

Contents

<i>Preface</i>	xv
1 Basic concepts, units, and laws of circuit theory	
1.1 Properties of the electrical circuit	1
1.2 The lumped circuit model	3
1.3 Charge and current	5
1.4 Potential difference, energy and power	7
1.5 Ideal voltage and current sources	11
1.6 Kirchhoff's laws	13
1.6.1 The current law	13
1.6.2 Worked example on the current law	15
1.6.3 The voltage law	16
1.6.4 Worked example on the voltage law	17
1.7 Resistance	18
1.7.1 Ohm's law	18
1.7.2 Power dissipation in resistance	20
1.7.3 Resistances in combination	21
1.8 Capacitance	23
1.8.1 The voltage–current relationship for capacitance	23
1.8.2 Energy storage in capacitance	24
1.8.3 Capacitances in combination	24
1.9 Inductance	26
1.9.1 The voltage–current relationship for inductance	26
1.9.2 Energy storage in inductance	28
1.9.3 Inductances in combination	29
1.10 Inductively coupled circuits	30
1.10.1 Mutual inductance	31
1.10.2 The coefficient of coupling	33

viii **Contents**

1.10.3 The effective inductance of two series-connected coupled coils 35

1.11 Passive circuit components 36

1.12 Summary of basic circuit relations 37

1.13 Problems 37

2 Theorems and techniques of linear circuit analysis

2.1 Introduction 42

2.2 Voltage and current dividers 44

2.3 Mesh analysis 47

2.4 Worked example 50

2.5 The general mesh equations 52

2.6 The superposition and reciprocity theorems 55

2.6.1 Superposition 55

2.6.2 Reciprocity 58

2.7 Thévenin's theorem 58

2.8 Worked example 61

2.9 Network transiormations 64

2.9.1 The Thévenin–Norton transformation 64

2.9.2 The star–delta transformation 66

2.10 Nodal analysis 67

2.11 Comparison of mesh and nodal analysis 71

2.12 Worked example 73

2.13 Analysis of networks containing dependent sources 75

2.14 Worked example 78

2.15 Miscellaneous theorems and techniques 81

†2.15.1 The substitution and compensation theorems 81

2.15.2 Circuit reduction 84

†2.15.3 Ladder networks 87

†2.15.4 Ring mains 88

†2.15.5 Worked example 90

2.16 Summary 92

2.17 Problems 93

3 Alternating current circuits

3.1 Introduction 98

3.2 A.C. voltage–current relationships for the linear circuit elements 101

3.3 Representation of a.c. voltage and current by the complex exponential: Phasors 105

<i>Contents</i>	ix
3.4 Voltage–current relationships for the general network branch: Impedance	109
3.5 Phasor and impedance diagrams	113
3.6 Linear circuit theorems and techniques in a.c. circuit analysis	115
3.7 Worked example	119
3.8 Admittance	123
3.9 Frequency response: transfer function	126
3.10 A.C. bridges	132
3.10.1 The Schering bridge	133
3.10.2 The Wien bridge	135
3.11 Worked example	136
3.12 Inductively coupled circuits	141
3.13 Resonant circuits	146
3.13.1 Losses in inductors and capacitors	146
3.13.2 The series resonant circuit	151
3.13.3 The parallel resonant circuit	164
3.13.4 Worked example	166
†3.13.5 Definition of Q -factor in terms of stored energy	169
†3.13.6 Multiple resonance	169
†3.13.7 Inductively coupled resonant circuits	173
3.14 Summary	178
3.15 Problems	179
4 Power and transformers in single-phase circuits	
4.1 Introduction	187
4.2 Average power	187
4.3 Reactive power and apparent power	190
4.4 Power factor	194
4.5 Worked example	196
4.6 Complex power	198
4.7 The ideal transformer	199
4.8 Worked example	201
4.9 Single-phase power transformers	201
4.10 Worked example	208
4.11 Transformer tests	209
4.12 Voltage regulation	211
4.13 Conditions for maximum efficiency	213
4.14 The autotransformer	214
4.15 Maximum power transfer	217
†4.16 The transformer bridge	221

x	Contents	
4.17	Summary	224
4.18	Problems	225
5	Three-phase alternating current circuits	
5.1	Introduction	231
5.2	Advantages of three-phase systems	233
5.3	Three-phase circuits	233
5.3.1	Phase and line voltages	233
5.3.2	Balanced load	236
5.3.3	Worked example	237
5.3.4	Star and delta connections	239
5.3.5	Worked example	241
5.3.6	Use of Y- Δ transformation	244
5.3.7	Unbalanced load	245
5.3.8	Worked example	245
5.4	Power, reactive power and apparent power in balanced loads	248
5.5	Worked example: power factor correction	249
5.6	Three-phase power measurement	251
5.6.1	Alternating current meters	251
5.6.2	Methods of power measurement	253
5.6.3	Worked example	257
5.7	Transformers for three-phase systems	258
5.7.1	Applications	258
5.7.2	Equivalent circuit parameters	261
5.7.3	Worked example	261
†5.7.4	Harmonic currents	269
†5.8	Phase transformation	270
†5.9	Instantaneous power to balanced load	273
5.10	Summary	275
5.11	Problems	276
6	Transient and steady-state analysis	
6.1	Introduction	280
6.2	Qualitative analysis of the <i>RL</i> circuit	281
6.3	Mathematical analysis of the <i>RL</i> circuit	283
6.4	Time constant	286
6.5	Natural response of some basic series circuits	288
6.5.1	<i>RL</i> circuit	288
6.5.2	<i>RC</i> circuit	290
6.5.3	<i>RLC</i> circuit	291
6.5.4	<i>Q</i> -factor and logarithmic decrement	294

<i>Contents</i>	xi
6.6 Total response	295
6.6.1 <i>RL</i> circuit with sinusoidal driving voltage	296
6.6.2 <i>RC</i> circuit with constant voltage source	297
6.6.3 Worked example	297
6.6.4 <i>RLC</i> circuit with constant voltage source	299
6.6.5 <i>RLC</i> circuit with sinusoidal driving voltage	300
6.6.6 <i>RLC</i> circuit with sinusoidal driving voltage and $\omega_0 \simeq \omega_n$	301
6.7 The D-operator	303
6.7.1 The operators <i>D</i> and D^{-1}	304
6.7.2 Solution of differential equations by D-operator	305
6.7.3 D-impedance	309
6.7.4 Worked example	309
6.7.5 Thévenin's theorem in transient analysis	313
6.7.6 Differentiating and integrating circuits	316
6.8 The unit step and related driving functions	317
6.8.1 Step function	318
6.8.2 Impulse function	319
6.8.3 Worked example	323
6.8.4 Ramp and other singularity functions	325
6.8.5 Delayed functions	326
6.9 The Laplace transform	327
6.9.1 Definition of the Laplace transform	328
6.9.2 Laplace transforms of some functions of time	328
6.9.3 Partial fractions	334
6.9.4 Network analysis by Laplace transform	340
6.9.5 Worked example	345
6.9.6 Generalized impedance, network function and impulse response	347
6.9.7 Third and higher order networks	352
6.9.8 Worked example	355
6.9.9 Further Laplace transform theorems	357
6.10 Pole-zero methods	359
6.11 Worked example	372
6.12 Pulse and repeated driving functions	375
6.12.1 Pulse response of first order circuits	375
6.12.2 Delayed singularity functions: transforms of recurrent waveforms	380
6.12.3 Response by the Laplace transform	385
6.13 Worked example	389
†6.14 Convolution	392
6.14.1 Representation of a function by an impulse train	392

xii	Contents	
	6.14.2 The convolution integral	394
	6.14.3 The convolution theorem	401
	6.14.4 Worked example	403
6.15	Summary	405
6.16	Problems	408
7	Non-linear circuit analysis	
7.1	Introduction: linear and non-linear elements	418
7.2	Graphical analysis	419
7.3	Small-signal models	425
	7.3.1 Non-linear resistor model	425
	7.3.2 Transistor model	426
7.4	Piecewise-linear circuits	428
	7.4.1 Piecewise-linear approximation	428
	7.4.2 The ideal diode	429
	7.4.3 Combinations of resistances and ideal diodes	430
	7.4.4 The real diode	437
	7.4.5 The Zener diode	437
	7.4.6 Analysis of piecewise-linear circuits	440
	7.4.7 Worked example	440
	7.4.8 Synthesis of piecewise-linear circuits	441
	7.4.9 Worked example	443
7.5	Analytical methods	443
7.6	Rectifier circuits	448
	7.6.1 Half-wave rectifier	448
	7.6.2 Worked example	451
	7.6.3 Full-wave rectifier	453
7.7	Thyristor circuits	455
7.8	Fourier analysis of periodic waves	460
	7.8.1 Fourier expansion	460
	7.8.2 Worked example	463
	7.8.3 Odd and even functions	466
	7.8.4 Worked example	466
	7.8.5 Fourier expansion for rectifier output	469
	7.8.6 Expansion of functions of time	471
	7.8.7 Complex exponential form of Fourier series	471
	†7.8.8 Expansions for r.m.s. values and power	474
	7.8.9 Summary of formulae	479
†7.9	Filter circuits for rectifiers	481
	7.9.1 Inductor	482
	7.9.2 L-section	484

<i>Contents</i>	<i>xiii</i>
7.9.3 Capacitor	484
7.9.4 π -section	486
7.10 Summary	487
7.11 Problems	488
8 Two-port networks	
8.1 Introduction	501
8.2 Admittance, impedance and hybrid parameters	503
8.2.1 Admittance parameters	503
8.2.2 Impedance parameters	505
8.2.3 Hybrid and inverse hybrid parameters	506
8.3 Equivalent circuits and circuit models	507
8.4 Transmission, inverse transmission and <i>ABCD</i> parameters	511
8.5 Matrix notation	513
8.6 Worked example	514
8.7 Relationships between direct and inverse <i>ABCD</i> parameters	515
8.8 Parameter relationships for π - and T-networks	516
8.9 Worked example	517
8.10 Cascaded two-ports and chain matrices	518
8.11 Worked example	526
†8.12 Series and parallel connections of two-ports	527
†8.13 Worked example	528
†8.14 Iterative and image impedances	530
8.14.1 Iterative impedances	530
8.14.2 Image impedances	531
†8.15 Attenuators	533
†8.16 Worked example	534
†8.17 Insertion loss	536
†8.18 Worked example	536
8.19 Summary	537
8.20 Problems	538
Appendices	
A Units, symbols and abbreviations	542
B The general mesh equations and proofs of the network theorems	545
C Computer programs	549
D Laplace transform pairs	563
<i>Bibliography</i>	566
<i>Answers to problems</i>	567
<i>Index</i>	573