

# ELECTRONICS — from Theory into Practice

SECOND EDITION

by

J. E. FISHER

*Cranfield Institute of Technology*

and

H. B. GATLAND

*Auckland University*

# ELECTRONICS — from Theory into Practice

SECOND EDITION

by

**J. E. FISHER**

*Cranfield Institute of Technology*

and

**H. B. GATLAND**

*Auckland University*

(内部交流)



**PERGAMON PRESS**

OXFORD · NEW YORK · TORONTO

SYDNEY · PARIS · FRANKFURT

**5505076**

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, Pferdstasse 1, Frankfurt-am-Main, West Germany

Copyright © 1976 Pergamon Press Ltd.

*All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means: electronic, electrostatic, magnetic tape, mechanical, photocopying, recording or otherwise, without permission in writing from the publishers*

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

22/12/20

Printed 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- $\Omega$  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 k $\Omega$  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 k $\Omega$  with an output voltage swing of  $\pm 5$  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.
- D.E.7.1. Nominal 100-V supply for a 25-mA load current, obtained from a 200-V source.
- D.E.7.2. Stabilized 6.8-V voltage supply providing a load current of  $15 \text{ mA} \pm 10 \text{ mA}$ , 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.
- D.E.8.3. Modified Wien Bridge oscillator covering a frequency range of 1 to 10 kHz.
- 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  $5 \mu\text{s}$  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.



73.6  
F524

**PERGAMON INTERNATIONAL LIBRARY**  
**of Science, Technology, Engineering and Social Studies**  
*The 1000-volume original paperback library in aid of education,  
industrial training and the enjoyment of leisure*

Publisher: Robert Maxwell, M.C.

**ELECTRONICS—**  
**from Theory into Practice**



**THE PERGAMON TEXTBOOK  
INSPECTION COPY SERVICE**

An inspection copy of any book published in the Pergamon International Library will gladly be sent to academic staff without obligation for their consideration for course adoption or recommendation. Copies may be retained for a period of 60 days from receipt and returned if not suitable. When a particular title is adopted or recommended for adoption for class use and the recommendation results in a sale of 12 or more copies, the inspection copy may be retained with our compliments. If after examination the lecturer decides that the book is not suitable for adoption but would like to retain it for his personal library, then a discount of 10% is allowed on the invoiced price. The Publishers will be pleased to receive suggestions for revised editions and new titles to be published in this important International Library.

# APPLIED ELECTRICITY AND ELECTRONICS DIVISION

*General Editor:* P. HAMMOND

---

## SOME OTHER BOOKS IN THIS SERIES

ABRAHAM, J. R. & PRIDHAM, G. J.  
Semiconductor Circuits: Theory, Design and Experiments

BADEN FULLER, A. J.  
Microwaves

BROOKES, A. M. P.  
Basic Instrumentation for Engineers and Physicists

CRANE, P. W.  
Electronics for Technicians

GATLAND, H. B.  
Electronic Engineering Applications of Two-port Networks

HAMMOND, P.  
Electromagnetism for Engineers

HARRIS, D. J. & ROBSON, P. N.  
The Physical Basis of Electronics

HOWSON, D. P.  
Mathematics for Electrical Circuit Analysis

PRIDHAM, G. J.  
Solid State Circuits

SPARKS, J. J.  
Junction Transistors

WHITFIELD, J. F.  
Electrical Installations Technology

The terms of our inspection copy service apply to all the above books. Full details of all books listed will gladly be sent upon request.

# Contents

Preface	xi
Design Examples	xiii
1. <i>The Semiconductor</i>	1
Introduction	1
1.1. The Junction Diode	2
1.2. Leakage Current	3
1.3. Diode Transient Response	4
1.4. Diode Logic	5
1.5. Functional Survey of Diode Types	6
1.6. RF and Microwave Diodes	10
1.7. The Junction Transistor	16
1.8. Fundamental Current Relationships	18
1.9. Elementary Considerations of Frequency Effects	19
1.10. Voltage Breakdown	21
1.11. Power Dissipation	22
1.12. Summary of Transistor Types	23
1.13. Static Characteristics of the Junction Transistor	25
1.14. Small Signal Representation	28
1.15. Transistor Biasing	31
1.16. Transistor Amplifier Characteristics	37
1.17. Examples	46
1.18. Summary of the Characteristics of Transistor Amplifiers in Terms of $h$ Parameters	49
2. SCR-UJT-FET	50
Introduction	50
2.1. The Silicon-controlled Rectifier	50
2.2. Switching Off	53
2.3. Switching Characteristics	55
2.4. Applications	57
2.5. Load Effects	61
2.6. Thyristor Ratings	63
2.7. Gate Characteristic	66
2.8. The Unijunction Transistor	70
2.9. The UJT for Thyristor Triggering	77
2.10. A Bipolar Transistor Analogy	81
2.11. Field Effect Transistors	81
2.12. FET Amplifier Characteristics	88

3.	<i>Integrated Circuits</i>	94
	Introduction	94
	3.1. Manufacturing Processes	94
	3.2. Bipolar Integrated Circuits	96
	3.3. Digital Logic Families	98
	3.4. Noise Immunity	106
	3.5. Summary of Bipolar Digital Circuits	108
	3.6. Linear Circuits	109
	3.7. MOS Integrated Circuits	110
	3.8. Complementary MOS	112
	3.9. Charge-coupled devices	114
4.	<i>Amplifiers</i>	120
	Introduction	120
	4.1. Power Amplifiers	120
	4.2. Audio Power Amplifier, Class A	125
	4.3. The Class B Push-pull Amplifier	128
	4.4. The Capacitively Coupled Amplifier	131
	4.5. High-frequency Performance	132
	4.6. High-frequency Response	137
	4.7. Asymptotic Approximation	139
	4.8. Low-frequency Performance of Capacitively Coupled Stages	140
	4.9. Tandem Stages	143
	4.10. Amplifier Time Response	151
	4.11. Zero Frequency Amplifiers	153
	4.12. The Direct-coupled Amplifier	154
	4.13. Drift in Transistor d.c. Amplifiers	159
	4.14. Integrated Circuit Amplifiers	165
	4.15. Operational Amplifier Characteristics	166
	4.16. Types and Applications	170
5.	<i>Tuned Amplifiers</i>	174
	Introduction	174
	5.1. The Parallel-tuned Circuit	174
	5.2. Single-tuned Circuit Amplifier	175
	5.3. Tunable RF Amplifier with Constant Selectivity	181
	5.4. Cascaded Single-tuned Amplifier	185
	5.5. Staggered-tuned Amplifiers	187
	5.6. Double-tuned Circuits	189
	5.7. Tuned Amplifiers using Bipolar Transistors	196
	5.8. Neutralization	198
	5.9. Integrated Circuits	208
6.	<i>Negative Feedback Amplifiers</i>	211
	6.1. Introduction	211
	6.2. Feedback Connections	213
	6.3. Examples of Series-Parallel Feedback Systems	221
	6.3.1. Emitter follower buffer amplifier	221
	6.3.2. Output stage for a direct-coupled amplifier	226
	6.3.3. Augmented emitter follower	233
	6.3.4. Field effect source follower	234

## CONTENTS

vii

6.3.5. Operational amplifier voltage follower	237
6.3.6. Applications of the voltage follower	241
6.3.7. The voltage follower using operational amplifiers	247
6.3.8. Capacitor-coupled voltage amplifier	251
6.3.9. Selective amplifier using series-parallel feedback	254
6.4. Applications of Parallel-Series Feedback	255
6.4.1. Common base amplifier	255
6.4.2. Transistor current amplifier	256
6.4.3. Operational amplifier current amplifiers	257
6.5. Examples of Parallel-Parallel Feedback	258
6.5.1. Performance of parallel-parallel voltage amplifier	260
6.5.2. Functional operations—integration	262
6.5.3. Difference integrator	268
6.5.4. Double integrator	270
6.5.5. Differentiation	271
6.6. Example of Series-Series Feedback	276
6.7. Instrumentation using Feedback Amplifiers	277
6.7.1. Millivoltmeter	277
6.7.2. Transducer amplifier	278
6.7.3. Difference amplifier	279
6.7.4. Bridge amplifier	281
6.7.5. High-input impedance difference amplifiers	281
6.8. Low-input Resistance Amplifier	283
6.9. Automatic Zeroing	287
6.10. Stabilization against Oscillation	293
6.11. Active Resistor-Capacitor Filters	294
6.11.1. First-order filters	294
6.11.2. Basic second-order filters	296
6.11.3. Resistance-capacitance form of second-order system	298
6.11.4. Active second-order filter	299
6.11.5. Higher-order filters	301
6.11.6. Multiple feedback band-pass filter	302
<i>Power Supplies</i>	305
Introduction	305
7.1. The Basic Rectifier	305
7.2. The Full-wave Rectifier	306
7.3. Effect of Load Capacitance	306
7.4. <i>L-C</i> Smoothing Filter	309
7.5. Choke Input Filter	309
7.6. Voltage Multipliers	312
7.7. Voltage Stabilization	313
7.8. Semiconductor Stabilizer Diodes	315
7.9. Emitter Follower as a Voltage Stabilizer	317
7.10. Closed-loop System	319
7.11. Current Limitation	323
7.12. Application of Operational Amplifiers as Voltage Regulators	324
7.13. Fully Integrated Regulators	325

8. <i>Oscillators</i>	326
Introduction	326
8.1. Sinusoidal Oscillators—Basic Considerations	326
8.2. Negative Resistance	328
8.3. Amplitude Stabilization	329
8.4. Survey of Feedback $L$ - $C$ Oscillators	331
8.5. The Tuned Drain Oscillator	333
8.6. Colpitts Oscillator using a Bipolar Transistor	337
8.7. Resistance-Capacitance Oscillators	341
8.8. Wien Bridge Oscillator	342
8.9. Closed-loop Level Control	345
8.10. Frequency Stability	347
8.11. The Series Resonant Oscillator	348
9. <i>Waveform Generators</i>	353
Introduction	353
9.1. Multivibrators—General Survey of the Three Types	354
9.2. Transistor Switching	355
9.3. Speed of Transistor Switching	358
9.4. Bistable Multivibrator	359
9.5. Triggering	362
9.6. Alternative Gating Methods	364
9.7. Emitter-coupled BMV	364
9.8. Symmetrical Trigger BMV	367
9.9. Complementary Bistable Networks	368
9.10. Integrated Circuit Bistables	369
9.11. Monostable Multivibrators	374
9.12. The Direct Coupled MMV	378
9.13. Asymmetrical MMV	380
9.14. Integrated Circuit MMV	380
9.15. Astable Multivibrators	382
9.16. Emitter-coupled AMV	385
9.17. Complementary AMV	386
9.18. Integrated Circuit AMV	387
9.19. Voltage-controlled AMV	388
9.20. Pulse Generators	390
9.21. Linear Sweep Generators	392
9.22. Use of a Constant-current Generator	393
9.23. Sawtooth Generator using Avalanche Switching	394
9.24. Miller Timebase Generator	397
9.25. Reduction of Recovery Time	400
9.26. Integrated Circuit Waveform Generator/VCO	401
10. <i>Digital Techniques</i>	403
Introduction	403
10.1. Interface Elements	404
10.2. Basic Combinational Logic Elements	405
10.3. Basic Identities for Logic Variables	407
10.4. Example—Data Handling	409
10.5. Exclusive OR	411

## CONTENTS

ix

10.6.	NAND Bistable	412
10.7.	Examples	413
10.8.	Clocked Bistable	418
10.9.	Delta Modulator	419
10.10.	Master-Slave <i>JK</i> Bistable	420
10.11.	Flip-flop Binary Counters	421
10.12.	Decoding	423
10.13.	Decade Counter	424
10.14.	Counter Applications	425
11.	<i>Some General Design Considerations</i>	432
11.1.	Resistors	432
11.2.	Resistor Types	435
11.3.	Capacitors	436
11.4.	Capacitor Types	438
11.5.	Practical Use of TTL Devices	440
11.6.	Screening	442
Appendix A.	Solutions of Simple Network Problems	447
Appendix B.	Application of the Laplace Transform	453
Appendix C.	Symbols used in this Book	457
Appendix D.	The Thermionic Valve	461
Bibliography		481
Index		483

## 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<sup>(1)</sup>

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.

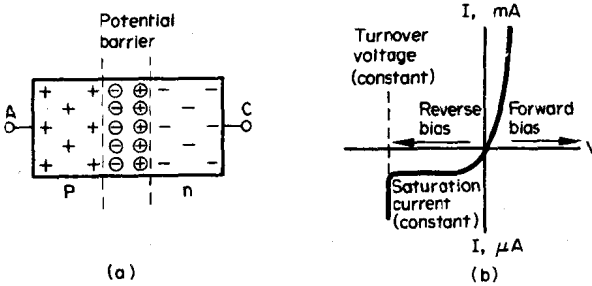


Fig. 1.1. (a) Semiconductor junction showing the potential barrier caused by the diffusion of charge carriers. Under these conditions a potential exists between A and C. (b) Characteristic curve of a semiconductor diode. Note the change in current scale as the curve passes through the origin.

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).