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The ENCYCLOPEDIA of ELECTRONICS

Edited by

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PREFACE

Users of the Encyclopedia will appreciate the difficulties inherent in dividing all of electronics into some 500 topics and securing an authoritative article on each, the whole to fit into a single volume directed primarily at professional readers. Various groupings suggested themselves. The scheme finally adopted, of single entries alphabetically arranged (which had been so successfully employed in the Clark-Hawley *Encyclopedia of Chemistry* published by Reinhold previously), proved to be the most suitable. The bulk of the material is arranged in this manner, but there are a few entries (e.g., Antennas, Magnetism, Navigation and Navigational Systems, Network Theory, Propagation) in which it was manifestly preferable to group articles written by several contributors under a single heading. Other hints to readers appear further below.

Editorial space was a severe limitation: massive textbooks have been written on many a subject covered here in two pages (in not a few instances, by the same authors). The motto for the entire enterprise was inadvertently supplied by a literate electronics engineer—a type, the editor was relieved to find as contributions began to pour in, far more prevalent than his years of reading college examinations would have given him any right to expect; this contributor protested the space limitations imposed on his entry but ended by accepting the challenge of compressing his material with good grace, citing Goethe to the effect that “*in der Beschränkung zeigt sich erst der Meister*” (“under restraint the Master first shows plain”). Goethe’s sonnet, intended above all as an epigrammatic appeal to the artist to keep himself in check, surely has much broader implications, extending even to the exacting task of the technical encyclopedist.

The editor wishes to acknowledge the conscientious (and eminently successful) efforts of the contributors to work within these limitations. Authors were drawn from several countries and represent universities, industrial and government laboratories, and private concerns. Several organizations supplied a number of contributors, sometimes with one of them acting as a volunteer coordinator. The campuses of the editor’s own university and of nearby Stanford University provided the largest contingents, but particular thanks are also due to D. B. Harris of the Stanford Research Institute and H. P. McCartney of the Burroughs Laboratories (now with IBM) for coordinating the contributions of the sizable groups of authors at their respective institutions. Finally, the editor gratefully acknowledges the help of G. G. Hawley, Executive Editor of the Reinhold Book Division, who conceived the idea of publishing a series of technical encyclopedias; if the present volume is a worthy addition to the series, some of the credit should go to him for his encouragement, his unfailing courtesy, and his wise counsel and guidance at every point of the publication process.

Berkeley, California, 1962

CHARLES SUSSKIND

PLAN OF THE BOOK

Entries are arranged alphabetically. Further cross-headings have been added to aid in the location of the appropriate articles, but not simple inversions: it is assumed that a reader who cannot find an entry on, say, Linear Systems will be willing to look also for Systems (Linear). (In particular, the adjective *electronic* invariably appears second in main headings.) Each entry is followed by a list of other articles in the book that bear on allied topics. Additional in-text references to other articles are frequently made by a parenthetical *q. v.* (*quod vide*, "which see"). As a final aid, a list of all the entries, arranged according to an approximate subject grouping, is as follows:

1. **ANTENNAS, PROPAGATION, and RADIATION**
 - Antennas
 - General Considerations
 - Antenna Arrays
 - End-Fire Antennas
 - Frequency-Independent Antennas
 - Horn Antennas
 - Lenses
 - Reflector Antennas
 - Electronically Scanned Antennas
 - Slotted-Guide Antennas
 - Special Types
 - Extraterrestrial Radio Sources
 - Propagation
 - General Considerations
 - Ionospheric Propagation
 - Tropospheric Propagation
 - Ground-Wave Propagation
 - Propagation Through Conducting Media
 - VLF Propagation
 - Radio Effects of Aurorae
 - Radar Astronomy
 - Radiation (Terrestrial)
 - Whistlers
 - Radiometeorology
 - Radomes
 - Satellite Communications
2. **BIOELECTRONICS**
 - Bionics
 - Electric Shock
 - Hearing Aids
 - Human Engineering
 - Larynx (Electronic)
 - Medical Electronics
 - Neuristor
 - Neuron
 - Radiation Hazards (Nonionizing Radiation)
3. **CIRCUITS and NETWORKS**
 - Amplifiers
 - AC Amplifiers
 - DC Amplifiers
 - Feedback Amplifiers
 - Pulse Amplifiers
 - Counter and Scaler Circuits
 - Coupled Circuits
 - Equivalent Circuits
 - Filters
 - Network Synthesis
 - Approximation
 - Realization
 - Network Theory
 - Generalized Equations and Topological Analysis
 - Mesh-Node Analysis
 - Time-Domain Analysis
 - Two-Port Networks
 - Linearity
 - Reciprocity
 - Nonlinear Circuits
 - Oscillators
 - Harmonic Oscillators
 - Relaxation Oscillators
 - Sequential Circuits
 - Switching Circuits
4. **COMMUNICATION THEORY and MATHEMATICAL TECHNIQUES** (*see also* Control, Modulation, Transmission)
 - Boolean Algebra and Symbolic Logic
 - Channel Capacity
 - Complex Notation
 - Congestion and Waiting Systems
 - Decision and Game Theory
 - Distribution Functions
 - Fourier Analysis
 - Fourier Integrals and Their Applications
 - Information Theory
 - Laplace and Fourier Transforms
 - Linear Programming
 - Markov Processes
 - Matrix Algebra
 - Minimal-Time Problems
 - Monte Carlo Method
 - Phase-Space Representation

- Probability
- Random Processes
- Sampling Theorem
- Statistical Communication Theory
- Stress Tensor
- Vector Algebra
- 5. **COMPONENTS**
 - Attenuators and Isolators
 - Autotransformers
 - Batteries
 - Dry Batteries
 - Rechargeable Batteries
 - Capacitors
 - Circuit Breakers
 - Circulators
 - Coils
 - Connectors
 - Contacts
 - Fuses
 - Magnetic Amplifiers
 - Potentiometers
 - Relays
 - Resistors
 - Carbon Composition Resistors
 - Film Resistors
 - Wirewound Resistors
 - Rheostats
 - Servo Components
 - Switches
 - Transducers
 - Transformers
- 6. **COMPUTERS**
 - Analog Computers
 - Character Recognition
 - Coding and Coding Circuits
 - Computer Applications
 - Computer Logic
 - Computer Printout and Reading
 - Computer Programming
 - Data Processing
 - Digital Computers
 - Logic Circuits
 - Phonetic Typewriting
 - Storage
 - General Considerations
 - Magnetic Storage
 - Translation by Machine
- 7. **CONTROL AND SYSTEM THEORY** (*see also* Communication Theory)
 - Automation
 - Cybernetics
 - Feedback Systems
 - Missile Guidance
 - Randomly Varying Systems
 - Sampled-Data Systems
 - Satellite Electronics
 - Signal-Flow Graph
 - System Identification
 - Systems (Linear)
 - Stability Criteria
 - Systems (Nonlinear)
 - Adaptive Systems
 - Maximum-Effort Systems
 - Relay Systems
 - Undesirable Nonlinearities
 - Systems (Time-Varying)
 - Telemetry
- 8. **ELECTROACOUSTICS**
 - Acoustics
 - Earphones
 - Electroacoustics
 - Feedback Elimination
 - Artificial Reverberation
 - Loudspeakers and Microphones
 - Musical Instruments (Electric)
 - Sound Recording
 - Stereophonics
 - Ultrasonics
 - Underwater Sound
 - Visible Speech
 - Vocoder
- 9. **HISTORY OF ELECTRONICS**
 - Armstrong
 - Baird
 - Barkhausen
 - Braun
 - Crookes
 - De Forest
 - Edison
 - Fleming
 - Hansen
 - Heaviside
 - Hertz
 - Historical Background of Electronics
 - Langmuir
 - Lodge
 - Lorentz
 - Marconi
 - Meissner
 - Popov
 - Poulsen
 - Pupin
 - Steinmetz
 - Tesla
 - Thomson, J. J.
 - Watson-Watt
 - Zworykin
- 10. **INDUSTRY and MANUFACTURING**
 - Automobile Traffic Control
 - Clean Rooms
 - Cooking (Electronic)
 - Electrochemistry
 - Electrodeposition
 - Electroforming
 - Electron-Tube Manufacture
 - Electrostatic Precipitation

- Electrostatic Printing
- Environmental Testing
- Facsimile
- Farming (Electronic)
- Geophysical Prospecting
- Heating (Electronic)
- Integrated Circuits and Devices
- Ion Propulsion
- Machining (Electronic)
- Microcircuitry
- Miniaturization
- Modular Construction
- Packaging
- Plasma Propulsion
- Printed Circuits
- Refining (Electronic)
- Reliability and Quality Control
- Safety
- Semiconductor Manufacture
- Vacuum Techniques
 - Mechanical Pumps
 - Diffusion Pumps
 - Getter-Ion Pumps
- Welding
- Zone Melting
- 11. INSTRUMENTATION and MEASUREMENT**
 - Analyzers
 - Waveform Analyzers
 - Spectrum Analyzers
 - Atomic Clocks
 - Bolometers
 - Bridges
 - Digital Instrumentation
 - Electroscope and Electrometer
 - Errors in Measurement
 - Frequency Measurement
 - Frequency Multipliers
 - Frequency Standards
 - Impedance Measurements
 - Indicating Instruments
 - Integrating Instruments
 - Interferometer Method (Optical)
 - Ionization Counters
 - Magnetometer
 - Mass Spectrometry
 - Microwave Measurements
 - Microwave Spectroscopy
 - Oscilloscopes
 - Pyrometers
 - Radiation Measurements (Nonionizing Radiation)
 - Refractometers
 - Resonators and Wavemeters
 - Scintillation Counters
 - Smith Chart
 - Spectroscopy (Light and Infrared)
 - Standards
- Standing-Wave Ratio
- Temperature Scales
- Thermal Detectors
- Thermistors
- Thermocouples
- Vacuum Gages
- 12. MATERIALS and CHEMISTRY**
 - Ceramics
 - Chemical Elements
 - Epoxy Molding Compounds
 - Ferrites
 - Microwave Applications
 - Ferroelectrics
 - Ferromagnetic Crystals
 - Gases
 - Glass
 - Isotopes
 - Magnetic Cores
 - Magnetic Tape
 - Materials Used in Tube Technology
 - Permanent Magnets
 - Semiconductors
 - Solders and Brazing Compounds
 - Wire (Multiconductor)
- 13. MODULATION and NOISE**
 - Bandwidth Reduction
 - Brownian Motion
 - Class A, AB, B, C, Operation
 - Compression and Expansion
 - Frequency Conversion and Serrodyne
 - Interference
 - Modulation and Demodulation
 - Noise Characterization and Measurement
 - Noise Generation
 - Noise in Electron Beams
 - Noise in Semiconductors
 - Noise in Vacuum Tubes
 - Noise (Statistical Theory)
 - Noise (Thermal)
 - Pulse-Code Modulation (PCM)
 - Pulse Generation
 - Low-Power Pulses
 - High-Power Pulses
 - Signal Detection
- 14. NAVIGATION**
 - Air-Traffic Control
 - Altimeters (Electronic)
 - Automatic Pilot
 - Doppler Navigation
 - Inertial Guidance and Gyroscope
 - Integrated Instrumentation
 - Navigation and Navigational Systems
 - General
 - Air Navigation
 - Marine Navigation
 - Direction-Finding Systems
 - Radio Beacons

- Radar-Beacon Systems and Distance-Measuring Equipments (DME)
- Hyperbolic Navigation and Surveying Systems
- Flight Directors
- Doppler Radar
- Radar
- Radar Displays
- Pictorial Displays
- Sonar
- 15. **PHYSICAL ELECTRONICS**
 - Cathodoluminescence
 - Electroluminescence
 - Field Emission
 - Fluorescence
 - Photocell
 - Photoconductivity
 - Photoelectric Emission
 - Secondary Emission
 - Thermionic Emission
 - Work Function
- 16. **PHYSICS**
 - (a) **Classical Physics; Magnetism**
 - Antiferromagnetism
 - Conduction
 - Electrical
 - Thermal
 - Contact Potential
 - Diamagnetism
 - Dielectric Theory
 - Dipole Moment
 - Electric Discharge
 - Electromagnetic Theory
 - Transmission-Line Formulation
 - Energy
 - Faraday Effect
 - Ferrimagnetism
 - Ferroelectricity
 - Ferromagnetism
 - Hall Effect
 - Kerr Effect
 - Magnetism
 - Eddy Currents
 - Generation of Very High Fields
 - Permanent Magnetism
 - Shielding
 - Thin Films
 - Magnetostriction
 - Optics
 - Geometrical Optics
 - Physical Optics
 - Paramagnetism
 - Piezoelectricity and Pyroelectricity
 - Polar Molecules
 - Refractive Index
 - Skin Effect
 - Static (Tribo-) Electricity
 - Thermal Radiation
 - (b) **Modern Physics**
 - Alpha Particles
 - Antiparticles
 - Atoms
 - Cosmic Rays
 - Cryogenics
 - Electron Diffraction and Scattering
 - Electrons
 - Gamma Rays
 - Ion Scattering
 - Ionization
 - Ions
 - Mesons
 - Molecules
 - Mössbauer Effect
 - Neutrinos
 - Neutron Diffraction
 - Nucleonics
 - Photovoltaic Effect
 - Positrons
 - Protons
 - Radiation (Ionizing)
 - Basic Interactions
 - Damage to Materials
 - Measurements, Dosimetry, Hazards
 - Processing of Materials
 - Sterilization of Food
 - Radioactivity
 - Relativity Theory
 - Stark Effect
 - Statistical Mechanics
 - Superconductivity
 - Zeeman Effect
 - (c) **Energy Conversion; High-Energy Physics**
 - Accelerators
 - Alternating-Gradient Focusing
 - Betatron and Cyclotron
 - Bremsstrahlung
 - Cerenkov Radiation
 - Cockcroft-Walton Accelerator
 - Cosmotron
 - Energy Conversion
 - Photoelectric
 - Thermoelectric
 - Thermionic
 - Fission
 - Fusion
 - Linear Accelerators
 - Hansen Linear Accelerator
 - Ion Linear Accelerator
 - Magnetohydrodynamics (MHD)
 - Microtron
 - Plasma
 - High-Temperature Plasmas
 - Reactors
 - Synchrotron and Bevatron