An Introduction to Electrical Instrumentation

Some other ELBS low-priced editions

Benson and Harrison	ELECTRIC-CIRCUIT THEORY	<i>Arnold</i>
Betts	SIGNAL PROCESSING, MODULATION AND NOISE	<i>Hodder & Stoughton</i>
Brown	TELECOMMUNICATIONS	<i>Chapman & Hall</i>
Bryan	CONTROL SYSTEMS FOR TECHNICIANS	<i>Hodder & Stoughton</i>
Burnside	ELECTROMAGNETIC DISTANCE MEASUREMENT	<i>Crosby Lockwood Staples</i>
Draper	ELECTRICAL MACHINES	<i>Longman</i>
Francis	ELECTRICAL INSTALLATION WORK	<i>Longman</i>
Fraser	TELECOMMUNICATIONS	<i>Macdonald</i>
Hughes	ELECTRICAL TECHNOLOGY	<i>Longman</i>
Jeffrey	MATHEMATICS FOR ENGINEERS AND SCIENTISTS	<i>Nelson</i>
John	INTRODUCTION TO ENGINEERING MATERIALS	<i>Macmillan</i>
Lewin	LOGICAL DESIGN OF SWITCHING CIRCUITS	<i>Nelson</i>
Morley and Hughes	PRINCIPLES OF ELECTRICITY	<i>Longman</i>
Paddock and Galvin	ELECTRICAL INSTALLATION TECHNOLOGY AND PRACTICE	<i>Hodder & Stoughton</i>
Ryder	STRENGTH OF MATERIALS	<i>Macmillan</i>
Scroggie	FOUNDATIONS OF WIRELESS AND ELECTRONICS	<i>Newnes-Butterworths</i>
Shepherd, Morton and Spence	HIGHER ELECTRICAL ENGINEERING	<i>Pitman</i>
Stephenson	MATHEMATICAL METHODS FOR SCIENCE STUDENTS	<i>Longman</i>
Uvarov, Chapman and Isaacs	A DICTIONARY OF SCIENCE	<i>Penguin</i>
Young and Griffiths	AUTOMOBILE ELECTRICAL EQUIPMENT	<i>Newnes-Butterworths</i>

An Introduction to Electrical Instrumentation

A guide to the use, selection, and limitations of electrical instruments and measuring systems

B. A. Gregory

*Senior Lecturer Specialising in Electrical Instrumentation, Department of
Electrical and Electronic Engineering, Brighton Polytechnic*

Macmillan Education

© B. A. Gregory 1973

All rights reserved. No part of this publication may be reproduced or transmitted, in any form or by any means, without permission.

First edition 1973

Reprinted 1975 (with corrections), 1977

ELBS edition first published 1977

Published by

THE MACMILLAN PRESS LTD

London and Basingstoke

Associated companies in Delhi Dublin

Hong Kong Johannesburg Lagos Melbourne

New York Singapore and Tokyo

ISBN 978-1-349-01882-6   ISBN 978-1-349-01880-2 (eBook)

DOI 10.1007/978-1-349-01880-2

The paperback edition of this book is sold subject to the condition that it shall not, by way of trade or otherwise, be lent, resold, hired out, or otherwise circulated without the publisher's prior consent in any form of binding or cover other than that in which it is published and without a similar condition including this condition being imposed on the subsequent purchaser.

Contents

PREFACE	ix
INTRODUCTION	1
1. ANALOG (POINTER) INSTRUMENTS	4
SECTION A. ELECTROMECHANICAL INSTRUMENTS	4
1.1 Moving coil instruments	6
1.2 Moving iron instruments	13
1.3 Electrodynanic instruments	15
1.4 Rectifier instruments	20
1.5 Thermocouple instruments	21
1.6 Electrostatic instruments	24
1.7 Energy meters	26
SECTION B. ELECTRONIC INSTRUMENTS	27
1.8 D.C. voltmeters	27
1.9 A.C. voltmeters	30
1.10 Null detectors	32
1.11 The 'Q' meter	34
1.12 Hall effect devices	39
1.13 Instrument comparisons	41
2. ANALOG (GRAPHICAL) INSTRUMENTS	43
2.1 Moving coil recorders	43
2.2 Potentiometric recorders	45
2.3 Event recorders	47
2.4 X–Y plotters	47
2.5 U.V. recorders	49
2.6 C.R.O.	62
2.7 Recorder Comparisons	75

3. COMPARISON METHODS	77
3.1 D.C. potentiometer	77
3.2 A.C. potentiometer	83
3.3 D.C. bridges	88
3.4 A.C. bridges	90
3.5 Simple transformer ratio bridges	94
3.6 Transformer double ratio bridges	100
3.7 Twin 'T' networks	107
3.8 Self balancing bridges	110
3.9 The unbalanced bridge	112
3.10 Comparisons	116
4. INTERFERENCE AND SCREENING	118
4.1 Component impurities	118
4.2 Component impurity effects on signals	128
4.3 Probes	135
4.4 Electrostatic interference	137
4.5 Electromagnetic interference	145
4.6 Multiple earths and earth loops	146
4.7 Drift and noise	148
5. SIGNAL CONDITIONING	150
5.1 Impedance effects	150
5.2 Voltage scaling	153
5.3 Current scaling	161
5.4 Attenuators	167
5.5 Operational amplifiers	171
5.6 Modulators	178
5.7 A—D Conversion	181
5.8 Comparisons	183
6. DIGITAL INSTRUMENTS	185
6.1 Display methods	185
6.2 Differential voltmeters	188
6.3 Counters	190
6.4 Digital clocks	196
6.5 Digital voltmeters	197
6.6 Comparisons	206
7. ERRORS IN MEASUREMENT	208
7.1 Standards	208
7.2 Error analysis	214
7.3 Calibration procedures	221

CONTENTS

vii

8. TRANSDUCERS	230
8.1 Resistance change transducers	234
8.2 Electromagnetic transducers	252
8.3 Reactance change transducers	254
8.4 Semiconductors	261
8.5 Piezoelectric transducers	264
8.6 Digital transducers	265
8.7 Thermoelectric transducers	267
8.8 Comparisons	273
9. DATA RECORDING AND ANALYSIS	275
9.1 Digital recording systems	275
9.2 Instrumentation tape recorders	279
9.3 Data analysers	290
9.4 Comparisons	294
10. INSTRUMENT SELECTION AND SPECIFICATIONS	297
10.1 Instrument selection	297
10.2 Specification analysis	300
10.3 Instrument comparisons	310
11. INSTRUMENTATION SYSTEMS	311
11.1 Open and closed loop systems	311
11.2 Bench instrumentation	312
11.3 Permanent installation (example)	313
APPENDIX I, UNITS, SYMBOLS AND CONVERSION FACTORS	317
(a) Multiples	317
(b) Units	318
APPENDIX II, DYNAMIC BEHAVIOUR OF MOVING COIL SYSTEMS	322
(a) Equation of motion; damping magnitude	322
(b) Deflection amplitude for a vibration galvanometer	325
(c) Amplitude and phase distortion of the trace from a u.v. recorder galvanometer	326
APPENDIX III, EQUATIONS TO DETERMINE THE COMPONENTS OF A RESISTIVE 'T' ATTENUATOR PAD	329
INDEX	331

Preface

Our ability to measure a quantity determines our knowledge of that quantity, and since the measuring of electrical quantities — or other parameters in terms of electrical quantities — is involved in an ever expanding circle of occupations of contemporary life, it is essential for the practising engineer to have a thorough knowledge of electrical instrumentation and measurement systems. This is especially so since in addition to his own requirements, he may be called upon to advise others who have no electrical knowledge at all.

This book is primarily intended to assist the student following an electrical or electronic engineering degree course to adopt a practical approach to his measurement problems. It will also be of use to the engineer or technician, who now finds himself involved with measurements in terms of volts, ampères, ohms, watts, etc., and faced with an ever increasing variety of instruments from a simple pointer instrument to a complex data logging and processing system. Thus, the object of this book is to help the engineer, or instrument user, to select the right form of instrument for an application, and then analyse the performance of the competitive instruments from the various manufacturers in order to obtain the optimum instrument performance for each measurement situation.

During that period of my career when I was employed in the research department of an industrial organisation I was, at times, appalled by the lack of ability exhibited by some graduates in selecting a suitable, let alone the best, instrument to perform quite basic measurements. Since entering the field of higher education to lecture in electrical measurements and instrumentation, my philosophy has been to instruct students to consider each measurement situation on its merits and then select the best instrument for that particular set of circumstances. Such an approach must of course include descriptions of types of instruments, and be presented so that the student understands the functioning and limitations of each instrument in order to be able to make the optimum selection. Hence the general theme of this book is to describe various types of instrument and then compare their characteristics. Unfortunately there is a limit to the number of instruments that can be described in a book of realistic size, and I have therefore omitted

specialised topics such as medical instrumentation, gas chromatography, radio frequency measurements, power system measurements, acoustic measurements, and high voltage instruments such as discharge detectors. Further, since some of the established methods are extensively covered elsewhere they are only summarised in this book; there is a list of references for further reading at the end of each chapter.

I would like to thank all the instrument manufacturers who have willingly assisted me in producing this volume by providing application notes, specifications, reproductions of articles, and also their obliging field engineers. I have endeavoured to acknowledge all sources of diagrams and other material, but I hope that any oversights will be excused. I should also like to thank my colleagues in the Department of Electrical and Electronic Engineering at Brighton Polytechnic for their assistance and encouragement; in particular my thanks are due to Dr B. H. Venning and Dr E. M. Freeman. Finally may I record my thanks and appreciation to my wife for her perseverance and courage in typing the manuscript.

B. A. Gregory