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# COMPUTER HANDBOOK

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# PREFACE

The *Computer Handbook* in one comprehensive volume presents the general principles of design and utilization of both analog and digital computers. In either field sufficient detail is presented so that anyone competent in the field can proceed to construct a computer, or, having a computer, can proceed to use it. Components are discussed in detail, and many actual circuit diagrams have been included as concrete examples of design principles or for direct adaptation to the designer's problem. The organization of problems for solution on computers is described, and examples of applications of computers to a variety of problems are given.

For the younger engineer and for newcomers to the control and computer fields, the handbook provides quick access to exactly that industrial know-how which is necessarily neglected in a modern engineering-school curriculum stressing principles rather than techniques. For those desiring to solve problems on computers, techniques for producing flow diagrams are described and representative problems are worked out.

Since analog-computer design is often intimately related to computer applications and problem-solving methods, a rather comprehensive review of analog-computer applications and methodology has been added. A very large number of special computer setups and trick circuits are presented in tables and grouped illustrations for convenient reference.

Sections 1 through 9 are concerned with analog computers, while Sections 10 through 21 cover digital computers.

Specifically, Section 1 introduces the *basic terminology* for analog computers, and Sections 2 and 3 describe *the design of electronic-analog-computer building blocks*, including late *electronic multiplier and resolver circuits*. Section 4 deals with the *design of analog-computer systems, problem checking, computer-laboratory organization*, and *computer maintenance*.

Section 5 reviews the significant applications of electronic analog computers. *Control-system design, flight simulation, partial system tests*, and *process-control applications* are described; the section also contains information on *random-process studies, algebraic-equation solvers, linear programming*, and *solution of partial differential equations* with electronic analog computers. *Economic dispatch computers* are described as examples of special-purpose machines.

Section 6 introduces newer techniques, such as *dynamic-storage computation, repetitive computer techniques for statistical problems*, and *combined* *analog-digital computation.* A special part deals with the use of *analog computers as control-system components.* Section 7 is entirely devoted to *solid-state* (transistor) *analog-computer components* and describes many new solid-state circuits.

Sections 8 and 9 deal entirely with important analog techniques less familiar to many engineers, viz., *network-type analogies for fields, structures,* and *power systems,* and with *mechanical, electromechanical, hydrodynamic,* and *heat-transfer computing elements.*

Section 10 presents the details of *components* used in digital computers, with particular emphasis on *semiconductor diodes* and *transistors.* Section 11 deals with *cathode* and *emitter followers, signal modifying circuits,* and *amplifiers. Ferromagnetic shift registers, magnetic drum* and *magnetic tape systems,* and *magnetic core memories* are discussed in detail in Section 12.

Section 13 describes *logical circuits,* including AND, OR, and other *switching circuits.* Section 14 presents material on *error-detecting* and *error-correcting codes* and on the use of *Boolean algebra* in switching-circuit design. *Arithmetic circuits* are discussed in Section 15. Section 16 on digital-computer-system design considers *plugboard control* as well as *stored-program control,* and compares *synchronous* and *asynchronous* aspects of design. *Programming* and *coding* and a description of the algorithmic language *ALGOL* is given in Section 17. Section 18 on input and output discusses *paper-tape* and *punched-card devices, symbol-display devices, analog-conversion devices,* and *plotters.*

Section 19 discusses various *special-purpose computers* including the *digital differential analyzer.* Section 20 presents material on *general-purpose computers,* and Section 21 discusses *scientific* and *engineering applications, data-processing applications, management applications, simulation,* and *process control* by use of computers.

This handbook is a result of interest originally expressed by the Professional Group on Electronic Computers of the Institute of Radio Engineers. Jean Felker of Bell Telephone Laboratories was helpful in the initial arrangements.

It has been the editors' privilege to work with a really outstanding group of contributors, including both computer design experts and applications specialists. In addition to the contributors proper, the editors are very grateful to many individuals and organizations for contributing engineering data, circuits, and general information. The following persons deserve particular mention:

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# CONTENTS

# ANALOG COMPUTERS

# *Section* 1

# INTRODUCTION AND BLOCK-DIAGRAM NOTATION

By

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PART 1: INTRODUCTION



PART 2: BLOCK-DIAGRAM SYMBOLS FOR ELECTRONIC ANALOG COMPUTERS



## PART 1: INTRODUCTION

**1.1.1. Analog Computers.** In the most general sense, an *analog computer* is any physical system which establishes definite prescribed relations between continuously variable physical quantities. Definite relationships are necessarily stated in terms of mathematical relations. It follows that every analog computer, whether used for problem solving or for direct control, implements a requirement for at least approximate physical realization of a mathematical model, which can be understood and manipulated with relative ease.

Most analog-computing systems are combinations of *analog-computing elements* which establish elementary mathematical relations (e.g., addition, multiplication, integration). Analog computers can be classified according to the nature of the physical quantities used to represent mathematical variables and according to the computing elements used. Slide rules, network calculators, and Bush differential analyzers are, respectively, examples of mechanical, electrical, and electromechanical analog computers.

Analog computers used to solve problems represent each problem variable by a corresponding physical quantity (voltage, shaft displacement) on a convenient scale (*problem scaling,* Sec. 5.1). These *machine variables* are made to obey mathematical relations corresponding to those of the given problem. In particular, a *differential analyzer* starts a set of machine variables from specified initial values and employs *analog integrators* (Secs. 2.2 and 8.1) together with other computing elements to enforce a system of prescribed ordinary differential equations; records of the machine variables constitute solutions of the differential equations (Sec. 5.1). Physical time serves, ultimately, as the independent variable in most such machines. The dependen variables are most frequently represented by instantaneous values of voltages (*electronic differential analyzer, d-c analog computer*) or shaft displacements (*electromechanical differential analyzer,* Sec. 8.1).

An analog *equation solver* determines solutions $x, y, \ldots$ of a system of simultaneous equations $f_1(x,y, \ldots) = 0$, $f_2(x,y, \ldots) = 0, \ldots$ either by rapid trial-and-error computations of an "error function" like $f_1^2(x,y, \ldots) + f_2^2(x,y, \ldots) + \ldots$ until the desired combination of unknowns $x, y, \ldots$ is found, or the machine enforces a system of ordinary differential equations whose solutions converge to the desired unknowns $x, y, \ldots$ (Sec. 5.11). Analogous methods determine a set of unknown parameters $x, y, \ldots$ which *maximize* or *minimize* a given function $F(x,y, \ldots)$ (Sec. 5.11).

**1.1.2. An Appraisal of Analog Computers.** Unlike digital computers, most analog computers employ distinct computing elements for each mathematical operation required to solve a given problem (parallel operation).[1] Parallel operation is an essential reason for the *very high computing speeds* possible with d-c analog computers: most problems, regardless of complication, are solved within 2 minutes by "slow" d-c analog computers and within fractions of a second by repetitive machines (Sec. 6.2). On the other hand, parallel operation imposes *practical limits on the complexity of problems* which can be solved on analog computers. Also, the cost of analog computers with component accuracies better than 0.1 per cent rises sharply for even small improvements in accuracy. The use of digital computers is thus indicated for computations requiring high accuracy.

The relatively low cost of some d-c analog computers is of interest in certain applications. Practical and useful low-cost d-c analog differential-equation solvers have been constructed and are particularly well suited for instruction purposes and for industrial organizations wishing to provide individual engineers with desk-top analog computers (Sec. 4.5). In the case of larger, more flexible, and more generally applicable d-c analog-computer installations, the gap between the costs of analog and digital computing equipment has closed; many research and development groups own d-c analog-computer installations whose cost easily rivals that of their large digital computers.

What are the concrete reasons for such investments in comparatively inaccurate computing equipment? In the writer's opinion, analog computers should *not* be regarded as low-cost substitutes for digital computers. Analog computers can only rarely compete with digital machines in the mass production of numerical data required as *end products* of scientific or engineering analyses. In such applications, the high computing speeds of analog equipment are often outweighed by the more advanced automatic programming of digital computers, even if only slide-rule accuracy is required.

The really important contributions of analog computers to modern research and development techniques go beyond mere numerical computation. In many applications, the analog approach functions as a direct aid to a research worker's or engineer's thinking process: an analog-computer setup serves as a *model* which helps to bridge the gap between mathematical symbolism and physical reality. Simple patchcord connections and potentiometer settings enable the system designer to create a scale model which permits convenient investigation of the performance and interaction of components and systems. New ideas can be tested at once: blocks of computing elements represent system components and are readily replaced or assembled into different system designs. Design parameters may be changed instantly by corresponding resistance changes, and high computing speeds permit optimization of system performance by successive parameter adjustments.[1]