DIVISION V

In the late summer of 1945 it appeared likely that many of the electronic circuits and experimental techniques that were employed in what is now known as the Los Alamos Scientific Laboratory would be of appreciable value to the scientific world outside the Los Alamos Laboratory. Moreover, it was already apparent that many of the physicists, chemists, and engineers most prolific in devising circuits and techniques would not remain indefinitely with the Laboratory. Thus, for the sake of the history of accomplishment in the Laboratory, the inheritors of the physical plant, and the general scientific community, it became necessary to record in intelligible form some of the practices that were found most useful.

After much discussion it was decided that the only feasible approach to this problem must be made with the purely utilitarian objective of producing a laboratory manual. We decided to write down how to do things we knew how to do. In the great majority of these cases the "know how" was the result of experimentation and thought by many members of the laboratory staff, and very frequently fundamental ingredients were imported from the vast fields of common scientific knowledge, from other laboratories associated with the Manhattan Engineer District, and from other wartime projects. In particular, a large number of the electronic circuits involve fundamental elements or ideas derived from the work carried on at the Radiation Laboratory at Massachusetts Institute of Technology. During the war years much of the work of the Laboratory was either described sketchily in local reports or not described at all. Under these conditions it was apparent that proper credit for the development of circuits or techniques could not be given to individuals or even to groups. Yet it was felt that the value of a systematic recording would outweigh any demerit arising from an unorthodox omission of references. The work is not written completely without references but, in general, references are given only when it is thought that they would be of distinct aid to the reader. These are our excuses and apologies for omission of recognition to the hundreds of investigators whose work made these volumes possible.

Preparation for the writing was begun by circularizing the Laboratory for topics that should be included and indexing the topics. About

this time the plan of writing the Los Alamos Technical Series was given considerable momentum, and the present work naturally became part of that series. The magnitude of the job became apparent at about the same time, and the authors of the various chapters were persuaded to undertake the task. In each case an author was selected for his intimate knowledge of the material and of the accomplishments of the Laboratory in the field. In every case at least some of the developments described are attributable directly to the authors. Little attempt has been made to make the various chapters uniform in mode of presentation since the clarity might have been impaired by altering the presentation of the authors.

We wish to express our appreciation for the efforts of the Laboratory's Declassification Section and Patent Group in expediting the release of the information in the present volumes on "Experimental Techniques." Since many of the developments appeared in writing for the first time in the manuscripts of these volumes, the job of tracing a device or part back to its inventor and writing adequate patent applications was a very major undertaking. Obviously the work could not be released until it was carefully reviewed to protect the interests of the U.S. Government.

The preparation of these volumes of Division V of the Manhattan Project Technical Section was encouraged in every possible way by the administration of the Laboratory under the direction first of J Robert Oppenheimer and second of Norris E. Bradbury.

The work on "Experimental Techniques" is divided into three volumes by subject matter and for ease in binding. It may be that many readers will want only one volume, and for this reason some items are duplicated in different volumes. Also, an attempt has been made to keep cross-references to a minimum.

It is our earnest hope that these volumes will be found of practical value to experimentalists, particularly nuclear physicists, in spite of the fact that many of the techniques and circuits are now well known and some are even obsolescent.

Darol Froman
Los Alamos Scientific Laboratory

June, 1949

AUTHORS' PREFACE

The Electronics Group, a subdivision of the Los Alamos Laboratory, was responsible for the design of electronic instruments for the research program of the Laboratory. During the period from 1943 to 1945 this group devised several hundred circuits for specific requirements of other research groups. In August, 1945, Dr. Darol K. Froman invited the authors, who were members of the Electronics Group through most of its existence, to write a report of the work that had been done by the Laboratory in electronic instrumentation.

The first step in the preparation of this account was the selecting of circuits that appeared to be worth describing. At the time of the writing there were more than seven hundred diagrams of circuits in the files of the Electronics Group and many diagrams of circuits in the Laboratory devised by other groups. Circuits chosen for inclusion in this volume were judged on the basis of their general usefulness as proved at the Laboratory, and of their probable usefulness in other laboratories. Some special-purpose circuits were chosen which have no general utility but which illustrate some particular method or technique. For reasons of security no circuits having a special application to weapon technology were included.

The collection of diagrams, a few reports, the two years of experience that the authors had in the Electronics Group, and the counsel of other staff members constituted the raw materials for this book. The circuits selected are arranged in five general categories, and these form the basis of Chapters 3 to 7. Certain "circuit elements," or parts of a complete circuit such as amplifier stages or blocking oscillators, are used repeatedly in the design of the complete circuits described. The elements most often used are presented separately in Chapter 2, and the circuits of later chapters are described in terms of these elements. Chapter 2 by itself should prove useful to those who desire to acquire a background of information for use in designing electronic circuits for special applications. Chapter 1, "Circuit Components and Construction Practice," deals briefly with the properties of such circuit components as resistors and capacitors, and with such problems as the physical layout of circuits. It gives a far from exhaustive account of these particular topics, since no systematic testing or selection of electronic components was undertaken at the Laboratory.

The task of writing this account was essentially completed by July, 1946. Since no new material has been added since that time, a number of the circuits are already obsolescent. It is hoped, however, that at least some of the material is of more than historical interest.

The circuits described in this book were designed by many individuals and often by groups of individuals in collaboration. It appeared impossible to trace the origin and to give credit to the source of each idea in every circuit. It would be unjust to attribute any single circuit to the individual who was responsible for the final design of the circuit. Accordingly no attempt is made in this volume to attach names to specific circuits. Several of the more important circuits have been described in the journals since this account was written. For the development of many of the circuits and the writing of this volume we owe much to Darol K. Froman and William A. Higinbotham, who were successively Group Leaders of the Electronics Group; and to Robert F. Bacher, of whose Division the Electronics Group was a part. The authors are indebted to the many unnamed members of the Electronics Group and of the Laboratory who made numerous contributions to the design, construction, and testing of the circuits described here.

William C. Elmore
Matthew Sands

July, 1949

CONTENTS

	Page
Foreword.	v
Preface.	vii
Los Alamos Project Foreword.	xi
Preface to the "Experimental Techniques" Volumes of Division V.	xiii
Authors' Preface.	xv

CHAPTER 1

Circuit Components and Construction Practice	1
By William C. Elmore	

CHAPTER 2

Circuit Elements.	27
By William C. Elmore and Matthew Sands	

CHAPTER 3

Voltage Amplifiers	124
By William C. Elmore	

CHAPTER 4

Electronic Counters.	202
By Matthew Sands and William C. Elmore	

CHAPTER 5

Oscillographs and Associated Equipment.	280
By William C. Elmore	

CHAPTER 6

Test and Calibration Equipment.	308
By William C. Elmore	

CHAPTER 7

Power Supplies and Control Circuits.	363
By William C. Elmore	

Index.	411
----------------	-----

Chapter 1

CIRCUIT COMPONENTS AND CONSTRUCTION PRACTICE

By William C. Elmore

1. INTRODUCTION

The first part of this chapter is devoted to a brief discussion of components that have been found suitable for constructing the various electronic circuits described in later chapters. It is not intended to make an exhaustive treatment of circuit components here, nor to present information of the sort readily available in standard handbooks or the catalogues of manufacturers. The second part of the chapter will be devoted to a description of a number of different methods that have been used at Los Alamos for the mechanical construction of electronic circuits. It is felt that a discussion of these two matters will be useful to anyone wishing to build electronic apparatus for research purposes. The discussion forms a necessary supplement to the circuits presented in later chapters, since emphasis there has been placed mainly on the function of circuits and on how this function is accomplished by combinations of various circuit elements. Other than indicating the values, and possibly the type of components to be used, a circuit diagram in itself usually contains little information of the sort required by a technician. The present discussion is an attempt to supply some of the necessary background material that will later be assumed to be part of the reader's knowledge.

2. CIRCUIT COMPONENTS

The term "circuit component" is used to distinguish the elementary parts with which an electronic circuit is constructed: a resistor, a capacitor, a transformer, etc. The term "circuit element" will later be used to signify combinations of circuit components that together