

CONTENTS

ACKNOWLEDGEMENTS	v
PREFACE	vi
CHAPTER ONE	
Introduction	1
1.1 Electronics	1
1.2 Conduction — A Simple View	2
1.2.1 Superconductivity	3
CHAPTER TWO	
Historical Background	5
2.1 Introduction	5
Part 1 — Printed Boards	5
2.2 Early days	5
2.2.1 Prior Art	5
2.2.2 The Birth of the Printed Circuit	6
2.2.3 The First Printed Circuit Symposium	7
2.2.4 Module Development	7
2.3 Further Development	8
2.3.1 Plated-through Hole Boards	8
2.3.2 Multilayer Boards	8
2.3.3 Additive Processes	8
2.3.4 Discrete Wired Boards	9
2.3.5 Flexible Circuits	10
2.3.6 Other PB Developments	10
2.4 Materials and Processes	10
2.4.1 Laminates	10
2.4.2 Resists and Etchants	11
2.4.3 Machining	12
2.4.4 Hole Pretreatment, Metallising and Plating	12
2.4.5 Finishes	14
2.4.6 CAD	14
2.5 In Conclusion	15
2.5.1 Printed Boards and the Environment	16
2.5.2 The Future of Printed Circuits	17

Part 2 — Electronic Components	17
2.6 General	17
2.7 1701-1800	17
2.8 1801-1900	18
2.8.1 1801-1830	18
2.8.2 1831-1860	18
2.8.3 1861-1880	19
2.8.4 1881-1900	19
2.9 1901- Present day	20
2.9.1 1901-1920	20
2.9.2 1921-1940	21
2.9.3 1941-1960	21
2.9.4 1961-1980	22
2.9.5 1981- Present day	24
Part 3 — Soldering	26
2.10 From Ancient Craft to Modern Science	26
CHAPTER THREE	
Conventional Components	31
3.1 General	31
3.2 Classification	31
3.3 Resistors	32
3.3.1 Packages	32
3.3.2 Characteristics	33
3.3.3 Manufacturing Technology	35
3.3.4 Identification	37
3.3.5 Variable Resistors	40
3.4 Capacitors	40
3.4.1 Packages	40
3.4.2 Characteristics	42
3.4.3 Manufacturing Technology	43
3.4.4 Electrolytic Capacitors	46
3.4.5 Identification	49
3.4.6 Variable Capacitors	49
3.5 Semiconductor Diodes	50
3.5.1 Packages	50
3.5.2 Characteristics	51
3.5.3 Technology	56
3.5.4 Identification	58
3.5.5 Rectifiers	58
3.6 Transistors	58
3.6.1 Packages	62
3.6.2 Characteristics	63
3.6.3 Manufacturing Technology	65
3.6.4 Identification	67
3.7 Silicon Controlled Rectifiers and Thyristors	67
3.8 Optoelectronic Devices	69
3.8.1 Packages	73
3.9 Monolithic Integrated Circuits	74
3.9.1 Classification	74
3.9.1.1 Technology	74
3.9.1.2 Operating Mode	77

3.9.1.3	Function	78
3.9.1.4	Level of Integration	78
3.9.2	Manufacturing Technology	79
3.9.3	Analogue ICs	80
3.9.4	Digital ICs	82
3.9.4.1	Elementary Circuits	82
3.9.4.2	Memories	84
3.9.4.3	Microprocessors	86
3.9.4.4	ASICs	86
3.9.5	Packages	87
3.10	Hybrid Integrated Circuits	93
3.10.1	Thin Film Hybrids	94
3.10.2	Thick Film Hybrids	97
3.10.3	Packages	97

CHAPTER FOUR

Surface Mounted Components	102	
4.1	General	102
4.2	Classification	103
4.3	Passive Surface Mounting Components	105
4.3.1	MELF Components	106
4.3.1.1	Resistors	107
4.3.1.2	Jumpers	108
4.3.1.3	Positive Temperature Coefficient (PTC) Resistors	108
4.3.1.4	Capacitors	108
4.3.1.5	Inductors	109
4.3.2	Mini-MELF Components	109
4.3.3	Other Cylindrical Components	110
4.3.4	Chip Components	112
4.3.4.1	Resistors	112
4.3.4.2	Jumpers	115
4.3.4.3	Thermistors	115
4.3.4.4	Ceramic Chip Capacitors	115
4.3.4.5	Microchip Capacitors	118
4.3.4.6	Chip Inductors	119
4.3.5	Other Flat Components	119
4.3.5.1	Metal Film Square Chip Resistors	119
4.3.5.2	High Power Resistors	120
4.3.5.3	Metallised Polyester Capacitors	120
4.3.5.4	Wet Type Aluminium Electrolytic Capacitors	120
4.3.5.5	Solid Aluminium Electrolytic Capacitors	123
4.3.5.6	Tantalum Electrolytic Capacitors	124
4.3.5.7	Inductors	125
4.3.5.8	Oscillators and Filters	127
4.3.6	Miscellaneous Passive Components	128
4.3.6.1	Aluminium Electrolytic Capacitors	128
4.3.6.2	Potentiometers	129
4.3.6.3	Trimmer Capacitors	129
4.3.6.4	Connectors	130
4.4	Active Surface Mounting Components	132
4.4.1	Diodes	133
4.4.2	SOT-23	135
4.4.3	SOT-89	137
4.4.4	SOT-143	137

4.4.5	SOT-223	137
4.4.6	Adapted Packages	138
4.4.7	Small Outline Integrated Circuits — SOICs	139
4.4.8	Very Small Outline Packages — VSOs	141
4.4.9	Flatpacks and Quadpacks — QFPs	141
4.4.10	Plastic Flat Packs — PFPs	143
4.4.11	Plastic Leaded Chip Carrier — PLCC	144
4.4.12	Small Outline J-leaded Package — SOJ	147
4.4.13	Leadless Ceramic Chip Carrier — LCCC	148
4.4.14	Leaded Ceramic Chip Carrier — LDCC	150
4.4.15	Other Complex Packages	150
4.4.16	Tape Automated Bonding — TAB	152
4.4.17	Chip-on-board (COB) and Multichip Modules (MCMs)	155
4.4.17.1	Chip-on-board	155
4.4.17.2	Multichip Modules	156
4.5	Supply Packaging	157
4.5.1	Bulk	157
4.5.2	Magazine	158
4.5.3	Rail and Tube	158
4.5.4	Tray or Palette	159
4.5.5	Adhesive Tape	159
4.5.6	Tape-on-reel	160
4.6	Advantages of SMT	161
4.6.1	Design Freedom	162
4.6.2	Size and Weight	165
4.6.3	Reliability	166
4.6.4	Electrical Characteristics	166
4.6.5	Effect of SMT on Automation	167
4.6.6	Cost	167
4.7	Disadvantages of SMT	168
4.8	The Future of Surface Mounting	169

CHAPTER FIVE

Manual Assembly	171	
5.1	General	171
5.1.1	Manpower and Manual Assembly	172
5.2	Low Volume Assembly	173
5.3	Mass Production	178
5.3.1	Without Pre-cut and Formed Components	178
5.3.2	Automatic Positioning Tables	179
5.3.3	Using Pre-cut and Formed Components	180
5.4	Lead Preforming	180
5.4.1	Types of Preformed Shape — Axial Components	181
5.4.2	Manual Preforming — Axial Components	186
5.4.3	Preforming Equipment for Axial Components	186
5.4.4	Preforming Non-axial Leaded Components	190
5.5	Production Aids	194
5.5.1	Layout Memorisation	195
5.5.2	Stage Assembly	196
5.5.3	Sequence Assembly	197
5.5.4	Component Sequencing	199
5.6	Visual Aids	200
5.6.1	Screen Printing	200
5.6.2	Slide Projection	202
5.6.3	Lamp Displays	202
5.6.4	LED Displays	203

5.6.5	Optical Fibre Displays	204
5.6.6	Laser Scanning Systems	204
5.7	Assembly Inspection	206
5.7.1	Visual Inspection	206
5.7.2	Equipment Assisted Inspection	207

CHAPTER SIX

Automatic Assembly — Conventional Components	209	
6.1	Introduction	209
6.1.1	Economics of Automation	209
6.1.2	The 'Mechanical Horse'	210
6.2	Early Automation	212
6.2.1	Semi-automatic Equipment	212
6.2.2	The Transfer Line	214
6.3	Component Packaging	215
6.3.1	Axial Component Taping	215
6.3.2	Radial Component Taping	218
6.3.3	DIP Components	221
6.3.4	Odd Components	222
6.4	Machine Types	222
6.4.1	Dedicated Inserters	223
6.4.2	Off-line Sequencing	224
6.4.2.1	Axial Component Sequencing	224
6.4.2.2	Sequence Verifiers	228
6.4.3	In-line Sequencing	228
6.4.3.1	Chain Sequencing	228
6.4.3.2	Air Delivery	229
6.4.3.3	Shuttle Delivery	230
6.4.3.4	Gravity Chute	230
6.4.3.5	Sort and Place	232
6.4.3.6	Pick-and-place	232
6.4.4	X-Y Tables and Rotary Tables	232
6.4.5	Positioning Aids — Optical Verifiers	234
6.4.6	Cutting and Clinching	235
6.4.7	Insertion Verification On-line	236
6.4.8	Control Unit	237
6.5	Axial Component Insertion Machines	238
6.5.1	Inserters versus Sequence-inserters	239
6.5.2	Fixed versus Variable Centre Distance	241
6.5.3	Insertion Programs	242
6.5.4	Insertion Cycle	245
6.5.5	Typical Axial Inserters	247
6.6	Radial Component Insertion Machines	248
6.6.1	Machine A	248
6.6.2	Machine B	249
6.6.3	Machine C	249
6.7	Dual Inserters	250
6.8	DIP Insertion Machines	250
6.8.1	Component Feeding	252
6.8.2	Insertion Cycle	253
6.8.3	Typical DIP Sequencer-inserters	254
6.8.3.1	Example A	254
6.8.3.2	Example B	254
6.8.3.3	Example C	254
6.8.3.4	Example D	255
6.8.3.5	Equipment Manufacturers	255

6.9	Odd Component Insertion Machines	255
6.9.1	Dedicated Insertion Machines for Odd Components	256
6.9.2	General Purpose Robots	257
6.10	Assembly Inspection	259
6.10.1	Visual Inspection	260
6.10.2	Inspection Equipment	261
6.11	Board Handling	262

CHAPTER SEVEN

Automatic Assembly — Surface Mount Components 266

7.1	Types of Surface Mount Assembly (SMA)	266
7.1.1	Single-sided SMA	267
7.1.2	Double-sided SMA	269
7.1.3	Mixprint — SMDs One Side Only	269
7.1.4	Full Mixprint	272
7.2	Surface Mounting Adhesives	272
7.2.1	Requirements for Adhesives	274
7.2.2	Application Methods	276
7.2.2.1	Pin Transfer	276
7.2.2.2	Syringe	280
7.2.2.3	Screen Printing	281
7.2.3	Adhesive Dot Criteria	281
7.2.4	Storage of Boards	283
7.2.5	Adhesive Curing	283
7.3	Solder Pastes	285
7.4	Conductive Adhesives	286
7.5	Component Mounting	287
7.5.1	Evolution of Pick-and-place Equipment from Manual Assembly	288
7.5.2	Automatic Mounting	289
7.5.3	An Automatic Mounting Machine	291
7.5.4	PB Loading and Positioning	292
7.5.5	Component Feeding	293
7.5.5.1	Rails and Tubes	295
7.5.5.2	Vibratory Bowl	295
7.5.5.3	Vibrating Conveyor	296
7.5.5.4	Hopper	296
7.5.5.5	Tape on Reel	297
7.5.5.6	Others	297
7.5.6	Application Heads	297
7.5.6.1	Picking Up	298
7.5.6.2	Centring	299
7.5.6.3	Rotation	299
7.5.6.4	Testing	300
7.5.6.5	Placement Control	301
7.5.6.6	Teach-in Options	302
7.5.6.7	Bad Circuit Detector	303
7.5.6.8	Optical Recognition Equipment	303
7.5.6.9	Turret Heads	303
7.5.6.10	Adhesive Applicators	304
7.5.7	Control	304
7.5.8	Software Packages	307
7.6	Mounting Equipment	308
7.6.1	Table-top	308
7.6.2	Pick-and-place	309
7.6.2.1	Examples of Sequential Pick-and-place Machines	310
7.6.3	Multiple Arm Pick-and-place	315

7.6.4	Parallel Equipment	316
7.6.5	Parallel-sequential Equipment	321
7.7	Ancillary Equipment	322
7.7.1	Curing Ovens	322
7.7.2	General Purpose Robots	324
7.8	Integrated Assembly Lines	324
7.9	Equipment Selection	326

CHAPTER EIGHT

General Principles of Design and Layout (of Printed Board Assemblies) 328

8.1	General	328
8.2	Basic Definitions	329
8.3	Classification of PBs	334
8.4	Initial Assessment	340
8.5	Tentative Dimensioning	342
8.5.1	Vertical Mounting	343
8.6	Working Out the Volume	344
8.7	Multiple Board Assembly	345
8.7.1	Advantages of a Single Board Solution	345
8.7.2	Advantages of a Multiple Board Solution	345
8.7.3	Point-to-point Wiring	346
8.7.4	Soldered Backplanes	348
8.7.5	Book Connection	349
8.7.6	Motherboard	350
8.7.7	Soldered Add-ons	351
8.7.8	Sandwich	351
8.7.9	Others	352
8.8	Design of Boards	352
8.8.1	Partition of the Assembly	352
8.8.1.1	Number of Connections	353
8.8.1.2	Assembly Technology	353
8.8.1.3	Making a Layout	353
8.8.1.4	Testability and Reparability	354
8.8.1.5	Maintainability	354
8.8.1.6	Environment	355
8.8.1.7	Logistics	355
8.8.1.8	Costs	356
8.8.2	Gross and Net Area	356
8.8.3	PIH Assembly	359
8.8.4	SMC Assembly	364
8.8.5	Mixprint Assemblies	370
8.8.6	Heavy Components	371
8.8.7	Other Points	372
8.9	Conductor Dimensioning	373
8.10	Further Reading	382

CHAPTER NINE

Layout of Printed Circuit Boards 384

9.1	Introduction	384
9.1.1	Manual Layout	384
9.1.2	Amateur's Layout	387
9.1.3	Manual Drawing of Artworks	387
9.1.4	Master Drawing	393
9.1.5	Component Map	395

9.2	Automated Production of Films	396
9.2.1	Digitising	396
9.2.2	Editing	397
9.2.3	Photoplotting	398
9.3	General Principles	400
9.3.1	Why Use a Grid?	401
9.3.2	Grid Selection	402
9.3.3	Grid Sizes in Common Use	404
9.3.4	A Bad Example	409
9.3.5	A Good Example	413
9.4	PIH (Pin-in-hole) Components	414
9.4.1	Axial Components	415
9.4.2	Other Discrete Components	418
9.4.3	Integrated Circuits	419
9.5	Surface Mounted Components	421
9.5.1	Is a Grid Essential?	423
9.5.2	Minimum Distance	423
9.5.3	Dimensioning of Lands	425
9.5.3.1	Wave Soldering	425
9.5.3.2	Reflow Soldering	428
9.5.4	Footprints	428
9.5.4.1	Chip SMD Footprints	429
9.5.4.2	MELF Component Footprints	429
9.5.4.3	Other Discrete SMC Footprints	430
9.5.4.4	SM Integrated Circuit Footprints	431
9.6	Multiple Boards	432
9.7	Conclusion	433

CHAPTER TEN

CAD/CAM		439
10.1	Introduction	439
10.2	Input Formats	439
10.2.1	Pin List	439
10.2.2	Schematic Entry	440
10.2.2.1	Style of Schematic Entry	443
10.2.2.2	Hierarchical Design	443
10.2.2.3	Libraries	443
10.2.3	No Format Supplied	444
10.3	Simulation	444
10.3.1	PAL, PLA and ASIC	445
10.4	Printed Board Layout Requirements	446
10.4.1	Capability Required	446
10.4.1.1	Co-ordinate System	446
10.4.1.2	Resolution	446
10.4.1.3	Layers	446
10.4.1.4	Track/Trace Widths	447
10.4.1.5	Pad Shapes	447
10.4.2	Placement	447
10.4.2.1	Autoplacement	448
10.4.3	Routing	449
10.4.3.1	Manual Routing	449
10.4.3.2	Autoroute Styles	449
10.4.4	Design Checking	452

10.4.5	Modifications	454
10.4.6	Schematic Annotation	455
10.4.7	Automatic Test	455
10.4.8	Mechanical Drawing	456
10.5	Outputs	456
10.5.1	Schematics	456
10.5.2	Layouts	457
10.5.3	Photoplotting	457
10.5.3.1	Pen Plotters	458
10.5.3.2	Matrix Plotters	459
10.5.3.3	Laser Printers	460
10.6	Computer Aided Manufacturing (CAM)	460
10.7	Interfaces	461
10.8	The Processing Platform	462
10.8.1	The Personal Computer (PC)	462
10.8.2	Memory Needs	463
10.8.3	Data Transfer	464
10.8.4	Machine Architecture	464
10.8.5	Graphics	465
10.8.6	Networks and Workstations	465
10.8.7	Processor Performance	465
10.9	Man-machine Interaction	466
10.10	Choosing a CAD System	467

CHAPTER ELEVEN

Thermal Management Aspects	469	
11.1	Introduction	469
11.1.1	Thermal Design	469
11.1.1.1	The Influence of Components and Cooling Methods on Temperature	470
11.1.1.2	The Rôle of Temperature Prediction	471
11.1.1.3	How Far Thermal Design?	471
11.1.2	Format of this Chapter	471
11.2	Heat Transfer Mechanisms and Temperature Effects	472
11.2.1	Mechanisms of Heat Transfer	473
11.2.1.1	Conduction	473
11.2.1.2	Convection	473
11.2.1.3	Radiation	473
11.2.1.4	Phase-change Heat Absorption	474
11.2.2	Difficulties Involved in Evaluating the Effects of Temperature on Reliability and Performance	474
11.2.3	Approach to Thermal Design	475
11.2.4	Designing for Reliability and Performance	476
11.2.4.1	Will the System Operate?	476
11.2.4.2	Can the System be Improved?	477
11.2.4.3	Relationship Between Temperature and Performance	477
11.3	Printed Board Construction and Examples	478
11.3.1	Types of Printed Board	478
11.3.1.1	A Combination of Circuit Board Types	479
11.3.2	Circuit Board Thermal Properties	480
11.3.2.1	The Thermal Conductivity of Basic Epoxide Printed Boards	480
11.3.2.2	Effective Thermal Conductivity of Printed Circuit Boards Having a High Thermal Conductivity Core	482
11.3.2.3	Surface Heat Loss and Gain from Boards Having a High Thermal Conductivity Core	483

11.3.2.4	Poor Thermal Conductivity Boards Having Designed Heat Pathways Bonded to Their Surface	483
11.3.3	Circuit Board Examples for Illustrating the Estimation of Effective Thermal Properties	485
11.4	'First Look' Methods of Circuit Board Thermal Design	488
11.4.1	'First Look' Temperature Prediction for Circuit Boards Without Surface Heat Loss	489
11.4.1.1	Concentration of Heat Generation at the Mean Distance from the Heat Sink	489
11.4.1.2	Uniform Distribution of Heat Generation with No Surface Heat Loss	490
11.4.1.3	Effect of Component Size	491
11.4.1.4	Estimate of Component Area Temperatures	492
11.4.2	'First Look' Temperature Prediction for Surface-cooled Circuit Boards	493
11.4.2.1	Simplification of Temperature Profile Approach	494
11.4.2.2	Exact Evaluation of Uniformly Heated Circuit Board with Surface Heat Loss	498
11.4.2.3	Effect of Component Size Under Surface Heat Loss Conditions	500
11.4.2.4	Estimate of Component Area Temperatures for Surface Cooling	502
11.4.3	General Features of Temperature Prediction Using 'First Look' Methods	502
11.4.3.1	Area of Sparse Power Dissipation	503
11.4.3.2	Poor Thermal Conductivity Circuit Boards	504
11.4.4	'First Look' Temperature Prediction for Circuit Boards Cooled by a Rear-mounted Heat Sink	506
11.4.5	'First Look' Temperature Values for Components	509
11.5	More Accurate Methods of Estimating the Temperatures Reached in Circuit Boards	510
11.5.1	Balanced Circuits	510
11.5.1.1	Balanced Circuits Mounted on Conduction-only Cooled Circuit Boards	512
11.5.1.2	Balanced Circuits Mounted on Surface-cooled Circuit Boards	513
11.5.2	Excess Temperature Estimation	514
11.5.2.1	A Graphical Method of Temperature Prediction for Conduction-cooled Circuit Boards	514
11.5.2.2	Temperature Estimates for Surface-cooled Circuit Boards	518
11.5.3	Estimates of Temperatures Arising on Circuit Boards Cooled by a Rear-mounted Heat Sink	518
11.5.4	Temperature Values for Components	519
11.6	Desk-computer-supported Circuit Board Thermal Design	519
11.6.1	Defects of Computer Packages when used for Thermal Design	519
11.6.2	Two Reliable Computer-assisted Methods	521
11.6.2.1	A Method for Edge-cooled Circuit Boards	521
11.6.2.2	A Method for Rear-cooled Circuit Boards	525
11.7	Convection Cooling	525
11.7.1	The Mechanisms of Convection	525
11.7.1.1	Design Features of Air-cooled Systems	526
11.7.2	Accuracy of Heat Transfer Coefficients	527
11.7.2.1	Influence of Changes in Air Temperature and Edge-connector Efficiency	529
11.7.3	Packages with an Attached Heat Sink	529
11.7.3.1	The Use of Die-cast Zinc Heat Sinks	529
11.7.4	Cooling Within the Cabinet	530
11.8	Other Aspects of Thermal Design	534
11.8.1	Thermal Expansion Mismatch	534
11.8.1.1	Soft Solder Joint Embrittlement	534
11.8.1.2	Component Features	534
11.8.2	Liquid Cooling	535

11.8.2.1	Convection Cooling Using Liquids	535
11.8.2.2	Phase-change Cooling by Nucleate Boiling	535
11.8.3	Heat Pipes	535
11.9	Postscript	536

CHAPTER TWELVE

Soldering		538
12.1	Fundamentals of Soldering	538
12.2	Making a Solder Joint	539
12.3	Cost Breakdown (The Economics of Soldering)	539
12.3.1	Manufacturing Costs	539
12.3.2	Materials Cost versus Failure Cost	540
12.3.3	Machine Cost	541
12.3.4	Quality Costs	541
12.4	Problem Areas in Soldering	542
12.5	Prerequisites for a Sound, Reliable Solder Joint	543
12.5.1	The Design Phase	544
12.5.1.1	Placement of the Solder Joint	544
12.5.1.2	The Joint Design (Dimensions, Geometry and Tolerances)	544
12.5.1.3	Thermal Problems	545
12.5.1.4	Repair	545
12.5.1.5	Demands Placed on the Solder Joint in Manufacturing, Storage, Transport and Operation	
12.5.1.6	Properties of the Materials Used	546
12.5.1.7	Choice of Solder and Flux	546
12.5.1.8	Choice of Soldering Method	547
12.5.2	Preproduction Phase	547
12.5.2.1	Equipment and Workshop	547
12.5.2.2	Personnel	548
12.5.2.3	Preparation for Soldering	548
12.5.2.4	Preproduction Checks	548
12.5.2.5	Storage of Material	548
12.5.3	Production Phase	548
12.6	Metallurgy	549
12.6.1	Soldering	549
12.6.2	Dissolution of Metals	549
12.6.3	Solidification of Solder	552
12.6.4	Intermetallic Phases	552
12.6.5	Diffusion	552
12.7	Wetting	555
12.8	Thermal Considerations	558
12.9	Solderability	560
12.9.1	General	560
12.9.2	What is Solderability?	560
12.9.3	The Advantages of Solderability Testing	561
12.9.4	Preservation of Solderability	561
12.9.5	Solderability Testing Methods	563
12.9.5.1	The Wetting Balance Method	564
12.9.5.2	The Scanning Method	565
12.9.5.3	The Workshop Method	567
12.9.5.4	The Solder Globule Method	568
12.9.5.5	The Spread Test	569
12.9.5.6	Testing of Printed Boards	570
12.9.5.7	Artificial Ageing Methods	572

12.9.5.8	Analysing Solderability Results	574
12.9.5.9	Solderability Testing <i>versus</i> Actual Performance	576
12.9.6	Correcting Bad Solderability	576
12.10	Quality and Reliability	577
12.10.1	Education, Information, Training	579
12.10.1.1	Management	579
12.10.1.2	Designers	579
12.10.1.3	Soldering Operators and Inspectors	579
12.10.2	Statistical Considerations	580
12.10.2.1	The Problem of the Great Number of Solder Joints	580
12.10.2.2.	How Exact is a Measured Value?	581
12.10.2.3	SPC — Statistical Process Control	582
12.10.3	Inspection of Solder Joints	586
12.10.3.1	Visual Inspection	586
12.10.3.2	Automated Optical Inspection (AOI)	587
12.10.3.3	X-ray Inspection	589
12.10.3.4	Ultrasonic Inspection	589
12.10.3.5	Thermal Inspection	589
12.10.4	Soldering Defects	590
12.10.4.1	What is a Soldering Defect?	590
12.10.4.2	Soldering Defects and Failure Rate	591
12.10.4.3	Solder-filled Through-plated Holes or not?	592
12.10.4.4	Defect Terminology	594
12.10.5	Expert Systems in Soldering	598
12.11	Mounting Methods	600
12.12	Classification of Assemblies	600
12.13	Health and Safety	601
12.13.1	Solders	601
12.13.2	Fluxes	602
12.3.3	Soldering Equipment	602
12.14	Terms and Definitions	603
12.14.1	General Definitions Related to Soldering	603
12.14.2	Terms Related to Soldering	604
12.14.3	Time-temperature Terms	604
12.14.4	Terms Related to Joint Form and Size	606
12.14.5	Terms Related to Solder Joints	607
12.14.6	Materials to be Joined	607
12.14.7	Flux Terms	608
12.14.8	Solder Terms	609
12.14.9	Soldering Aid Material	610
12.14.10	Soldering Methods and Processes	610
12.14.11	Quality Terms	610
12.14.12	Soldering Defects	611

CHAPTER THIRTEEN

13.1	General	614
13.2	Base Materials	614
13.3	Surface Treatments	614
13.3.1	Methods of Surface Treatment	615
13.3.2	Mechanism of Bonding	615
13.3.3	Layer Structure	615
13.3.3.1	The Bond	616
13.3.3.2	Diffusion Barriers	617
13.3.3.3	Protective Layers	617
13.3.3.4	Materials Build-up for Soldering	617

13.3.4	Solderable Coatings	618
13.3.4.1	Electrolytic Tinning	618
13.3.4.2	Hot Tinning	619
13.3.4.3	Nickel	620
13.3.4.4	Gold	620
13.3.4.5	Silver, Silver-palladium Plating	628
13.3.4.6	Problems in Plating	629
13.3.4.7	Points to be Checked	629
13.4	Solder for Electronic Purposes	629
13.4.1	General	629
13.4.2	Properties of Solder	630
13.4.3	Requirements Specified for Solders	630
13.4.4	Low Melting Point Solders	631
13.4.5	High Melting Point Solders	631
13.4.6	Step Soldering	632
13.4.7	Impurities in Solder	632
13.4.7.1	Copper	635
13.4.7.2	Gold	636
13.4.7.3	Silver	636
13.4.7.4	Iron	636
13.4.7.5	Nickel	637
13.4.7.6	Bismuth	637
13.4.7.7	Antimony	637
13.4.7.8	Arsenic	637
13.4.7.9	Aluminium, Zinc and Cadmium	637
13.4.7.10	Oxygen	638
13.4.7.11	Sulphur	638
13.4.7.12	Phosphorus	639
13.4.7.13	Dross	639
13.5	Fluxes	639
13.5.1	Definition of Fluxes	639
13.5.2	General	640
13.5.3	Classification of and Tests on Fluxes	640
13.5.4	Resin Fluxes	644
13.5.5	Colophony (Rosin)	644
13.5.6	Activated Rosin Fluxes	644
13.5.7	Halogen-containing Fluxes and Corrosion	645
13.5.8	Water-soluble Fluxes	645
13.5.9	Gaseous Fluxes and Soldering Without Fluxes	646
13.5.10	Low Solid Content Flux, No Residue Flux	647
13.5.11	Cleaning Off Fluxes and Flux Residues	647
13.6	Solder Pastes	648
13.6.1	General	648
13.6.2	Solder Balling	648
13.6.3	Viscosity	649
13.6.4	Slump	649
13.6.5	Corrosion of Residues	649
13.6.6	Assessment of Shape and Size of Solder Powder Particles	649
13.6.7	Storage of Solder Pastes	650
13.7	Properties of Solder Influencing the Solder Joint	650
13.7.1	Cracks in the Solder Joint	650
13.7.2	Mechanisms of Solder Joint Failure	651
13.7.3	The Different Types of Strength	653
13.7.4	Fatigue	656
13.7.4.1	Lifetime Prediction	658
13.7.4.2	Testing of Fatigue Properties	662
13.7.4.3	Measures to Increase the Lifetime of a Solder Joint	662

13.7.5	Tin Pest	665
13.7.6	Whiskers	666

CHAPTER FOURTEEN

Manual Soldering		668
14.1	Manual Soldering	668
14.2	The Soldering Iron	668
14.2.1	How Does a Soldering Iron Work?	669
14.2.2	The Soldering Iron Tip	671
14.2.3	The Wear of the Soldering Iron Tip	673
14.2.4	Heat Flow from the Iron to the Workpiece	673
14.2.5	Measuring the Tip Temperature	675
14.2.6	The Rating of the Soldering Iron	676
14.2.7	Tip Temperature and Heat Output from the Tip	676
14.2.8	Criteria for a Soldering Iron	677
14.2.9	Soldering Iron Support	679
14.2.10	'Tin Surplus' Collector	679
14.3	Soldering Printed Board Assemblies	680
14.3.1	Boards, Components and Solder Requirements	680
14.3.2	Operator and Working Conditions	680
14.3.3	Soldering Conditions	680
14.3.4	Making the Joint	681
14.4	Rework and Repair	681
14.4.1	Repair of Conductors on the Board	682
14.4.2	Repair of Solder Joints	682

CHAPTER FIFTEEN

Mass Soldering		685
15.1	General Considerations	685
15.1.1	Heat Supply	686
15.1.2	Temperature Profiles	686
15.1.3	Reflow Soldering	687
15.1.4	Controlled Atmosphere Soldering	688
15.2	The Mass Soldering Machine	690
15.2.1	The Soldering Fixture	691
15.2.2	The Conveyor	691
15.2.3	The Fluxing Station	692
15.2.3.1	Brush Fluxing and Dip Fluxing	693
15.2.3.2	Rotary Brush Fluxing	693
15.2.3.3	Wave Fluxing	693
15.2.3.4	Foam Fluxing	694
15.2.3.5	Spray Fluxing	694
15.2.3.6	Density Control	695
15.2.4	The Preheating Station	696
15.2.5	The Soldering Station	698
15.2.5.1	Solder Replacement	699
15.2.6	The Cleaning Station	700
15.2.7	Process Control Aids	700
15.2.7.1	Temperature Indication	700
15.2.7.2	Soldering Process Testing	700
15.2.8	The Maintenance of a Soldering Machine	701
15.2.9	Buying a Soldering Machine	703
15.3	Dip Soldering	704
15.4	Drag Soldering	704
15.5	Wave Soldering	705

15.5.1	The Wave Form and the Nozzles	708
15.5.2	Wave Soldering Machines for SMT	709
15.5.2.1	The Double Wave Soldering Machine	709
15.5.2.2	The Pulsed Wave Soldering Machine	709
15.5.3	Oil in the Wave	710
15.6	Infra-red Soldering	711
15.7	Convection and Forced Convection Soldering	711
15.8	Vapour Phase Soldering or Condensation Soldering	712
15.9	Laser	715
15.9.1	Types of Laser used for Soldering	715
15.9.2	Pulsed and CW Lasers	716
15.9.3	Controlled Laser for Soldering	716
15.9.4	The Heat Flow in Metals Radiated by Laser	716
15.9.5	The Laser Solder Joint	717
15.9.6	Maximising the Advantages of Laser Soldering	718
15.9.7	Areas for Laser Soldering	719
15.9.8	The Economics of Laser Soldering	720
15.10	Light Soldering	720
15.11	Hot Bar Soldering	721
15.12	Hotplate Soldering	722
15.13	Belt Soldering	722
15.14	Hot Gas Soldering	722
15.15	Furnace Soldering	723
15.16	Robot Soldering	723
15.17	Ultrasonic (US) Soldering	724
15.18	High Frequency (HF) Soldering	724

CHAPTER SIXTEEN

Microjoining Methods		726
16.1	Introduction	726
16.2	The Principles of Metallurgical Joining Methods	727
16.2.1	Soldering Methods	728
16.2.2	Welding Methods	728
16.2.2.1	Resistance Welding	729
16.2.2.2	Diffusion Welding	729
16.2.2.3	Ultrasonic (US) Welding	731
16.2.3	The Equipment	731
16.2.4	The Materials	732
16.2.4.1	Materials to be Joined	732
16.2.4.2	Chips, Dice or Die	732
16.2.4.3	Electrodes and Thermodes	733
16.2.5	Process Control	734
16.3	Different Joining Methods	734
16.3.1	Wire Bonding	734
16.3.2	Tape Automated Bonding (TAB)	735
16.3.3	Flip-chip	738
16.3.4	Beam Lead	739
16.3.5	Isothermal Soldering	740
16.3.6	Wire Wrap	740
16.3.7	Explosive Welding	741
16.3.8	Adhesives	741
16.3.9	Chip-on-board (COB) and Multichip Module (MCM)	742
16.3.10	Board Wiring Techniques	742
16.3.10.1	Impulse Bonded Wiring	742
16.3.10.2	Stitchwire	743
16.3.10.3	Multiwire and Microwire	743