

Table of Contents

1 SCOPE	1	3.3.1 Component Orientation	21
1.1 Assembly and Joining Technology	1	3.3.2 Accessibility	22
1.2 Through-Hole Technology	1	3.3.3 Design Envelope	22
1.3 Surface Mount Technology	1	3.3.4 Clearances	22
1.4 Related Documents	2	3.3.5 Physical Support	23
1.4.1 Joint Industry Standards	2	3.4 Design for Automated Assembly	23
1.4.2 IPC - Association Connecting Electronics Industries Documents	4	3.4.1 Fiducial Marks	23
1.4.3 United States Government Documents	10	3.4.2 Automated Through Hole Assembly	23
1.4.4 American Society of Mechanical Engineers	11	3.4.3 Automated Surface Mount Assembly	23
1.4.5 ASTM International	11	3.4.4 Automated Mixed-Technology Assembly	24
1.4.6 SAE International	12	3.5 Through Hole Assembly	24
1.4.7 Federal Aviation Regulations (FARs)	12	3.5.1 Lead Configuration	24
1.4.8 Underwriters Laboratories	12	3.5.2 Lead/Hole Relationship	28
1.4.9 IEC Standards	12	3.5.3 Through Hole Land Patterns	28
1.4.10 Independent Distributors of Electronics Association (IDEA)	12	3.6 Surface Mount Assembly	29
1.4.11 Electrostatic Discharge Association	13	3.6.1 Basic Printed Board Features	29
2 HANDLING ELECTRONIC ASSEMBLIES	13	3.6.2 Manufacturing Allowances	29
2.1 Definitions	13	3.6.3 SMT Land Pattern Details	29
2.1.1 Electrostatic Discharge (ESD)	13	3.6.4 SMT Assembly Processing	30
2.1.2 Electrostatic Discharge Sensitive Components (ESDS)	13	4 PRINTED CIRCUIT BOARDS	32
2.1.3 Electrical Overstress (EOS)	13	4.1 General Considerations	32
2.2 Handling of ESDS Items (Components and/or Assemblies)	13	4.2 Design Issues	34
2.2.1 Electrical Overstress (EOS) Damage Prevention	14	4.2.1 Structures	34
2.2.2 Electrostatic Discharge (ESD) Damage Prevention	14	4.2.2 Leaded vs. Leadless Components	34
2.3 Physical Handling	15	4.2.3 CTE Issues	34
2.3.1 Handling after Soldering	15	4.3 PCB Materials	34
2.4 Contamination	15	4.3.1 Thermosetting Base Resins	34
2.5 Processing Moisture Sensitive Components	15	4.4 Printed Boards with Non-Metallic Constraining Cores	36
2.6 Classification of Non-IC Electronic Components for Assembly Processes (IPC/IPC/JEDEC J-STD-075)	16	4.5 Base Conductors	36
3 DESIGN CONSIDERATIONS	19	4.5.1 Metallic Foils	36
3.1 Background and Theory	19	4.5.2 Electrodeposited Copper Foil	37
3.2 Basic Considerations	19	4.5.3 Rolled-Annealed Copper Foil	37
3.2.1 End-Product Usage	19	4.5.4 Additive Circuit Plating	37
3.2.2 Performance and Reliability	20	4.6 Plating and Surface Finishes	37
3.2.3 Designing for Producibility	20	4.6.1 Electroless Copper Plating	37
3.3 Packaged-Component Assembly Considerations	21	4.6.2 Semi-Conductive Coatings	37
		4.6.3 Electrolytic Copper Plating	37
		4.6.4 Gold Plating	38
		4.6.5 Immersion Silver	41
		4.6.6 Immersion Tin	42
		4.6.7 Organic Solderability Preservative (OSP)	42
		4.6.8 Nickel Plating	43

4.6.9	Tin/Lead Plating	44	6.6	Printed Wiring Board Weak Knee Phenomena	56
4.6.10	Solder Coating	44	6.7	Troubleshooting a Solderability Problem	57
4.6.11	Other Metallic Coatings for Edge Printed Board Contacts	45	6.8	Solderability Tests	57
4.7	Printed Board Handling and Storage Guidelines	45	6.8.1	IPC J-STD-002	57
5	ELECTRONIC CIRCUIT COMPONENTS	45	6.8.2	Force Measurement	58
5.1	Lead/Termination Finishes	46	6.9	IPC J-STD-003	59
5.2	Moisture Sensitivity	46	6.10	The Importance of Flux Material in Solderability Testing	60
5.3	Components	46	7	ASSEMBLY AND JOINING MATERIALS	61
5.3.1	Active versus Passive Components	46	7.1	Introduction	61
5.3.2	Discrete versus Integrated Components	46	7.2	Presoldering Chemicals	62
5.4	Through Hole versus Surface Mount Components	46	7.2.1	Metal Surface Activating Solutions	62
5.4.1	Through Hole Lead Components	47	7.2.2	Solder Mask	63
5.4.2	Surface Mount - Leadless Components	47	7.2.3	Protective Coatings	63
5.4.3	Surface Mount - Leaded Components	47	7.3	Solder Fluxes	64
5.5	Electronic Assemblies	47	7.3.1	Choosing the Proper Flux	64
5.6	Packaging of Component	47	7.3.2	Flux Types	64
5.7	Printed Circuit Board Connectors	47	7.3.3	Rosin/Resin Fluxes (RO or RE Classification)	65
5.7.1	Printed Circuit Board Connector Selection	47	7.3.4	“No Clean” Fluxes	66
5.8	Sockets	48	7.3.5	Organic Fluxes (OR Classification)	66
5.9	Test Points and Test Jacks	49	7.3.6	Inorganic Fluxes (IN Classification)	67
5.10	Design and Assembly Process Implementation for BGAs (IPC-7095)	50	7.3.7	Topping Oils	67
5.10.1	Scope	50	7.4	Solder	67
5.10.2	Purpose	50	7.4.1	Solder Alloy Selection	67
5.11	Design and Assembly Process Implementation for Bottom Termination Components (BTC) (IPC-7093)	50	7.4.2	Economics	68
5.12	Design and Assembly Process Implementation for Flip Chips (IPC-7094)	50	7.4.3	Processing and Application	69
5.13	Counterfeit Electronic Components and/or Counterfeit Mechanical Fasteners	50	7.4.4	Solder Specifications	69
5.13.1	Counterfeit Mechanical Fasteners	50	7.5	Low Temperature Solder Alloys	70
5.13.2	Counterfeit Electronic Components	51	7.5.1	Applications	70
6	SOLDERABILITY	52	7.5.2	Forms and Techniques	72
6.1	Introduction	52	7.5.3	Wave Soldering	72
6.2	Inherent Solderability	53	7.5.4	Special Considerations	73
6.3	Surface Finishes	54	7.6	Traditional Solder Alloys	73
6.3.1	Organic Surface Finishes	54	7.6.1	High Temperature Soldering Flux	74
6.3.2	Soluble Finishes	54	7.6.2	High Temperature Stripping and Tinning	74
6.3.3	Fusible Finishes	54	7.7	Lead-Free Solder Alloys	75
6.3.4	Barrier Underplate	54	7.8	Solder Paste	88
6.4	Degradation of Solderability	54	7.8.1	Solder Paste Alloys	88
6.5	Accelerated Conditioning	56	7.8.2	Test Methods to Evaluate Solder Paste Properties	89
			7.8.3	Solder Paste Application	89
			7.9	Solder Preforms	89
			7.9.1	Solder Preform Alloys	90
			7.9.2	Designing Solder Preforms	90

7.9.3	Preform Heating	91	8.6	Component Characteristics, Through-Hole	116
7.10	Adhesive Materials	91	8.6.1	Axial-Leaded Discrete Components	116
7.10.1	Epoxy Adhesives	91	8.6.2	Radial-Leaded Discrete Components	116
7.10.2	Silicone Adhesives	92	8.6.3	Dual-Inline Packages	117
7.10.3	Polyurethane	92	8.6.4	Single-Inline Packages	117
7.10.4	Acrylic Adhesives	92	8.6.5	Ribbon-Lead Components	117
7.10.5	Cyanoacrylates	93	8.6.6	Pin Grid Arrays	117
7.10.6	Electrically Conductive Adhesives	93	8.6.7	Through-Hole Connectors	117
7.10.7	Surface Mount Adhesives	94	8.6.8	Through-Hole Sockets	120
7.10.8	Thermally Conductive Adhesives	94	8.7	Assembly Sequence, Through-Hole	121
7.10.9	Cure Verification	94	8.7.1	Process Steps	121
7.10.10	Workmanship Verification	94	8.7.2	Component Placement	131
7.11	Tin Whiskers	94	8.7.3	Vertical Mounting	132
7.11.1	Executive Summary	94	8.7.4	Mixed Technology	135
7.11.2	General Guidelines for Migrating to RoHS Compliant Finishes	95	8.7.5	Manual Techniques	135
7.11.3	Electronic Component Lead and Terminal Finishes	99	8.7.6	Automated Techniques	135
7.11.4	Separable Connectors	101	8.8	Temporary Masking Guidelines	138
7.11.5	Bus Bars	102	8.9	Surface Mount	138
7.11.6	Heat Sinks	103	8.9.1	Assembly Hierarchy	138
7.11.7	Printed Circuit Boards (PCB)	103	8.9.2	Manual Assembly Techniques	145
7.11.8	How Can I Tell If A Component Contains A Tin-Finish?	104	8.9.3	Automated Assembly Techniques	145
7.11.9	Testing to Detect the Presence of Various Metals that may, or may not be Present in a Component Lead/ Termination Finish	104	9	SOLDERING	147
7.11.10	Energy Dispersive Spectroscopy	104	9.1	Introduction	147
8	COMPONENT MOUNTING	107	9.1.1	The Process of Wetting	147
8.1	Assembly Classifications	107	9.1.2	Wetting and Solderability	147
8.1.1	Producibility Levels	107	9.1.3	Solder	148
8.1.2	Printed Circuit Board Assembly Types	107	9.2	Solder Alloys	148
8.2	General Guidelines	108	9.2.1	Structure of the Solder Bond	148
8.2.1	Design Options and Considerations	108	9.2.2	Intermetallic Growth Rates	149
8.2.2	Assembly Considerations	109	9.2.3	Factors Affecting Physical Properties of Solder Alloys	149
8.3	Other Mounting Structure Materials and Considerations	112	9.2.4	Strain Rate Effects	150
8.3.1	Heat Sinks	112	9.2.5	“Grain Size” Effects	152
8.3.2	Spacers	112	9.2.6	Lead-Free Soldering: Process Considerations:	154
8.3.3	Component-Lead Spreaders	113	9.3	Gold Removal	156
8.3.4	Thermally Conductive Insulators	113	9.3.1	Reason for Gold Removal	156
8.4	Assembly Design Cycle	113	9.4	Solder Purity	157
8.5	Placement Guidelines	114	9.4.1	Reasons for Testing	157
8.5.1	Construction Formats and Process Sequences	114	9.4.2	Testing Frequency	157
8.5.2	Automated Assembly	115	9.4.3	Copper	157
			9.4.4	Gold	157
			9.4.5	Cadmium	157
			9.4.6	Zinc	158
			9.4.7	Aluminum	158

9.4.8	Antimony	158	9.18.2	Meniscus in Solder	168
9.4.9	Iron	158	9.18.3	Interfacial Connection Without Lead - Vias	168
9.4.10	Arsenic	158	9.18.4	Hole Obstruction	168
9.4.11	Bismuth	158	9.19	Machine Soldering	169
9.4.12	Silver	158	9.19.1	Wave Soldering	169
9.4.13	Nickel	159	9.19.2	Machine Controls	169
9.4.14	Solder Pot Contamination	159	9.19.3	Fluxing	169
9.4.15	Effect of Contamination on Solder Process	159	9.19.4	Foam Fluxing	169
9.4.16	Resolving Contamination Problems	159	9.19.5	Wave Fluxing	169
9.5	Tin Depletion	159	9.19.6	Brush Fluxing	170
9.6	Soldering Processes	159	9.19.7	Spray Fluxing	170
9.7	Manual/Hand Soldering	159	9.19.8	Preheating	170
9.7.1	Flux Application	159	9.19.9	The Solder Wave	170
9.8	Solder Application	160	9.19.10	Parabolic Wave	170
9.9	Hand Soldering	160	9.19.11	Bi-Directional Wide Wave	170
9.9.1	Heat Transfer Considerations	161	9.19.12	Asymmetrical (Sump) Wave	171
9.10	Temperature Control - Thermal Considerations for Components and Boards	162	9.19.13	Special Provisions	171
9.10.1	Heat Sinks	162	9.19.14	Printed Board Conveyors	171
9.11	Tip Selection	162	9.19.15	Pallet Conveyors	171
9.11.1	Tip Materials	162	9.19.16	Finger Conveyors	171
9.11.2	Soldering Iron Tip Selection	162	9.19.17	Outer Conveyors	171
9.11.3	Shape/Physical Configuration	162	9.19.18	Conveyor Control	171
9.11.4	Tip Maintenance	163	9.19.19	Inert Atmospheres	171
9.11.5	Soldering Iron Station Maintenance	163	9.19.20	Preparation Fluids	172
9.11.6	Extending Tip Life	163	9.19.21	System Considerations	173
9.12	Hand Soldering-Soldering Tools and Equipment	164	9.19.22	Design Considerations	173
9.13	Terminal Soldering	165	9.19.23	Process Control	173
9.13.1	Flared Flange Hardware	165	9.19.24	Maintenance	173
9.13.2	Shank Discontinuities	165	9.19.25	Solder Dross Reclamation and Recovery	175
9.13.3	Flared Flange Angles	165	9.19.26	Training	175
9.13.4	Terminal Mounting	165	9.19.27	Safety	175
9.13.5	General Requirements	166	9.20	Flow-Well/Minipot	175
9.14	Soldering To Terminals	166	9.21	Static Solder Pots	176
9.14.1	Turret and Hook Terminals	166	9.22	Selective Soldering	176
9.14.2	Bifurcated, Pierced or Perforated Terminals	166	9.22.1	Key Process Elements	176
9.14.3	Cup and Hollow Cylindrical Terminal Soldering	167	9.22.2	Process Expectations	176
9.15	Unsupported Holes	167	9.22.3	Process Optimization and Control	176
9.16	Supported Holes (PTH)	167	9.23	Reflow Soldering	176
9.17	Vertical Fill of Hole	167	9.23.1	The Test Assembly	177
9.18	PTH Mounted Components - Solder Conditions	168	9.23.2	Attachment of Thermocouples	177
9.18.1	Solder in Lead Bend	168	9.23.3	Baseline Profile	178
			9.23.4	PIN-In-PASTE	183
			9.23.5	Hold Down of Surface Mount Leads	183
			9.24	Other Reflow Soldering Methods	183

9.24.1	Hot Bar Reflow Soldering-Resistance “Hot Bar”/Pulse soldering	183	10.3.1	Component Mounting with Adhesives	205
9.24.2	Laser Reflow Soldering	184	10.3.2	Outer Lead Bonding with Anisotropic Adhesives	205
9.24.3	Vapor Phase Soldering	186	10.3.3	Thermally-Conductive Adhesive Bonding ..	205
9.24.4	IR Soldering	188	10.3.4	Adhesive Application	206
9.24.5	The IR Reflow Process	188	10.3.5	Curing	207
9.24.6	MVC Temperature Determination	193	10.3.6	Heat Sink Materials and Processing	207
9.24.7	Air/Atmosphere Quality	194	10.3.7	Adhesive Testing and Evaluation	209
9.24.8	Monitoring and Control	194	10.4	Mechanical Pressure Connections	211
9.24.9	Profiling Devices	194	10.4.1	Solderless Backplane Contact Terminations	212
9.24.10	Temperature Control	194	10.4.2	Solderless (Wire) Wrapping	213
9.24.11	Inert Atmosphere Operation	194	10.4.3	Conductive-Elastomer Pressure Connections	217
9.24.12	No-Clean Processing	194	11	CLEANLINESS REQUIREMENTS	219
9.24.13	Processing Bare Copper	195	11.1	Definitions	220
9.24.14	Inert Atmosphere Control	195	11.1.1	Solvency	220
9.24.15	Machine Selection	195	11.1.2	Solvent Solubility	220
9.24.16	Conveyor Type	195	11.1.3	Film Drying Characteristics	220
9.24.17	Wavelength	196	11.1.4	Soil Capacity	220
9.24.18	Longitudinal Process Temperature Profiles	196	11.1.5	Surface Tension or Solvent Wetting	220
9.24.19	Lateral Temperature Profiles	196	11.2	Historical Perspective on Cleaning	221
9.24.20	Other Concerns	197	11.3	Toxicity	221
9.24.21	Can the Equipment Do the Job?	197	11.4	Ultrasonic Cleaning	222
9.24.22	Critical Parameters for IR Process Control	197	11.5	Forms of Cleaning	222
9.25	SMT	197	11.5.1	Aqueous Cleaning	222
9.25.1	Surface Mount Assemblies Acceptance Requirements	197	11.5.2	Semi-Aqueous Cleaning	223
9.25.2	High Voltage or High Power Applications ..	197	11.5.3	Solvent Cleaning	223
9.25.3	Quality Assurance (Visual Inspection)	197	11.6	Cleaning Agent Considerations	223
9.26	Process Verification Inspection	198	11.6.1	Types of Solvents	223
9.26.1	Magnification Aids and Lighting	198	11.6.2	Cleaning Agent Compatibility	224
9.26.2	Sampling Inspection - Process Control	198	11.6.3	Vented Components	224
9.26.3	Statistical Process Control (SPC) - Refer to IPC-9101	198	11.7	Cleaning Agent Delivery Considerations	224
9.3	Reference	198	11.7.1	In-Line Cleaning	224
10	OTHER ASSEMBLY AND JOINING METHODS	199	11.7.2	Batch Cleaning	224
10.1	Wire Bonding (Chip and Wire)	199	11.7.3	Interim or Spot Cleaning	224
10.1.1	Thermocompression (TC) Bonding	199	11.7.4	Vapor Degreasing	224
10.1.2	Ultrasonic Bonding	200	11.7.5	Ultrasonic Cleaning	224
10.1.3	Thermosonic (TS) Bonding	202	11.7.6	Cleaning Process Development	225
10.1.4	Choice of Wire Bonding Method	202	11.7.7	Removal of Contaminants from Underneath Parts	225
10.2	Tape Automated Bonding (TAB)	203	11.8	Cleaning requirements	225
10.2.1	Inner Lead Bonding (ILB)	204	11.8.1	Pre-Soldering Cleanliness Requirements	225
10.2.2	Outer Lead Bonding (OLB)	204	11.8.2	Post-Soldering Cleaning	225
10.3	Polymer Bonding	205	11.8.3	Particulate Matter	225
			11.9	Cleanliness Verification	226

11.9.1	Visual Inspection	226	13.4.13	Hybrid	241
11.10	Post-Soldering Cleanliness Designator	226	13.4.14	Hydrophobic-Oleophobic Encapsulations ...	241
11.11	Tests for Cleanliness	227	13.4.15	Inhibition	241
11.11.1	Residual Rosin	227	13.4.16	Mealing	241
11.11.2	Ionic Cleanliness (ROSE)	227	13.4.17	Monomer	241
11.11.3	SIR Testing	230	13.4.18	Multi-Layering	241
11.11.4	Surface Organic Contaminants	230	13.4.19	Oligomer	241
11.11.5	Other Residue Tests	230	13.4.20	Photoresist	241
11.11.6	UV-Vis Spectroscopy	230	13.4.21	Polymer	241
11.11.7	A General Caution on Extraction- Based Tests	231	13.4.22	Polymerization	241
11.11.8	Other Contamination	231	13.4.23	Polysiloxane	241
11.11.9	Other Analytical Tests	231	13.4.24	Pot Life	241
11.11.10	Cleanliness Testing for No Clean Assemblies	233	13.4.25	Priming	242
11.12	Other Guidance on Cleaning	234	13.4.26	Shadowing	242
12	CONFORMAL COATING	234	13.4.27	Shrinkage	242
12.1	Function of Conformal Coating	234	13.4.28	Spectroscopy	242
12.2	Conformal Coating Specifications	234	13.4.29	Stripping	242
12.3	Kinds of Conformal Coating	235	13.4.30	Surface Tension	242
12.4	Finding a Qualified Conformal Coating	235	13.4.31	Transfer Efficiency	242
12.5	Advantage and Disadvantages	235	13.4.32	Wetting	242
12.6	Storage and Shelf Life	236	13.4.33	Young's Modulus	242
12.7	Surface Preparation	236	13.5	Environmental, Health and Safety Considerations	242
12.8	Application Methods	237	13.5.1	Emissions	242
12.9	Curing Methods	237	13.5.2	Disposal of Hazardous Waste	242
12.10	Process Control	237	13.5.3	Governmental Regulations	242
12.11	Coating Defects	237	13.6	Types of Encapsulation	242
12.12	Coating Rework	237	13.6.1	Acrylic	243
13	POTTING AND ENCAPSULATION	240	13.6.2	Epoxy	243
13.1	Introduction	240	13.6.3	Silicone	243
13.2	Purpose	240	13.6.4	Polyurethane & Polysulfide	243
13.3	Scope	240	13.6.5	UV and Solvent Cure	243
13.4	Terms and Definitions	240	13.7	Design for Encapsulation Application	244
13.4.1	Adhesion Promotion	240	13.7.1	Design Philosophy	244
13.4.2	Adhesion Failure	240	13.7.2	PCBs	244
13.4.3	Anisotropic	240	13.7.3	Component	245
13.4.4	AFUK	241	13.7.4	Electrical	246
13.4.5	Cross-linking	241	13.7.5	Encapsulation Coverage	247
13.4.6	Cure	241	13.7.6	Masking	247
13.4.7	Delamination	241	13.7.7	Drawings & Design Guidelines	247
13.4.8	Durometer	241	13.7.8	Reworkability/Repairability	248
13.4.9	EMC	241	13.8	Raw Materials Characteristics	248
13.4.10	Filler	241	13.8.1	Viscosity	248
13.4.11	Gel Time	241	13.8.2	Viscosity vs. Rheology	248
13.4.12	Glass Transition Temperature T_g	241	13.8.3	Effect of Temperature on Viscosity	248
			13.8.4	Surface Properties	248

13.9	Compatibility	248	13.15.4	Environmental, Health and Safety Rework and Repair Considerations	266
13.9.1	Compatibility with Process	248	13.16	End Use Environment	267
13.9.2	Inhibition	250	13.16.1	Outdoor Environment	267
13.10	Adhesion	251	13.16.2	Automotive	268
13.10.1	Solder Mask/Substrate	251	13.16.3	Avionics Environment	268
13.10.2	Components	251	13.16.4	Space Environment	268
13.10.3	Surface Finishes	252	13.16.5	Medical Environment	269
13.10.4	Cleanliness	252	13.16.6	Geothermal Environment	269
13.10.5	Interlayer Adhesion	252	13.16.7	Nuclear Biological Chemical Warfare Environment	269
13.11	Methods of Assessing Compatibility and Performance	252	13.17	Long Term Reliability and Testing	269
13.12	Processing	253	13.17.1	Failure Mechanism	269
13.12.1	Cleanliness	253	13.17.2	Accelerated Testing	271
13.13	Processing Environment	254	13.18	Bibliography	271
13.13.1	Substrate Preparation	254	14	REWORK AND REPAIR	272
13.13.2	Priming	254	14.1	General Information and Common Procedure	272
13.13.3	Plasma Treatment	255	14.1.1	Scope	272
13.13.4	Mechanical Etching	255	14.1.2	Purpose	272
13.13.5	Masking	255	14.1.3	Background	272
13.13.6	Manual vs. Automated Masking	256	14.1.4	Terms and Definitions	272
13.13.7	Recommended Coverage	257	14.1.5	Applicability, Controls and Acceptability ...	274
13.13.8	Application Methods	257	14.1.6	Basic Considerations	274
13.13.9	Cure Mechanisms	257	14.1.7	Workstations, Tools, Materials and Processes	274
13.13.10	Cure Process Considerations	258	14.1.9	Lead Free	279
13.13.11	Application Process Monitoring	258	14.2	Handling Electronic Assemblies - See Chapter 2 of this document.	280
13.13.12	Inspection Guidelines	259	14.3	Cleaning - See Chapter 11 of this document.	280
13.13.13	Environmental, Health and Safety Processing Considerations	259	14.4	Coating Removal	280
13.14	Encapsulation Properties	259	14.4.1	Coating Removal, Identification of Conformal Coating	280
13.14.1	Appearance/Color	260	14.4.2	Coating Removal, Solvent Method.....	281
13.14.2	Dielectric Properties	260	14.4.3	Coating Removal, Peeling Method.....	282
13.14.3	Thermal Properties	260	14.4.4	Coating Removal, Thermal Method	282
13.14.4	Flammability	261	14.4.5	Coating Removal, Grinding/ Scraping Method	283
13.14.5	Flexibility	261	14.4.6	Coating Removal, Micro Blasting Method	283
13.14.6	Abrasion Resistance	262	14.5	Replacement of Conformal Coating	283
13.14.7	Hydrolytic Stability	262	14.5.1	Coating Replacement, Solder Resist.....	283
13.14.8	Permeability	262	14.5.2	Coating Replacement, Conformal Coatings/Encapsulants	284
13.14.9	Chemical Compatibility and Chemical Resistance	262	14.6	Conditioning – Baking and Preheating	284
13.14.10	UV Stability	263	14.7	Epoxy Mixing and Handling	284
13.14.11	Radiation Resistance	263	14.8	Legends/Markings	285
13.14.12	Outgassing	264			
13.15	Rework and Repair	264			
13.15.1	Removal Methods	264			
13.15.2	Cleaning after Stripping	266			
13.15.3	Re-Encapsulation	266			

14.8.1	Stamping Method	285
14.8.2	Hand Lettering.....	285
14.8.3	Stencil Method	285
14.9	Tip Care and Maintenance.....	285
14.10	IPC-7711 Rework Procedures.....	286
14.11	IPC-7721 Modification and Repair.....	288

Figures

Figure 2-1	J-STD-075 Process Flow Diagram	17
Figure 3-1	Component Orientation with Respect to Boundaries and Mounting Accessibility	22
Figure 3-2	Uncoated Printed Board Clearance	23
Figure 3-3	Lead Terminations	24
Figure 3-4	Clinched Through Hole Leads	26
Figure 3-5	Dual-Inline Package (DIP) Lead Bends	26
Figure 3-6	Lead Forming and Stress Relief Lead Bends	27
Figure 3-7	Component Mounting Configurations	27
Figure 3-8	Through Hole Flat-Pack Mounting with Staggered Plated Through Holes	29
Figure 3-9	Modified Fan-Out Lands, mm [in]	30
Figure 3-10	Custom-Grid Fan-out Land Pattern	30
Figure 3-11	Gull Wing Flat Pack Surface Mounting	31
Figure 3-12	Flat-Pack Lead Forming for (Planar) Surface Mounting	31
Figure 3-13	Surface-Mount Flat Ribbon Lead Features	31
Figure 3-14	Coined Round Leads	32
Figure 4-1	HASL Surface Topology Comparison	45
Figure 5-1	One-Part Printed Circuit Board Connector	48
Figure 5-2	Printed Circuit Board with Edge-Board Contacts	48
Figure 5-3	Typical One-Part Connector with Blow Contacts	48
Figure 5-4	Typical One-Part Connector Turret-Fork Contacts	48
Figure 5-5	Typical One-Part Connector Cantilever Contacts	48
Figure 5-6	Typical One-Part Connector Readout Configuration	49
Figure 5-7	Typical Two-Part Blade-and-Fork Contacts	49
Figure 5-8	Typical Zero-insertion-Force (ZIF) Pin-Grid Array Socket	49
Figure 5-9	Typical Printed Board Test Points	49
Figure 6-1	Resolution of Selected Elements in Sn/Pb Solder	55
Figure 6-2	Intermetallic Growth Rates	55
Figure 6-3	Comparison of Oxidized and Non-oxidized Sn/Pb Surface Finish	56
Figure 6-4	Schematic of the Wetting Balance Test	58
Figure 6-5	Idealized Wetting Balance Curve	59
Figure 7-1	Tin Lead Phase Diagram	68

Figure 7-2	Tin allotropic crystallographic structure; (left) tetragonal β -tin, (right) cubic α -tin	69
Figure 7-3	Tin Pest Transformation from Sweatman et al Investigation	70
Figure 7-4	Solder Wire Core Flux Comparison	76
Figure 7-5	Solder Alloy Solidification Example: Blue line - Eutectic, Red line - Non-Eutectic	76
Figure 7-6	Solder Alloy Fracture Toughness Testing Results	77
Figure 7-7	Solder Alloy Drop Shock Testing Results	77
Figure 7-8	NASA Tin-Whisker Photograph	105
Figure 7-9	Tin Whiskers - Observed Problems Caused by Whiskers	105
Figure 7-10	Additional Tin Whisker Problems	106
Figure 8-1	Type 1 Printed Board Assembly	107
Figure 8-2	Type 2 Printed Board Assembly	108
Figure 8-3	Staggered Hole Pattern Mounting "MO" Flatpack Outline Drawing (Only Inches Shown)	110
Figure 8-4	Component Modification for Surface Mounting Applications	110
Figure 8-5	Modifying DIP for Surface Mounting	110
Figure 8-6	Mixed Assemblies	111
Figure 8-7	Clin-Mounted Component	112
Figure 8-8	Strap Securing	112
Figure 8-9	Typical Spacers	113
Figure 8-10	Transistor Mounting with Spacer	113
Figure 8-11	Multiple Lead Spreader	113
Figure 8-12	Thermally Conductive Insulator	113
Figure 8-13	Single-Sided Surface Mount Assembly, Reflow Only	114
Figure 8-14	Single-Sided Surface Mount Assembly, Immersion Only	114
Figure 8-15	Mixed Technology Assembly, Double-Sided, Reflow Only	114
Figure 8-16	Mixed Technology Assembly, Double-Sided: Reflow and Immersion	115
Figure 8-17	Mixed Technology Assembly, Double-Sided Reflow and Manual	115
Figure 8-18	Mixed Technology Assembly, Double-Sided, Immersion Only	115
Figure 8-19	Panel Assembly Tooling Holes	116
Figure 8-20	Panel Assembly Tooling Holes	116
Figure 8-21	Taped Axial-Leaded Components	116
Figure 8-22	Polarized Axial Lead Component (Typical Polarity Markings)	116
Figure 8-23	16-Lead Dip	117
Figure 8-24	Flatpack Outline Drawing	118
Figure 8-25	Typical Ribbon Leaded Discrete Device Outline Drawing (Flat Leads)	118
Figure 8-26	Pin Grid Array	119
Figure 8-27	I/O Density Versus Lead Count (All Dimensions in Inches)	119
Figure 8-28	Connector with Press Fit Contacts	119

Figure 8-29	Surface Mount Clip Carrier Socket	120	Figure 8-71	DIP Clearances	137
Figure 8-30	Section Through Socket Solder Contact	120	Figure 8-73	DIP Slide Magazines	138
Figure 8-31	Component Mounting Sequence	122	Figure 8-74	No Bridging	139
Figure 8-32	Thermal Shunt	123	Figure 8-75	Lead Forming for Surface Mounting	139
Figure 8-33	Termination Examples	123	Figure 8-76	Criteria for Lead Attachment to Leadless Type A (Leaded Type B)	140
Figure 8-34	Clinch Patterns	125	Figure 8-77	SO-16 Package Drawings Typical Dimension	140
Figure 8-35	Semiclinched Lead	125	Figure 8-78	Typical SOT Packages	141
Figure 8-36	Lead Diameter Versus Bend Radius	126	Figure 8-79	Modifying DIP for Surface Mounting	141
Figure 8-37	Bend Configuration	127	Figure 8-80	Gull-Wing Lead for SIP-Type Component	141
Figure 8-38	Simple-Offset Preformed Lead	127	Figure 8-81	Surface Mount Receptacle	142
Figure 8-39	Dimple Preformed Leads	127	Figure 8-82	Surface Mount Connector	142
Figure 8-40	Compound Lead Form Examples	127	Figure 8-83	D-Subminiature Surface Mount Connector	142
Figure 8-41	Stress Relief Leads	128	Figure 8-84	Box-Contact Surface Mount Connector	142
Figure 8-42	TO Can Lead Forming	128	Figure 8-85	Leadless Grid Array Socket	142
Figure 8-43	Dimple Preformed Leads	128	Figure 8-86	Surface Mount Clip Carrier Socket	142
Figure 8-44	Typical Mounting Pattern for 12-Lead Cans with Clinched Leads Mounting	128	Figure 8-87	High Speed Circuit Socket	143
Figure 8-45	Mechanical Mounting - Lead Forming	128	Figure 8-88	Snap Down Cover	143
Figure 8-46	Single-Inline Component	129	Figure 8-89	Pressure Mounted Socket	143
Figure 8-47	Lead Configuration (After Assembly)	129	Figure 8-90	Preferred Mounting Orientations	146
Figure 8-48	Resilient Spacer to Heat Sink Frame	129	Figure 9-1	Structure of a Solder Bond	148
Figure 8-49	Staggered Hole Pattern Mounting (Flatpack Outline Drawing)	130	Figure 9-2	Property Changes as a Function of Temperature	150
Figure 8-50	Component Mounting - Lead Forming	130	Figure 9-3	Stress Relaxation with Time and Temperature	151
Figure 8-51	Through-Hole Board Mounting with Unclinched Leads	130	Figure 9-4	Cylindrical Deformation Leading to Joint Failure	151
Figure 8-52	Through-Hole Mounting with Clinched Leads and Circumscribing Land	130	Figure 9-5	Property Change with Strain Rate	151
Figure 8-53	Through-Hole Mounting with Offset Land	130	Figure 9-6	Cyclic Shear Strain Range (Figure Courtesy of J.P. Clech)	151
Figure 8-54	Components Mounted Over Conductors	131	Figure 9-7	Solder Joint Grain Size Structure (As Soldered)	152
Figure 8-55	Hardware Clearance	132	Figure 9-8	Solder Joint Grain Size Structure (After accelerated Cycling)	152
Figure 8-56	Component Alignment	132	Figure 9-9	Solder Joint Grain Size Structure (After Field Failure)	152
Figure 8-57	Component Alignment	132	Figure 9-10	Schematic Diagrams of The Microstructure Formation in Lead-Free Paste - Lead-Free Solder Balls Under Reflow	153
Figure 8-58	Horizontal Mounting of Radial Leaded Component	133	Figure 9-11	A Lead-free BGA Microstructure; Left - As Reflowed, Right - After Thermal Cycling	153
Figure 8-59	Horizontal Mounting of Radial Leaded Component with Heat Sink	133	Figure 9-12	Solder Alloy Microstructure Differences: Left - Tin/lead Solder Alloy, Right: SAC305 Solder Alloy	153
Figure 8-60	Horizontal TO Mounting	133	Figure 9-13	Lead-free Solder Alloy/Component Surface Finish Incompatibility Example (Reference: D. Hillman and R. Wilcoxon, "JCAA/JG-PP Lead-free Solder Testing for High Reliability Applications: -55 °C to +125 °C Thermal Cycle Testing," SMTAI Conference, 2006) ...	154
Figure 8-61	Vertically Mounted Axial Lead Components ...	133	Figure 9-14	left: Non-uniform Solder Joint Microstructure, right: Incomplete Solder Joint Reflow (Head-on-Pillow)	155
Figure 8-62	Vertically Mounted Radial-Lead Components .	134			
Figure 8-63	Vertically Mounted Components Coating Meniscus	134			
Figure 8-64	Radial Components Mounting (Unsupported Holes)	134			
Figure 8-65	Offset Lead Can Mounting	134			
Figure 8-66	Offset Lead Can Mounting	134			
Figure 8-67	Metal Power-Package Transistor Mounted on Resilient Standoffs	134			
Figure 8-68	Dual-Inline Package Gripping Tools	136			
Figure 8-69	Transistor Assembly Tools	136			
Figure 8-70	Taping Specifications (only inches shown) ..	137			
Figure 8-72	DIP Layout in Rows and Columns	137			

Figure 9-15 Component Degradation Due to Lead-free Soldering Process Incompatibility 156

Figure 9-16 Lead-free Solder Alloy Attack of Wave Solder Equipment (Photograph Reference: “Pb-free Technology and the Necessary Changes in Soldering Process and Machine Technology,” H. Schlessmann, APEX 2002 Conference Proceedings) 156

Figure 9-17 Copper Erosion Due to Lead-free Soldering Processes 156

Figure 9-18 Lead-free Soldering Iron Tip Damage (Courtesy of Hakko) 163

Figure 9-19 Thermal Profile of a Soldering Iron Tip 164

Figure 9-20 Properly Wrapped Wires 166

Figure 9-21 Soldering To Terminals 166

Figure 9-22 Acceptable Soldered Cup 167

Figure 9-23 Wave Soldering Problems and Solutions Reference Chart 174

Figure 9-24 Typical Tin-Lead Reflow Soldering Thermal Profile 189

Figure 9-25 Typical Type RMA Flux Thermal Profile 190

Figure 9-26 Typical Type OA Flux Thermal Profile 191

Figure 9-27 Typical “No-Clean” Flux Thermal Profile 191

Figure 9-28 Typical Reactive Atmosphere Flux Thermal Profile 192

Figure 9-29 Lateral Temperature Profiles 196

Figure 10-1 Wire Bonding Variables 200

Figure 10-2 Mechanics of Thermocompression Wire Bonding 200

Figure 10-3 Mechanics of Ultrasonic Wire Bonding 201

Figure 10-4 Solderless Wire Wrap 214

Table 4-8 ENEPIG Surface Finish Advantages and Disadvantages 41

Table 4-9 Immersion Silver Surface Finish Advantages and Disadvantages 42

Table 4-10 Immersion Tin Surface Finish Advantages and Disadvantages 42

Table 4-11 OSP Surface Finish Advantages and Limitations 43

Table 6-1 Solderability of Some Common Surfaces 53

Table 6-2 Flux Compositions 60

Table 7-1 Types of Contaminants 61

Table 7-2 Flux Identification System 65

Table 7-3 Solder Alloys and Their Melting Points 68

Table 7-4 Alloy Properties 69

Table 7-5 Indium-Based Solder Alloys 71

Table 7-6 Bismuth-Based Solder Alloys 72

Table 7-7 Traditional Solder Alloys 73

Table 7-8 Lead-Free Solder Alloys 75

Table 7-9 Lead-Free Solder Alloys and Their Melting Temperatures 76

Table 7-10 Hewlett Packard Proposed Test Protocol for Pb-Free Solder Alloys 78

Table 7-11 Solder Powder Size Designations (JEITA-TD-005) 88

Table 7-12 Tin Whisker Mitigation 95

Table 7-13 Component Lead-Free Finishes (Tin Whisker Test Requirements) 100

Table 7-14 iNEMI Ratings for Whisker Risk on Termination Finishes for Separable Connectors 102

Table 7-15 Bus Bars - Tin Whisker Concerns 103

Table 7-16 Heat Sink Finishes and Tin Whiskers 103

Table 7-17 Printed Circuit Boards 104

Table 8-1 Lead Clinch Length 125

Table 9-1 Intermetallic Compounds and Diffusion Constants for Near-Eutectic SnPb Solders 149

Table 9-2 Common Physical Property Values for Lead-Free Solder 150

Table 9-3 Effect of Temperature on Lap Shear Strength PSI (Pa) 150

Table 9-4 Maximum Limits of Solder Bath Contaminant 158

Table 9-5 Soldering Process Comparison 160

Table 9-6 Hand Soldering Tools 161

Table 9-7 Unsupported Holes with Component Leads, Minimum Acceptable Conditions 168

Table 9-8 Supported Holes with Component Leads, Minimum Acceptable Conditions Note 168

Table 9-9 Problems and Solutions in Vapor Phase Soldering 187

Table 10-1 Wire Bonding Technologies 202

Table 10-2 K Values for Common Materials (watts/meter-°C) 206

Tables

Table 2-1 Typical Static Charge Sources 15

Table 2-2 Typical Static Voltage Generation 15

Table 2-3 General Rules for Handling Electronic Assemblies 15

Table 2-4 Wave Solder PSL Classification 18

Table 2-5 Reflow Solder PSL Classification 18

Table 2-6 PSL 3rd Character 19

Table 3-1 Integrated Circuit Packaging Technology Comparison 22

Table 4-1 PCB Typical Material Properties 33

Table 4-2 Cross Reference of Plastic Laminate Specifications 35

Table 4-3 Properties of Metallic Foils 36

Table 4-4 Final Finish and Coating Requirements 39

Table 4-5 Gold Plating Uses 40

Table 4-6 ENIG Surface Finish Advantages and Disadvantages 40

Table 4-7 ENIG/EG Surface Finish Advantages and Limitations 41

Table 10-3	Methods of Mounting Power Devices to Heat Sinks	208	Table 10-11	Solderless Wrap Wire/Terminal Size Relationships	215
Table 10-4	Thermal Greases and Their Properties	208	Table 10-12	Elastomeric Connector Troubleshooting Guide	219
Table 10-5	Physical Properties of Compressible Pads	209	Table 12-1	Comparison of Conformal Coating Materials ..	236
Table 10-6	Performance Properties of Electrically Insulating Epoxies and Acrylics	210	Table 13-1	Material Compatibility	251
Table 10-7	Standard Joining Material	210	Table 13-2	Temperature Classifications of Automotive Industry	268
Table 10-8	Alternate Joining Material Evaluation Test Method	210	Table 14-1	Conformal Coating Characteristics	280
Table 10-9	Number of Solderless (Wire) Wrap Turns	214	Table 14-2	Removal Method	280
Table 10-10	Solderless (Wire) Wrap Strip Force	215			

This Page Intentionally Left Blank

Assembly and Joining Handbook

IPC-AJ-820 OUTLINE

The purpose of this Assembly and Joining Handbook is to provide practical and useful information regarding various approaches and techniques for the interconnection of electronic components. The table of contents is an indication of the variety of data included in this document.

Chapter 1	Introduction
Chapter 2	Handling Electronic Assemblies
Chapter 3	Design Considerations
Chapter 4	Printed Boards
Chapter 5	Electronic Circuit Components
Chapter 6	Solderability
Chapter 7	Assembly and Joining Materials
Chapter 8	Component Mounting
Chapter 9	Solder Techniques and Connections
Chapter 10	Other Assembly and Joining Methods
Chapter 11	Cleaning and Cleanliness
Chapter 12	Conformal Coating (HDBK-830)
Chapter 13	Encapsulation and Potting
Chapter 14	Rework and Repair

1 SCOPE

This document provides guidelines and supporting information for manufacturing electronic assemblies. The intent is to explain the “how-to” and “why” information, and fundamentals for these processes.

Additional detailed information can be found in documents referenced within each individual section. Users are encouraged to use those referenced documents to better understand the applicable subject areas.

The words “shall,” “must,” etc., are used in various places within this handbook. However, nothing within this handbook is considered mandatory unless otherwise specified in the design or contract documentation. In event of a conflict between the content of this handbook and the requirements invoked by the design or contract documentation, the requirements of the design or contract documentation shall take precedence.

1.1 Assembly and Joining Technology Selection of appropriate assembly and joining techniques for electronic circuits should consider the requirements of the end product equipment and subassembly, including form, fit, function, cost effectiveness, performance, and marketability. Other factors include packaging density, assembly profile height, development time, development cost, circuit element factors, manufacturing costs, thermal considerations, reliability, and specific implementation details.

The assembly process steps differ according to the type of product being assembled, i.e., through-hole, surface mount, or mixed technology. They also vary according to manufacturer expertise, experience, and preference.

The selection of a particular method for mounting and terminating a component will also depend on the type of component (size, weight and shape), the equipment available for mounting and interconnecting, the connection method (e.g., soldering, welding, or crimping), the reliability and maintainability (ease of replacement) required, and of course, cost.

1.2 Through-Hole Technology The most significant advantage of through-hole mounting is compatibility with conventional mass soldering techniques, such as dip and wave soldering. One of the significant disadvantages is space. Through-hole parts usually take up a much larger footprint on the PWA than a similar surface mount component. They also require space on both sides of the board, as the leads protrude through to the opposite side.

1.3 Surface Mount Technology The most obvious benefits of surface mount technology (SMT) compared to older through-hole (THT) technology are increased circuit density and improved electrical performance. Less obvious benefits include lower process costs, higher product quality, reduced handling costs, and higher reliability.