ELECTRONICS — from Theory into Practice

SECOND EDITION

by

J. E. FISHER
Cranfield Institute of Technology

and

H. B. GATLAND
Auckland University

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（内部交流）

PERGAMON PRESS

OXFORD · NEW YORK · TORONTO

SYDNEY · PARIS · FRANKFURT

U.K.	Pergamon Press Ltd., Headington Hill Hall, Oxford OX3 0BW, England
U.S.A.	Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford, New York 10523, U.S.A.
CANADA	Pergamon of Canada Ltd., Box 9600, Don Mills M3C 2T9, Ontario, Canada
AUSTRALIA	Pergamon Press (Aust.) Pty. Ltd., 19a Boundary Street, Rushcutters Bay, N.S.W. 2011, Australia
FRANCE	Pergamon Press SARL, 24 rue des Ecoles, 75240 Paris, Cedex 05, France
WEST GERMANY	Pergamon Press GmbH, 6242 Kronberg/Taunus, Pferdstrasse 1, Frankfurt-am-Main, West Germany

First edition 1966

Second edition 1976

Library of Congress Cataloging in Publication Data

Fisher, Jack Edward.
Electronics from theory into practice.

(Applied electricity & electronics division)
(Pergamon international library)
Bibliography: p.
Includes index.
1. Electronics. I. Gatland, Howard Bruce, joint author. II. Title.
TK7815.F58 1976 621.381 75-44016
ISBN 0-08-019857-0 Vols 1 & 2
0 08 019855 4 Vol 1
0 08 019856 2 Vol 2

nted in Great Britain by A. Wheaton & Co., Exeter

Preface

To all students of electronics there comes a time when a specification is presented to them, and they are expected to turn their theoretical knowledge into practice. Many find this a difficult step to take. The aim of this book is, where possible, to formalize design procedures covering a wide range of electronic circuitry, and thus to bridge the gap between theory and practice. It is also hoped that the book will be of use to practising engineers, particularly those trained in other disciplines who, due to the widespread application of industrial control and automation, are obliged to undertake a certain amount of electronic design.

The first two chapters introduce the reader to the bipolar and field effect transistor, the unijunction transistor and the silicon controlled rectifier, and show how data sheets, provided by the manufacturer, are used in design calculations. Also included are a number of devices which, by belonging to the realm of microwaves, are outside the scope of this book. This has been done for reference purposes. The third chapter traces the development of integrated circuits and gives details of the characteristics of such which are currently in use. It ends with an introduction to charge-coupled devices. There follows seven chapters devoted to specific subjects. Each of these contain a brief treatment of theory limited to the extraction of necessary design relationships. Design procedures are established, followed by worked design examples to meet given specifications. The main text is concluded with a chapter on general electronic engineering practice.

Since the publication of the first edition of this book there have been dramatic advances in electronic technology so that the thermionic valve has, except in highly specialized applications, been eliminated. Nevertheless, the authors feel that some place should be retained in the literature for these devices, if only for reference purposes. Accordingly, an appendix is devoted to this topic. Two other appendices give simple introductions to the use of the Laplace Transform for the solution of engineering problems, and to Network Analysis, in explanation of methods which are occasionally employed in the text of this book.

Cranfield J. E. FISHER

Design Examples

D.E.1.1. Transistor circuit to provide a peak output signal of 3 V without distortion.

D.E.2.1. Thyristor circuit to control the power supplied from a 240-V r.m.s., 50-Hz source to an 80-Ω load, in an ambient temperature of 45°C. The conduction angle to be variable between 30° and 120°.

D.E.2.2. Unijunction transistor astable multivibrator, having a frequency of 100 Hz, operating from a 20-V power supply.

D.E.4.1. Power amplifier to provide 2 W into a resistive load, with low distortion and a stability factor of 8.

D.E.4.2. Audio power amplifier providing 60 mW output.

D.E.4.3. Class B push–pull output stage to provide a peak power output of 1.25 W.

D.E.4.4. Amplifier stage with transfer resistance of 100 kΩ and bandwidth from 50 Hz to 20 kHz, to provide a peak output of 4 V.

D.E.4.5. Amplifier with voltage gain greater than 50,000, with signal inversion, over a frequency range of 100 Hz to 10 kHz and providing a peak output of 10 V.

D.E.4.6. Direct coupled amplifier with voltage gain greater than 5000 with signal inversion. Output resistance to be less than 1 kΩ with an output voltage swing of ± 5 V.

D.E.4.7. Longtail pair to provide a voltage gain greater than 40.

D.E.5.1. Single-tuned amplifier stage with gain of 100 at 200 kHz and having a 10-kHz bandwidth.

D.E.5.2. Tuned amplifier covering the range 540 to 1600 kHz, with constant selectivity.

D.E.5.3. Staggered-tuned amplifier, having a centre frequency of 50 MHz, a 6-MHz bandwidth, and an over-all gain of 60 dB.

D.E.5.4. Band-pass amplifier, having a centre frequency of 10 MHz and a bandwidth of 250 kHz, gain to be at least 2500.

D.E.5.5. Transistor i.f. amplifier to operate at a centre frequency of 470 kHz.

D.E.6.1. Parallel "T" band rejection filter with centre frequency of 1 kHz, and bandwidth variable from 1 Hz to 100 Hz.

D.E.6.2. Differentiator to provide an output of 10 V, for an input signal having a rate of change of 5 V/ms.

D.E.6.3. An electronic integrator having a time constant of 10^{-4} s. For an integration time of 1 s error is to be no greater than 1 per cent of the 10-V maximum output signal.

D.E.6.4. Active low-pass filter with 100 r/s bandwidth and a maximally flat characteristic.

D.E.6.5. Active second-order high-pass filter.

D.E.6.6. Second-order band-pass filter with 100 r/s centre frequency and a bandwidth of 10 r/s. Gain at the centre frequency to be 20.

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D.E.7.2. Stabilized 6.8-V voltage supply providing a load current of 15 mA ± 10 mA, derived from a 20-V source.

D.E.7.3. A 5-V supply for currents up to 1 A, from a nominal 12-V source.

D.E.7.4. Closed-loop stabilized power supply.

D.E.8.1. Tuned-drain oscillator to operate at 1 MHz.

D.E.8.2. Colpitts oscillator operating at 500 kHz, using a BC 108 transistor.

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D.E.8.4. Series resonant oscillator operating at 1 MHz.

D.E.9.1. Bistable multivibrator capable of operation up to 250 kHz.

D.E.9.2. Monostable multivibrator providing an output pulse of 5 μs duration.

D.E.9.3. Astable multivibrator with a PRF of 10 kHz.

D.E.9.4. Time base waveform generator, providing an output with 20 V amplitude, 10 ms duration and 10 ms recovery. The waveform is to have a linearity tolerance of 5 per cent.

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Publisher: Robert Maxwell, M.C.

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General Editor: P. HAMMOND

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CHAPTER 1

The Semiconductor

INTRODUCTION

A semiconductor material is one having a specific resistance intermediate between that of an insulator and a conductor, the value of which increases rapidly with rising temperature. Considering the atomic structure of such material, if sufficient energy is provided, by heating for instance, electrons will be released from their nuclei, each leaving behind it a hole. Under the influence of an electric field, an electric current will flow, which may be regarded as a movement of electrons in one direction and a movement of holes in the opposite direction. In the case of a pure or *intrinsic* semiconductor the numbers of holes and free electrons are always equal. The two materials which have been most commonly used are germanium and silicon, both of which come from chemical Group IV. Gallium arsenide, however, is a material which is now being used in ever increasing fields of application.

If a semiconductor is doped with an element from Group V, say arsenic, the equality of free electrons and holes will no longer exist, there being an excess of free electrons. An electric current through such a material will then consist mostly of a flow of electrons in one direction and relatively few holes moving in the opposite direction. In this case the electrons are called *majority carriers* and the holes, *minority carriers.* A semiconductor doped in this way is known as n-type material since the majority carriers possess negative charge.

A similar state of affairs will occur if the semiconductor is doped with an element such as indium from Group III. However, in this case an excess of holes will exist and these are the majority carriers. Since the majority carrier possesses positive charge such a material is known as p type. In the production of semiconductor devices, it is often required that the level of doping be controlled. The more heavily doped a material is, the lower is its resistivity. Heavily doped material is identified by the symbols n^+ and p^+.

1.1. The junction diode[1]

If a piece of semiconductor material is doped with *p*-type impurity at one end and *n*-type impurity at the other, then there will exist a junction between the two types. Some holes in the *p* region will diffuse into the *n* region leaving the *p* region slightly negative. Similarly, electrons from the *n* region will diffuse into the *p* region leaving the *n* region slightly positive. In a layer between the *n* and *p* regions, holes and electrons recombine and, since this layer is now depleted of free charge carriers, it is called the *depletion layer*. This layer acts as a potential barrier which opposes any further diffusion of charge, and the junction assumes a state of dynamic equilibrium. The condition is illustrated in Fig. 1.1a.

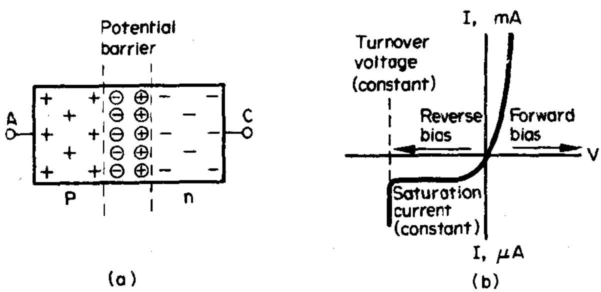

Fig. 1.1. (a) Semiconductor junction showing the potential barrier caused by the diffusion of charge carriers. Under these conditions a potential exists between *A* and *C*. (b) Characteristic curve of a semiconductor diode. Note the change in current scale as the curve passes through the origin.

If bias is applied to the terminals such that *A* is positive with respect to *C*, it has the effect of reducing the thickness of the depletion layer. The potential barrier is thus reduced and current will flow. This current increases exponentially with increasing voltage until the potential barrier is reduced to zero, when it is limited only by the resistance of the semiconductor material. If the bias is now reversed, the potential barrier is increased and the majority carrier is blocked. There is, however, a finite current which flows, called the *reverse saturation current*. As the reverse bias is increased this current remains constant until the turnover point is reached, when the current increases rapidly at constant voltage (Fig. 1.1b).