

SI UNITS USED



ELECTRICAL CIRCUIT THEORY AND TECHNOLOGY

JOHN BIRD
FIFTH EDITION

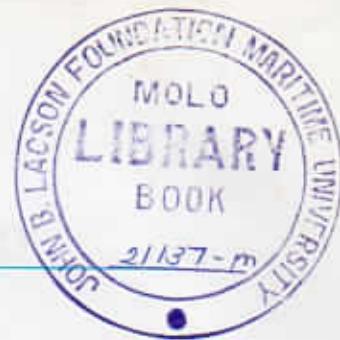
COMPANION
@
WEBSITE



R4
Q21.3/92
9/6/18
2014

3495

27891



Electrical Circuit Theory and Technology

Contents

Preface	xii		
Part 1 Basic electrical engineering principles	I		
1 Units associated with basic electrical quantities	3	4.5 E.m.f. and internal resistance of a cell	29
1.1 SI units	3	4.6 Primary cells	31
1.2 Charge	4	4.7 Secondary cells	32
1.3 Force	4	4.8 Cell capacity	33
1.4 Work	4	4.9 Safe disposal of batteries	35
1.5 Power	5	4.10 Fuel cells	35
1.6 Electrical potential and e.m.f.	6	4.11 Alternative and renewable energy sources	35
1.7 Resistance and conductance	6		
1.8 Electrical power and energy	6		
1.9 Summary of terms, units and their symbols	7		
2 An introduction to electric circuits	8	Revision Test 1	37
2.1 Standard symbols for electrical components	9		
2.2 Electric current and quantity of electricity	9	5 Series and parallel networks	38
2.3 Potential difference and resistance	10	5.1 Series circuits	39
2.4 Basic electrical measuring instruments	10	5.2 Potential divider	40
2.5 Linear and non-linear devices	11	5.3 Parallel networks	42
2.6 Ohm's law	11	5.4 Current division	44
2.7 Multiples and sub-multiples	11	5.5 Loading effect	47
2.8 Conductors and insulators	13	5.6 Potentiometers and rheostats	48
2.9 Electrical power and energy	13	5.7 Relative and absolute voltages	51
2.10 Main effects of electric current	16	5.8 Earth potential and short circuits	52
2.11 Fuses	16	5.9 Wiring lamps in series and in parallel	52
2.12 Insulation and the dangers of constant high current flow	17		
3 Resistance variation	18	6 Capacitors and capacitance	54
3.1 Resistor construction	19	6.1 Introduction to capacitors	55
3.2 Resistance and resistivity	19	6.2 Electrostatic field	55
3.3 Temperature coefficient of resistance	21	6.3 Electric field strength	56
3.4 Resistor colour coding and ohmic values	23	6.4 Capacitance	56
4 Batteries and alternative sources of energy	26	6.5 Capacitors	56
4.1 Introduction to batteries	27	6.6 Electric flux density	57
4.2 Some chemical effects of electricity	27	6.7 Permittivity	57
4.3 The simple cell	28	6.8 The parallel plate capacitor	59
4.4 Corrosion	29	6.9 Capacitors connected in parallel and series	60
		6.10 Dielectric strength	64
		6.11 Energy stored	65
		6.12 Practical types of capacitor	65
		6.13 Supercapacitors	67
		6.14 Discharging capacitors	68
		7 Magnetic circuits	69
		7.1 Introduction to magnetism and magnetic circuits	70
		7.2 Magnetic fields	70
		7.3 Magnetic flux and flux density	71
		7.4 Magnetomotive force and magnetic field strength	71
		7.5 Permeability and B - H curves	72
		7.6 Reluctance	73

7.7	Composite series magnetic circuits	75	11 Semiconductor diodes	128
7.8	Comparison between electrical and magnetic quantities	78	11.1 Types of material	129
7.9	Hysteresis and hysteresis loss	78	11.2 Semiconductor materials	129
Revision Test 2		80	11.3 Conduction in semiconductor materials	131
			11.4 The p-n junction	131
			11.5 Forward and reverse bias	132
			11.6 Semiconductor diodes	135
			11.7 Characteristics and maximum ratings	136
8 Electromagnetism		81	11.8 Rectification	136
8.1	Magnetic field due to an electric current	82	11.9 Zener diodes	136
8.2	Electromagnets	83	11.10 Silicon controlled rectifiers	138
8.3	Force on a current-carrying conductor	85	11.11 Light emitting diodes	138
8.4	Principle of operation of a simple d.c. motor	88	11.12 Varactor diodes	139
8.5	Principle of operation of a moving-coil instrument	89	11.13 Schottky diodes	139
8.6	Force on a charge	89		
9 Electromagnetic induction		91	12 Transistors	141
9.1	Introduction to electromagnetic induction	92	12.1 Transistor classification	142
9.2	Laws of electromagnetic induction	92	12.2 Bipolar junction transistors (BJTs)	142
9.3	Rotation of a loop in a magnetic field	95	12.3 Transistor action	143
9.4	Inductance	96	12.4 Leakage current	144
9.5	Inductors	97	12.5 Bias and current flow	145
9.6	Energy stored	98	12.6 Transistor operating configurations	145
9.7	Inductance of a coil	99	12.7 Bipolar transistor characteristics	145
9.8	Mutual inductance	100	12.8 Transistor parameters	147
10 Electrical measuring instruments and measurements		103	12.9 Current gain	148
10.1	Introduction	104	12.10 Typical BJT characteristics and maximum ratings	149
10.2	Analogue instruments	104	12.11 Field effect transistors	150
10.3	Moving-iron instrument	104	12.12 Field effect transistor characteristics	150
10.4	The moving-coil rectifier instrument	105	12.13 Typical FET characteristics and maximum ratings	152
10.5	Comparison of moving-coil, moving-iron and moving-coil rectifier instruments	105	12.14 Transistor amplifiers	152
10.6	Shunts and multipliers	106	12.15 Load lines	155
10.7	Electronic instruments	107		
10.8	The ohmmeter	108	Revision Test 3	159
10.9	Multimeters	108		
10.10	Wattmeters	108	Main formulae for Part 1 Basic electrical and electronic principles	161
10.11	Instrument 'loading' effect	109		
10.12	The oscilloscope	111		
10.13	Virtual test and measuring instruments	116	Part 2 Electrical principles and technology	163
10.14	Virtual digital storage oscilloscopes	116		
10.15	Waveform harmonics	120	13 D.c. circuit theory	165
10.16	Logarithmic ratios	120	13.1 Introduction	165
10.17	Null method of measurement	123	13.2 Kirchhoff's laws	166
10.18	Wheatstone bridge	123	13.3 The superposition theorem	169
10.19	D.c. potentiometer	123	13.4 General d.c. circuit theory	172
10.20	A.c. bridges	124	13.5 Thévenin's theorem	174
10.21	Measurement errors	125	13.6 Constant-current source	178

14 Alternating voltages and currents	187	18.3 Op amp inverting amplifier	256
14.1 Introduction	188	18.4 Op amp non-inverting amplifier	258
14.2 The a.c. generator	188	18.5 Op amp voltage-follower	259
14.3 Waveforms	189	18.6 Op amp summing amplifier	259
14.4 A.c. values	190	18.7 Op amp voltage comparator	260
14.5 Electrical safety – insulation and fuses	193	18.8 Op amp integrator	261
14.6 The equation of a sinusoidal waveform	193	18.9 Op amp differential amplifier	262
14.7 Combination of waveforms	196	18.10 Digital to analogue (D/A) conversion	264
14.8 Rectification	199	18.11 Analogue to digital (A/D) conversion	264
14.9 Smoothing of the rectified output waveform	200		
Revision Test 4	202	Revision Test 5	266
15 Single-phase series a.c. circuits	203	19 Three-phase systems	267
15.1 Purely resistive a.c. circuit	204	19.1 Introduction	268
15.2 Purely inductive a.c. circuit	204	19.2 Three-phase supply	268
15.3 Purely capacitive a.c. circuit	205	19.3 Star connection	268
15.4 $R-L$ series a.c. circuit	206	19.4 Delta connection	271
15.5 $R-C$ series a.c. circuit	209	19.5 Power in three-phase systems	273
15.6 $R-L-C$ series a.c. circuit	211	19.6 Measurement of power in three-phase systems	274
15.7 Series resonance	214	19.7 Comparison of star and delta connections	279
15.8 Q-factor	215	19.8 Advantages of three-phase systems	279
15.9 Bandwidth and selectivity	217		
15.10 Power in a.c. circuits	217		
15.11 Power triangle and power factor	219		
16 Single-phase parallel a.c. circuits	221	20 Transformers	280
16.1 Introduction	222	20.1 Introduction	281
16.2 $R-L$ parallel a.c. circuit	222	20.2 Transformer principle of operation	281
16.3 $R-C$ parallel a.c. circuit	223	20.3 Transformer no-load phasor diagram	283
16.4 $L-C$ parallel a.c. circuit	224	20.4 E.m.f. equation of a transformer	285
16.5 $LR-C$ parallel a.c. circuit	226	20.5 Transformer on-load phasor diagram	287
16.6 Parallel resonance and Q-factor	229	20.6 Transformer construction	288
16.7 Power factor improvement	233	20.7 Equivalent circuit of a transformer	288
17 D.c. transients	238	20.8 Regulation of a transformer	290
17.1 Introduction	239	20.9 Transformer losses and efficiency	291
17.2 Charging a capacitor	239	20.10 Resistance matching	293
17.3 Time constant for a $C-R$ circuit	240	20.11 Auto transformers	296
17.4 Transient curves for a $C-R$ circuit	240	20.12 Isolating transformers	298
17.5 Discharging a capacitor	244	20.13 Three-phase transformers	298
17.6 Camera flash	246	20.14 Current transformers	299
17.7 Current growth in an $L-R$ circuit	246	20.15 Voltage transformers	300
17.8 Time constant for an $L-R$ circuit	247		
17.9 Transient curves for an $L-R$ circuit	247		
17.10 Current decay in an $L-R$ circuit	249		
17.11 Switching inductive circuits	251		
17.12 The effect of time constant on a rectangular waveform	251		
18 Operational amplifiers	253	Revision Test 6	301
18.1 Introduction to operational amplifiers	254	21 D.c. machines	302
18.2 Some op amp parameters	255	21.1 Introduction	303
		21.2 The action of a commutator	303
		21.3 D.c. machine construction	304
		21.4 Shunt, series and compound windings	304
		21.5 E.m.f. generated in an armature winding	305
		21.6 D.c. generators	306
		21.7 Types of d.c. generator and their characteristics	307

21.8 D.c. machine losses	311	23.6 De Moivre's theorem – powers and roots of complex numbers	352
21.9 Efficiency of a d.c. generator	311		
21.10 D.c. motors	312		
21.11 Torque of a d.c. machine	313	24 Application of complex numbers to series a.c. circuits	354
21.12 Types of d.c. motor and their characteristics	314	24.1 Introduction	354
21.13 The efficiency of a d.c. motor	318	24.2 Series a.c. circuits	355
21.14 D.c. motor starter	320	24.3 Further worked problems on series a.c. circuits	361
21.15 Speed control of d.c. motors	321		
21.16 Motor cooling	323		
22 Three-phase induction motors	324	25 Application of complex numbers to parallel a.c. networks	366
22.1 Introduction	325	25.1 Introduction	366
22.2 Production of a rotating magnetic field	325	25.2 Admittance, conductance and susceptance	367
22.3 Synchronous speed	327	25.3 Parallel a.c. networks	370
22.4 Construction of a three-phase induction motor	328	25.4 Further worked problems on parallel a.c. networks	374
22.5 Principle of operation of a three-phase induction motor	328	26 Power in a.c. circuits	377
22.6 Slip	329	26.1 Introduction	377
22.7 Rotor e.m.f. and frequency	330	26.2 Determination of power in a.c. circuits	378
22.8 Rotor impedance and current	331	26.3 Power triangle and power factor	380
22.9 Rotor copper loss	331	26.4 Use of complex numbers for determination of power	381
22.10 Induction motor losses and efficiency	332	26.5 Power factor improvement	385
22.11 Torque equation for an induction motor	333		
22.12 Induction motor torque-speed characteristics	335	Revision Test 8	390
22.13 Starting methods for induction motors	336		
22.14 Advantages of squirrel-cage induction motors	337	27 A.c. bridges	391
22.15 Advantages of wound rotor induction motor	338	27.1 Introduction	391
22.16 Double cage induction motor	338	27.2 Balance conditions for an a.c. bridge	391
22.17 Uses of three-phase induction motors	338	27.3 Types of a.c. bridge circuit	393
Revision Test 7	339	27.4 Worked problems on a.c. bridges	397
Main formulae for Part 2 Electrical principles and technology	340	28 Series resonance and Q-factor	401
Part 3 Advanced circuit theory and technology	343	28.1 Introduction	402
23 Revision of complex numbers	345	28.2 Series resonance	402
23.1 Introduction	345	28.3 Q-factor	404
23.2 Operations involving Cartesian complex numbers	347	28.4 Voltage magnification	406
23.3 Complex equations	349	28.5 Q-factors in series	408
23.4 The polar form of a complex number	349	28.6 Bandwidth	409
23.5 Multiplication and division using complex numbers in polar form	350	28.7 Small deviations from the resonant frequency	413
29 Parallel resonance and Q-factor	416		
29.1 Introduction	416		
29.2 The $LR-C$ parallel network	417		
29.3 Dynamic resistance	418		
29.4 The $LR-CR$ parallel network	418		
29.5 Q-factor in a parallel network	419		
29.6 Further worked problems on parallel resonance and Q-factor	423		
Revision Test 9	426		

30 Introduction to network analysis	427	36.10 Resonance due to harmonics	536
30.1 Introduction	427	36.11 Sources of harmonics	538
30.2 Solution of simultaneous equations using determinants	428		
30.3 Network analysis using Kirchhoff's laws	429		
31 Mesh-current and nodal analysis	437	37 A numerical method of harmonic analysis	542
31.1 Mesh-current analysis	437	37.1 Introduction	542
31.2 Nodal analysis	441	37.2 Harmonic analysis on data given in tabular or graphical form	542
		37.3 Complex waveform considerations	546
32 The superposition theorem	448		
32.1 Introduction	448	38 Magnetic materials	549
32.2 Using the superposition theorem	448	38.1 Revision of terms and units used with magnetic circuits	550
32.3 Further worked problems on the superposition theorem	453	38.2 Magnetic properties of materials	550
33 Thévenin's and Norton's theorems	458	38.3 Hysteresis and hysteresis loss	552
33.1 Introduction	458	38.4 Eddy current loss	556
33.2 Thévenin's theorem	459	38.5 Separation of hysteresis and eddy current losses	559
33.3 Further worked problems on Thévenin's theorem	465	38.6 Non-permanent magnetic materials	561
33.4 Norton's theorem	469	38.7 Permanent magnetic materials	562
33.5 Thévenin and Norton equivalent networks	476		
Revision Test 10	481	Revision Test 12	563
34 Delta-star and star-delta transformations	482		
34.1 Introduction	482	39 Dielectrics and dielectric loss	564
34.2 Delta and star connections	482	39.1 Electric fields, capacitance and permittivity	564
34.3 Delta-star transformation	483	39.2 Polarization	565
34.4 Star-delta transformation	491	39.3 Dielectric strength	565
35 Maximum power transfer theorems and impedance matching	495	39.4 Thermal effects	566
35.1 Maximum power transfer theorems	496	39.5 Mechanical properties	567
35.2 Impedance matching	501	39.6 Types of practical capacitor	567
Revision Test 11	504	39.7 Liquid dielectrics and gas insulation	567
		39.8 Dielectric loss and loss angle	567
36 Complex waveforms	505		
36.1 Introduction	506	40 Field theory	571
36.2 The general equation for a complex waveform	506	40.1 Field plotting by curvilinear squares	572
36.3 Harmonic synthesis	507	40.2 Capacitance between concentric cylinders	575
36.4 Fourier series of periodic and non-periodic functions	514	40.3 Capacitance of an isolated twin line	580
36.5 Even and odd functions and Fourier series over any range	519	40.4 Energy stored in an electric field	583
36.6 R.m.s. value, mean value and the form factor of a complex wave	523	40.5 Induced e.m.f. and inductance	585
36.7 Power associated with complex waves	526	40.6 Inductance of a concentric cylinder (or coaxial cable)	585
36.8 Harmonics in single-phase circuits	528	40.7 Inductance of an isolated twin line	588
36.9 Further worked problems on harmonics in single-phase circuits	532	40.8 Energy stored in an electromagnetic field	590
		41 Attenuators	593
		41.1 Introduction	594
		41.2 Characteristic impedance	594
		41.3 Logarithmic ratios	596
		41.4 Symmetrical T- and π -attenuators	598
		41.5 Insertion loss	603
		41.6 Asymmetrical T- and π -sections	606

41.7 The L-section attenuator	609	45.3 Response of $R-L$ series circuit to a step input	696
41.8 Two-port networks in cascade	611	45.4 $L-R-C$ series circuit response	699
41.9 $ABCD$ parameters	614	45.5 Introduction to Laplace transforms	702
41.10 $ABCD$ parameters for networks	617	45.6 Inverse Laplace transforms and the solution of differential equations	706
41.11 Characteristic impedance in terms of $ABCD$ parameters	623	45.7 Laplace transform analysis directly from the circuit diagram	712
Revision Test 13	625	45.8 $L-R-C$ series circuit using Laplace transforms	721
42. Filter networks	626	45.9 Initial conditions	724
42.1 Introduction	626	Revision Test 14	728
42.2 Basic types of filter sections	627	Main formulae for Part 3 Advanced circuit theory and technology	729
42.3 The characteristic impedance and the attenuation of filter sections	629		
42.4 Ladder networks	630		
42.5 Low-pass filter sections	631		
42.6 High-pass filter sections	637		
42.7 Propagation coefficient and time delay in filter sections	642		
42.8 'm-derived' filter sections	648		
42.9 Practical composite filters	653		
43. Magnetically coupled circuits	656	Part 4 General reference	735
43.1 Introduction	656	Standard electrical quantities – their symbols and units	737
43.2 Self-inductance	656	Greek alphabet	740
43.3 Mutual inductance	657	Common prefixes	741
43.4 Coupling coefficient	658	Resistor colour coding and ohmic values	742
43.5 Coils connected in series	659	Answers to Practice Exercises	743
43.6 Coupled circuits	662	Index	763
43.7 Dot rule for coupled circuits	667		
44. Transmission lines	674		
44.1 Introduction	674	On the Website	
44.2 Transmission line primary constants	675	Some practical laboratory experiments	
44.3 Phase delay, wavelength and velocity of propagation	676	1 Ohm's law	2
44.4 Current and voltage relationships	677	2 Series-parallel d.c. circuit	3
44.5 Characteristic impedance and propagation coefficient in terms of the primary constants	679	3 Superposition theorem	4
44.6 Distortion on transmission lines	683	4 Thévenin's theorem	6
44.7 Wave reflection and the reflection coefficient	685	5 Use of a CRO to measure voltage, frequency and phase	8
44.8 Standing-waves and the standing-wave ratio	688	6 Use of a CRO with a bridge rectifier circuit	9
45. Transients and Laplace transforms	693	7 Measurement of the inductance of a coil	10
45.1 Introduction	694	8 Series a.c. circuit and resonance	11
45.2 Response of $R-C$ series circuit to a step input	694	9 Parallel a.c. circuit and resonance	13
		10 Charging and discharging a capacitor	15
		To download and edit go to: www.routledge.com/cw/bird	

Index

- ABCD networks in cascade, 615
parameters, 614
for networks, 617
- Absolute permeability, 72, 550
permittivity, 57, 58
voltage, 51
- A.c. bridges, 124, 391
generator, 188, 538
values, 190
- Acceptor circuit, 214
- Active networks, 627
power, 219, 380, 387, 527
- Admittance, 367
- Air capacitor, 65
- Alkaline cell, 27
- Alternating current, 187
waveforms, 189
- Alternative energy sources, 35
- Aluminium, 130
- Ammeter, 10, 106
- Ampere, 4, 9
- Amplifier gain, 256, 258
- Amplitude, 112, 190
- Analogue instrument, 104
- Analogue-to-digital conversion, 113, 264
- Anderson bridge, 487
- Angular velocity, 194
- Anode, 27, 136
- Antimony, 130
- Antinode, 689
- Apparent power, 219, 380
- Applications of resonance, 230
- Argand diagram, 345
- Argument, 350
- Armature, 304
reaction, 305
- Arsenic, 130
- Asymmetrical π -section, 606
T-section, 595, 606
- Atom, 9, 551
- Attenuation, 594, 597
bands, 626
coefficient, 643, 684
constant, 643, 678
- Attenuators, 593
asymmetrical π , 606
asymmetrical T, 594, 606
cascade, 611
- L-section, 609
symmetrical π , 599
symmetrical T, 594, 598
- Attraction type of m.i. instrument, 104
- Audio-frequency transformer, 288
- Auto transformer, 296
starting, 337
- Auxiliary equations, 700
- Avalanche effect, 134
breakdown, 136
- Average value, 190
- Avometer, 10
- Back e.m.f., 312
- Band-pass filter, 628, 641
-stop filter, 628
- Bandwidth, 217, 255, 409
- Barrier potential, 132
- Base, 144
- Batteries, 26, 27, 30
disposal of, 33
- Bell, electric, 16, 83
- B-H curves, 72, 552
- Bias, 145
- Bipolar junction transistor, 142, 145
characteristics, 145, 149
- Boron, 130
- Breakdown voltage, 134
- Bridge, a.c., 124, 391
- Bridge megger, 10, 108
rectifier, 136, 200
- Brush contact loss, 311
- Brushes, 303
- Buffer amplifier, 259
- Calibration accuracy, 125
- Camera flash, 246
- Candela, 4
- Capacitance, 56, 564, 675
between concentric cylinders, 575
of isolated twin line, 580
- Capacitive reactance, 205, 355
- Capacitors, 55, 56
charging, 239
discharging, 68, 244
energy stored in, 65
in parallel, 60
in series, 61
parallel plate, 59
- practical types, 65, 567
reservoir, 201
- Carbon resistors, 19
- Car ignition, 16
- Cartesian complex numbers, 345
- Cathode, 27, 136
- Cell, 28, 31, 33
capacity, 33
- Ceramic capacitor, 66
- Characteristic impedance, 594, 623
in terms of ABCD parameters, 623
in terms of primary line constants, 679
of filters, 629
of transmission lines, 679
- Characteristics, d.c. generator, 306–311
d.c. machines, 305
d.c. motor, 312–318
of semiconductors, 136
of transistor, 145, 152
- Charge, 4, 57
density, 57
- Charged particles, 27
- Charging of cell, 30, 31
capacitor, 239, 694
- Chemical effect of electric current, 16
electricity, 27
- Choke, 98
- Circuit magnification factor, 406
theory, 172
- CIVIL, 206
- Class A amplifier, 154
- Closed-loop gain, 257
- Coaxial cable, 575
- Coefficient of coupling, 658
- Coercive force, 78, 552
- Cofactor, 429
- Coils in series, cumulatively coupled, 659
differentially coupled, 659
- Collector, 145
- Combination of waveforms, 196
- Commercial bridge, 125
- Common-mode rejection ratio, 255
- Commutation, 303
- Commutator, 303, 304
- Complex conjugate, 347
equations, 349

- Complex numbers, 345
 applications to parallel networks, 366
 applications to series circuits, 354
 Cartesian form, 345
 De Moivre's theorem, 352
 determination of power, 381
 equations, 349
 operations involving, 347
 polar form, 349
 Complex wave, 120, 506
 form factor, 525
 frequency, 713
 general equation, 506
 harmonics in single-phase circuits, 528
 mean value, 525
 power associated with, 526
 resonance due to harmonics, 536
 r.m.s. value, 523
 sources of harmonics, 538
 waveform considerations, 546
 waveforms, 505
 Composite filters, 653
 series magnetic circuits, 75
 Compound motor, 318
 winding, 304
 wound generator, 309
 Concentric cable, 575, 585
 field plotting, 578
 Conductance, 6, 367, 675
 Conductor, 9, 13, 129
 Constant-current source, 178
 Constant-k high-pass filter, 640
 low-pass filter, 634
 Contact potential, 131, 132
 Continuity tester, 11, 108
 Continuous function, 515
 loading, 684
 Cooker, 16
 Copper loss, 291, 311
 Core loss, 311
 component, 284
 Core type transformer construction, 288
 Corrosion, 29
 Coulomb, 4, 9, 57
 Coulomb's law, 56
 Coupled circuits, 662
 dot rule, 667
 Coupling coefficient, 658
 Covalent bonds, 130
 Critically damped circuit, 700, 723
 Cumulative compound motor, 318
 Curie temperature, 552
 Current, 4, 9
 decay in L-R circuit, 249, 698
 division, 44, 370
 gain, 148
 growth in L-R circuit, 246, 696
 magnification, 230, 419
 main effects of, 16
 transformer, 299
 Current gain in transistors, 148
 Curvilinear squares, 572
 Cut-off frequency, 627, 631
 Cycle, 189
 Damping, 89, 104, 722
 device, 104
 D.c. circuit theory, 165, 172
 generators, 396
 machine construction, 304
 machine losses, 311
 machines, 302
 motors, 89, 303, 312
 motor starter, 320
 potentiometer, 123
 transients, 238
 Decibel, 120, 596
 meter, 121
 Delta connection, 271, 482
 Delta-star comparison, 279
 transformation, 483
 De Moivre's theorem, 352
 Depletion layer, 131, 132
 Derived units, 3
 De Sauty bridge, 125, 395
 Design impedance, 632
 Detector types, a.c. bridges, 392
 Determinants, 428
 Deviation from resonant frequency, 413
 Diamagnetism, 551
 Dielectric, 56, 58, 564
 hysteresis, 567
 liquid, 567
 loss, 567
 strength, 64, 565
 stress, 576
 Differential amplifier, 261, 262
 compound motor, 318
 equation solution, 709
 voltage amplifier, 254
 Differentiator circuit, 252
 Diffusion, 132
 Digital multimeter, 108
 oscilloscopes, 104, 111, 113
 voltmeter, 107
 Digital-to-analogue conversion, 264
 Dimensions of most economical
 cable, 577
 Diode characteristics, 136
 Dirac function, 704
 Discharging of capacitors, 68, 244, 696
 cells, 30, 32
 Disposal of batteries, 33
 Dissipation factor, 568
 Distortion on transmission line, 683
 Diverter, 322
 Domains, 552
 Doping, 130
 Dot rule for coupled circuits, 667
 Double beam oscilloscope, 112
 cage induction motor, 338
 layer capacitance, 67
 Drift, 9
 Dust core, 562
 Dynamic current gain, 147, 157
 resistance, 229, 418
 Earth, 51
 potential, 52
 Edison cell, 33
 Eddy current loss, 291, 556
 Effective value, 190
 Efficiency of d.c. generator, 311
 d.c. motor, 319
 induction motor, 332
 transformer, 291
 Electrical energy, 6, 14
 measuring instruments and
 measurements, 10, 103
 potential, 6
 power, 6, 13
 quantities and units, 737
 safety, 193
 symbols, 9
 Electric bell, 16, 83
 cell, 28
 circuit, 8
 current, 19
 field strength, 56, 564
 fire, 16
 flux density, 57, 564
 force, 55
 potential, 6
 Electrochemical series, 28
 Electrodes, 27
 Electrolysis, 27
 Electrolyte, 27, 32
 Electrolytic capacitors, 67
 Electromagnetic induction, 91, 92
 laws of, 92
 Electromagnetic wave, 675
 Electromagnetism, 81
 Electromagnets, 83
 Electromotive force, 6, 29
 Electron, 9, 27, 129
 Electronic instruments, 107
 Electroplating, 16, 28

- Electrostatic field, 55
 E.m.f., 6, 29
 equation of transformer, 285
 in armature winding, 305
 Emitter, 144
 Energy, 4
 associated with travelling wave, 686
 electrical, 6, 14
 stored in capacitor, 65
 stored in electric field, 583
 stored in electromagnetic field, 590
 stored in magnetic field of inductor, 98, 591
 Equipotential lines, 572
 Equivalent circuit, transformer, 288
 Errors, measurement, 125
 Exponential growth and decay curves, 239
 Even function, 519, 546

 Farad, 56
 Faraday's laws of electromagnetic induction, 92
 Ferrites, 79, 562
 Ferromagnetic-cored coils, 538
 materials, 73, 551
 Field effect transistor, 142, 140
 amplifiers, 152
 characteristics, 150, 152
 Field plotting, 572
 theory, 571
 Filter networks, 201, 626
 band-pass, 628
 band-stop, 628
 composite, 653
 high-pass, 627, 637
 low-pass, 627, 631
 'm derived', 648
 time delay, 646
 Final value theorem, 705
 Finite discontinuities, 515
 Fleming's left-hand rule, 86
 right-hand rule, 93
 Fluke, 10, 108
 Flux density, 71, 550
 electric, 57
 linkage, 585
 Flux, magnetic, 71, 550
 Force, 4
 on a charge, 89
 current-carrying conductor, 85
 Forced magnetization, 539
 resonant frequency, 419
 Form factor, 190, 525
 Formulae, 161, 340, 729

 Forward bias, 132
 characteristics, 133
 transconductance, 151
 Fourier coefficients, 515
 Fourier cosine series, 519
 Fourier series, 508, 514
 for non-periodic functions, 516
 for periodic functions, 514
 over any range, 521
 Fourier sine series, 520
 Free magnetization, 539
 Frequency, 112, 189, 194
 resonant, 214, 229
 Friction and windage losses, 311
 Fuel cell, 35
 Full wave rectification, 136, 200
 Fundamental, 120, 506, 515
 Furnace, 16
 Fuse, 16, 193

 Gallium arsenide, 130
 Galvanometer, 123
 Gas insulation, 567
 Generator, 16, 303, 306
 a.c., 188
 efficiency of, 311
 Geothermal energy, 36
 Germanium, 130, 134
 Gravitational force, 4
 Greek alphabet, 740
 Grip rule, 83

 Half-power points, 217, 409
 -wave rectification, 199
 -wave rectifier, 136, 199
 Harmonic analysis, 507
 numerical method, 508, 542
 Harmonic resonance, 536
 synthesis, 507, 508
 Harmonics, 120, 506, 515
 in single phase circuits, 528
 sources of, 538
 Hay bridge, 125, 394
 Heating effect of electric current, 16
 Heaviside bridge, 125
 Henry, 96, 585
 Hertz, 189
 High-pass filter, 627, 631, 637
 ladder, 631
 'm derived', 651
 Hole, 131
 Hydroelectricity, 36
 Hydrogen cell, 35
 Hysteresis, 78, 552
 loop, 78, 553
 loss, 78, 291, 553

 Image impedance, 606
 Imaginary numbers, 345
 Impedance, 206, 210
 matching, 501
 triangle, 206, 210
 Impulse, 703
 Impurity, 130
 Incident wave, 685
 Indium, 130
 Indium arsenide, 130
 Induced e.m.f., 88, 585
 Inductance, 96, 585, 675
 mutual, 96, 100
 of a coil, 99
 of a concentric cylinder, 585, 586
 of an isolated twin line, 588, 675
 Induction motor, three-phase, 324, 325
 construction, 328
 copper loss, 331
 double cage, 338
 impedance and current, 331
 losses and efficiency, 332
 principle of operation, 328
 production of rotating magnetic field, 325
 rotor e.m.f. and frequency, 330
 starting, 336
 torque equation, 333
 speed characteristic, 335
 uses, 338
 Inductive circuit, switching, 251
 reactance, 204, 355
 Inductors, 97
 Initial conditions, 724
 value theorem, 705
 Initial slope and three-point method, 240
 Input bias current, 255
 impedance, 257, 259, 629
 offset current, 255
 voltage, 255
 Insertion loss, 603
 ratio, 604
 Instantaneous values, 190
 Instrument 'loading' effect, 109
 Insulated gate field effect transistor (IGFET), 150
 Insulation, 193
 Insulation and dangers of high current, 17
 Insulation resistance tester, 11, 108
 Insulator, 9, 13, 129
 Integrated circuit, 139
 Integrator circuit, 251
 op amp, 261
 Internal resistance of a cell, 29
 Interpoles, 304

- Inverse Laplace transforms, 706
 Inverting op amp, 256
 Ion, 9, 27
 Iron, 16
 loss, 291, 311
 Isolating transformer, 298
 Iterative impedance, 594, 606
 Joule, 4, 6, 14
 Junction gate field effect transistor (JFET), 150
 Kelvin, 4
 Kettle, 16
 kilo, 4
 Kilowatt-hour, 6, 14
 Kirchhoff's laws, a.c., 428, 429
 d.c., 164
 in the s-domain, 713
 network analysis, a.c., 428
 Ladder networks, 631
 Lag, angle of, 193
 Lamps in series and parallel, 52
 Laplace transforms, 702
 by partial fractions, 708
 capacitor, 712
 definition of, 702
 elementary functions, 702
 final value theorem, 705
 inductor, 712
 initial conditions, 724
 initial value theorem, 705
 inverse, 706
 L-R-C circuit, 721
 of derivatives, 705
 resistor, 712
 to solve differential equations, 709
 Lap winding, 304
 Laws of electromagnetic induction, 92
 L-C parallel network, 224
 Lead-acid cell, 32
 Lead, angle of, 193
 Leakage currents, 144, 567
 Leclanche cell, 32
 Lenz's law, 92
 Letter and digit code for resistors, 24
 Level compounded machine, 310
 Lifting magnet, 16, 84
 Light emitting diodes, 136, 138
 Linear device, 11
 scale, 104
 Liquid dielectrics, 567
 Lithium-ion battery, 27
 Loading effect, 47, 109
 Load line, 155
 Local action, 28
 Logarithmic ratios, 120, 596
 Long shunt compound generator, 309
 motor, 318
 Loop currents, 437
 inductance, 589
 Loss angle, 567
 Losses in d.c. machines, 311
 induction motor, 332
 transformers, 291
 Loudspeaker, 85
 Low-pass filter, 627, 631, 635
 ladder, 630
 'm derived', 650
 LR-C parallel network, 226
 resonance, 417
 L-R-C circuit using Laplace transforms, 721
 LR-CR parallel network resonance, 418
 L-R-C series circuit, 699
 L-section attenuator, 609
 Luminous intensity, 4
 Lumped loading, 684
 Magnetically coupled circuits, 656
 Magnetic effect of electric current, 16
 circuit, 69, 70
 field, 70, 550
 strength, 71, 550
 flux, 70, 550
 density, 70, 550
 force, 70
 materials, 549
 moment, 551
 properties of materials, 550
 screens, 73
 space constant, 72
 Magnetic field due to electric current, 82
 Magnetising component, 283
 force, 71
 Magnetization curves, 72, 550
 Magnetomotive force, 71, 550
 Magnification factor, 406
 Majority carriers, 131, 132
 Manganese battery, 27
 Matched network, 604
 Matching transformer, 293, 501
 Maximum efficiency, transfer, 292
 Maximum power transfer theorems,
 d.c., 184
 a.c., 495, 496
 Maximum repetitive reverse voltage, 136
 Maximum value, 190
 Maxwell bridge, 125, 393
 Maxwell-Wien bridge, 395
 Maxwell's theorem, 438
 Mechanical analogy of parallel resonance, 230
 Mean value, 190
 of complex wave, 525
 Measurement errors, 125
 of power in three phase systems, 274
 'm derived' filter, 648
 Mega, 4
 Megger, 11, 108
 Mercury cell, 32
 Mesh-connection, 271, 482
 current analysis, 437
 Metal oxide resistors, 19
 Mica capacitor, 66
 Micro, 4
 Microelectronic systems, 541
 Milli, 4
 Minor, 429
 Minority carriers, 131
 Mismatched load, 685
 Modulus, 350
 Mole, 4
 Moore's circle technique, 573
 Motor, 16, 303, 312
 compound, 318
 cooling, 323
 d.c., principle of operation, 88
 efficiency, 318
 speed control, 321
 starter, 330
 Moving coil instrument, principle of, 89
 rectifier instrument, 105
 Moving iron instrument, 104
 Multimeter, 108
 Multiples, 11
 Multiplier, 106
 Mutual inductance, 96, 100, 657
 Nano, 4
 National grid, 188
 Natural frequency, 419
 Negative feedback, 255
 Nepers, 596
 Network analysis, 427
 Neutral point, 268
 Neutron, 9
 Newton, 4, 85
 Nickel cadmium cells, 33
 Nickel-iron alloys, 562
 Nickel metal cells, 33
 NiFe cell, 33
 Nodal analysis, 441
 Node, 441, 689
 No load phasor diagram, transformer, 283

- Nominal impedance, 632, 638
 Non inverting amplifier, 258
 Non-linear device, 11
 scale, 104
 Nonpermanent magnetic materials, 561
 Norton and Thévenin equivalent networks, a.c., 476
 d.c., 181
 Norton's theorem, a.c., 469
 d.c., 178
 n-p-n transistor, 144
 n-type material, 130
 Nucleus, 9
 Null method of measurement, 123
 Numerical methods, 508
 of harmonic analysis, 542
 Nyquist, 117

 Odd functions, 520, 546
 Ohm, 6, 10
 Ohmic values, 23, 24, 742
 Ohmmeter, 10, 108
 Ohm's law, 11
 On load phasor diagram, transformer, 287
 Operating point, 156
 Operational amplifiers, 253
 differential, 262
 integrator, 261
 inverting amplifier, 256
 non-inverting amplifier, 258
 parameters, 255
 summing amplifier, 259
 voltage comparator, 260, 265
 voltage follower, 259
 Oscilloscope, analogue, 10, 111
 digital, 111, 113
 double beam, 114
 Over-compounded machine, 310
 Over-damped circuit, 700, 723
 Owen bridge, 125, 394

 Paper capacitor, 66
 Parallel networks, 42, 212, 366, 370
 plate capacitor, 59
 resonance, 229, 416
 Paramagnetism, 551
 Partial fractions, 708
 Passbands, 626
 Passive network, 627
 Peak factor, 190
 Peak inverse voltage, 136
 value, 112, 190
 Peak-to-peak value, 190
 Pentavalent impurity, 130

 Period, 189, 506
 Periodic function, 506, 515
 time, 189, 194
 Permanent magnet, 70, 562
 magnetic materials, 562
 Permeability, absolute, 72, 550
 of free space, 72, 550
 relative, 72, 550
 Permeance, 550
 Permittivity, 57
 absolute, 58
 Permittivity of free space, 58
 relative, 58, 564
 Phase delay, 676
 shift coefficient, 643, 678, 684
 Phasor, 193
 Phosphorus, 130
 Photovoltaic cells, 35
 Pico, 4
 π -attenuator, 595, 599, 606
 π -connection, 482
 π -section m-derived filter, 649
 Plastic capacitors, 67
 p-n junction, 131
 p-n-p transistor, 143
 Polar form of complex number, 349
 Polarization, 28, 565
 Poles, 304
 Potential difference, 6, 10
 divider, 40
 gradient, 56
 Potentiometer, 40, 48, 123
 Power, 5, 13
 associated with complex waves, 526
 factor, 219, 380, 527, 568
 improvement, 233, 385
 gain, 157
 in a.c. circuits, 217, 222, 377
 in three phase systems, 273
 loss, 568
 transformer, 288
 triangle, 219, 380
 Practical types of capacitor, 65
 Prefixes, 4, 12, 741
 Primary cell, 16, 27, 31
 constants, 675
 Principal node, 441
 Principle of operation, d.c. motor, 88
 m.c. instrument, 89
 three-phase induction motor, 328
 transformer, 281
 Product-arm bridge, 393
 Propagation coefficient, 642, 680
 constant, 642, 678
 Protons, 9, 129
 Prototype filter, 635

 Pseudocapacitance, 67
 p-type material, 130

 Q-factor, 215, 230, 404, 419
 in series, 408
 Quantity of electric charge, 9
 Quiescent point, 155

 Radio frequency transformer, 288
 Rating of a machine, 380
 transformer, 282
 Ratio-arm bridge, 393
 R-C parallel network, 223
 series circuit, 209, 357, 694
 Reactive power, 219, 380
 Real number, 345
 Reciprocity theorem, 616
 Rectangular complex number, 345
 Rectification, 136, 199
 Rectifier, 136, 538
 Rectifier diode, 136
 Reference level, 121
 Reflected impedance, 664
 wave, 685
 Reflection coefficient, 686
 Regulation of a transformer, 290
 Rejecter circuit, 230
 Relative permeability, 72, 550
 permittivity, 58, 564
 voltage, 51
 Relay, 16, 84
 Reluctance, 73, 550
 Remanence, 78, 552
 Renewable energy sources, 35
 Repulsion type of m.i. instrument, 105
 Reservoir capacitor, 201
 Residual flux density, 78, 552
 Resistance, 6, 10, 19, 675
 dynamic, 229
 internal, 29
 matching, 293
 variation, 18
 Resistivity, 19
 Resistor colour coding, 23, 742
 construction, 19
 Resonance, applications of, 230
 Resonance, by tuning capacitors, 665
 due to harmonics, 536
 parallel, 229, 416
 series, 211, 214, 401, 402
 Reverse bias, 132
 characteristics, 133
 Rheostat, 49
 Ripple, 201
 R-L-C circuit using Laplace transforms, 721

- R-L-C series circuit, 211, 357
 R-L parallel network, 222
 series circuit, 206, 356, 696
 R.m.s. value, 112, 190
 complex wave, 523
 Roots of auxiliary equation, 701
 Rotation of loop in magnetic field, 95
 Rotor copper loss, 331
 s-domains, 712
 Kirchhoff's laws, 713
 Saturation flux density, 78, 552
 Schering bridge, 125, 396, 398
 Schottky diodes, 139
 Screw rule, 82, 83
 Secondary cell, 16, 27, 32
 line constants, 678
 Selective resonance, 536
 Selectivity, 217, 411
 Self-excited generator, 306
 Self inductance, 96, 656
 Semiconductor diodes, 128, 135
 materials, 129, 130
 Semiconductors, 128, 130
 Separately-excited generator, 306, 307
 Separation of hysteresis and eddy
 current losses, 559
 Series circuit, 39
 a.c., 354, 355
 Series magnetic circuit, 75
 resonance, 211, 214, 401, 402
 winding, 304
 wound motor, 316, 322
 generator, 309
 Shells, 9, 129
 Shell type transformer construction, 288
 Short circuits, 52
 Short-shunt compound motor, 318
 Shunt, 106
 field regulator, 321
 winding, 304
 wound generator, 308
 motor, 314, 321
 Siemens, 6, 367
 Silicon, 130
 Silicon controlled rectifiers, 138
 Silicon-iron alloys, 561
 Silver oxide batteries, 27
 Simple cell, 28
 Simultaneous equations using
 determinants, 428
 Single-phase parallel a.c. network, 221
 series a.c. circuit, 203
 supply, 268
 Sine wave, 189
 general equation, 193
 S.I. units, 3, 4
 Skin effect, 585
 Slew rate, 256
 Slip, 329
 Smoothing of rectified output, 200
 Solar energy, 35
 Soldering iron, 16
 Solenoid, 82
 Sources of harmonics, 538
 Spectrum analysis, 119
 Speed control of d.c. motors, 321
 Squirrel-cage induction motor, 336
 applications of, 337
 rotor, 328, 336
 Standing wave, 688, 689
 ratio, 690
 Star connection, 268, 483
 Star-delta comparison, 279
 starting, 337
 transformation, 491
 Star point, 268
 Stator, 304
 Steady state, 239, 694
 Steinmetz index, 554
 Step input, L-R-C circuit, 721
 R-C circuit, 694
 R-L circuit, 696
 Stopbands, 626
 Streamline, 572
 Stroboscope, 11
 Sub-multiples, 11
 Summing amplifier, 250, 264
 point, 260
 Supercapacitors, 67
 applications of 67
 Superposition theorem, a.c., 448
 d.c., 169
 Surface mount technology, 19
 Susceptance, 367
 Switched-mode power supplies, 139
 Switching inductive circuits, 251
 Symmetrical lattice, 620
 π -attenuator, 599
 T-attenuator, 594, 598
 Synchronous speed, 325, 327
 Tachometer, 11
 Tangent method, 240
 T-attenuator, 598
 T-connection, 483
 T-section m-derived filter, 648
 Telephone receiver, 84
 Temperature coefficient of resistance, 21
 Tesla, 71, 550
 Thermal effects of dielectrics, 566
 Thermodynamic temperature, 4
 Thévenin's theorem, a.c., 458
 d.c., 174
 Thévenin and Norton equivalent
 networks, 181, 476
 Three-phase induction motors, 324,
 325
 construction, 328
 copper loss, 331
 double cage, 338
 impedance and current, 331
 losses and efficiency, 332
 principle of operation, 328
 production of rotating magnetic field,
 325
 rotor e.m.f. and frequency, 330
 starting, 336
 torque equation, 333
 speed characteristics, 335
 uses, 338
 Three-phase systems, 267
 advantages of, 279
 power, 273
 transformers, 298
 Thyristor, 138, 540
 Tidal power, 36
 Time constant, C-R circuit, 240
 L-R circuit, 247
 Time delay, 646
 Titanium oxide capacitor, 67
 Torque of a d.c. machine, 313
 Torque-speed characteristic of induction
 motor, 335
 Transfer characteristics, 146, 254
 Transformation ratio, 281
 Transformer, 16, 280
 a.f., 288
 auto, 296
 cooling, 288
 construction, 288
 current, 299
 e.m.f. equation, 285
 equivalent circuit, 288
 isolating, 298
 losses and efficiency, 291
 maximum efficiency, 292
 no-load phasor diagram, 283
 on-load phasor diagram, 287
 power, 288
 principle of operation, 281
 rating, 282
 regulation, 290
 r.f., 288
 three-phase, 298
 voltage, 300
 windings, 288

- Transient curves, C-R, 240, 694
L-R, 247, 696
- Transients, 239, 693
- Transistor, 141, 538
action, 143
amplifier, 143
characteristics, 145, 149
connections, 143
maximum ratings, 149
symbols, 143
- Transistor classification, 142
operating configurations, 142
parameters, 147
- Transit time, 646
- Transmission lines, 674
current and voltage relationships, 677
distortion, 683
primary constants, 675
secondary constants, 678
standing waves, 688
wave reflection, 685
- Transmission matrix, 615
parameters, 614
- Trapezoidal rule, 543
- Travelling wave, 675
- Trivalent impurity, 130
- True power, 219
- Two port networks, 594
in cascade, 611
- Types of a.c. bridge circuits, 393
capacitor, 65
material, 129
- UK supply voltage, 269
- Ultracapacitors, 67
- Under compounded machine, 310
- Underdamped circuit, 700, 722
- Unit of electricity, 14
- Units, 3, 7
S.I., 3, 4
- Universal bridge, 125
instrument, 108
- Vacuum, 57
- Valence electrons, 130
shell, 129
- Valves, 538
- Varactor diodes, 136, 139
- Variable air capacitor, 65
- Velocity of propagation, 677, 684
- Virtual digital storage oscilloscope, 116
earth, 256
test and measuring instruments, 116
- Volt, 6, 10
- Voltage, 9, 10
absolute, 51
comparator, 260, 265
follower op amp, 259
gain, 157
magnification at resonance, 215, 406
regulator, 137
relative, 51
- transformer, 300
triangle, 206, 209
- Voltmeter, 10, 27, 106
- Water heater, 16
- Watt, 5, 13
- Wattmeter, 11, 108
- Waveform analyser, 508
considerations, 546
harmonics, 120
- Waveforms, 189
combination of, 196
- Wavelength, 676
- Wave reflection, 685
winding, 304
- Weber, 71, 550
- Weight, 4
- Wheatstone bridge, 123, 167, 391
- Wien bridge, 125, 396, 398
- Wind power, 36
- Wire wound resistors, 19
- Work, 4
- Wound rotor, 328, 337
induction motor, 336
advantages of, 338
- Yoke, 304
- Zener diode, 136
effect, 134