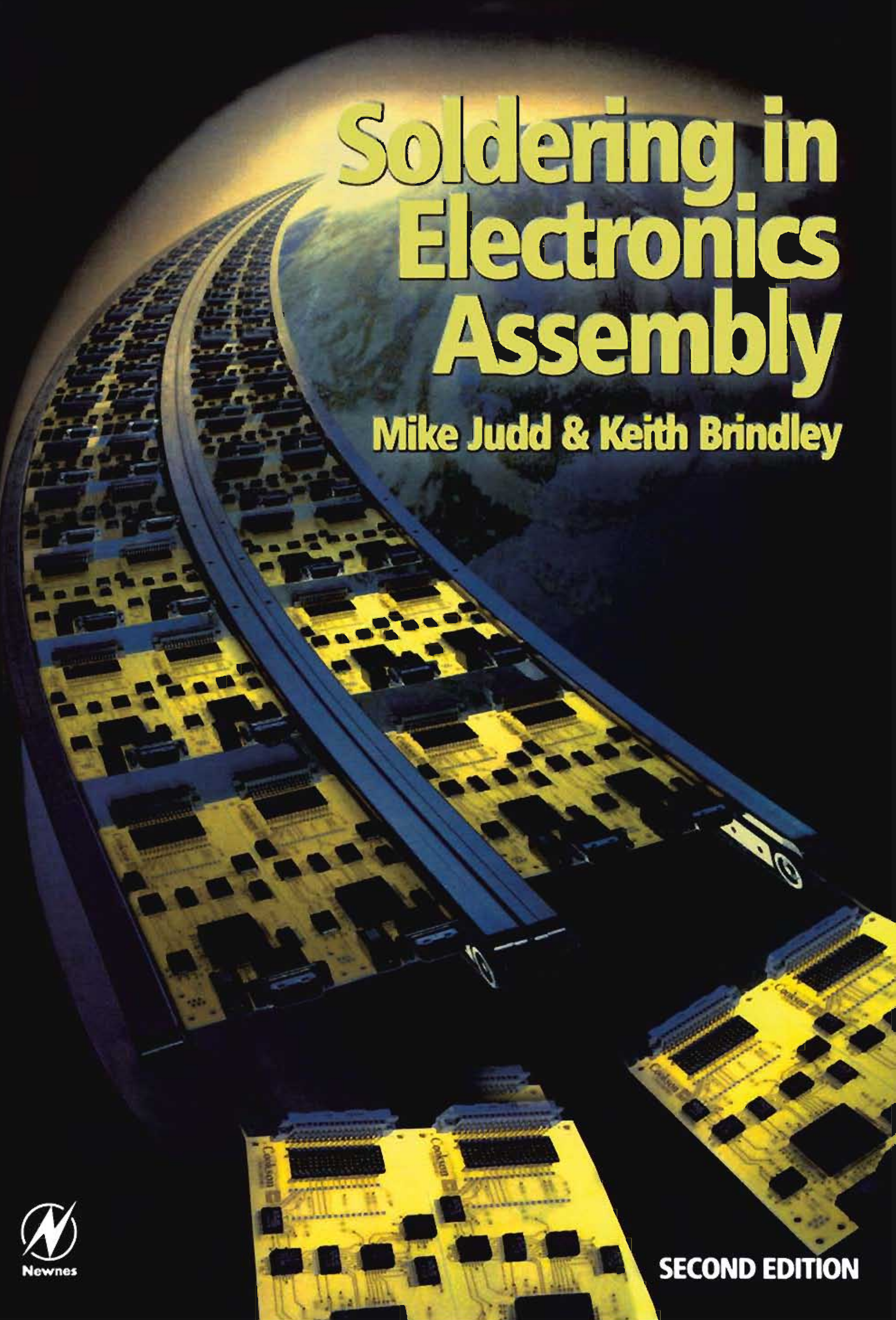

Soldering in Electronics Assembly

Mike Judd & Keith Brindley

Newnes

SECOND EDITION

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Foreword

by
David Crimp, Executive Vice President, Europe
Alpha Metals division of Cookson Electronics

As the World enters the third millennium we can look back over recent years and see the incredible advances made within our industry over a relatively short time. Not many years ago there were no computers, no CDs, no mobile telecommunications, and space travel was limited to science fiction — even radio networks have really only grown up within a lifetime. Much of the technology advances of our age have been made possible thanks to the innovation of the electronics industry which, with its development of new materials, machines and techniques, continues to grow on a global basis. We tend to take such things for granted, but now developing countries too are sharing in the electronics boom.

With further miniaturisation, increased board complexity and quality becoming even more critical, expertise in soldering assembly is a prerequisite, for both engineers and new recruits to the electronics business.

Soldering in electronics assembly is a complex skill, relying on the combination of personal expertise, quality materials, and efficient equipment. Quality management systems have helped raise the production yields, while equipment and materials technologies continue to keep abreast of the industry requirements. But behind all this are the engineers — and it's they, working with their suppliers, who are the key players in the growth of our industry in the future.

This book is written to provide a useful reference for engineers involved with the practical side of electronics assembly operations, and will prove interesting for a wide range of readers, in the broadest sectors of our industry.

I am pleased to be able to contribute to this important book, on behalf of Cookson Electronics. For over a century the electronics divisions within

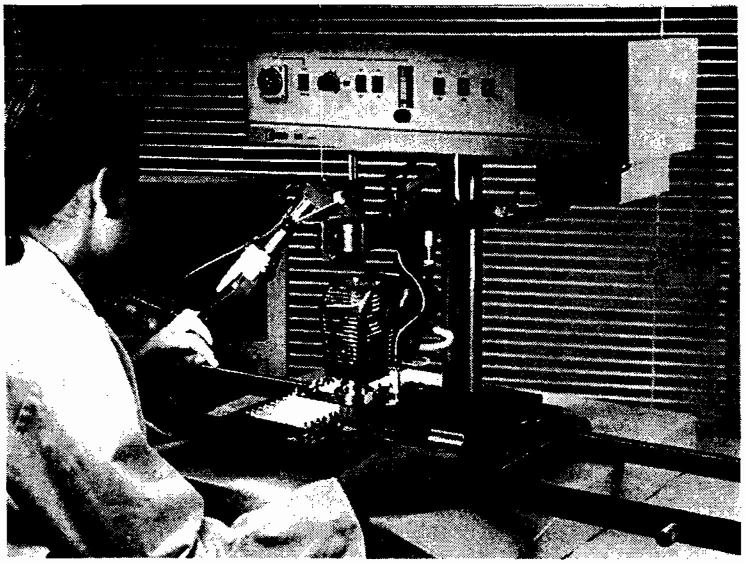


Photo 8.6 *Hot gas/air soldering machine, used typically in rework or individual component placement (Planer Industrial)*

- soldering irons — conventional soldering irons with specially shaped tips.

Comparison of soldering processes

All SC soldering processes are compared in Appendix 4, along with CS soldering processes.

Preface

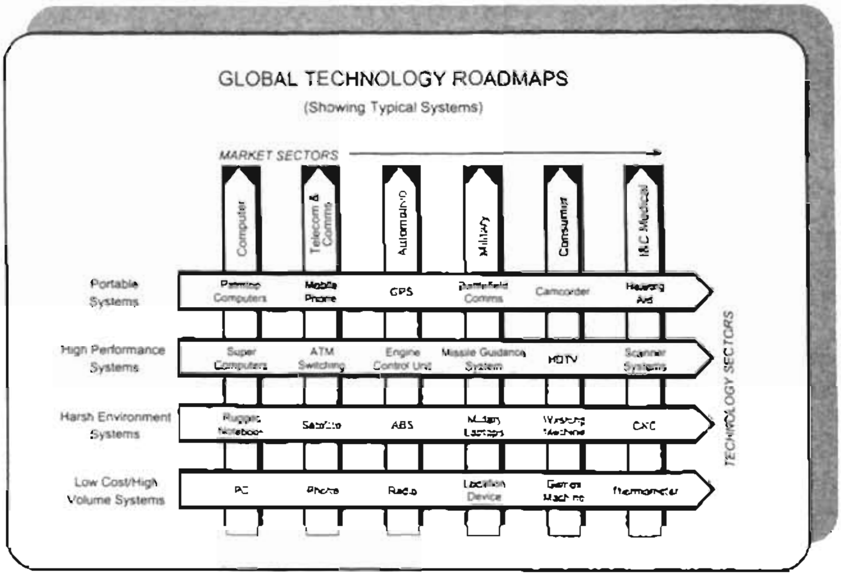
Electronics assembly is about components that are soldered onto a printed circuit board. Soldering, as a principle in electronics assembly, is straightforward and simple — two metal surfaces (component termination and a connecting pad on printed circuit board track) are joined by metallic bonds created by molten solder between them. Solder joints are supported by the solder when it solidifies, and the solder allows electrical contact between metals in the joints. Surface mounted components are changing, they are becoming smaller and lighter and in the case of ICs due to the increased demands of functionality, they also have a greater number of leads. This dimensional and weight change is driven by the increase in demand of portable products. Table 1 shows the growth in unit terms for portable products over the coming years.

The other sectors illustrated harsh environment, low cost/high value and high performance cut across the traditional market boundaries and focus more on the products technology requirement (Figure 1).

Increasingly, a number of companies are adopting one particular packaging strategy — that of small form-factor components ideal for portable products. These are increasingly being used in larger electronic systems such as exchanges, base stations etc as a company wishes to adopt one packaging strategy and hence assembly strategy for all types of products that they manufacture. This has obvious benefits with regards to stock holding

Table 1 Total equipment quantities by global technology roadmap sectors 1997–2007

	1997 *x 10^6*	%	*2002* *x 10^6*	%	*2007* *x 10^6*	%
Portables	1710	45.1	4480	57.2	7480	63.3
High performance	460	12.2	840	10.7	990	8.4
Harsh environment	275	7.3	670	8.6	1190	10.0
Low cost, high volume	1340	35.4	1840	23.5	2160	18.3
Total	3785	100.0	7830	100.0	11820	100.0

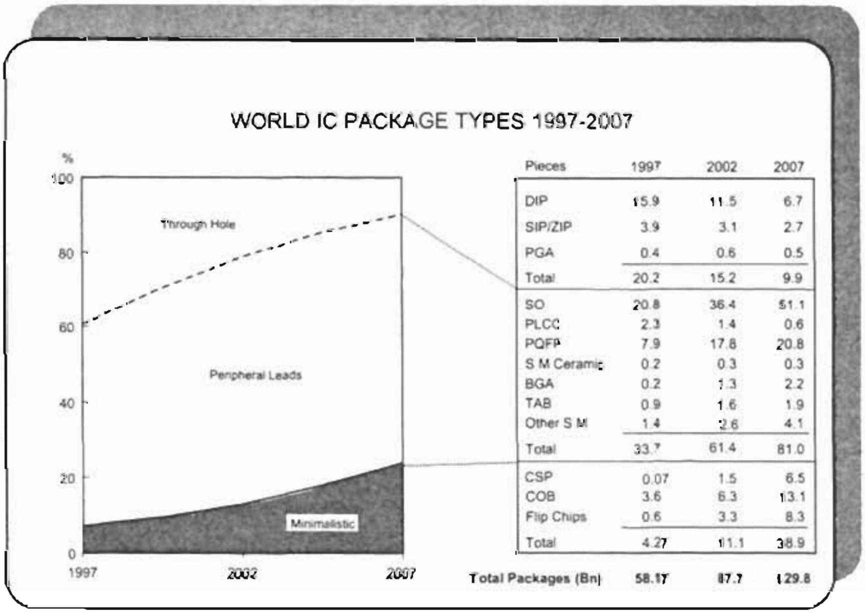


	Computer	Telecom & Comms	Automotive	Military	Consumer	I&C Medical
Portable Systems	Palmtop Computers	Mobile Phone	GPS	Battlefield Comms	Camcorder	Hearing Aid
High Performance Systems	Super Computers	ATM Switching	Engine Control Unit	Missile Guidance System	HDTV	Scanner Systems
Harsh Environment Systems	Rugged Notebook	Satellite	ABS	Military Laptops	Washing Machine	CNC
Low Cost/High Volume Systems	PC	Phone	Radio	Location Device	Games Machine	Thermometer

Figure 1 *Global technology roadmaps (BPA, 1998)*

and handling of parts as well as set up time for assembly equipment such as pick and place machines.

Figure 2 illustrates worldwide trends and movements away from through-hole components towards surface mount and a third format termed minimalist packaging. Minimalist packaging is the ultimate packaging technology. The future challenge for soldering and assembly technology is to manage the



Pieces	1997	2002	2007
DIP	15.9	11.5	6.7
SIP/ZIP	3.9	3.1	2.7
PGA	0.4	0.6	0.5
Total	20.2	15.2	9.9
SO	20.8	36.4	51.1
PLCC	2.3	1.4	0.6
PQFP	7.9	17.8	20.8
S M Ceramic	0.2	0.3	0.3
BGA	0.2	1.3	2.2
TAB	0.9	1.6	1.9
Other S M	1.4	2.6	4.1
Total	33.7	61.4	81.0
CSP	0.07	1.5	6.5
COB	3.6	6.3	13.1
Flip Chips	0.6	3.3	8.3
Total	4.27	11.1	38.9
Total Packages (Bn)	**58.17**	**87.7**	**129.8**

Figure 2 *Worldwide trends from through-hole components towards surface mounted components (BPA, 1998)*

attachment of through-hole, surface mount and minimalist packages on the same board. There are many instances where, particularly with through hole connectors, these older technology products will remain due to costs or robustness.

Small components and greater lead counts make soldering to printed circuit boards more and more difficult. New soldering techniques and modifications of existing techniques are required to meet the challenge of smaller surface mount and minimalist packages.

Our job in writing this book is to show all this. While looking at the principle of soldering, which has remained fixed since man first used molten metal to join two other metals (first known use of solder is Roman pipework, where sections of lead pipe were joined by melting their ends together), we also show how the techniques to fulfill the soldering process can change and, indeed, *are* changing with the requirements placed by components and printed circuit board assemblies on them.

More than anything else these days (and in the future), state of component and printed circuit board technologies means soldering has to be clean and precise. In the distant past, when components were huge and printed circuit board tracks were wide, soldering was often a case of throwing sufficient molten solder at a board to make an adequate joint. Joints were initially made by hand. This is no longer the case. With minute component terminations and tracks, too much solder can be devastating. On the other hand, too little solder will not make a joint at all. Even if economic considerations were not important, joints can no longer be made by hand because hand soldering cannot guarantee adequate results with such small joints. Control of soldering systems has to be precise and closely monitored. Soldering and, inevitably, its control must be performed by machines.

While it's impossible to summarize *all* we have to say, in this short preface, it *is* possible to make a list of points which our book, hopefully, spotlights. Overleaf we present the *10 rules of machine soldering.*

10 rules of machine soldering

1 machine soldering, correctly controlled, produces highest quality joints at lowest cost

2 machine soldering is a process and, like all processes, produces consistent results if properly controlled

3 touch-up of faulty soldered joints is costly, unreliable and unnecessary

4 anything that reduces solder joint defects is cost effective

5 design, handling, assembly and maintenance are *all* parts of the soldering process and must be properly controlled

6 solderability of printed circuit boards and components accounts for 60% of all faulty soldered joints

7 *never* use parts which fail solderability testing: the ultimate cost is too high

8 soldering problems are solved by process control — not more inspection and touch-up

9 everyone concerned with the soldering process must be formally and properly trained

10 zero-defect soldering is the lowest cost soldering.

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We'd like to thank a number of people who have helped us in major ways, as we have researched and written this book. In no particular order of priority, gratitude goes to:

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- Colin Lea; National Physical Laboratory, UK
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- Steve Harper; Speedline MPM, UK
- many people within the Electrovert group worldwide.

Finally, special thanks go to Bob Willis of Electronic Presentation Services in the UK, for help and guidance throughout.

This book is dedicated to a respected man, considered by many to be a guru in electronics soldering. Paul Bud, Technical Director of Electrovert is sadly missed. He was a kind man and a gentleman, always willing to listen and pass on his wide knowledge of soldering, communicating in many languages. He was an inspiration to us all.

In his memory, we hope the book proves helpful to all who read it.

The science of soldering has been known for many years. It is, indeed, a simple process of bringing parts to be joined together with solder, flux and heat. How to do this and to achieve a satisfactory result, though, is both a science and an *art*, when each by itself may vary. Methods and the principle used as years go by form a most fascinating subject.

Bob Willis, *Electronic Presentation Services*

Solder is truly a *magnificent trifle*, it gets little respect from management — yet it holds the entire electronics industry together. Thus another book on soldering is very welcome!

Howard H Manko, *Manko Associates*

After nearly 4000 years, soldering remains as much an art as a science. Progress is still accelerating in this field of electronic technology, forcing us — again and again — to rethink the idea of quality.

Soldering first forged weapons, but now it may help us develop intelligent machines towards assisting mankind in peaceful pursuits.

Armin Rahn, *rahn-tec Consultants*

The more we know about soldering electronics assemblies, the more we discover what we don't know. We may argue about the best solder fillet shapes, the benefits of controlling the solder joint microstructure, or the required cleanliness level of flux residues, but it is the practice of soldering that is of the essence: almost anyone can solder — but few can solder well.

Colin Lea, *National Physical Laboratory*

Printed wiring boards are the primary means of interconnecting circuit components. As such they have contributed greatly to the growth of electronics. Assembly and connection of printed wiring boards — also called printed circuits and etched wiring — involve a sequence of three basic operations. They are (1) manual or automatic insertion of electronic components, (2) metallurgical joining (soldering) of component leads or terminals to printed conductors, and, usually (3) a cleaning operation to remove flux and other residual contaminants.

In view of the interest of electronic equipment manufacturers in this subject and the increasing importance of electronics in industry and elsewhere, a review of the state of the art as it currently exists and discussion of the effects of recent developments in the field are in order.

Paul Bud (October 1980), then *Vice President of Electrovert Inc*

1 Soldering process

This chapter *could* be seen as just another introduction to soldering — it does, after all, explain in a fairly basic manner all important aspects of soldering in electronics assemblies. In this light many people may be tempted to skip it. However, this would be a mistake as it also explains philosophy behind the *complete* book. Further, it discusses main features and illustrates fundamental premises upon which we have based our text. Finally it also serves as a guide indicating where relevant and important information is to be found within the rest of the book. We strongly advise this chapter is looked at bearing all this in mind.

Soldering, in principle though not in practice, is a reasonably straightforward process, used in the electronics industry to bond components together, forming one or more electrical connections. From this description, it's easy to see that soldering serves two functions:

- mechanical support — holding components of an assembly together
- electrical support — forming required electrical connections within a circuit.

Most components in an assembly use the mechanical support of soldered joints alone to give adequate fixing into the assembly. A few isolated components (notably, larger, heavier components) may require additional mechanical support, in the form of straps, nuts, bolts and so on. Where possible, however, such large components should be *designed out* (that is, care should be taken when designing a circuit not to use such components) of an assembly to keep extra procedures and cost to a minimum.

On the other hand, all components may use solder as electrical support to form required electrical connections. No other method has yet been devised to take the place of solder in all assemblies to the same level of performance, cost and ease of operation.

Time on its side

Solder in one form or another has been around for a long time. The Romans are known to have used solder to form joints in their plumbing systems and, indeed, the word plumbing refers to the use of lead (from the Latin *plumbum* meaning lead) as a jointing compound. Nowadays, of course, pure lead plumbing is no longer considered, instead solder — which is an alloy of mostly tin and lead — is used. It's interesting to note that certain countries are already in the process of altering legislation to prevent lead being used in any plumbing where drinking water is present.

Solder has been adopted by the electronics industry as the best method of making joints within assemblies and, for many years, this jointing process was undertaken manually — hand soldering. Inevitably hand soldering is a slow, laborious, time-consuming and hence expensive process as each component must be soldered into position to the printed circuit board individually. Quality and repeatability of joints depend almost totally on the individual operator. This clearly makes cost of large-scale electronics assembly production uneconomical and unsatisfactory. Generally, therefore, hand soldering of electronics assemblies is undertaken only in development and prototype stages, although there remains a situation in which small-volume production of electronics assemblies is economical. Hand soldering is used regularly in rework stages of manufacture, where assemblies need to be partially disassembled for repair and service purposes. Because of this situation we need to consider hand soldering and so it is discussed in Chapter 7.

For the last 40 years or so, various methods of automating soldering processes have been developed. It's easy to see how vitally important automated soldering of assemblies has become, by remembering that the space programme of getting a man on the moon could not have been achieved without it.

Paul Bud, to whom this book is dedicated, related an interesting fact about NASA printed circuit boards used in spacecraft. Had NASA's assemblies been hand soldered, joints would have held more solder with the result that assemblies would have been 10% heavier. So many assemblies are used in spacecraft that with this additional weight, the three astronauts (totalling, say, 250 kg) could not have been carried!

Until just recently, however — say, the last ten years — soldering of really only one type of electronics assembly was in the main undertaken. This assembly type, a typical joint of which is illustrated in Figure 1.1, is commonly called the **through-hole printed circuit board**, simply because the components feature leads which are inserted through holes in the printed circuit board. Copper track interconnections exist between holes which make up the circuit of an assembly and component leads are soldered to the copper, so that mechanical and electrical support is provided with each solder joint. Note that, in this ideal joint, solder has been drawn inside the hole during the soldering operation — this occurs by capillary action. Solder between the copper track and the component lead is called the **fillet**.

Emergence of a different type of electronics assembly — **surface mounted assemblies** or SMAs — however, is altering the face of soldering processes used. So much is **surface mount technology** (SMT) changing soldering that, at present, somewhere around 50% of all electronics assemblies use at least a few **surface mounted components** (SMCs — also sometimes called **surface mounted devices** or SMDs). In 1980 the figure was, to all practical purposes outside of Japan, zero. This change in assembly technology has only been possible with developments bringing a parallel change in soldering technology. Changes in component technology, too, are pushing many companies along the surface mount route — a growing number of components simply cannot be obtained in through-hole forms and are only available as surface mounted components.

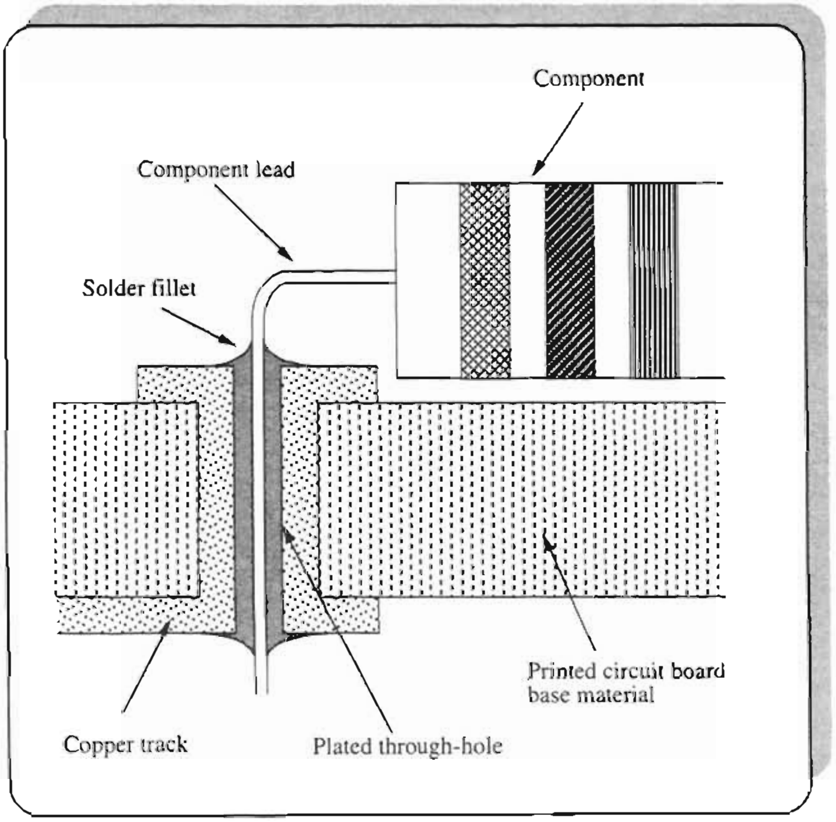


Figure 1.1 *Soldered joint formed between a component lead and copper track on a plated through-hole printed circuit board*

Figure 1.2 shows a typical surface mounted assembly joint, in which a surface mounted component is soldered to a printed circuit board. Difference between this and the through-hole assembly joint of Figure 1.1 is immediately apparent — surface mounted assemblies do not use holes to locate component leads prior to soldering. Indeed, surface mounted components do not have leads, a fact which prompts another descriptive term for them — **leadless components** — in contrast with components used in through-hole assemblies which are often called **leaded components**. While we're defining terms, we may as well go on to point out where leaded components are *inserted* into a printed circuit board, leadless components are loosely said to be *onserted* onto a board.

From this description it's easy to see that surface mount technology is based on a marriage of standard through-hole techniques with **hybrid** assembly techniques (hybrid assemblies are those in which film-based components are combined with leadless discrete components on a ceramic or similar substrate).

These two main assembly types are only categories, and within each category there are many variations, each with specific solder joint concerns and requirements. Relevant variations, joint types and solder processes are detailed in Chapter 2.

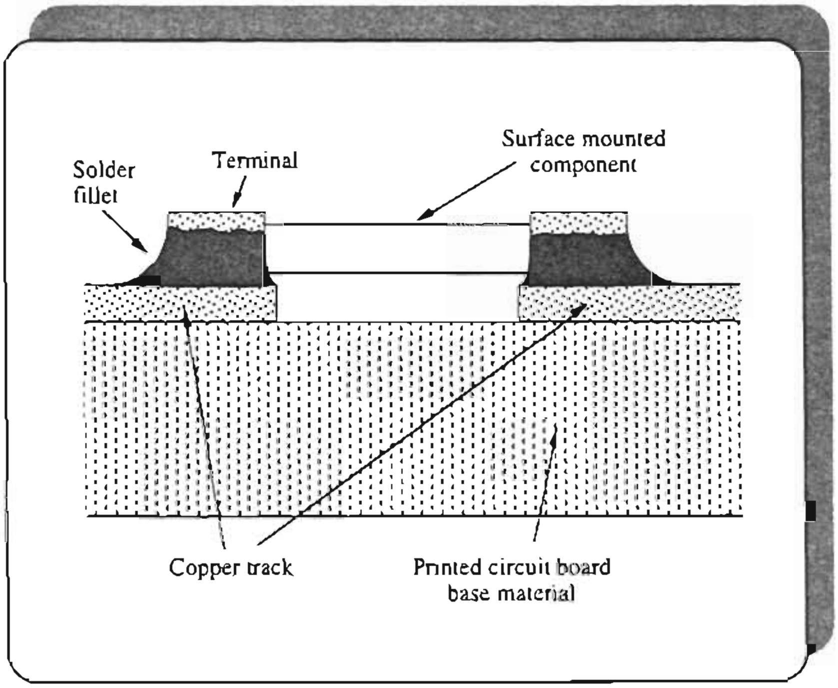


Figure 1.2 *Soldered joints formed between component terminals and copper track on a surface mount assembly printed circuit board*

Printed circuit board

Electronics assemblies are based on use of a printed circuit board of one form or another, to hold components. Construction of these printed circuit boards is critical to soldering processes, in that different printed circuit board types have different thermal characteristics, which can greatly affect how they must be soldered.

In principle, a printed circuit board (PCB), sometimes called a **printed wiring board** (PWB), or simply printed board, comprises: a **base**, which is a thin board of insulating material supporting all the components which make up a circuit; conducting **tracks**, usually copper, on one or both sides of the base making up the interconnections between components. Component connecting leads are electrically connected in some form of permanent or semi-permanent way, usually by soldering, to **lands**, sometimes called **pads** — the areas of track specially designated for component connection purposes. If lands have holes drilled or punched through the board to facilitate component mounting, the board is a through-hole printed circuit board. If lands have no holes the board is a surface mounted printed circuit board.

To clarify, the term *printed* is somewhat misleading, as tracks are *not* printed directly onto the board. It refers instead to just one stage within the whole printed circuit board manufacturing process, where the conducting track **layout**, sometimes called **pattern** or **image**, may be produced using some form of printing technique.

Printed circuit boards can be made in one of two main ways. First, in an **additive** process, the conductive track may be added to the surface of the base material. There's a number of ways in which this can be done. Second, in a **subtractive** process, where base material is supplied with its whole surface covered with a conductive layer, track pattern is defined, and excess conductive material is removed, leaving the required track. Sometimes, both processes may be combined to produce printed circuit boards with more than one layer of conductive track.

Printed circuit board types

There are three main categories of printed circuit boards:

- **single-sided** — in which copper track is on just one side of the insulating base material. In a through-hole single-sided printed circuit board (Figure 1.3a), components are situated on the non-track side of the circuit board while their leads go through the through-holes to the other side, where they are soldered to lands. In a surface mounted printed circuit board,

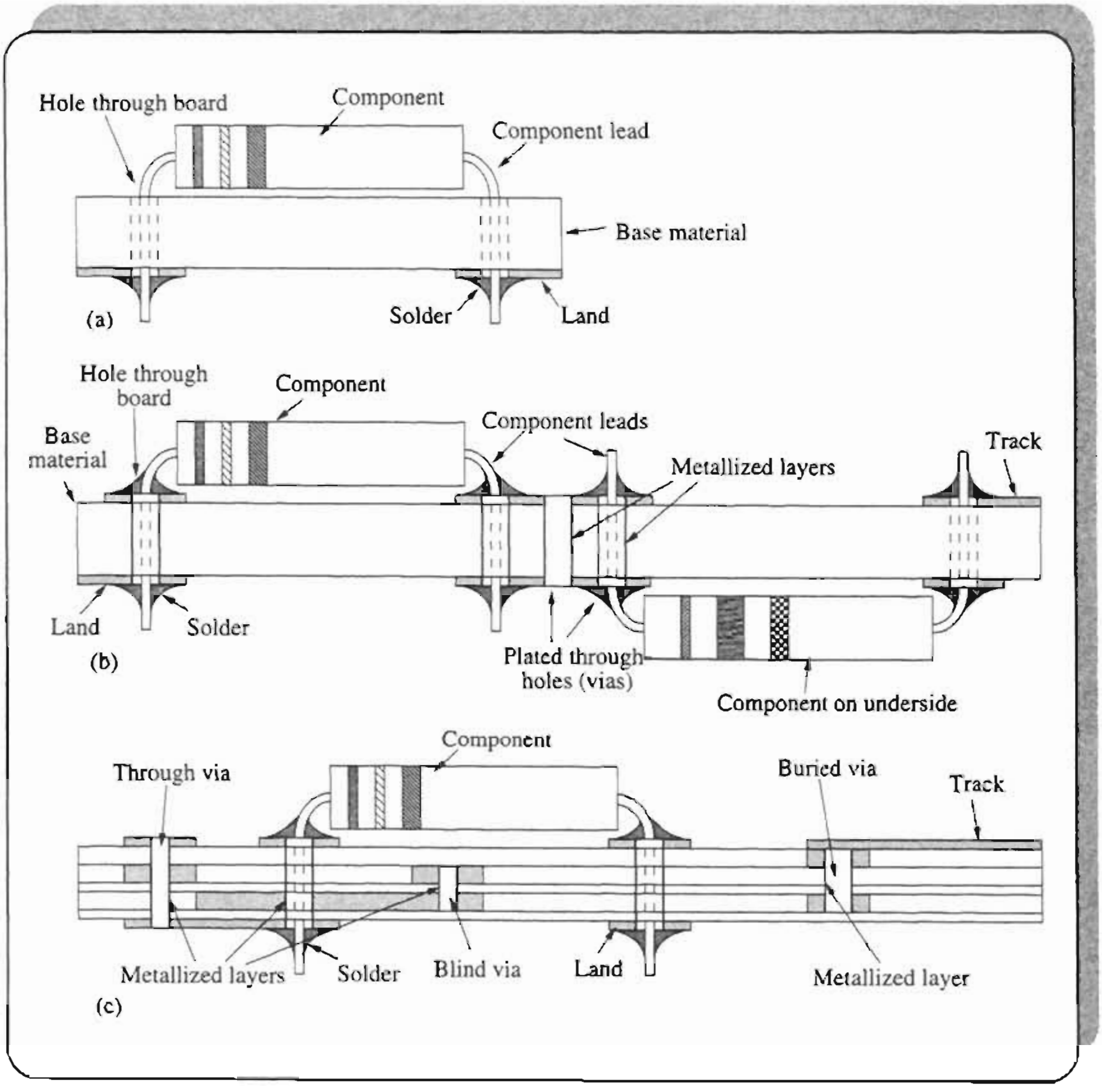


Figure 1.3 *Three main categories of printed circuit board (a) single-sided: track is present on only one side of the base and components are usually mounted on the other. Component leads connect through holes in the board to lands in the track (b) double-sided: track is on both sides of the board. Components are usually on just one side, but might be on both. Metallized holes or vias through the board are used to connect track on each side (c) multi-layered: tracks are layered and laminated together. Components may be on one or both sides. Vias are used to connect between layers*

components — and their leads or terminals — are situated on the same side of the board as the copper track

- **double-sided** — in which copper track is on both sides of the insulating base material. In a through-hole double-sided assembly, components are usually (though not always) situated on just one side, and soldered on the other (Figure 1.3b). Where through-holes are required to interconnect top and bottom copper track layers, they are plated inside hole barrels with copper, and are called plated through vias. Where a component lead also goes through a via it is called a plated through-hole (PTHs).

In a surface mounted double-sided assembly, components are on the same side as boards are soldered. Components may be mounted on both sides of the board. Note, however, a circuit track on one side of the board is not connected to track on the other side unless plated through-holes are used

- **multi-layered** — in which several circuit track layers are incorporated into a single board, laminated together with insulating layers between each copper layer. (Figure 1.3c). Plated through-holes can be used for either component terminal connection, or purely as electrical connections (in which case they are called **vias**). Vias passing from one outside track to the other are called **through vias**, while those connecting internal track layers are called **blind**, or **buried vias**. As many as 30 or so layers are typically made into a multi-layered printed circuit board of around 2 mm thickness. Maximum known to the authors is a board with 60 layers, although boards like this are unusual and very costly.

Printed circuit board base materials

There are many materials used to make printed circuit boards. Generally, for common applications, materials are of thermosetting or thermoplastic plastics, reinforced for rigidity. Reinforcement materials include sheet paper, glass fibre cloth, cotton fabric and nylon. Fillers can be added to influence characteristics.

Table 1.1 lists common printed circuit board laminates, according to British Standard BS 4584 and IEC 249 classifications. Where applicable, classifications according to the commonly known ANSI NEMA LI1 standard — which, incidentally, does not exist anymore — are also listed for information. To aid clarification of letter codes, Table 1.2 lists codes along with descriptions.

Physical and electrical properties of printed circuit board are also standardized by BS 4548 and IEC 249. These are listed in Table 1.3.

While the most common material in printed circuit board laminate production is currently woven glass fabric reinforced epoxide resin, it is worth noting that a trend towards flexible polyimide forms of printed circuit boards is taking place in many consumer products — purely for cost purposes. This trend is expected to continue.

Table 1.1 Common printed circuit board laminate materials, listed alphabetically by BS/IEC laminate code classification. Where applicable, the non-existent NEMA LI1 classification is also listed

Base materials BS 4584/IEC 249	*Classification*	*NEMA LI1*
Epoxide resin, woven glass fabric, bonding sheet for multi-layer printed circuit boards	EP-GC	
Epoxide resin, non-woven glass filaments in addition to woven glass fabric, copper conductor	EP-GCA-Cu	
Epoxide resin, woven glass fabric, copper conductor	EP-GC-Cu	G-10, G-11, FR-4, FR-5, CEM-1, CEM-3
Phenolic resin, woven glass fabric, copper conductor	PF-CP-Cu	X, XP, XPC, XX, XXP, XXPC, XXX, XXXP, XXXPC, FR-2
Polyethylene terephthalate (polyester) films, adhesive coated cover sheet for flexible printed circuit boards	PETP-F	
Polyethylene terephthalate (polyester), flexible, copper conductor	PETP-F-Cu	
Polyimide film, adhesive coated cover sheet for flexible printed circuit boards	PI-F	
Polyimide, flexible, copper conductor	PI-F-Cu	
Silicone resin, woven glass fabric, copper conductor	Si-GC-Cu	

Soldering

Soldering is unique in that it provides the functions of mechanical and electrical support cheaply and easily. Solders used for electronics assembly melt at temperatures around 185°C or so, therefore quite simple equipment (a soldering iron, say) can be used to create individual soldered joints.

Joints are formed by metallic bonds between the metals in the joint area (usually the copper track of a circuit board and component leads) and the solder. Modern solder is an alloy, usually of tin and lead (although other alloys are occasionally used, and selected impurities may be added to a conventional tin/lead solder to create changes in properties, as required),

Table 1.2 Letter codes for printed circuit board types

Letter code BS 4584/IEC249	*NEMA LI1*	*Description*
CP		Cellulose paper
Cu		Copper conductor
EP		Epoxide resin
F		Flexible
GC		Woven glass fabric
GCA		Woven glass fabric with reinforcements of non-woven glass filaments
PETP		Polyethylene terephthalate (polyester)
PF		Phenolic resin
PI		Polyimide
Si		Silicone resin
	FR	Flame retardant
	G	Glass fabric reinforced
	P	Punchable, if heated to between 50 and 80°C
	PC	Cold punchable, above 25°C
	X	Paper reinforced, poor electrical characteristics
	XX	Paper reinforced, fair electrical characteristics
	XXX	Paper reinforced, good electrical characteristics

which melts at a lower temperature than either of the metals to be joined — this means that joints can be made to metals which form the leads of otherwise quite fragile components. Further, the reasonably low melting point means many joints may be soldered at the same time with little fear of damaging components. On the other hand, where many joints are to be formed simultaneously, equipment becomes rather more elaborate, simply because of the problems associated with handling solder in molten bulk.

Note also that lead in solder may not have a very long life. Legislation may exist in the long-term, to prevent the use of lead as a constituent of solder.

The process of soldering only occurs on certain surfaces, usually metallic, and does not occur on insulating surfaces — this means solder may be applied in excess. Alternatives to soldering — welding, conductive adhesives — require much more complex equipment. In the case of welding, the greater heat required to create a welded joint precludes welding many joints en masse. Even welding joints consecutively may damage the component being welded. In the case of conductive adhesives, accuracy is extremely important — adhesive will adhere to conductors and insulators alike so if it conducts also, short circuits are probable.

Table 1.3 Summarized properties of common clad printed circuit board laminates

Laminate	*Resistance of foil at 305 gm^{-2} (mΩ)*	*Surface resistance at 125°C or 100°C*, minimum value (MΩ)*	*Surface resistance after damp heat and recovery, minimum value (MΩ)*	*Volume resistivity at 125°C or 100°C*, minimum value (MΩm)*	*Volume resistivity after damp heat and recovery, minimum value (MΩm)*	*Permittivity, maximum value*	*Loss tangent, maximum value*	*d value for bow, 305 gm^{-2}; 1.6 mm laminate, single-sided*	*d value for bow, 305 gm^{-2}; 1.6 mm laminate, double-sided*	*e value for twist, 305 gm^{-2}; 1.6 mm, single-sided*	*e value for twist, 305 gm^{-2}; 1.6 mm, double-sided*	*Pull-off strength, 152 gm^{-2} (N)*	*Pull-off strength, 305 gm^{-2} (N)*	*Peel strength after heat shock, 152 gm^{-2} (kNm^{-1})*	*Peel strength after dry heat, 152 gm^{-2} (kNm^{-1})*	*Peel strength after solvent exposure, 152 gm^{-2} (kNm^{-1})*	*Peel strength after plating, 152 gm^{-2} (kNm^{-1})*	*Flex strength (MNm^{-2})*	*Flammability: average burning time (s)*
EP-GC-Cu-2	3.5	1000	50000	100	20000	5.5	0.04	23	15	18	14	60	90	1.1	1.1	1.1	0.9	300	
EP-GC-Cu-3	3.5	500	50000	100	20000	5.5	0.04	23	15	18	14	60	90	1.1	1.1	1.1	0.9	300	10
EP-GCA-Cu-16	3.5	500	50000	100	20000	5.5	0.04	23	15	18	14	60	90	1.1	1.1	1.1	0.9	250	10
PETP-F-Cu-9	3.6		10^5		10^6	4									0.5	0.375	0.375		
PF-CP-Cu-5	3.5	100*	1000	10*	500	7	0.07	61	30	13	10	45	45	1.05	1.05	1.05	0.6	82	
PF-CP-Cu-6	3.5	15*	1000	10*	500	7	0.08	61	30	13	10	45	45	1.05	1.05	1.05	0.6	82	15
PF-CP-Cu-8	3.5	100*	1000	15*	1600	5.5	0.06	61	30	13	10	45	45	1.05	1.05	1.05	0.6	70	15
PF-CP-Cu-14	3.5	15*	1000	15*	500	6	0.07	61	30	13	10	45	45	1	1	1	0.6	80	10
PI-F-Cu-10	3.5		10^5		10^6	4								0.5	0.5	0.375	0.375		
Si-GC-Cu-13	3.5		50000		10000	4	0.008	23	15	18	14	63	63	0.7			0.7	100	

Notes:

Numbers at end of laminate code are serial numbers, indicating the part of BS 4584 which applies.

Tests as defined by BS 4584 Part 1.

Letter codes as defined in Table 1.2.

Requirements of the soldering process

There are a few important points to be understood when studying the soldering process.

In its simplest form, soldering is uncomplicated. Production of a soldered joint requires only that the parts to be soldered are positioned to remain relatively immobile. The surfaces are then heated to allow coverage with molten solder, and the solder is allowed to cool and solidify. However, controlling this process are five variables:

- flux
- wetting
- heat
- solderable surfaces
- time.

Flux

In most cases, a substance called **flux** is used in the process, primarily to clean the surfaces to be soldered and so aid wetting. However clean they are, all metals (with the exception of the noble metals) oxidize to form an oxide layer on their surfaces. Other tarnish products may occur, too. Presence of any tarnish layer will prevent wetting. Flux reacts with the tarnish layers, leaving a pure base metal surface for the solder to wet. A secondary function of the flux is to reduce the solder's surface tension, so increasing the solder fluidity and aiding wetting. Another is to protect the metal surface during subsequent heating.

Heat

Application of heat is a prime requirement of any soldering process: solder has a melting point of, typically, around 185 °C. So, to enable its application, the solder has to be heated to at least this temperature. This can be done, in the three extremes, by:

- heating the joint before solid solder is applied (for example, when hand soldering)
- heating the solder until molten before application to the joint (say, in wave soldering)
- applying solder to the joint, then heating both (say, simple infra-red soldering techniques).

While techniques exist formed by just one of the three extremes, many soldering processes are elaborate mixtures of two or all three.

Note, it is not a prerequisite that the *joint* be heated prior to application of solder although, for convenience, it often is.

Wetting

Wetting is the process in soldering where the solder comes into direct metallic contact with the metals to be soldered together into a joint, forming a specific alloy of solder and metal at the junction. In turn, this implies a joint's metallic surfaces should be so clean that metallic contact can be made.

Often, the term **intermetallic** is used to describe the bond which occurs between solder and metal when the solder wets the metal (as in **intermetallic bond**). This is incorrect: it is, in fact, a strict metallurgic term referring to **intermetallic compounds**, compounds of elements whose atoms have an extremely high affinity for each other — so high an affinity that their presence denies bonding of other elements by other means. To appreciate the difference between intermetallic compounds and alloys it's important to realize that intermetallic compounds have fixed *stoichiometric ratios*. Alloys, on the other hand, have ratios of metals which can vary.

Wetting occurs when solder comes into intimate contact with the metal atoms. If the metal surface is perfectly clean and metal atoms are present, then the solder wets the metal, forming a bond with the metal atoms at the interface (Figure 1.4). Once this interfacing bond, an intermetallic compound as it happens, has been created it cannot be removed.

If, on the other hand, the metal is unclean in any way, say, it is oxidized (Figure 1.5) such that metal atoms are not present on the surface, then wetting cannot occur — in a similar way to which a drop of water on a greasy surface will remain as a droplet.

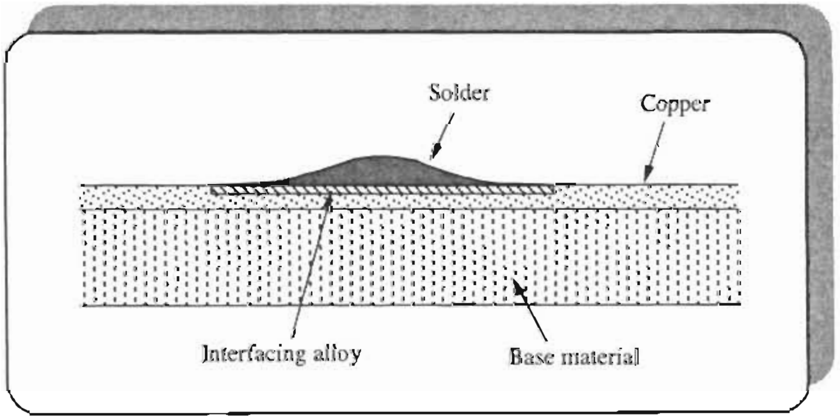


Figure 1.4 *Intimate contact between solder and a metal surface occurs when wetting takes place. An intermetallic compound is formed at the interface between the two*

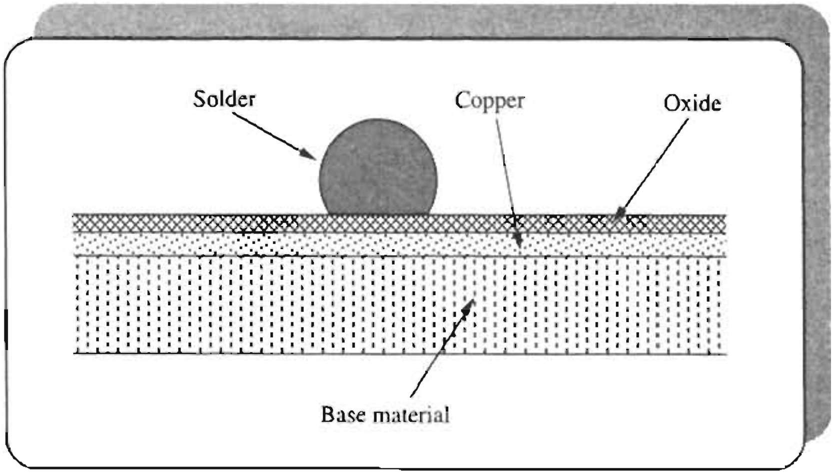


Figure 1.5 *If a contaminant such as oxide is present on the metal surface prior to soldering, no intermetallic compound is formed so wetting cannot take place*

In context with the wetting of metals, two other terms need to be defined. The first is **non-wetting**, where part or all of the metal to be soldered is devoid of solder. Usually this occurs where a contaminant or oxide has been left on the metal surface, so preventing the necessary alloy bond between metal and solder layer. The second is **dewetting**, where the alloy bond has occurred, but where the solder withdraws from the metal and forms dispersed, irregular droplets. Further solder cannot accumulate due to the high surface tension formed. Where dewetting occurs, it is sometimes difficult to determine; a simple visual check may not be sufficient.

Both problems are usually caused by lack of cleanliness, although dewetting can also occur when large amounts of intermetallic compounds form.

Cleaning

There are two areas in which cleaning may need to take place in the soldering process. First, the metallic surfaces to be soldered together must be perfectly clean, in order that solder can wet the metals involved. Second, residues left after soldering may need to be removed. These are usually thought of as separate issues, and termed **pre-assembly** and **post-assembly cleaning**. Both are discussed in Chapter 10.

Another pre-assembly area where cleaning is important, often out of the hands of the assembler, is cleanliness during board manufacture. Where an assembler simply buys-in ready-made boards, problems of cleanliness during manufacture may be difficult to isolate, and even more difficult to eliminate. Cleanliness of ready-made boards is of vital importance when certain fluxes (those with little reactional activity) are used. Modern trends indicate greater usage of such fluxes in the future, so clean boards are correspondingly more important.

Solderable surfaces

Solder will only join certain surfaces. Generally, in electronics assembly, these surfaces are of just one main type of metal: copper. (Occasionally iron, nickel iron and brass parts are found in assemblies.) Copper is, of course, an

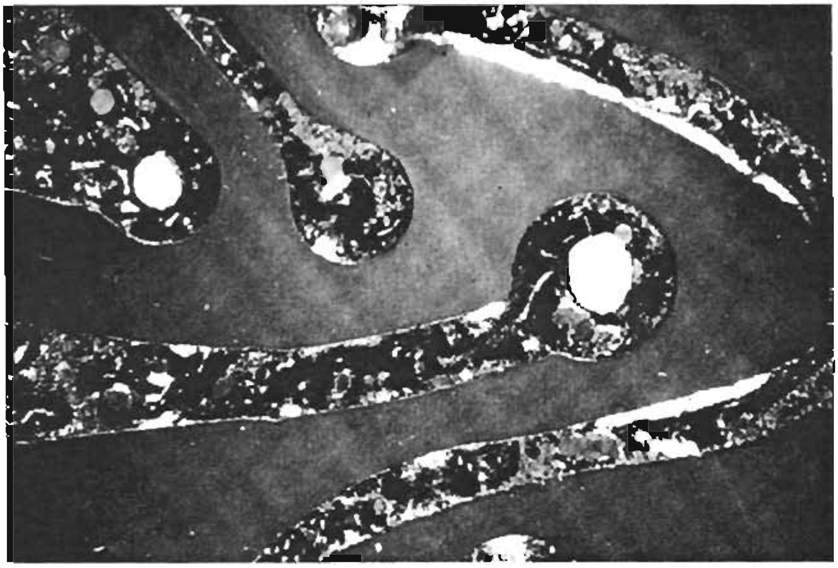


Photo 1.1 *Non-wetting, showing where copper surface is not wetted at all, so surface is visible (Alpha Metals)*

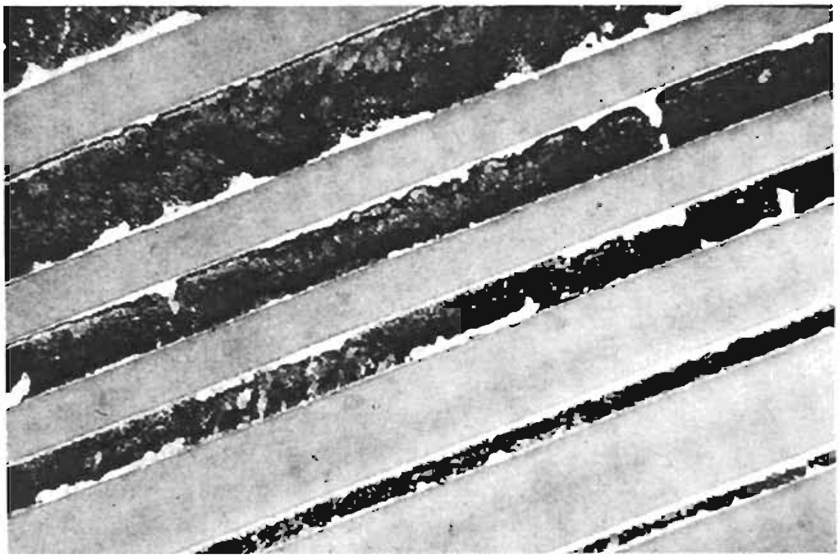


Photo 1.2 *Dewetting, showing surface which is originally wetted, followed by withdrawal of solder, leaving an alloy bond on the copper surface (Alpha Metals)*

extremely good electrical conductor and so is ideal for the purpose. It does, however, oxidize fairly easily in air and is generally protected somehow to prevent oxidation (which may prevent soldering taking place) prior to soldering.

Ability of a surface to be completely wet by solder is scientifically measured as its **solderability** and the term is one of the most important in the subject of soldering. In other words, it refers to how well and how uniform the interfacing alloy bond between solder and metal is made.

It follows that solderability is concerned with *every* aspect of the soldering process (ie, fluxing, wetting, heating, cleaning), and the main aspects of board manufacture, too (ie, copper plating, tin/lead plating, solder resist application). Further, solderability generally decreases with age, as tarnishing of the metals involved occurs naturally in normal atmosphere.

One of the major problems of guaranteeing adequate solderability is the difficulty in measuring exactly what solderability is. Not so very long ago, solder joint quality (and hence, solderability of the metals involved) was determined by an over-simple visual check: the joint's brightness and smoothness was thought an indicator of joint quality. Indeed, it sometimes still is. However, modern joints on surface mounted assemblies, say, are

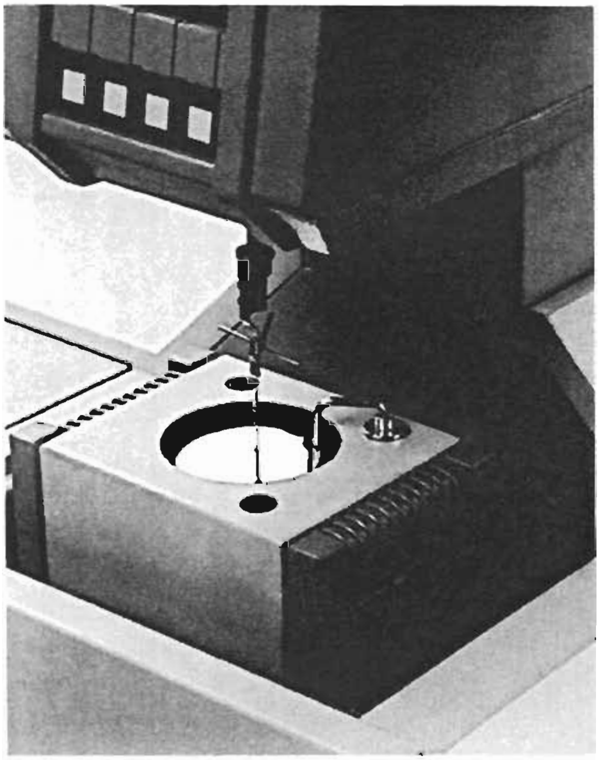


Photo 1.3 *A computer-controlled solderability tester (Multicore)*

rarely bright and certainly never smooth, yet are known to be joints of perfect quality.

In effect, solder joint quality can *never* be determined by appearance of the outside layer of the solder. Actual quality is determined solely by what has happened at the interface between the solder and the metal. As this is impossible to view, visual inspection consequently serves little purpose in assuring joint quality. More cohesive tests for solderability and for joint quality are discussed in Chapter 3.

Once a board or component is known to have an acceptable solderability, it is usual to coat it with a substance known as a **protective coating**, in an attempt to maintain solderability.

Protective coatings come in many forms, but their simple task is to cover the copper with a layer of material which doesn't oxidize so readily, yet still allows copper to be soldered to. This is only an *attempt*, note, as no coating can maintain solderability indefinitely. Extent to which solderability decreases under storage conditions depends primarily on the protective coating used, but also on the storage conditions and the thicknesses of coatings, so estimates of solderable lifespans, that is, shelf-life, can only be approximate. Boards should be re-tested for solderability after storage, before use. Protective coatings are discussed in Chapter 3.

Soldering processes

A number of methods exist by which electronics assembly soldering processes may be categorized, the first is whether soldering is performed by hand or by machine.

Hand soldering

Hand soldering is usually performed alongside hand assembly. It involves use of purpose-built tools and specific operations, which depend primarily on the components being soldered. As a complete process, hand soldering is discussed later in Chapter 7.

Machine soldering

Machine soldering methods are, very simply, methods to solder components into or onto a board en masse. For this reason, they are often called **mass soldering methods**. Primary aim of mass soldering methods is to speed up the manufacture of electronics assemblies.

Another method by which soldering processes may be categorized is by the mass soldering process used. There are two main categories of mass soldering processes:

- those processes which rely on the insertion or onsertion of components *prior* to application of solder — from here called **component/solder** (CS) processes — sometimes, graphically, called **flow** or **wave** soldering processes
- those processes which rely on the onsertion of components *after* the application of solder — from here called **solder/component** (SC) processes — sometimes called **reflow** soldering processes. The term *reflow* is, however, a misnomer as it implies previously molten solder is reheated until molten once more. In many cases a solid form of solder in a paste mixture is used in SC soldering processes which, correctly therefore, cannot be referred to as reflow processes.

At this point it's worth reinforcing what we've just stated. We're introducing new terms into an area already crowded with expressions describing various applications and processes in the soldering of electronics assemblies. All we're trying to do with these *new* terms is to clarify the complex area.

Put simply: *all types of soldering processes for all types of assemblies can be categorized in just two groups* — **CS soldering processes** and **SC soldering processes**.

CS soldering processes

CS soldering processes position components onto the printed circuit board then apply solder.

Position **component** then apply **solder = CS**

SC soldering processes

SC soldering processes, on the other hand, apply solder before positioning components onto printed circuit boards.

Apply **solder** then position **component = SC**

Component/solder (CS) processes

There are three main CS soldering processes:

- dip soldering
- drag soldering
- wave soldering.

Dip soldering

In dip soldering processes the assembled board is fluxed then lowered near-horizontally, into a bath of molten solder as shown in Figure 1.6. Once the lower edge of the board comes into contact with the solder, the board is dropped to a horizontal position on top of the solder. After a suitable period during which the solder achieves wetting over the whole of the areas to be soldered, one edge of the board is lifted (usually the edge which first came into contact with the solder), then the whole board is lifted clear of the bath.

Dip soldering suffers from problems in that flux gases are easily trapped under the board and, as a consequence, contact times must be quite long (about 10 seconds) to ensure adequate wetting and solder temperature must be quite high.

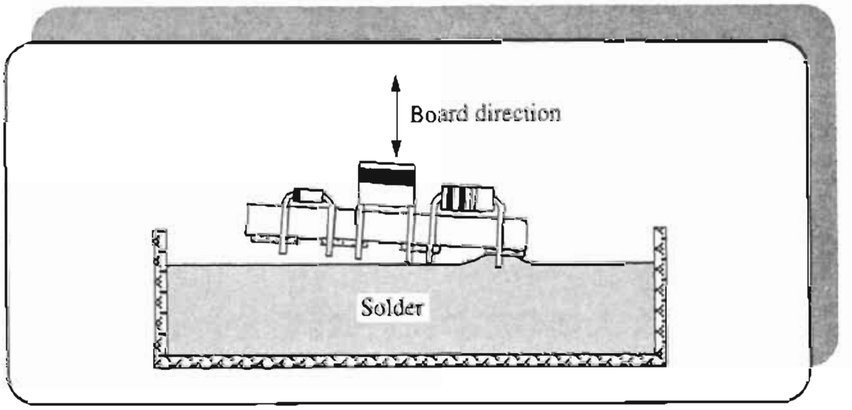


Figure 1.6 *A simple form of dip soldering — lowering and removing the printed circuit board near-horizontally*

Drag soldering

By dragging the assembled and fluxed board over the surface of molten solder (illustrated in Figure 1.7), the problems associated with dip soldering processes can be overcome. Consequent contact times are much shorter (about 5 seconds).

Wave soldering

Wave soldering processes use a pump to create a wave of solder over which the assembled and fluxed board is passed (illustrated in Figure 1.8). Contact times of only 2 to 4 seconds are usual, and required solder temperature is lowered.

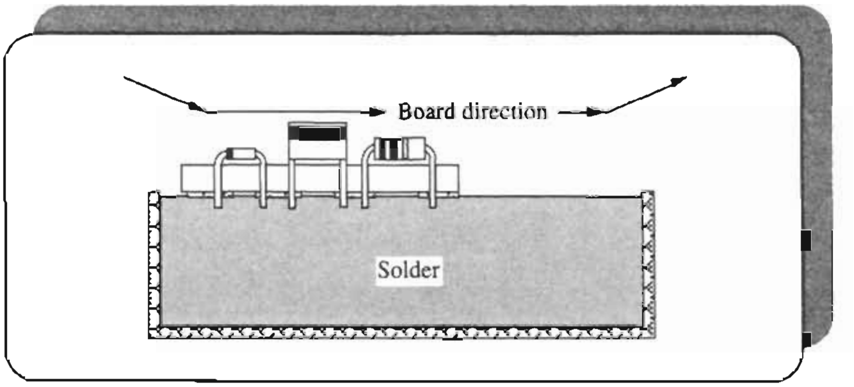


Figure 1.7 *Drag soldering, in which a printed circuit board is dragged over the surface of molten solder*

Dip and drag soldering processes are older than wave soldering processes and, although both are still used, neither normally forms the preferred method in most applications. For mass CS soldering, wave soldering techniques are the norm and are discussed in depth in Chapter 7.

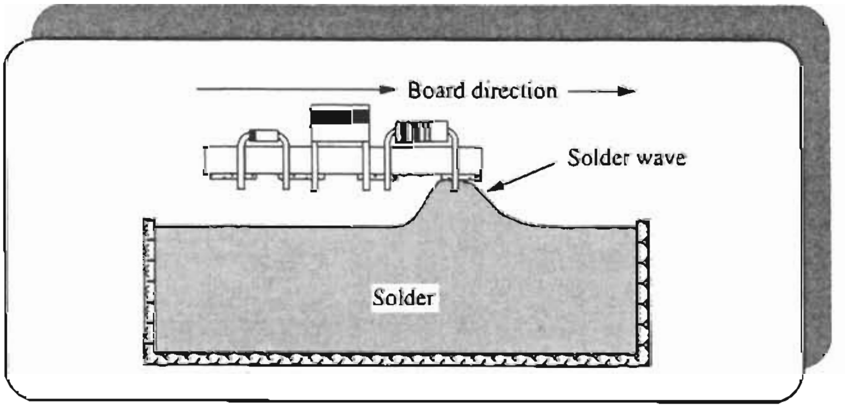


Figure 1.8 *Conveying the board over a wave of solder allows much shorter contact times and lower temperatures — the wave soldering principle*

Solder/component (SC) processes

SC soldering processes are used, primarily, in surface mounting assembly production, where solder and flux are applied as a paste followed by the placement of components and the application of heat (Figure 1.9). SC soldering processes are often termed reflow processes, known as such because the original idea uses a layer of previously applied solid solder which is reheated to cause it to melt, that is, flow, again.

Under this light, the term *reflow* as it is often *currently* used is something of a misnomer, as we've already discussed. This is simply because solder and flux paste — now the normal method of applying solder before components are assembled — in no way can be thought of as solid and previously molten solder. Further, soldering processes can't be classified simply by the two different assembly types of through-hole and surface mount designs, because some surface mount assemblies use CS processes. Likewise, it is feasible — though not currently usual — for some through-hole assemblies to be soldered by SC means.

As an aside here, a growing number of large manufacturers such as Motorola and Hewlett Packard are looking to produce mixed surface

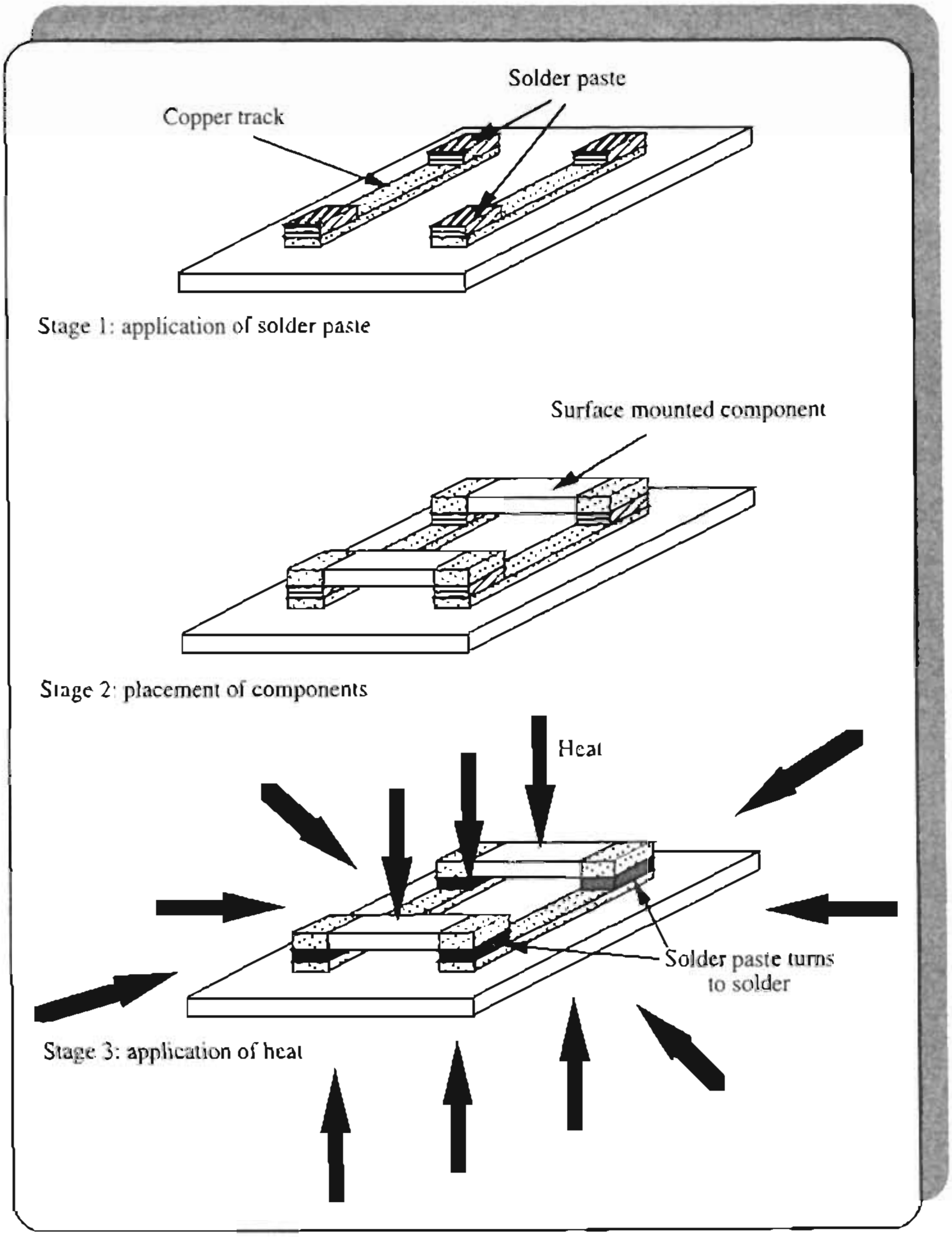


Figure 1.9 *One type of surface mount assembly in which solder is applied, in the form of paste, before components are placed in position. Once assembled, applied heat allows soldered joints to be formed*

mounted assemblies by wholly SC processes. By 1994, in fact, some intend to have already implemented this, and will no longer use CS wave soldering methods at all.

Mass SC soldering techniques are generally categorized by type and direction of applied heat. These are all discussed (including through-hole SC processes) in Chapter 8.

Cleaning

While cleanliness of electronics assemblies is an asset which all manufacturers should strive for, never has it been so important as in production of modern densely-populated printed circuit boards. The smaller the components are which are located on a printed circuit board, and the closer they are together, the harder it becomes to ensure they are totally clean after all manufacturing processes — particularly soldering.

Environmental concerns regarding the damage which certain chemicals do to the ozone levels in earth's atmosphere has restricted the use of those chemicals. In a short time (ie, by the end of the century, say) those chemicals — and indeed some others which may have otherwise been considered as alternatives — will not be available for use at all as cleaning agents. Consequently, manufacturers need to ensure cleaning agents which cause no danger to our environment are used in cleaning processes.

Chapter 10 discusses this cleaning dilemma in electronics assembly manufacture, and describes all cleaning processes.

Quality

Given that a circuit is properly designed, component parts are of good quality and printed circuit boards are assembled correctly, then solder processes hold the fundamental key to an assembly's quality. Modern machine soldering equipment is capable of tremendous achievement, much of which is under automatic control. While things work properly and perfect zero-defect assembled printed circuit boards are coming off the production line, everybody's happy.

But what happens if things go wrong? How do you tell if a particular fault is related specifically to your solder machine or to peripheral equipment and processes? There are so many variables in production of electronics assemblies — particularly in the soldering process part — that it is often not possible to isolate the problem and effect a cure.

Answers are not always easy to come by and so for this reason we have attempted to make things just a little less complicated with Chapter 11, which considers the question of solder process quality. In it, some examples are used to illustrate some of the main problems which occur in finished electronics assemblies. We think they form a unique collection of visual aids to assist in the identification of solder process-specific problems.

Safety

Soldering of electronics assemblies, indeed the whole assembly process, is a potentially dangerous procedure. You have to remember *any* industrial process can be lethal. Equipment in electronics assembly is often used with solvents which may be poisonous or explosive. Materials used are often flammable. In many assembly processes, particularly soldering itself, heat is a hazard when combined with these solvents and materials.

Solder itself is a lead alloy, so can cause lead poisoning. In molten form solder, need we say it, is hot — *very hot* — usually at temperatures between 200°C and 350°C in, say, operational wave soldering systems! It can severely burn skin, and will burn through non-protective clothing to get to skin.

Most equipment is of a mechanical nature, with moving parts: pulleys, sprockets, pumps, chains and so on. Fingers, hair, neckties, bracelets and so on can easily get caught in moving parts. Mechanically, these moving parts are very strong and may not be stopped simply by a trapped person trying to pull out an object caught in the machine. Serious physical injury can result.

All equipment is electrically-powered. High voltages are present in various system parts. At best electric shocks make you jump. Often they cause burns and severe bodily harm. At worst they stop the heart and so kill.

Safety is of vital concern to all personnel involved in soldering processes. Consequently, in Appendix 3, we consider specific safety aspects: describing hazards and possible effects; suggesting ways to avoid them; and detailing first aid which may be required within the varied aspects of soldering. However, these *are* only items of immediate interest in soldering processes. It is strongly recommended that relevant and sufficient safety procedures be laid down and closely followed at *all* stages of electronics assembly. Three highly important points regarding safety throughout manufacturing are:

- follow suppliers' manuals and instructions closely
- invest in proper safety training
- keep up-to-date with control of substances hazardous to health regulations regarding such aspects as safety, materials use, materials storage.

2 Electronics assemblies

It's the purpose of this chapter to itemize what main processes are available in electronics assemblies, and how soldering systems cope with this wide variety. To do this, we look at electronics assemblies in two ways. First we consider assemblies in terms of solder joints. For example, what types of joints are used in electronics assemblies and what are their strengths, weaknesses, physical constraints and anomalies.

Having done this we, second, consider the main variations of electronics assembly techniques which soldering systems have to cope with now — and must cope with in the near-future. This we do by looking at combinations of assembly techniques and components used.

Joints

For electronics assemblies there are two main categories of joints:

- through-hole joints
- surface mount joints.

Within each category, though, there are a few variations. Differences between them lie not only in obvious factors such as whether components have leads or terminations, whether holes exist in the printed circuit board, and size (albeit important differences) but in a more obscure attribute of strength.

Whatever the category of joint and whether through-hole or surface mount components are jointed, there remain just four simple types of solder joint of interest in electronics assemblies:

- butt — a straightforward wetted mating of two end surfaces of metal by solder

- single overlap — where two plates of metal overlap, and solder wets the two touching surfaces. Overlap joints of single or double form are also commonly known as lap joints
- double overlap — where the joint comprises three metal plates, one within the space formed between two others
- ring and plug — in which a ring of metal and a corresponding plug are jointed.

These are illustrated in Figure 2.1.

Strength

Mechanical strength is a most important criterion when designing soldered joints. Obviously the joint should be strong enough to withstand all possible stresses it may experience: usually tensile, shear or a combination of both. On the other hand, there is little need to design a joint simply to be technically strongest. A knowledge of use of an assembly after manufacture is thus necessary at the first development stages, in order that correct joint types may be incorporated, strong enough to make the product reliable yet not so strong as to make it inordinately expensive.

Insofar as measuring mechanical strengths of solder joints, the practice is largely a matter of testing these four joint types to destruction and collating results. Naturally, certain assumptions are taken regarding whether joints depend totally on tensile or shear strength or not.

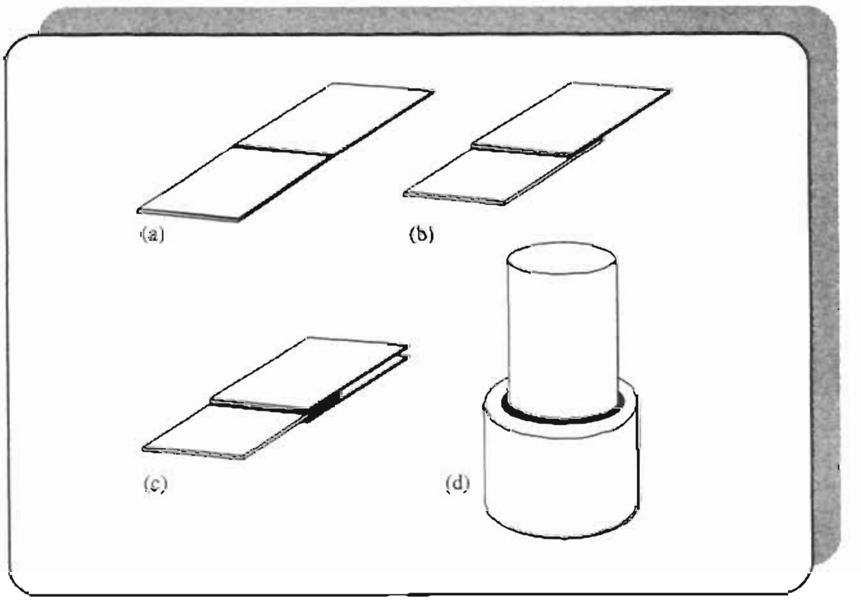


Figure 2.1 *Four simple types of solder joint (a) butt, (b) single overlap, (c) double overlap, (d) ring and plug*

Tensile strength

The joint which relies most on tensile strength for its function is a butt joint. It is the simplest joint form and solder in the joint is theoretically stressed at 90° to its interfaces, thus is the best indicator of maximum tensile strength of a solder joint.

As stress occurs at 90° to joint interfaces, strength is high; Thwaites and Duckett [Thwaites, 1976 #1] report measured strengths of 9.4 kgf mm^{-2}. Strength does however vary considerably with solder thickness (ie, joint gap). Figure 2.2 shows variation of tensile strength for solder thickness in a standard butt joint. Interestingly tensile strength of butt joints is greater than that of bulk solder (3.5 kgf mm^{-2}), also shown on the graph for reference.

Shear strength

Remaining three joint types are felt, by Thwaites and Duckett, to more closely demonstrate shear strength, with ring and plug even more so than the others. A shear strength of 3.7 kgf mm^{-2} is typical in a ring and plug joint, while the overlap joint has a joint strength of 4 kgf mm^{-2} — which indicates other strengths exist in an overlap joint. This is probably due to the fact the two metal plates cannot lie in the same plane as they are offset (part of the joint design), so while shear strength is initially measured as load is applied, twisting of the joint adds some tensile strength into the result. Interestingly double overlap joints are typically less strong than single overlap joints.

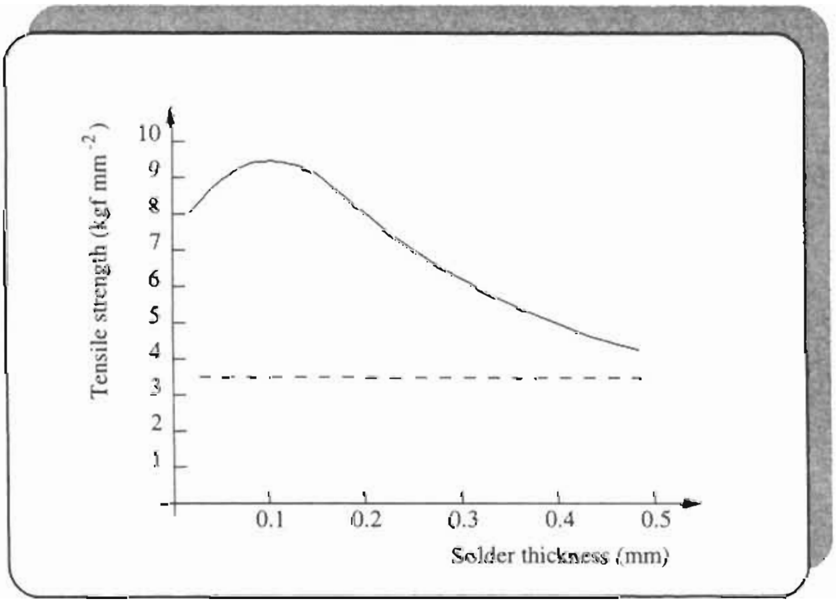


Figure 2.2 *Solder tensile strength variation with solder thickness*

Again solder thickness means shear strength varies, as shown in Figure 2.3, where a graph of the variation in shear strength which may be expected for differing thicknesses of solder between two layers of copper in a lap joint is given.

Finally, joint strength also varies with soldering temperature, as shown in Figure 2.4, where overlap, ring and plug, and butt joint strengths are compared.

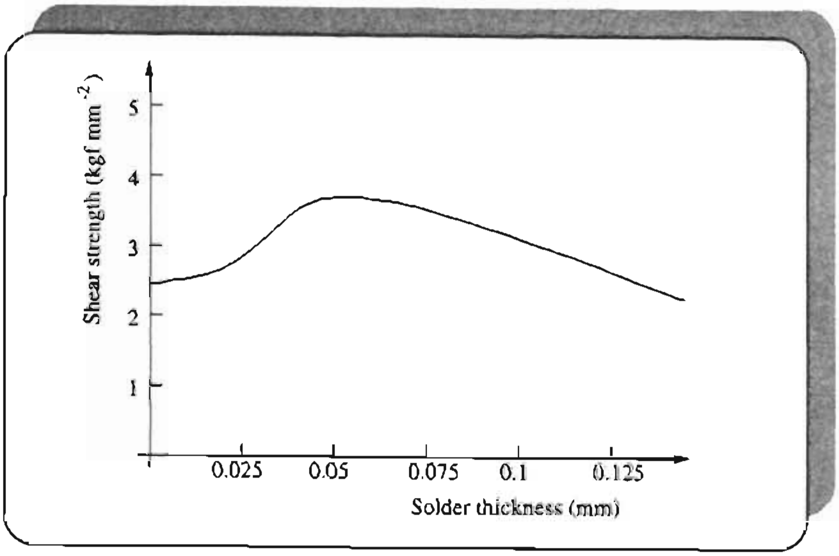


Figure 2.3 *Solder shear strength variation with solder thickness*

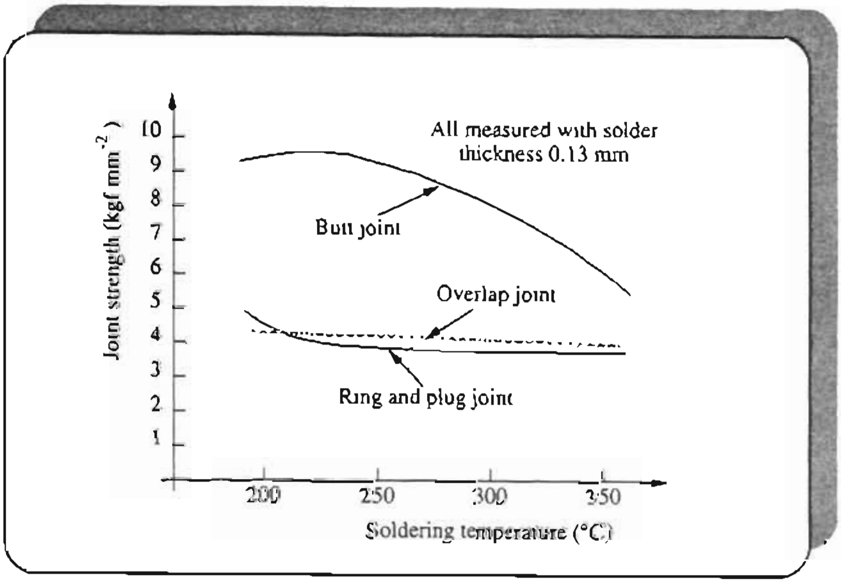


Figure 2.4 *Solder joint strength variation with soldering temperatures*

Performance of a joint is such that typical tensile strengths around 8 kg mm^{-2}, and shear strengths around 3 kg mm^{-2}, are easily obtained when soldering two pieces of copper.

To put this in perspective, peel strengths of typical printed circuit boards are such that copper track peels from a circuit board if a force of just a small fraction of possible solder joint tensile strength is applied over the few square millimetres of a soldered joint. In effect, materials surrounding a perfectly made joint usually form a limit to a solder joint — *not the joint itself.*

Through-hole joints

Through-hole joints rely on the single fact that a wire lead is inserted through a hole in the board, then soldered to bond to a metal track. However, certain factors may differ and affect the exact type of joint, such that four different types of through-hole joint have been specified by previous authors:

- non-plated through-hole, straight lead
- non-plated through-hole, clinched lead
- plated through-hole, straight lead
- plated through-hole, clinched lead.

In the following discussion, it is assumed that all joints are perfect, with good, continuous, wetting all round the area.

Non-plated through-hole, straight lead

Figure 2.5 shows the joint obtained when a straight component lead is soldered in a non-plated through-hole, such as would be obtained in a single-sided circuit board.

This is the easiest through-hole joint to manufacture, as few processes, apart from insertion and soldering, are called for. It is, correspondingly, the weakest through-hole joint, however.

Seen in cross-section as in Figure 2.5 it's clear the joint is similar to the ring and plug joint discussed earlier, which basically depends on shear strength of a solder joint for its strength, so can be expected to have strengths of at least 3 kgf mm^{-2}.

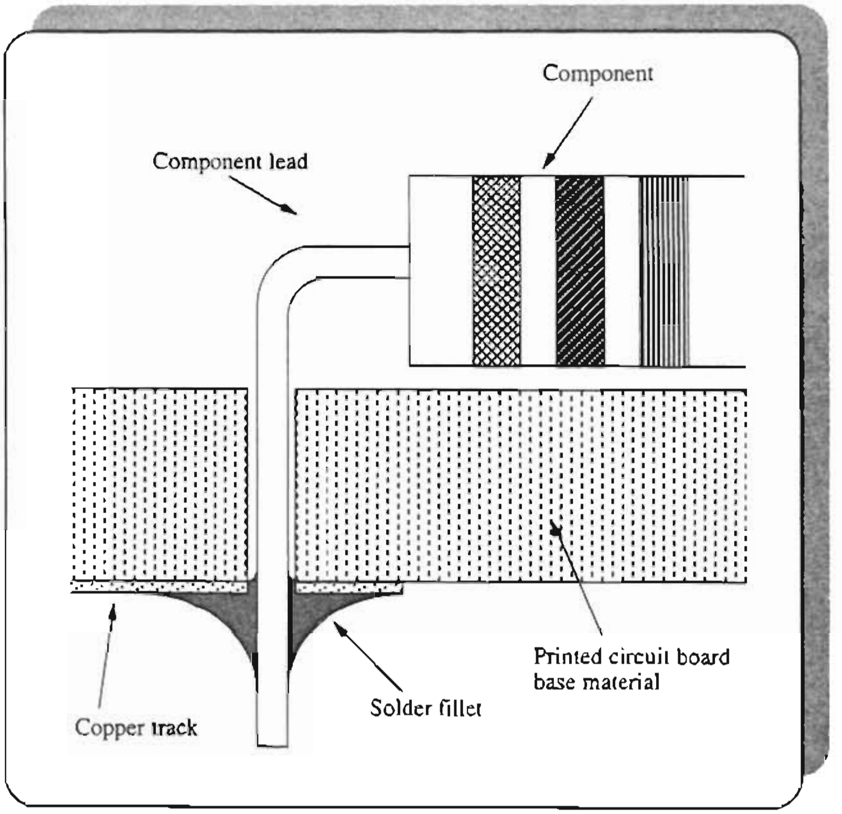


Figure 2.5 *Non-plated through-hole, straight lead printed circuit board joint*

Non-plated through-hole, clinched lead

This joint configuration is shown in Figure 2.6, for a lead clinched at a nominal 45° angle to the horizontal. Now, part of the joint is the same as the non-plated through-hole, straight lead soldered joint, so will have around 3 kgf mm^{-2} strength from shear strength of solder joints. However, the remaining part of the joint (between clinched lead and board) acts as a considerable reinforcement, relying on compression of solder *and*$^{8}/_{4}$mechanical support of the component lead against the printed circuit board, greatly increasing overall joint strength.

Plated through-hole, straight lead

This joint is shown in Figure 2.7. Effects of the metallized plated through-hole are to allow solder to be drawn up into the barrel of the hole, around the lead. This has the effects of increasing strength and decreasing the joint's electrical resistance, compared with the non-plated through-hole, straight lead joint of Figure 2.5. Where solder is drawn up through the barrel

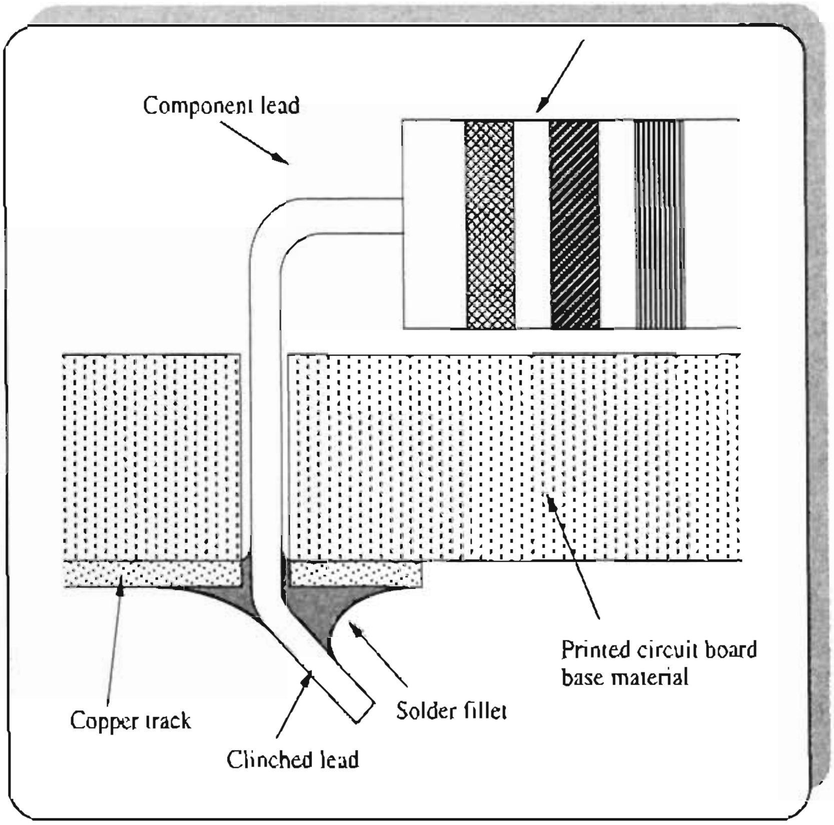


Figure 2.6 *Non-plated through-hole, clinched lead printed circuit board joint*

sufficiently, the joint may have quite a large top fillet, as shown in Figure 1.1. In turn this will again increase joint strength and lower resistance, but is by no means essential.

Plated through-hole, clinched lead

By far the strongest through-hole joint, this is shown in Figure 2.8. It includes the strength of the reinforcement joint between clinched lead and board and the shear strength of a ring and plug type of soldered hole barrel, together with lower joint electrical resistance of the soldered barrel.

An important consideration in all joints is the hole-to-lead size ratio (commonly known, among other things, as the stick-in-a-bucket ratio), which has a large effect on joint strength and ease of assembly. Generally, closer the lead diameter is to hole diameter, stronger is the joint, while the opposite is true for ease of assembly. Table 2.1 lists typical joint strengths as percentages of maximum possible joint strength for clearances between leads and hole, against ease of insertion, for straight leads. Figure 2.9, on the

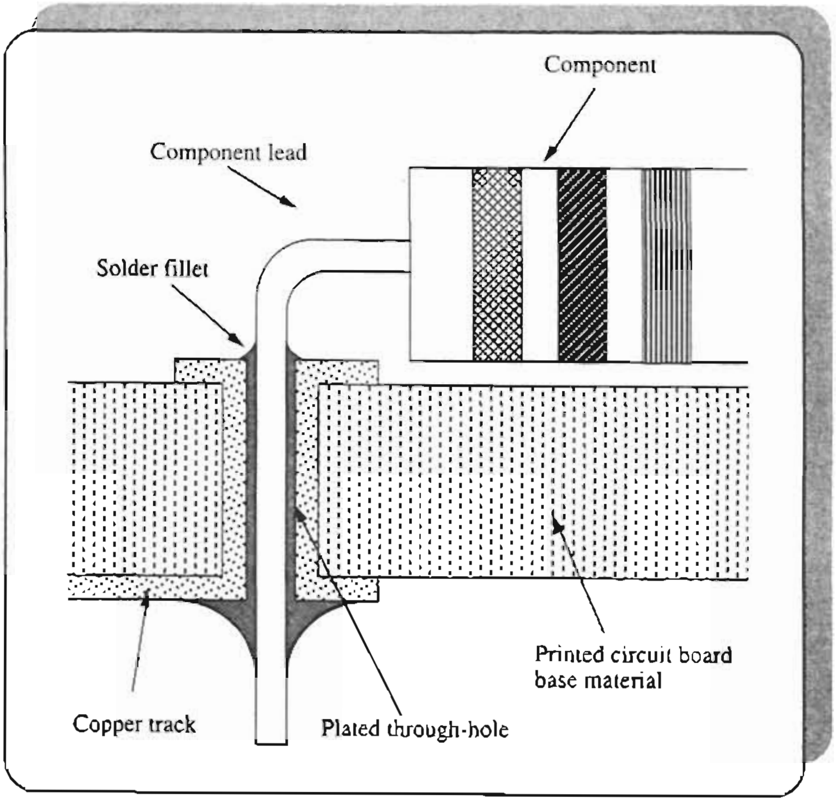


Figure 2.7 *Plated through-hole, straight lead printed circuit board joint*

other hand, shows how joint strength can be expected to decrease for increasing clearance between lead and hole diameters. A reasonable hole-to-lead ratio for easy assembly can be determined to be one where approximately 0.25 mm (0.01 inch) clearance between lead and hole

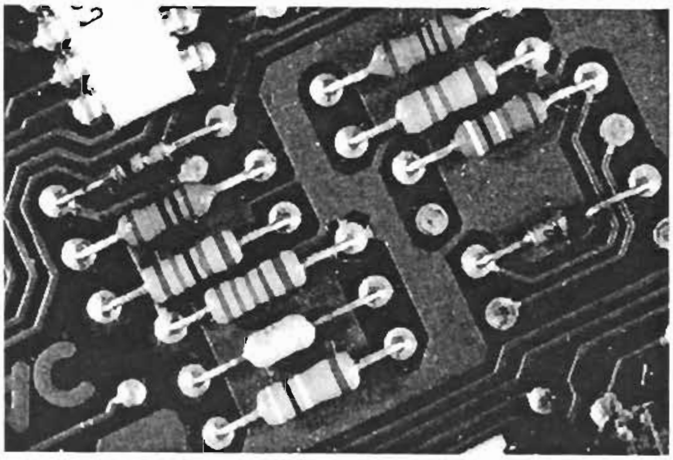


Photo 2.1 *An example of good soldering (Alpha Metals)*

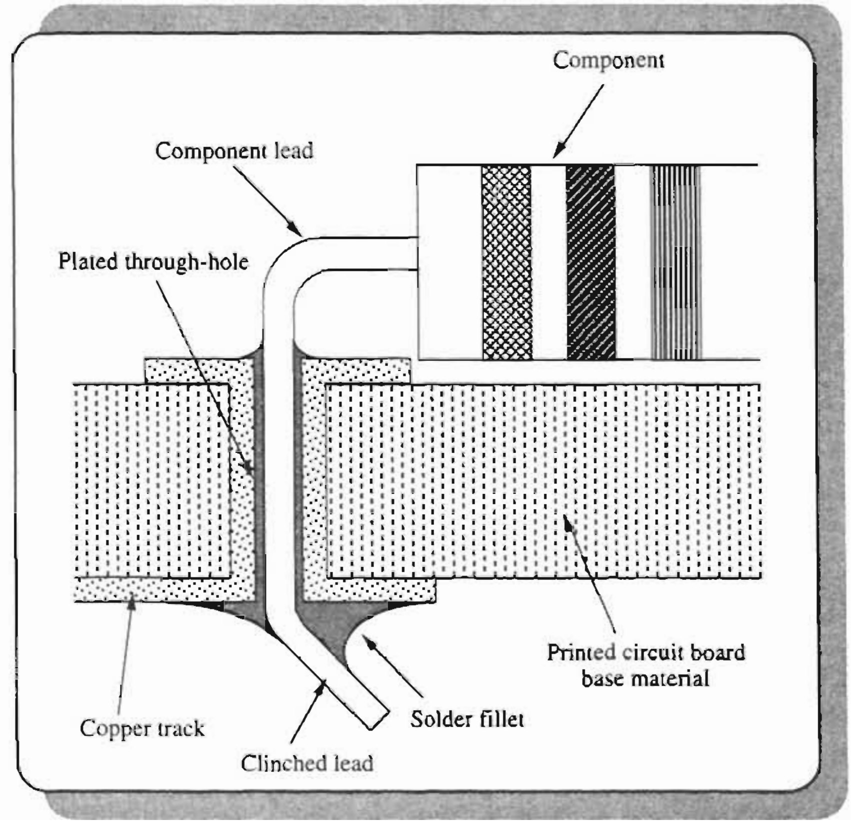


Figure 2.8 *Plated through-hole, clinched lead printed circuit board joint*

diameters is involved. If joint strength at this clearance (about 80% of maximum) is insufficient, it is advisable not to decrease hole diameter (thereby decreasing lead-to-hole clearance and making insertion more difficult), but to clinch the lead instead, prior to soldering.

Table 2.1 Joint strengths as percentages of maximum possible joint strength for clearances between leads and holes, against ease of insertion

Clearance between hole and lead (mm)	*Tensile strength (%age of maximum)*	*Ease of insertion*
0	100	Impossible
0.1	95	Impractical
0.2	87	Difficult
0.3	80	Possible
0.4	75	Easy
0.5	70	Easy
0.6	60	Sloppy

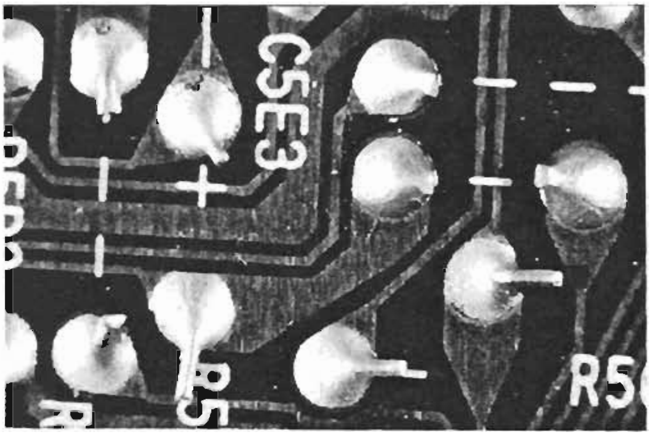


Photo 2.2 *An example of good soldering, shown with a dulling flux (Alpha Metals)*

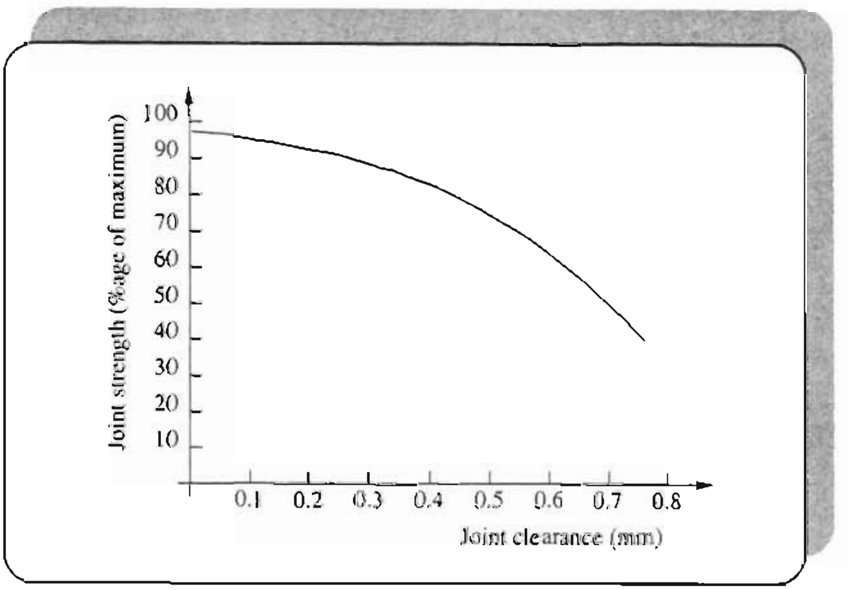


Figure 2.9 *Solder joint strength variation with joint clearance, for typical plated through-hole component joint*

Lead clinching

Clinching itself, however, is not without its problems. There are three considerations. First, if leads are clinched too close to horizontal, plated through-holes may be physically damaged (Figure 2.10a). Second, clinched leads with angles less than 45° from horizontal require asymmetrical lands (Figure 2.10b). Finally, too horizontal a clinch affects rework — smaller the clinch angle from horizontal, harder it is to extract components from a board. In most applications a clinch angle of 45° is ideal.

Care must be taken in track design if clinching is used in assembly. Where leads are clinched in closing directions (Figure 2.11a) solder bridges can often occur. It is generally best to specify that leads are clinched inwards for any single component (Figure 2.11b) or in the same direction (Figure 2.11c) to ensure possibility of solder bridging between component leads is minimized.

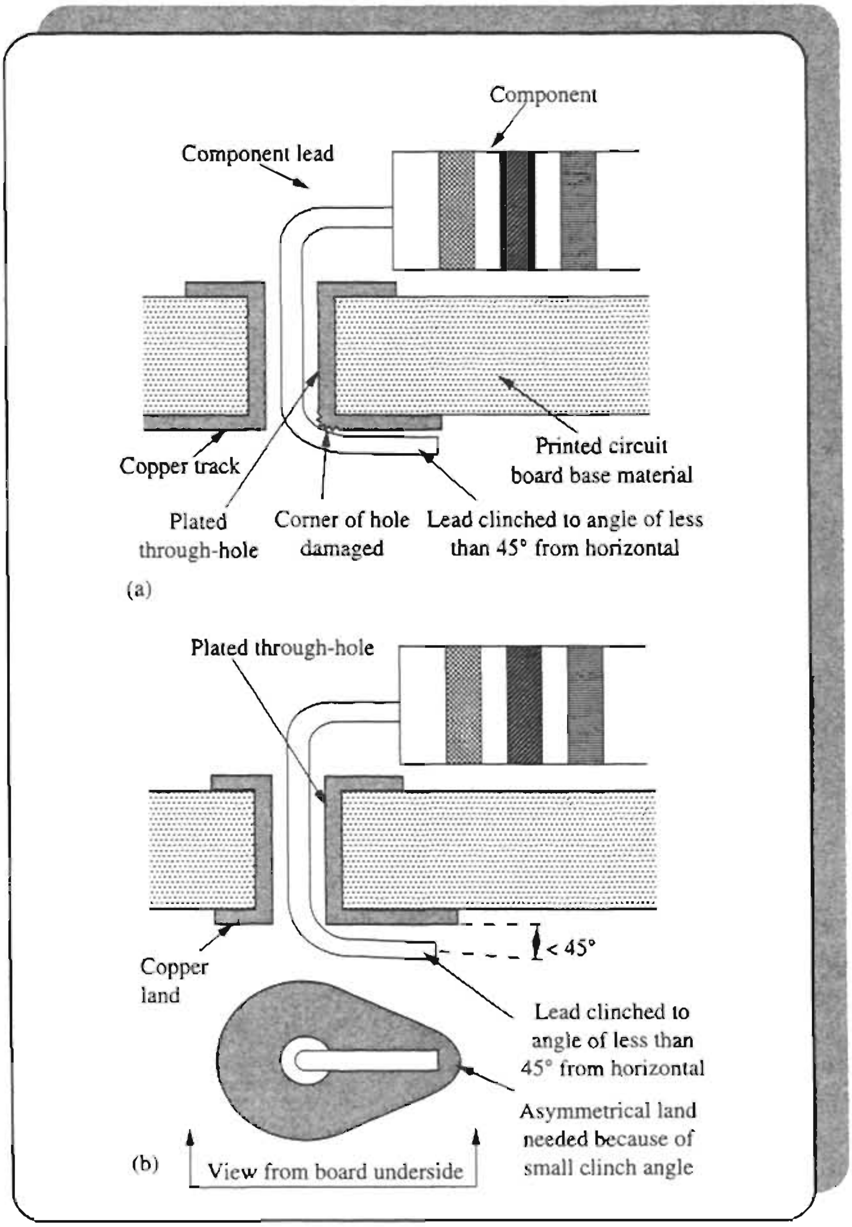


Figure 2.10 *Criteria to be considered when clinching through-hole component leads: if leads are clinched to angle of less than 45° from horizontal (a) track may be damaged (b) asymmetrical lands are needed*

Even under the most severe duties, components soldered in a through-hole printed circuit board aren't likely to encounter stresses sufficiently large to damage joints. Where, say, large heavy components are involved,

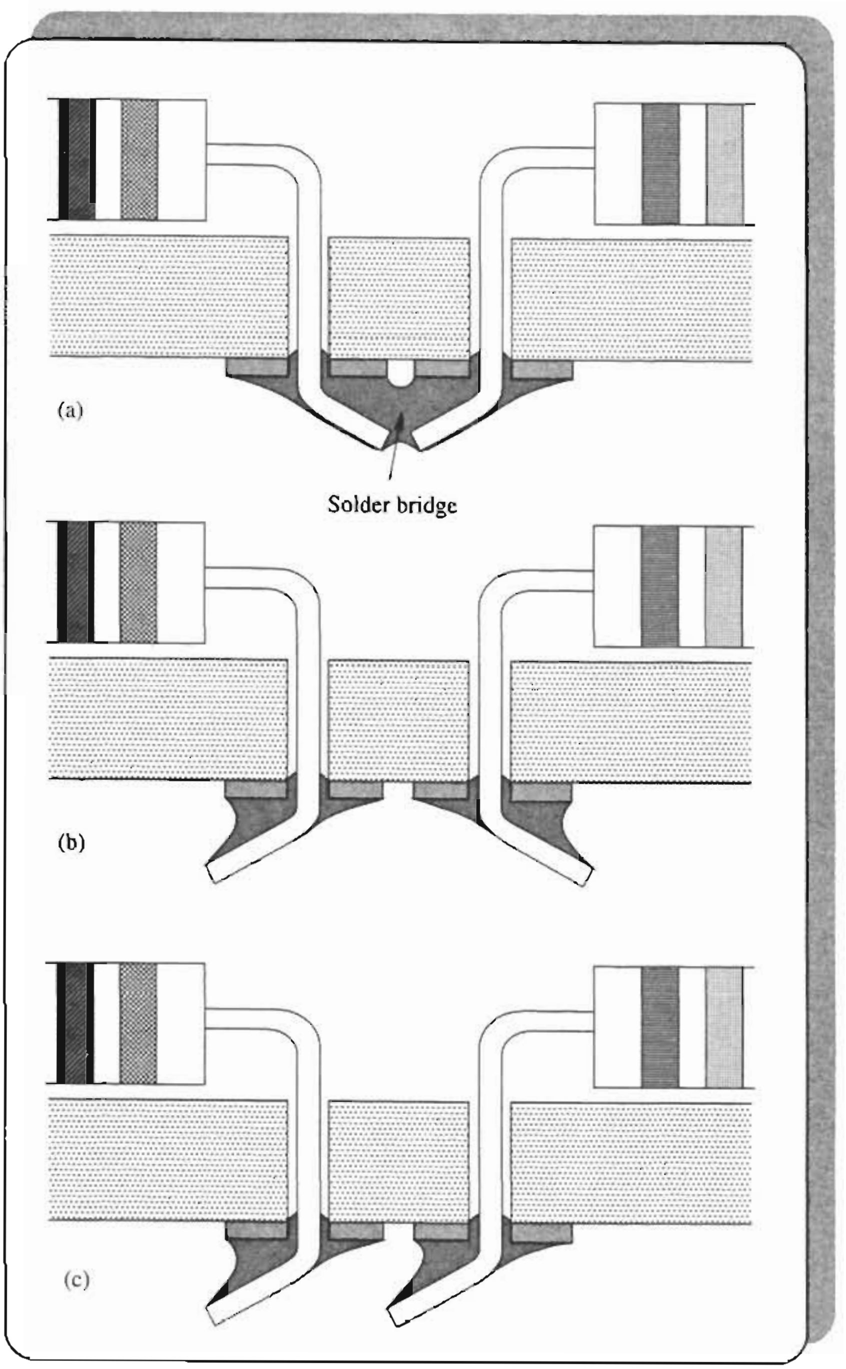


Figure 2.11 *Criteria to be considered if clinching through-hole component leads (a) where leads are clinched in a closing direction, solder bridges may form, whereas if leads are clinched in (b) an opening direction, or (c) the same direction, bridges can be avoided*

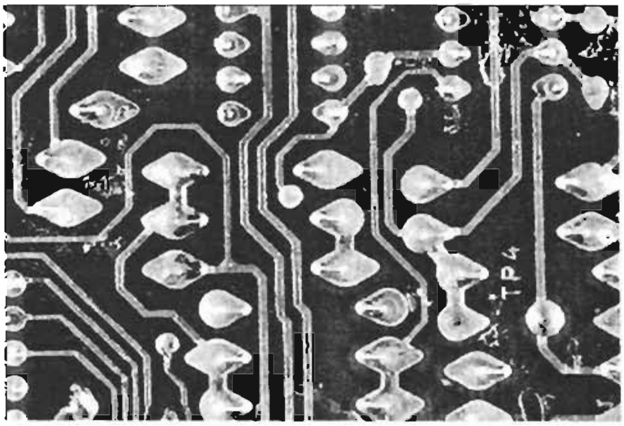


Photo 2.3 *Good soldering (Alpha Metals)*

damage is far more likely to occur because copper track peels away from the printed circuit board. Plated through-holes and, more particularly, clinching of leads form the best solutions where this is a possibility.

Surface mounted components

A number of component types has been developed specifically for use in surface mounted assemblies. New types are frequently being developed, too, so any categorization of those available must change just as frequently.

Types

The main types, some known simply by their abbreviation, include:

- chips — in this context, the term *chip* does not refer to an integrated circuit, but to a type of passive component (eg, resistor, capacitor, inductor), rectangular prism shape
- MELF — **metal electrode face bonded** components, cylindrical shape
- MIFI — **miniature ferrite inductors**, rectangular prism shape
- SO — small outline components, generally integrated circuits of rectangular prism shape
- SOD — **small outline diodes**, cylindrical shape
- SOIC — **small outline integrated circuits**, rectangular prism shape
- SOT — **small outline transistors**, rectangular prism shape
- QFP — **quad flat-pack** integrated circuits having four rows of terminals, rectangular prism shape
- TAB — **tape automated bonding**, sometimes called **mikropacks**, film integrated circuits in taped form, without protective packaging

- tubular — passive components, cylindrical shape
- VSO — very small outline components.

In addition, some integrated circuits are mounted into chip carriers, where the term *chip* does now refer to an integrated circuit, for assembly purposes. These carriers include:

- LCCC — **leadless ceramic chip carriers**, square prism shape
- PLCC — **plastic leaded chip carriers**, square prism shape.

General outline shapes of some of these components are shown in Figure 2.12. Dimensions of versions of surface mounted components and chip carriers are found in manufacturers' literatures.

Surface mounted joints

Although minor variations occur according to type of component being soldered, there are only two main types of surface mounted component soldered joints.

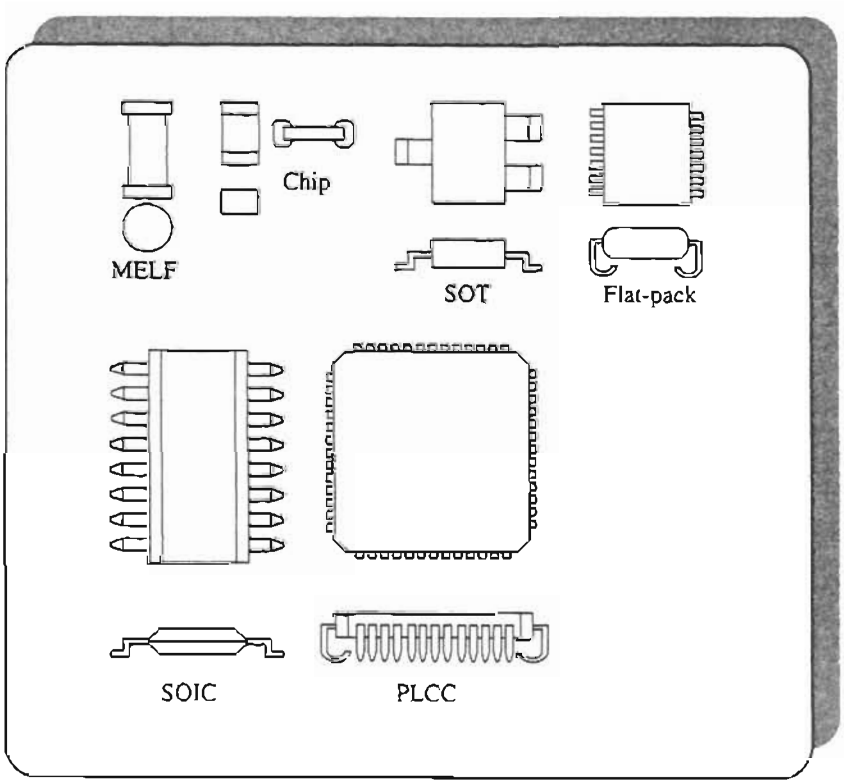


Figure 2.12 *Outline shapes of some common surface mounted components*

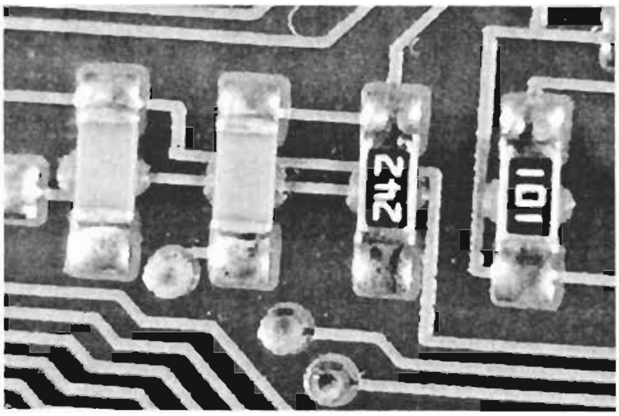


Photo 2.4 *Good soldering of surface mounted components (Alpha Metals)*

Surface mounted overlap joints

Figure 2.13 shows a surface mounted component (a chip, two-terminal device) mounted and soldered to a circuit board. A joint in such an arrangement is a simple overlap joint which, as seen earlier, can have a shear strength of much more than 3 kgf mm^{-2}. The joint is fairly rigid, there being no greatly flexible parts to the arrangement, so it is commonly called a **rigid lap joint**.

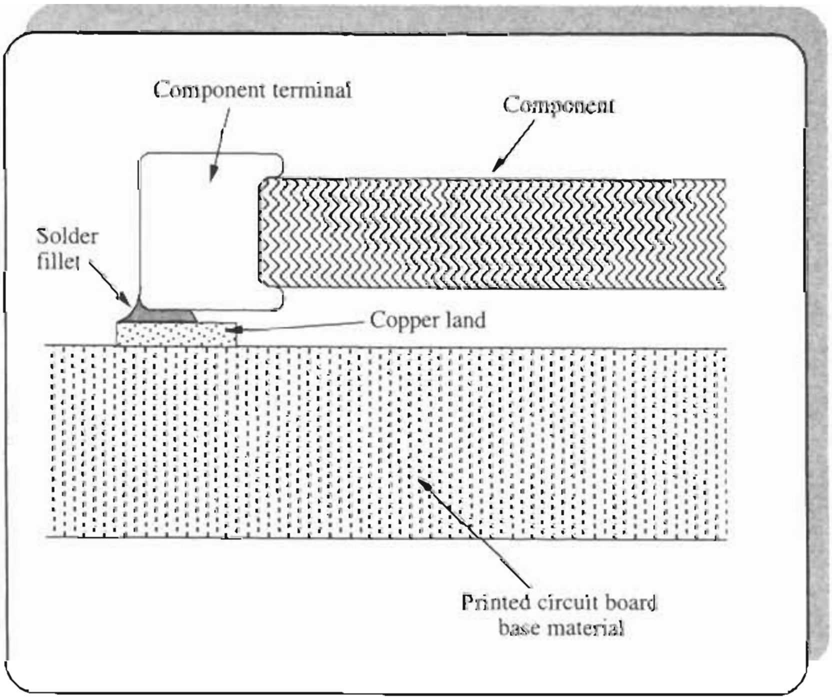


Figure 2.13 *Rigid lap joint, formed when soldering a two-terminal chip surface mounted component*

A second type of surface mounted overlap joint (Figure 2.14) is also common, in which the component terminations are formed by short leads — known as **gull-wings**. These leads ensure the overlap joint formed between termination and copper land is a little more flexible than the rigid lap joint. For this reason such a joint is called a **compliant lap joint**, though more commonly is known as a **gull-wing joint**.

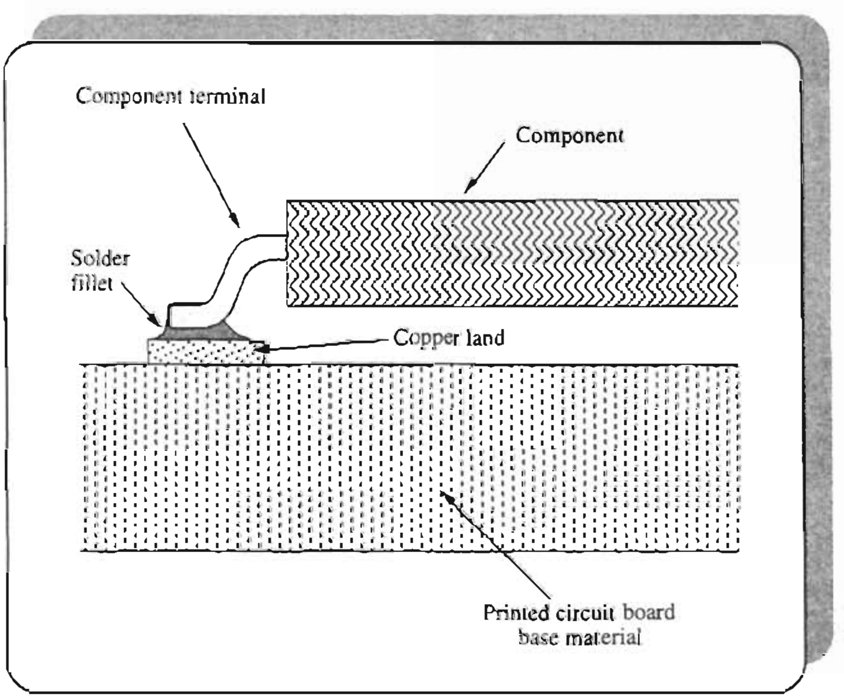


Figure 2.14 *Compliant lap joint — commonly called a gull-wing joint, formed when soldering a multi-terminal short-leaded surface mounted component*

Surface mounted butt joint

A typical surface mounted component butt joint is shown in Figure 2.15. Due to their shape, components with such joints are called **J-lead** components. A J-lead joint has a tensile strength of at least 5 kgf mm^{-2}. It is, due to its short nevertheless flexible termination, another compliant surface mounted component joint.

Another surface mounted butt joint is shown in Figure 2.16. It is not made with a conventional surface mounted component, though, instead a more-or-less standard dual-in-line packaged integrated circuit is adapted by cropping its terminals so the device sits on surface mount lands. Cropped lead applications used to be more common before wide ranges of true surface mounted components became available, but not so common now.

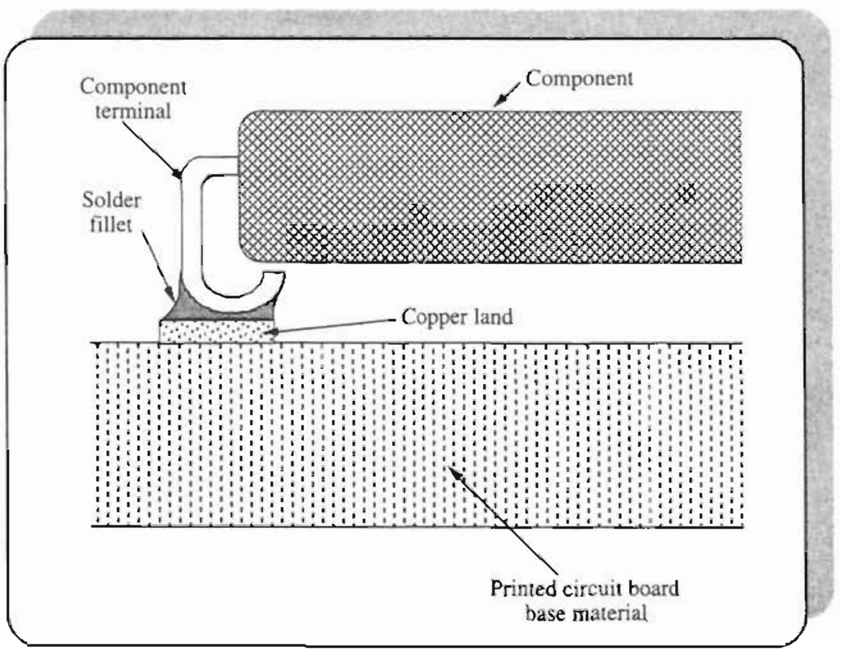


Figure 2.15 *Compliant butt joint, formed when soldering a J-leaded surface mounted component*

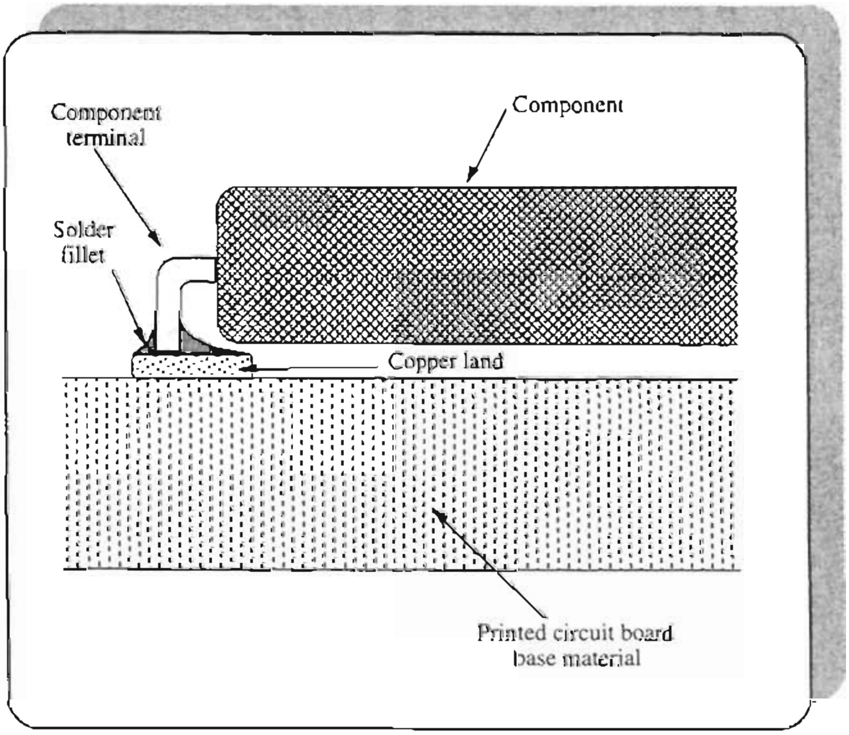


Figure 2.16 *Compliant butt joint, formed when soldering a cropped leaded component to a surface mounted assembly*

While, technically, both these surface mounted joint types are butt joints, only the second is commonly referred so. J-lead joints are usually classed as a different joint form.

Table 2.2 gives a comparison of vital statistics of the four typical surface mounted component joints, together with those of a non-plated through-hole straight lead joint. While land areas and, hence, strengths of the surface mounted component joints are considerably less than those of the through-hole joint, they are still more than amply sufficient to maintain them in position on the printed circuit board.

Table 2.2 Comparison of typical surface mounted component joints and non-plated through-hole straight lead joint

Land parameter	*Rigid lap*	*Compliant lap*	*Compliant butt*	*Through-hole*
Length (mm)	1.25	0.5	0.5	2 (diameter)
Width (mm)	0.5	0.6	0.4	
Area (mm^2)	0.625	0.3	0.2	3
Strength (kg)	1.9	0.9	1	9

Table 2.3 summarizes other important considerations when using surface mounted components. These are on a scale of one to five, with five showing best characteristics.

Surface mount joint failure

Obviously, like through-hole component joints, strengths of surface mounted component joints are not limited by the tensile or shear stress encountered on the joints from the components themselves. Similar to joint strength in through-hole joints which, in reality, is quite large (far larger, in fact, than the strength of the circuit board materials surrounding the joint), the type of joint possible when soldering surface mounted components is also considerably stronger than everyday forces likely to occur directly on the components. Instead, however, it is the printed circuit board base material which is more likely to bear the brunt of forces.

The problem arises simply because of the very small land which a surface mounted component is soldered to. Copper foil adhesion strength is no more than 20 kgf cm^{-1} [Murata, 1988 #2] on typical printed circuit board — much less than the tensile or shear stresses joints themselves can withstand. In effect, even the slightest shear force on a joint can pull the land off the printed circuit board surface.

Table 2.3 Important considerations when using surface mounted components of various types. Characteristics of component joints are on a scale of one to five. A score of five represents optimum characteristics

Characteristic	*Rigid lap*	*Compliant lap*	*Compliant butt*	
	chip	*gull-wing*	*J-lead*	*cropped lead*
Can self-align during soldering?	5	5	3	1
CS soldering?	5	5	2	3
Easy to clean?	5	4	4	4
Easy to probe test?	5	5	2	2
Easy to visibly inspect?	5	5	1	3
How small an area?	3	2	4	3
How thin is package?	4	4	3	1

Shear forces likely to do this occur in two main ways:

- thermal — due to differences in coefficients of thermal expansion between components and printed circuit board base material
- mechanical — due to movement of the printed circuit board, say, by bending.

Mismatch of coefficients of thermal expansion

Any differences in thermal coefficients of expansion between a component and the printed circuit board base material will mean, on heating prior to soldering, both component and board expand (Figure 2.17a) then, on cooling after soldering, component and circuit board shrink by different amounts. If the amount is great enough, stresses are set up which pull lands underneath the component terminals from the board's surface (Figure 2.17b).

How much this effect limits use of surface mounted components depends initially on the type of component. Components whose terminals form rigid lap joints, for example, suffer most from this effect, as there is no compliance built-in to the arrangement.

A general rule-of-thumb is used when soldering rigid lap jointed surface mounted components (generally those commonly called *chip* components) to epoxy resin-bonded, fibre glass reinforced circuit boards; which allows use of components upto about 6 mm in length. Many surface mounted components are within this size limit so lands remain unaffected by thermal coefficient of expansion mismatch.

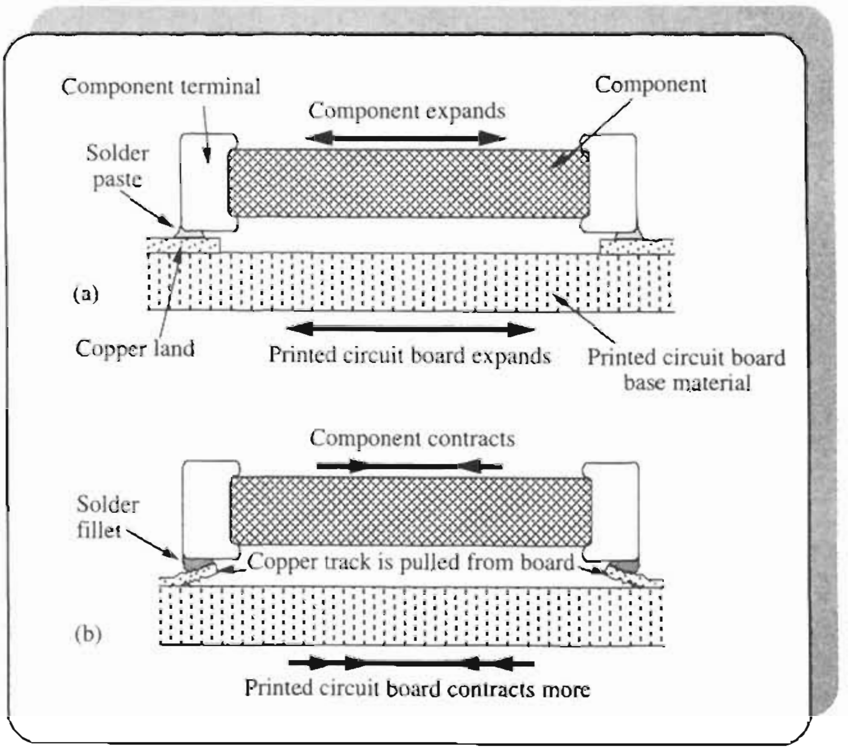


Figure 2.17 *Showing how a mismatch of thermal coefficients between surface mounted components and printed circuit board base can cause damage on cooling after soldering*

Many other rigid lap surface mounted components (leadless chip carriers form the main group), on the other hand, are larger than 6 mm. Such rigid lap jointing of these components to epoxy resin-bonded, glass fibre reinforced circuit board is not, therefore, possible and in the long run an ultimate solution can only be in use of printed circuit board base materials with thermal coefficients of expansion matching those of rigid components (eg, ceramic, metal-bonded).

On the other hand, compliant lap and compliant butt jointed surface mounted components larger than 6 mm do not suffer from any thermal coefficient mismatch problem.

Small outline diodes (SODs), small outline transistors (SOTs), small outline integrated circuits (SOICs), very small outline integrated circuits (VSOICs), tape automated bonded integrated circuits (TABs), and so on are all components having compliant lap terminations. Similarly, compliant butt jointing of components is obtained with such components as plastic leaded chip carriers (PLCCs). As surface mounted components are known for their advantage of being *leadless*, this is something of a backward step, not to mention a misnomer, but does form a short-term solution to a tricky problem.

Study of the soldered joint, in the context of through-hole and surface mounted components, in this manner is forcing a re-appraisal of the use of solder in electronics assembly. The comparatively low strength of the surface mounted joint appears to be of only minor concern.

In effect, compliant lap and butt joints illustrate a successful short-term method of enabling surface mounted components, in quasi-leaded form, to be used with cheaply produced circuit board materials. In the long-term, though, the only solution to enable *pure* leadless surface mounted assembly must be to develop cheap and easy manufacture of thermally matched circuit boards, or to develop newer bonding processes with significantly improved shear strengths.

Assembly variations

Having considered all types of solder joints, if we now look at categories of electronics assemblies and consider joint types within them we can form an idea of all possible requirements which are made of soldering processes. This is a useful thing to do, as from it we'll be able to deduce which soldering processes are best suited to particular assembly types and applications.

From all assembly methods in general use, we can work out a number of assembly categories. These are listed here, as varieties of component types:

- through-hole components on one side
- surface mounted components on one side
- surface mounted components on both sides
- mixed assembly (ie, through-hole *and* surface mounted components on one assembly), surface mounted components on one side
- mixed assembly, surface mounted components on both sides.

Figure 2.18 illustrates all categories as cross-sections of printed circuit boards.

Within each category there are different variants, which obviously affect soldering processes used to a large degree. Consequently we need now to look more closely at each category.

Through-hole components on one side

Assembly of through-hole printed circuit boards comprises two main processes:

- inserting leaded components
- soldering component leads to the printed circuit board copper track.

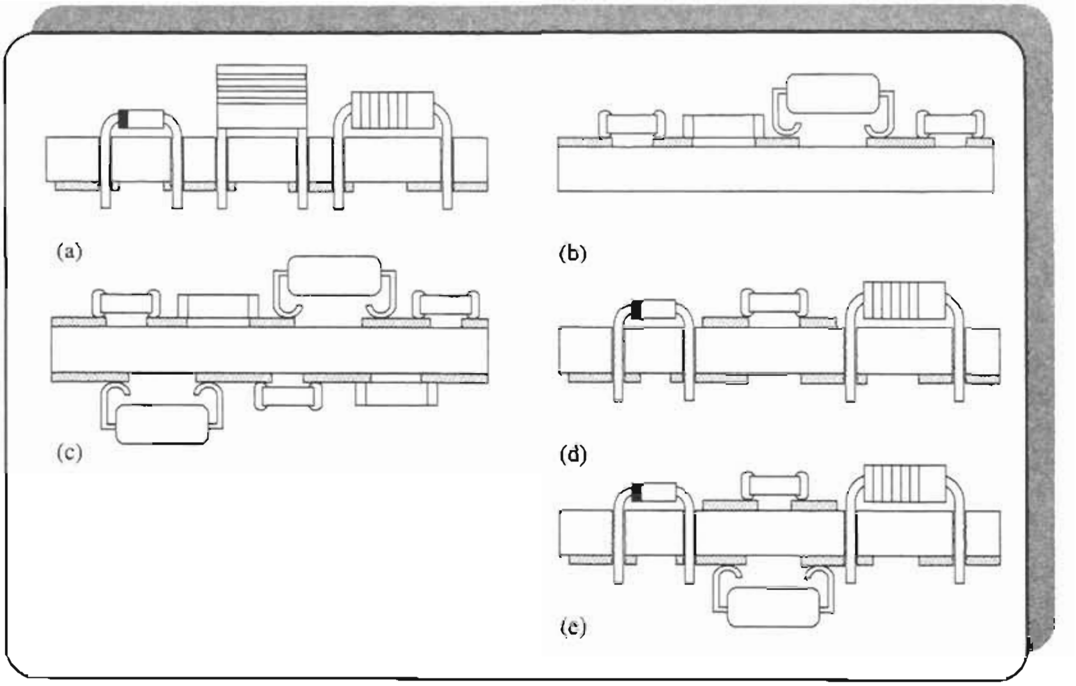


Figure 2.18 *Five variants of electronics assemblies, shown in cross-section (a) through-hole components on one side (b) surface mounted components on one side (c) surface mounted components on both sides (d) through-hole and surface mounted components on one side (e) through-hole and surface mounted components on both sides*

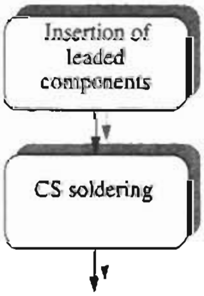


Figure 2.19 *Typical assembly method for through-hole printed circuit boards, using a CS soldering process*

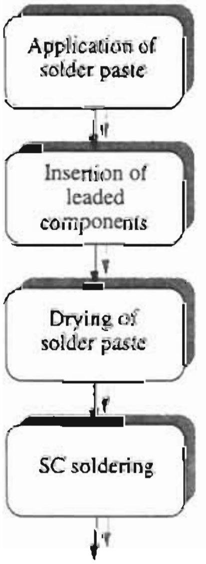


Figure 2.20 *Possible basis for assembly of through-hole printed circuit boards with an SC soldering process*

A typical assembly method for through-hole printed circuit boards is detailed in Figure 2.19. Quite naturally, basic through-hole assembly soldering is seen to be a CS process ie, components-before-solder. Typically, mass solder techniques are of wave solder formats, but dip and drag systems are possible and a few are used.

On the other hand, SC soldering processes of through-hole assemblies *are* possible — an example is shown in Figure 2.20 — it's just that they don't often exist in practice. However, there *is* a situation (mixed assemblies — see later) where SC soldering of leaded components is justified.

Surface mounted components on one side

Both CS and SC soldering processes may be used to solder assemblies of this category. Differences are fairly minimal.

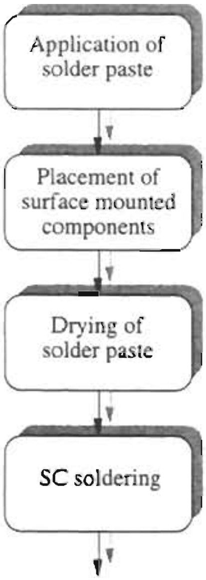


Figure 2.21 *Surface mounted components on one side, SC soldered*

Surface mounted components on one side, SC soldered

This is, in terms of the number of steps, the most straightforward method of manufacturing surface mounted assemblies, shown in Figure 2.21. For this reason, it forms an entry point into the manufacture of surface mounted assemblies for many companies.

Solder paste is first applied to the board in a pattern which matches positions of the terminations of components to be placed. Components are then placed onto the board, the paste is dried and the board is heated in an SC soldering process. Typically, drying of solder paste occurs in preheating stages of soldering processes, so drying and soldering are often thought of as a single operation.

Application of solder paste is most often undertaken in a screen-printing process of some kind. However, other methods are used, too. It is a sufficiently important topic to warrant a section of its own and is considered in depth at the end of this chapter.

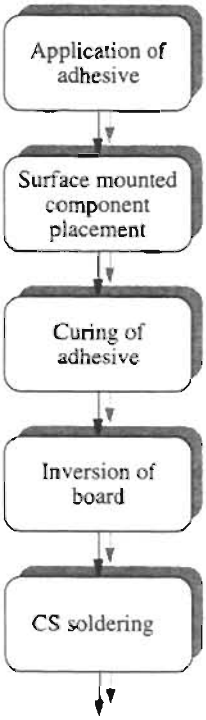


Figure 2.22 *Surface mounted components on one side, CS soldered*

Surface mounted components on one side, CS soldered

Although slightly more complex than the previous variation, use of a CS soldering process means companies with existing through-hole production facilities (which include a wave soldering machine) may be able to adapt production lines to manufacture surface mounted assemblies. Consequently, this variation (shown in Figure 2.22) forms another popular entry point into the manufacture of surface mounted assemblies, without too great an expense.

Adhesive is first applied, by similar methods as for solder paste application (see end of chapter). This stage is followed by component placement. Then, adhesive is cured, the board is inverted, and wave soldering of the assembly follows.

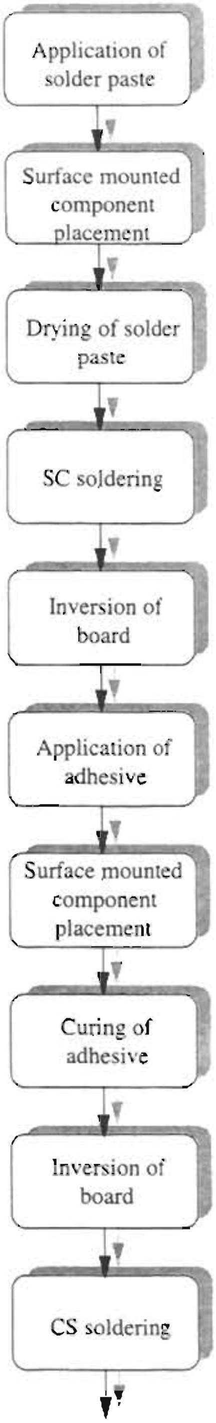


Figure 2.23 *Surface mounted components on both sides*

Surface mounted components, on both sides

Double-sided surface mounted assemblies usually require soldering by both SC *and* CS soldering processes, in sequence. Thus, for a company contemplating entry into surface mounted assembly manufacture, it is comparatively expensive.

As shown in Figure 2.23, the method of manufacture for this type of assembly is simple addition of the two previous variations. Initially, components on the top of the board must be soldered first. Application of solder paste is followed by component placement, paste drying and SC soldering.

Next, components on the other side of the board are placed and soldered. So, the board is inverted, adhesive is applied, components are placed, and the adhesive is cured. Following another board inversion, wave soldering is undertaken.

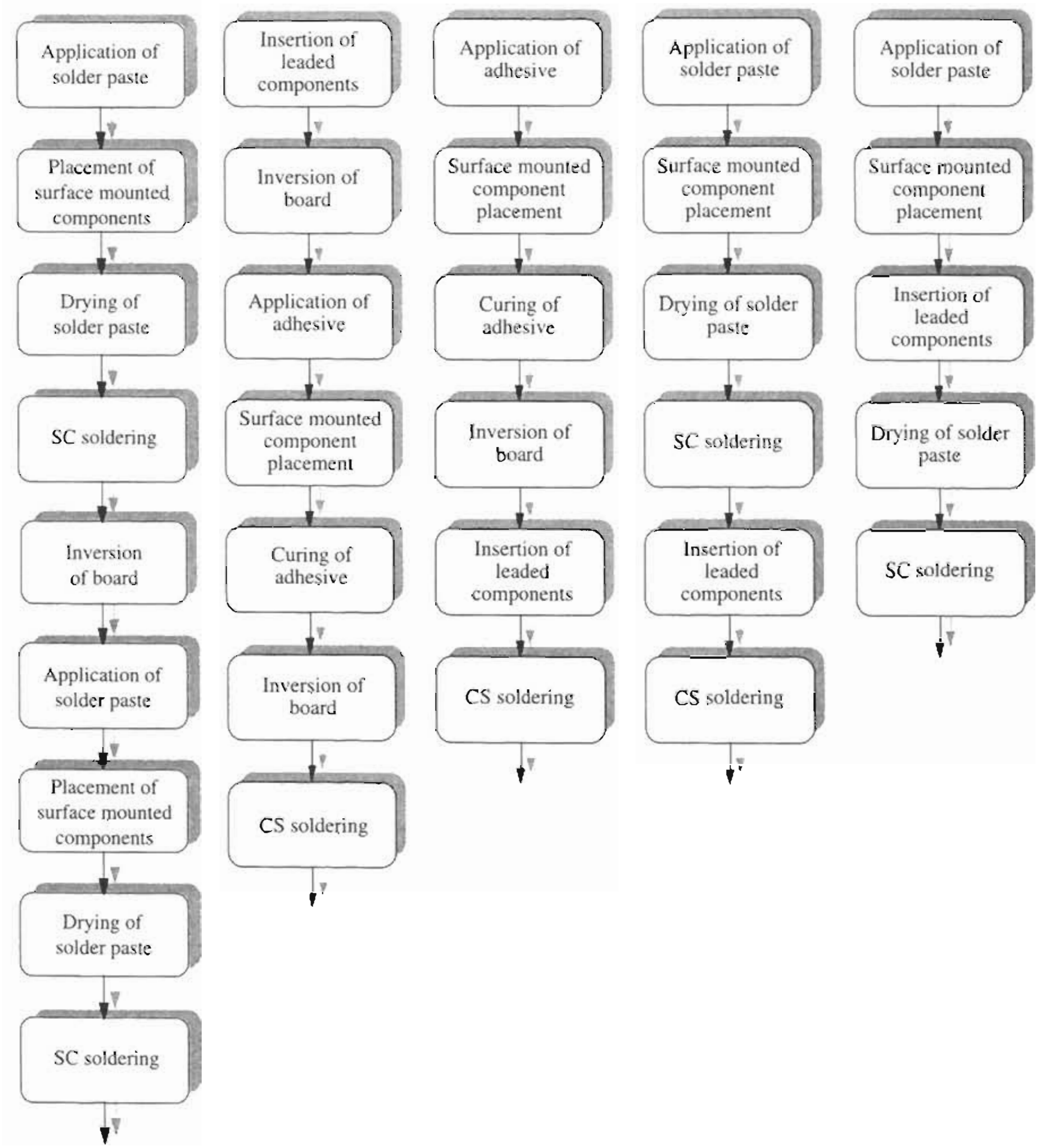
There is an alternative to this method, using two sequential SC soldering processes, illustrated in Figure 2.24. This is a very cost effective method of production with high yields. Although at first sight it might seem components soldered in the first soldering operation will fall off the board as it is soldered a second time, this is not so because surface tension holds them in place.

This is a cheaper method than that of Figure 2.23, simply because a single SC process is used twice, rather than separate CS and SC processes. Purchase of a CS system is thus avoided. Naturally, this is a popular method.

Mixed assembly, surface mounted components on one side

Here, there are four manufacturing variants. First is shown in Figure 2.25, where leaded components are inserted into the board, the board is inverted, adhesive is applied, surface mounted components are placed, and the adhesive is cured. Note that, as leaded components have been inserted (their leads now stick out of the bottom of the board) adhesive cannot be applied to the bottom of the board by screen-printing — pin transfer or dispensing nozzle methods must be instead used (see end of chapter). Following a second inversion, the board is wave soldered.

Second variant simply places surface mounted components before insertion of leaded components (Figure 2.26).



Figures 2.24 to 2.28 *Surface mounted components on both sides, using two SC soldering processes (Figure 2.24), mixed assemblies inserting leaded components first (Figure 2.25), mixed assemblies placing surface mounted components first (Figures 2.26 to 2.28)*

Both of these variants solder both leaded and surface mounted components in a single, wave, soldering process. There are problems here, in that CS soldering processes do not always suit complex surface mount components.

Third variant, however, completely separates soldering of each type of component, as shown in Figure 2.27. Surface mounted components are initially SC soldered, then leaded components are CS soldered.

Although marginally longer production times are required in this variant, it does give the advantage that complex surface mounted components, such as leaded and unleaded chip carriers, or TAB integrated circuits, may be placed on a mixed assembly. None of the previous methods allows this.

Fourth variant is a slightly unusual one, as it entails SC soldering of leaded components, using solder paste applied prior to placement of surface mounted components and insertion of leaded components. This is not a common variant, although it has significant potential; and there is a natural reason why through-hole SC (THSC) processes may become more popular — simply because use of surface mounted components is increasing, while that of leaded components is decreasing.

Situations naturally exist where all but a handful of components are surface mounted. Manufacturers face a choice whether to use one of the three previous methods — which all use CS soldering processes to one extent or another — but this may not be acceptable by manufacturers who only have SC soldering processes, and wish no further expenditure on equipment which may be used only a few times. The variant shown in Figure 2.28 has been used often for soldering of connectors and pin grid arrays, but is now being considered for conventional leaded components too.

Through-hole SC soldering processes require use of modified solder paste application processes (see end of chapter) which allow printing or dispensing of solder paste over the through-hole pad and into the hole itself. Component leads are then inserted (usually by hand, although automatic component insertion may be viable) carefully, pushing solder paste further into the hole. Remnants of solder paste may be left on lead ends of components. Prior to or following insertion of leaded components, surface mounted components are placed.

Assemblies are then soldered in any SC soldering process. Care must be taken, though, to support assemblies to allow leaded components to seat freely during the process. Generally a support jig is used to hold assemblies at their edges.

Two points need to be considered when SC soldering leaded components. First, leaded components must be able to withstand SC soldering process temperatures. In most CS processes, components do not reach a temperature above 120°C, but components soldered by SC processes may reach temperatures upto 235°C for some time.

Second, solder fillets of leaded components soldered by SC processes are considerably leaner than their CS process counterparts. This is due to the limited amount of solder paste applied during printing. When viewed, fillets have a depressed appearance, but this does not significantly affect joint strength.

Mixed assembly, surface mounted component on both sides.

Where surface mounted components are to be placed on both sides of a mixed assembly, it is common to separate soldering of components on the top and bottom sides of the board.

Procedure is illustrated in Figure 2.29. First, after the usual application of solder paste, surface mounted components are placed on the top of the board, the paste is dried, and the components are SC soldered.

Next, leaded components are inserted, the board is inverted, adhesive is applied, surface mounted components are placed, and the adhesive is cured. Again, as leaded components have been inserted, adhesive application cannot be by screen-printing. After final board inversion, wave soldering completes the process.

This method, like the previous, allows mixed assemblies to contain complex surface mounted components, such as leaded or leadless chip carriers, or TAB integrated circuits.

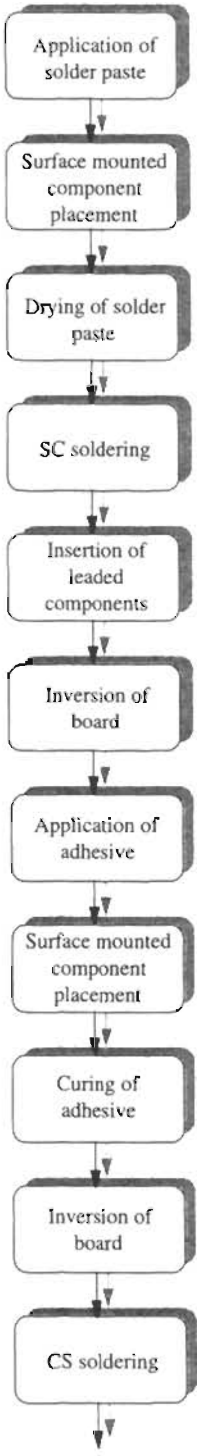


Figure 2.29 *Mixed assembly, with surface mounted components on both sides*

Assembly classification

Some of these assembly variations are so common that, by simple convention rather than by standard, a number of classifications are in common use. These are:

- type I — application of solder paste; placement of surface mounted components; drying of solder paste, SC soldering (in other words, the process previously shown in Figure 2.21), illustrated in Figure 2.30
- type II — insertion of leaded components; inversion of board; application of adhesive; placement of surface mounted components; curing of adhesive; inversion of board; CS soldering (in other words, the process previously shown in Figure 2.25), illustrated in Figure 2.31
- type III — application of solder paste; placement of surface mounted components; drying of solder paste; SC soldering; insertion of leaded components; inversion of board; application of adhesive; placement of surface mounted components; curing of adhesive; inversion of board; CS soldering (in other words, the process previously shown in Figure 2.29) illustrated in Figure 2.32.

While these are valid assembly variations, readers should note they are not the *only* variations. They are defaults which have been itemized simply because they are common. Choice of which of *all* variations we've looked at in this chapter (a total of *eleven*) should be made on an individual basis, and depends on available assembly equipment, available soldering equipment, available budget, particular components and so on. Readers should expect new assembly variations to be generated as new production equipment evolves, too. Electronics assembly is not a static process.

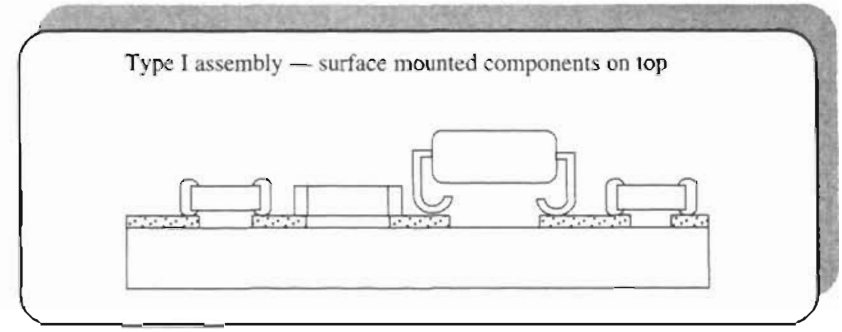


Figure 2.30 *Assembly classification — type I*

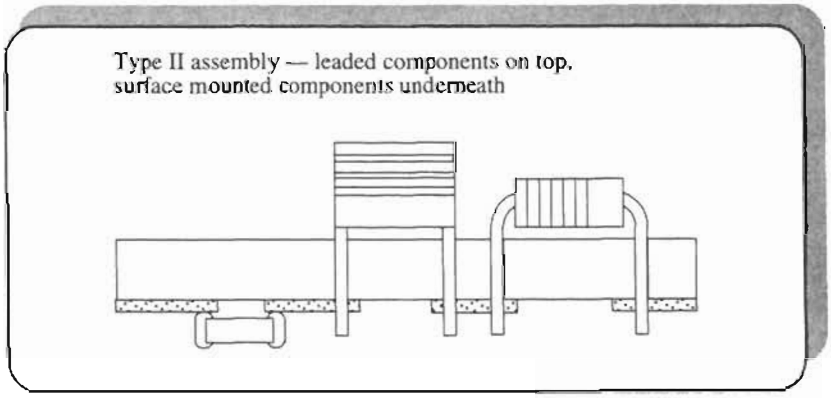


Figure 2.31 *Assembly classification — type II*

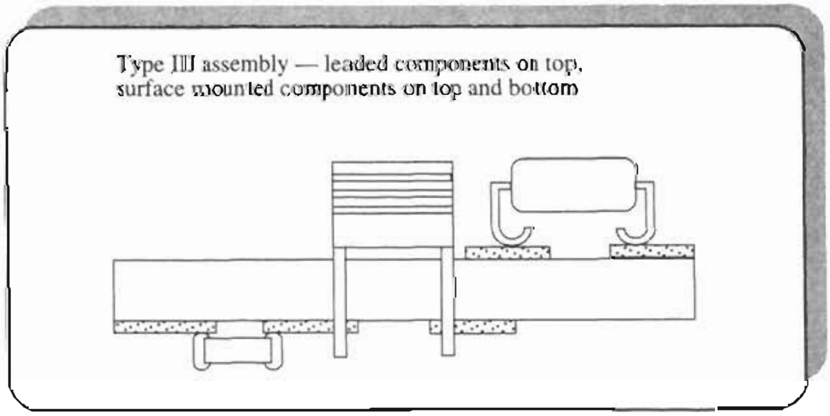


Figure 2.32 *Assembly classification — type III*

3 Solder

Most solders used in electronics assembly are basically alloys of tin and lead. Soldering, however, as a general process (more commonly called **soft soldering**) may be used to joint many more things than electronic component leads and copper tracks of printed circuit boards. In effect, soft soldering is the basis of any process in which metallic parts are jointed by a molten alloy with a melting temperature less than 450°C.

Soft soldering is also an extremely old process. As noted in Chapter 1, the Romans are known to have used a tin/lead alloy to joint lead water pipes. However, soft soldering using tin and lead may have but a limited life left — as an aside it's interesting to note that, at current production rates of tin, the world's resources of the metal will give less than fifty years' more use. There is also a move, currently, to create legislation against the use of lead in solder.

Metallurgical properties of tin/lead alloys

One of the most useful properties of tin/lead alloys as soft solders is the associated range of low melting temperatures. Table 3.1 lists melting temperatures of a selection of alloys, with proportions of the alloys shown as percentages. Note that over a central range of alloy proportions there is no particular melting-point, merely a range over which the alloy is neither molten nor solid — a pasty or plastic state. However, at one particular alloy proportion (62% tin/38% lead) the alloy melts at a single temperature (183°C) — also the lowest melting temperature of any tin/lead alloy. Figure 3.1 illustrates this, in what is known as a **phase diagram**, where liquid, plastic and solid states of tin/lead alloys are shown, together with the lowest melting temperature.

A 62% tin/38% lead alloy composition is known as a **eutectic** composition, and the 183°C melting-point of this alloy is the **eutectic point**. All electronics assembly processes, with few exceptions, use solder with constituents around the eutectic proportions, due simply to the guaranteed low melting-point.

Table 3.1 Melting temperatures of tin/lead alloys

Alloy as percentages of tin and lead	*Melting temperature (°C)*
100 lead	327
5 tin/95 lead	300
10 tin/90 lead	267
30 tin/70 lead	281
40 tin/60 lead	182 to 235
50 tin/50 lead	183 to 212
60 tin/40 lead	183 to 189
62 tin/38 lead	183
70 tin/30 lead	183 to 191
90 tin/10 lead	183 to 213
100 tin	232

Purely of interest, there appears to be some confusion over the exact eutectic proportions and melting-point of solders. Most authors refer to the eutectic composition as 63% tin/37% lead, but more recent studies and authors [Leonida, #3] [Klein Wassink, #4] have noted a eutectic composition of 61.9% tin/38.1%, which sounds altogether more impressive. In the

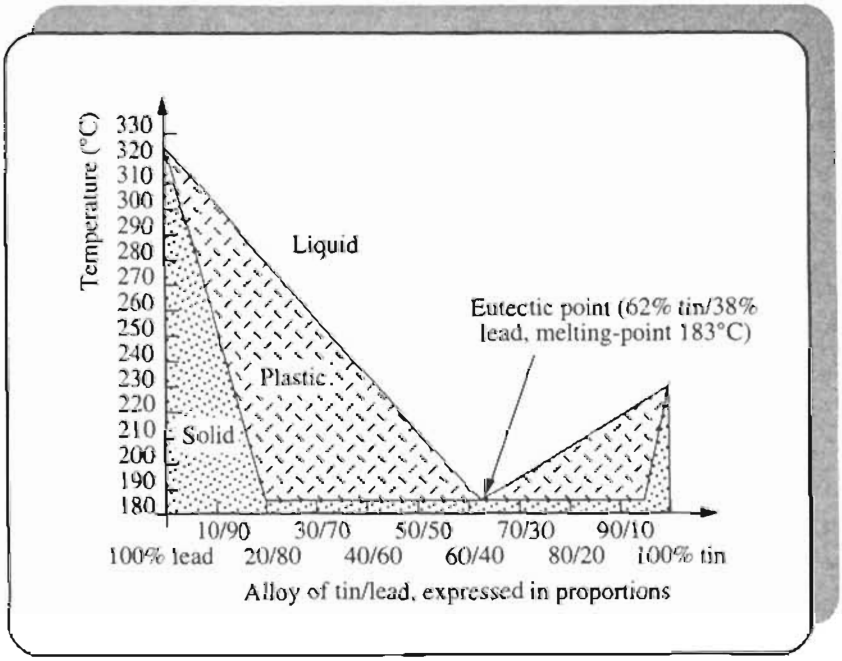


Figure 3.1 *Phase diagram of tin/lead alloys*

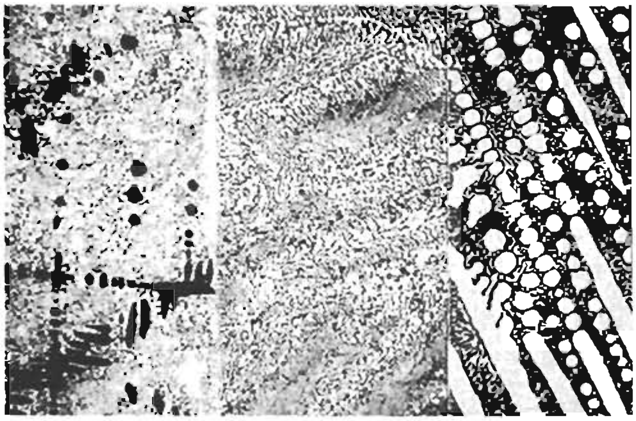


Photo 3.1 *Three types of solder: lead rich (left), eutectic (centre) and tin rich (right) (Alpha Metals)*

absence of first-hand proof (which we are sure most, if not all, other authors are similarly without) we shall comply with the more up-to-date findings. For practical purposes, at least, there is little difference, anyway, and many engineers within the industry consider the 63% tin/37% lead alloy to be eutectic.Typical tolerances of ± a few per cent exist anyway, in solder as delivered from suppliers.

Tin is an expensive metal, and so a reduction in the amount used in solder makes a cheaper solder, so a 60% tin/40% lead solder alloy is sometimes used in electronics assembly. It exhibits a melting temperature range of 6°C, rather than a defined melting-point, so this means a corresponding slightly higher process temperature is required; but this generally does not affect the soldering process significantly. Apart from precision soldering requirements of, say, multi-layer printed circuit boards and surface mounting of components, the cheaper 60% tin/40% lead alloy is often acceptable.

Most commonly, however, eutectic solder is used, simply because its lower soldering temperature gives a lower likelihood of component damage as well as lower dross formation in CS soldering process machines. Maintaining solder at eutectic proportions in, say, a CS soldering machine is a task which must be carefully attended too. With time, dross — in the form of tin oxide — is produced and so tin generally depletes from the solder, leaving an alloy rich in lead.

Strength and stress resistance

Once made, the soldered joint must be strong and resist reasonable stresses. Figure 3.2 shows graphs of how tensile strength and shear strength of solder vary with tin/lead alloy proportions. Although not quite at the peak of either graph, eutectic tin/lead solder still affords reasonable strength for joints.

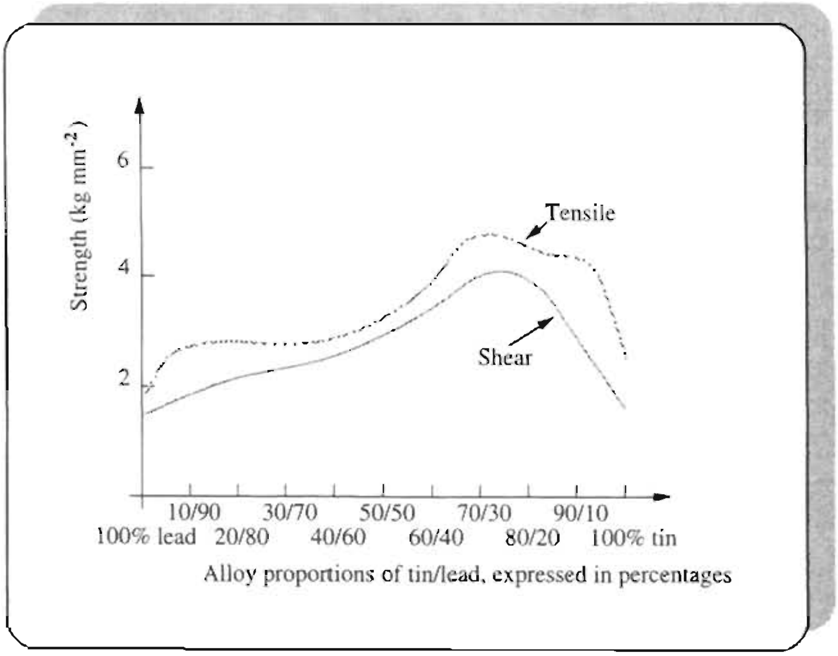


Figure 3.2 *Tensile and shear strength variation of solder with tin/lead alloy proportion*

Elasticity

Due to the fact that tin/lead solders exhibit significant **creep**, elasticity of solder is difficult to ascertain, but its modulus lies around 30,000 Nmm^{-2}.

Creep

Creep is a plastic deformation which occurs when a material is subjected to stress for a period. The closer the material is to its melting temperature the more likely it is for creep to occur. It is thus of significance even at ambient temperatures for tin/lead solder, because an ambient temperature of, say 25°C (298 K) is not too far from the melting-point of 183°C (461 K). Creep follows three distinct stages, illustrated in Figure 3.3:

- primary creep; occurring rapidly when stress is first applied, but decreasing with time
- secondary creep; occurring at a constant rate for the greater part of the joint's lifetime
- tertiary creep; occurring after the joint has been subjected to sufficient secondary creep to cause its final demise. Tertiary creep occurs at an increasing rate, and ends with the joint's rupture.

This property is therefore a disadvantage in any choice of solder for electronic printed circuit board assemblies, but given that other solders will

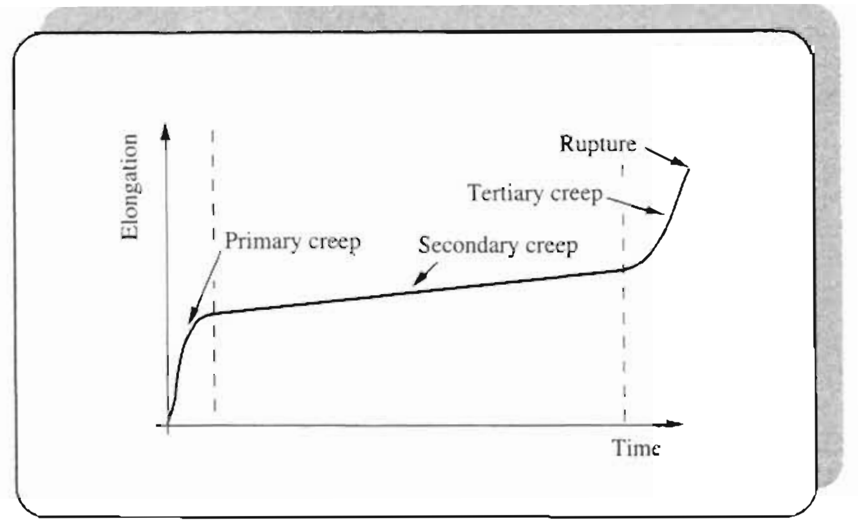


Figure 3.3 *Showing the three stages of metallurgical creep*

require a significantly higher soldering temperature which may damage the components being soldered, eutectic tin/lead solder is still preferable — a case of advantages outweighing a disadvantage.

Surface tension

Generally speaking, the lower the surface tension of a fluid, the easier it will wet a surface to which it is applied. Put the other way round, it's a fluid's surface tension which holds it together if the surface isn't easily wettable. Surface tension is the force which holds insects on the surface of pond water. It's also the reason why water can only form into globules on a greasy plate — a detergent wash reduces surface tension so water wets the plate and flows out into a thin layer.

In effect, surface tension of any liquid acts to minimize its surface area. In absence of other forces surface tension would therefore, quite naturally, hold the liquid into the three-dimensional shape which has the smallest surface area — a sphere. However, forces such as those between surfaces or gravity tends to distort the liquid's shape somewhat.

Molten lead has a much lower surface tension than molten tin, so it might be assumed that a higher content of lead than a eutectic solder is appropriate. However, lead itself exhibits a significant interfacial tension with copper which prevents wetting, so eutectic tin/lead solder remains the best option.

Resistivity

Eutectic tin/lead solder has an electrical resistivity some ten times that of pure copper, but it is still only around 0.17 $\mu\Omega m^{-1}$ at ambient temperatures, and given the much larger area of a soldered joint compared with a copper printed circuit conductor the difference is not really a significant problem at all.

Thermal conductivity

Thermal conductivity of tin/lead solder is about 50 $Jm^{-1}s^{-1}K^{-1}$ at ambient temperatures; some one eighth of copper's. If significant lengths of solder were used on a printed circuit board to make connections this could pose some problems, but the short distances filled by solder within soldered joints generally cause few problems here.

The soldered joint

Before a solder joint can be made it is imperative solder can wet the basic metals that will form the joint. This is the key to successful soldering.

There are two aspects to wetting. First, it is solder's surface tension which defines how well solder wets a metal. Consequently we should aim to use solder with as low a surface tension as possible.

Second, on the other hand, cleanliness of the surface to be soldered is also of paramount importance. If not clean, solder will *not* wet, however low its surface tension.

To illustrate these aspects Figure 3.4 looks at application of solder to a copper surface. There are three important parts to this application:

- a liquid — solder, heated beyond melting point
- a solid — copper, heated to the same temperature
- a gas — the surrounding atmosphere.

At one point alone all three parts meet. An angle formed between the liquid and solid, passing through this point, is technically called the **dihedral angle** (though more usually known as the **wetting angle** or sometimes the **contact angle**) and is given the symbol θ (lower case Greek letter *theta*). This wetting angle is a direct indication of how much the surface of the metal has been wetted by the solder.

Figure 3.5 shows four theoretical examples of various degrees of wetting. Figure 3.5a shows a situation where wetting has not occurred at all. Put another way, the surface of the metal is said to be completely **non-wetted**. Wetting angle θ here is equal to 180°. Although we've noted earlier that

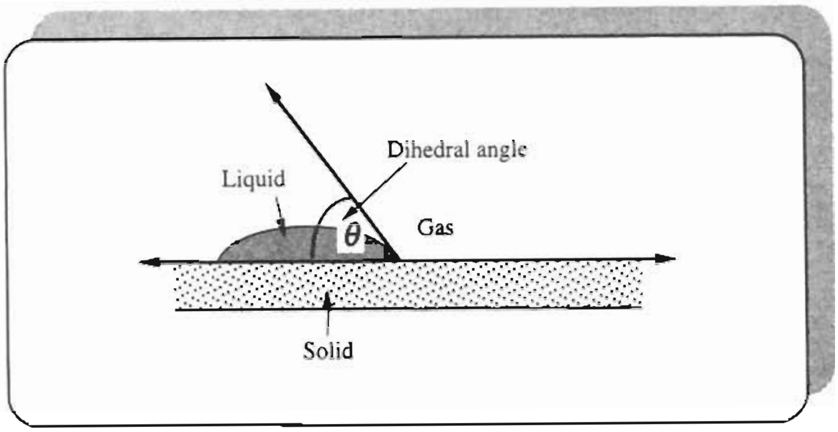


Figure 3.4 *Application of molten solder to a copper surface*

surface tension tends to hold a liquid in a spherical shape if no other forces are apparent, Figure 3.5a illustrates how gravity affects solder globule shape.

In Figure 3.5b **partial wetting** is said to have taken place, where wetting angle is between 0° and 180°.

A different wetting condition known as **dewetting** is shown in Figure 3.5c. Dewetting occurs when solder initially wets a metal surface then withdraws before solidifying as temperature falls below melting point. Really the only difference between dewetting and partial wetting is evidence of wetting has occurred prior to withdrawal. There is, however, no bonding between solder and metal surface.

Finally, Figure 3.5d shows the case where **total wetting** has occurred. Here wetting angle is 0°.

Obviously, solder processes should aim for a wetting angle of 0° although, in practice, this ideal is never reached. Instead a good practical wetting angle which gives good wetting is typically taken to be less than about 75° [Manko, #5].

If surface tension of solder is sufficiently low, wetting angle can be reduced to a minimum. Often this is simply a task of maintaining solder quality by eliminating or defining levels of impurities.

Impurities

There are three categories of impurities which may occur in the tin/lead solder alloy:

- those impossible to remove from base tin and lead metals in the refinement processes

- those added by solder manufacturers or users, to improve solder's performance
- those entering solder during the normal course of use.

Generally speaking, those in the first category aren't significant and don't usually affect solder performance. Impurities specifically added to solder with the aim of improving solder performance include small quantities of antimony and copper, which can reduce solder creep. Table 3.2 lists a selection of tin/lead soft solder alloys. Associated temperatures and approximate proportions of tin, lead and antimony are shown.

Antimony also can be used to allow a reduction in the amount of tin required in the solder — tin is an expensive metal and so the lower the percentage of tin in solder, the cheaper the solder! An alloy of 52% tin/45% lead/3% antimony, for example, exhibits a slightly raised melting temperature and is, in fact, stronger compared with eutectic or near-eutectic tin/lead solder.

Impurities entering solder during use, however, are generally most difficult to control and can certainly give the greatest problems regarding solder joint quality. This is really of concern only to mass CS soldering processes, where a bulk of solder is maintained at a molten temperature. Here impurities are really contaminants and are not specifically desired for acceptable operation. Contaminants can arise from anything which comes into contact with the solder. Items falling accidentally into the solder — tools, nuts, bolts and so on — are a possible cause, but in most cases contamination comes from the assemblies actually being soldered in the process. This is simply because various metals on each assembly all dissolve to a small extent in the solder. Obviously amounts concerned are minute, but in large volume production systems with consequent large numbers of assemblies each minute amount builds up to eventually affect soldering action to one degree or another. This might be reflected in solder joint quality.

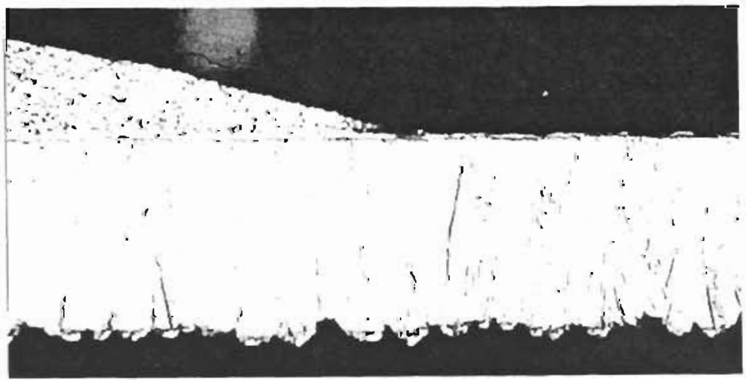


Photo 3.2 *Good wetting on copper, showing solder with a small wetting angle and an intermetallic compound layer (Alpha Metals)*

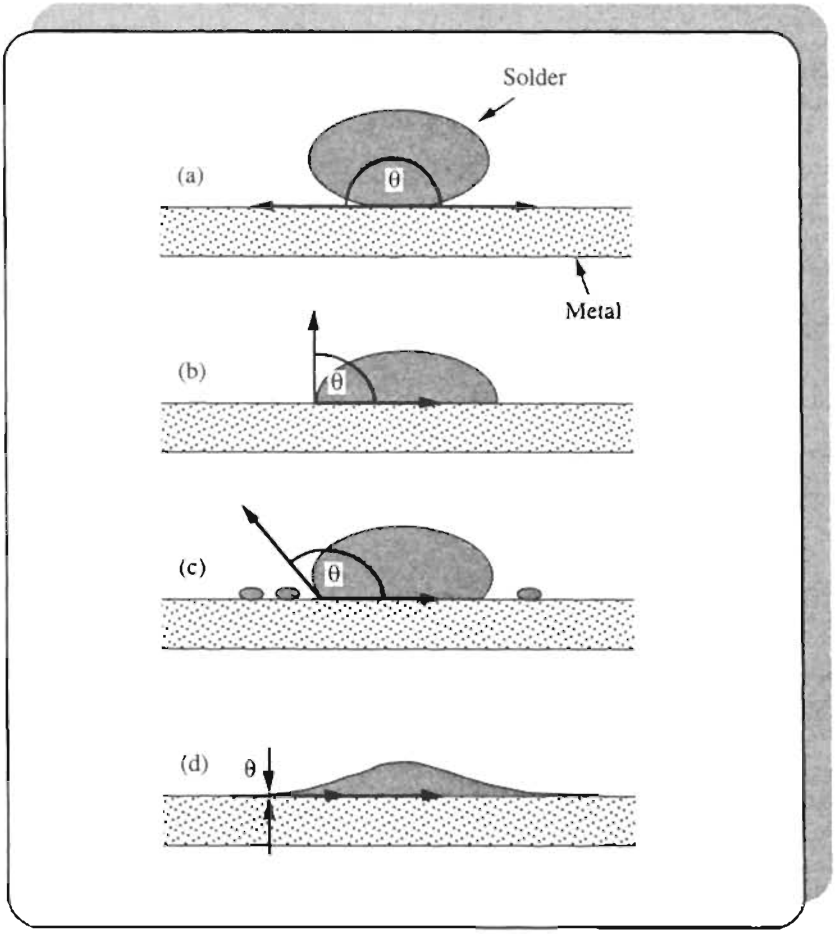


Figure 3.5 *Four extremes of soldered joints (a) non-wetting (b) partial wetting (c) de-wetting (d) total wetting*

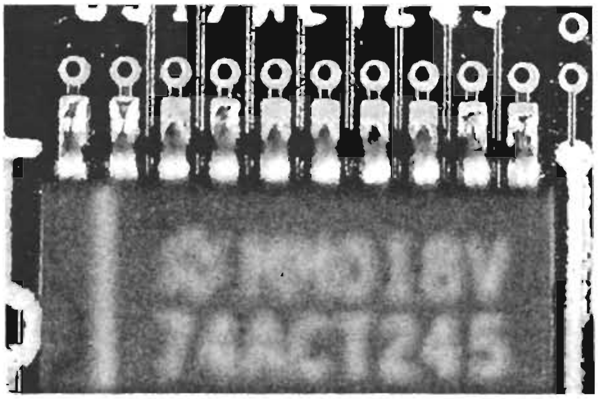


Photo 3.3 *(above) non-wetting (Alpha Metals)*

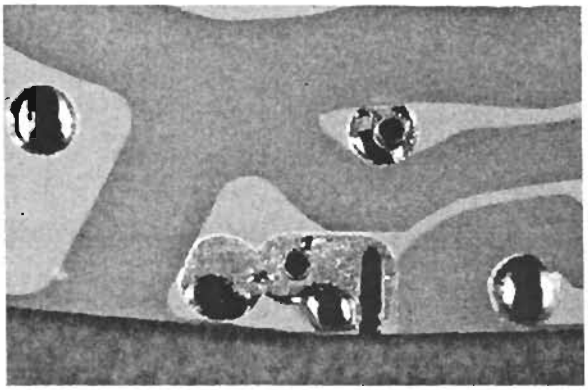


Photo 3.4 *(right) de-wetting (Alpha Metals)*

Whether contaminants reach a level sufficient to cause process problems depends on their rate of addition and the amount of solder removed in the soldering process. It is illustrated in a simple graph of contaminant level and time (Figure 3.6). If considerable amounts of solder are removed in the soldering process, equally considerable amounts of solder must be replaced to maintain correct solder volume. Each addition of fresh solder lowers the contaminant level as a percentage of total volume so causing steps in the graph.

As contamination level increases, tin's ability to dissolve more contaminant is reduced. Eventually, shown by the graph, an equilibrium is reached after which further additions of contaminant to the solder creates no further increase in contaminant level dissolved. If this equilibrium level is below maximum permitted levels (ie, levels above which the soldering process is degraded) no action need be taken.

Table 3.2 Selection of soft solder alloys

Grade	*Alloy number*	*Tin (%)*	*Antimony (%)*	*Lead (%)*	*Solid at (°C)*	*Liquid at (°C)*
Tin-lead alloys						
	1	62.5–63.5	0.12	remainder	183	183
	1a	62.5–63.5	0.05	remainder	183	183
	2	59.5–60.5	0.12	remainder	183	190
	2a	59.5–60.5	0.05	remainder	183	190
	3	49.5–50.5	0.12	remainder	183	215
	3a	49.5–50.5	0.05	remainder	183	215
	4	44.5–45.5	0.5	remainder	183	225
	5	39.5–40.5	0.5	remainder	183	235
	6	34.5–35.5	0.5	remainder	183	245
	7	29.5–30.5	0.5	remainder	183	255
	8	9.5–10.5	0.5	remainder	250	302
	9	7.5–8.5	0.5	remainder	280	305
	10	1.5–2.5	0.12	remainder	320	325
Tin-lead alloys with antimony						
	11	62.5–63.5	0.12–0.5	remainder	183	183
	12	59.5–60.5	0.12–0.5	remainder	183	190
	13	49.5–50.5	0.12–0.5	remainder	193	216
	14	39.5–40.5	2–2.4	remainder	185	231
	15	29.5–30.5	0.5–1.8	remainder	185	250
	16	24.5–25.5	0.5–2	remainder	185	263
	17	19.5–20.5	0.5–3	remainder	185	270

Note: (1) small amounts of other elements are always found in solder, so may affect solder properties accordingly

(2) temperatures are for information only, and are not specified requirements for the alloys

On the other hand, it is wise to regularly monitor contaminants' levels, at a frequency based on solder pot capacity, throughput of assemblies, time assemblies are in contact with solder, and solder temperature. Initially taking readings, say, at monthly intervals, may be a good starting point. This allows equilibrium levels to be established and identifies if and when further action has to be taken to remove contaminants.

Categories of contaminants

There are three main categories of contaminants:

- oxidizing metals — aluminium, cadmium, phosphor, zinc
- mixed crystal-forming metals — antimony, bismuth
- intermetallic phasing metals — arsenic, cobalt, copper, iron, nickel, palladium.

Generally these work in similar ways within each category, a factor which allows us to consider their effects on the solder they are added to. Basically, we are interested in how solder wets a copper surface, so the best way of comparing contaminants is to consider how they affect solder's wetting ability. Wetting ability is just one aspect of **solderability**, which is discussed later, but for now we can see how contaminant categories affect solder's wetting ability in the wetting force curves of Figure 3.7, where pure solder's wetting ability is compared against that of contaminated solder of each of the three categories.

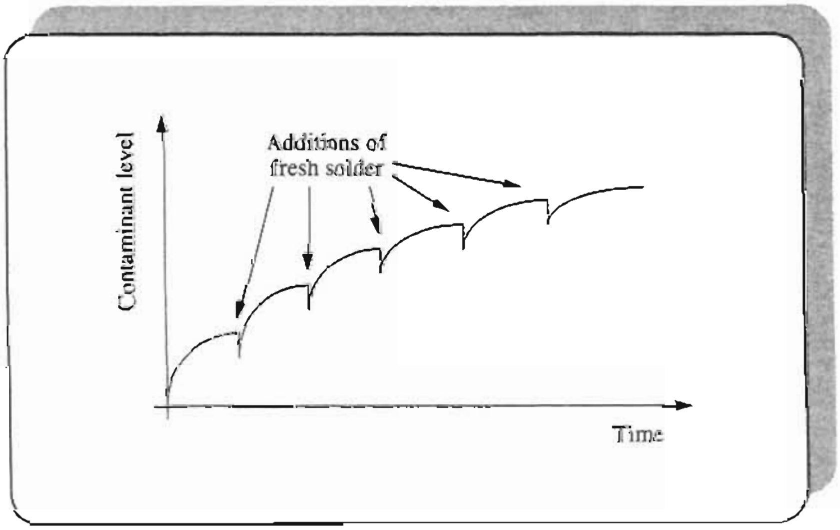


Figure 3.6 *Showing how additions of solder lower the contaminant level at that instant, but the overall contaminant level continues to increase (Electrovert)*

In simple terms, the lower the curve, the lower is that solder's wetting ability. So, contaminants which oxidize readily decrease solder's ability to wet. On the other hand, contaminants which are metals which form mixed crystals actually improve solder's ability to wet slightly.

Practically, contaminants have established and typical effects. Some common contaminants and their effects are:

- aluminium — gritty joints; increase in dross* on the solder surface; solder joint appears dull. Antimony eliminates these effects
- antimony — in amounts over about 0.5% can reduce solder's ability to wet; in smaller amounts improves low temperature capability of solder joint
- cadmium — reduces solder's wetting ability substantially; causes solder joints to look very dull, but in minute quantities reduces bridging between components
- copper — gritty looking joints; but there is no recorded deleterious effect on wetting ability
- gold — frosty looking joints; but there is no recorded deleterious effect on wetting ability
- iron — produces excessive levels of dross which can cause bridging; but there is no recorded deleterious effect on wetting ability
- nickel — in small concentrations causes tiny bubbles or blisters on solder joint surface; but there is no recorded deleterious effect on wetting ability
- silver — can cause dull joints; in high concentration makes solder less mobile. Silver is not generally classed as a bad contaminant and is deliberately added to some solder alloys
- zinc — causes dross rate to increase; joints look frosty.

*Dross is the oxide formed on the molten solder surface in the solder bath. Rate of dross generation depends on several variables, including; contaminants, temperature and agitation.

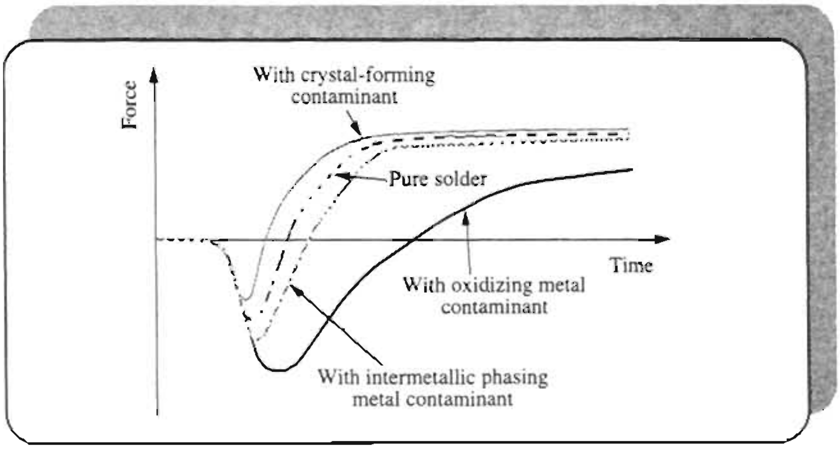


Figure 3.7 *Wetting force curves of solders with various contaminants*

Photo 3.5 *SC solder on a printed circuit board track (Alpha Metals)*

Metal surface preparation

Lowering solder surface tension, or adjusting solder performance by lowering or adding impurities is of no avail if metal surfaces to be jointed aren't adequately prepared. Problem is that copper very easily oxidizes, forming a thin layer of copper oxide on its surface very rapidly in air at ambient temperatures (at soldering temperatures oxidation is even more rapid). This oxide layer effectively forms a barrier preventing solder wetting the surface. In general, flux is used to prepare the copper surface, removing this oxide layer and maintaining a pure copper surface for solder to wet. It's important to note though, flux is *not* a prerequisite for good soldering — just a clean copper surface! Chapter 5 deals with fluxes together with preparation and maintenance of metal surfaces.

Intermetallic compound formation

If two strips of copper are soldered together as in Figure 3.8, magnification of the area immediately surrounding the joint by about 200 times shows presence of a compound material between the solder and each layer of copper's surface. This compound material was not there before soldering took place and is caused by combination of tin in the solder with the surface layer of copper to produce a new compound. The compound is a peculiar type of compound called an **intermetallic compound**. It has a chemical formula of one of two types: Cu_3Sn or Cu_6Sn_5. Formation of an intermetallic compound is always seen when solder wets copper and, in turn, is evidence that wetting has occurred. In other words, without intermetallic compound formation, soldering cannot take place.

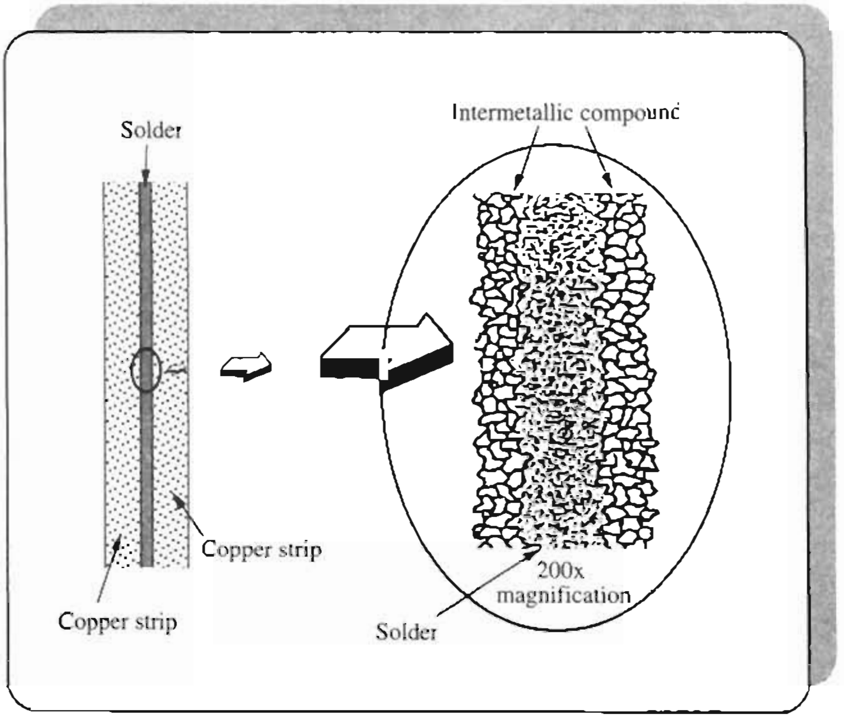


Figure 3.8 *Magnification of a solder joint between two copper strips shows an intermetallic compound layer*

Intermetallic compounds are molecular combinations of atoms of the metals concerned and so once an intermetallic compound between tin and copper exists on the surface of copper it cannot be removed by desoldering techniques. This is so because intermetallic compounds are compounds with strictly defined stoichiometric ratios of elements whose atoms have an extremely high affinity for each other. This affinity is high enough to deny bonding of other elements. Thus there is a strict metallurgic difference

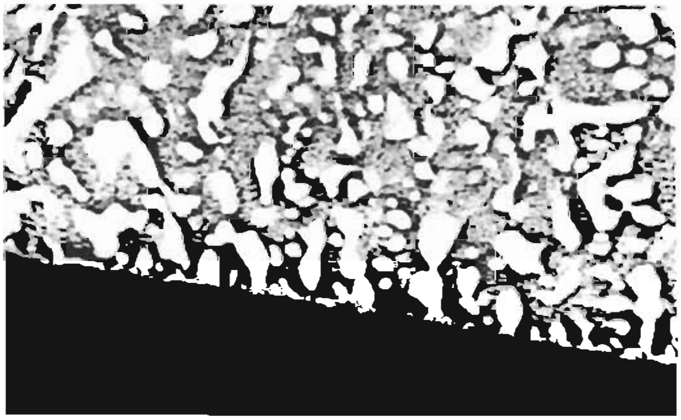


Photo 3.6 *Solder/copper interface, showing the copper/tin intermetallic compound layer as a line separating the two (Alpha Metals)*

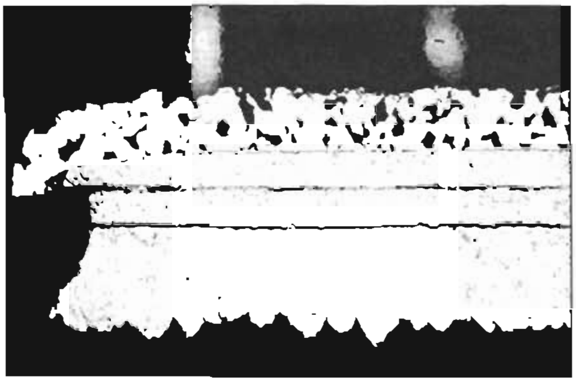


Photo 3.7 *CS process solder on a printed circuit board track (Alpha Metals)*

between alloys (such as solder — tin and lead) whose element proportions are variable, and intermetallic compounds whose element proportions are fixed by chemical formulae.

Factors affecting intermetallic compound formation

Thickness of the intermetallic compound in a soldered joint is determined by temperature of the joint as it is soldered and time spent at that temperature. Formation of a tin/copper intermetallic compound occurs even at room temperature, but the reaction is so slow it is of no practical importance to solder joints.

On the other hand, where bare printed circuit boards are coated with very thin solder layers such as those used to protect boards (see later), it's important to remember tin slowly combines with copper and so leaves a lead-rich external layer. This affects solderability after long storage periods.

Intermetallic compounds of tin and copper are harder than either solder or copper. They are also more brittle. If an intermetallic compound layer becomes too thick a possibility of damage under thermal or mechanical stress exists, where solder within the joint cracks. This is illustrated in Figure 3.9.

It is not possible to make a good soldered joint unless temperatures of all metal surfaces are above solder's melting-point temperature. Heat to do this depends on the soldering process used. CS soldering processes typically use a combination of pre-heating mechanisms together with temperature of the solder itself. SC processes use a variety of heating mechanisms.

In a CS wave soldering process the solder wave is the main supply of heat; but this only contacts the bottom of the printed circuit board. Consequently, if a joint's thermal path from board bottom to board top is incomplete it is not possible to heat it up in the small time a board is in contact with the solder.

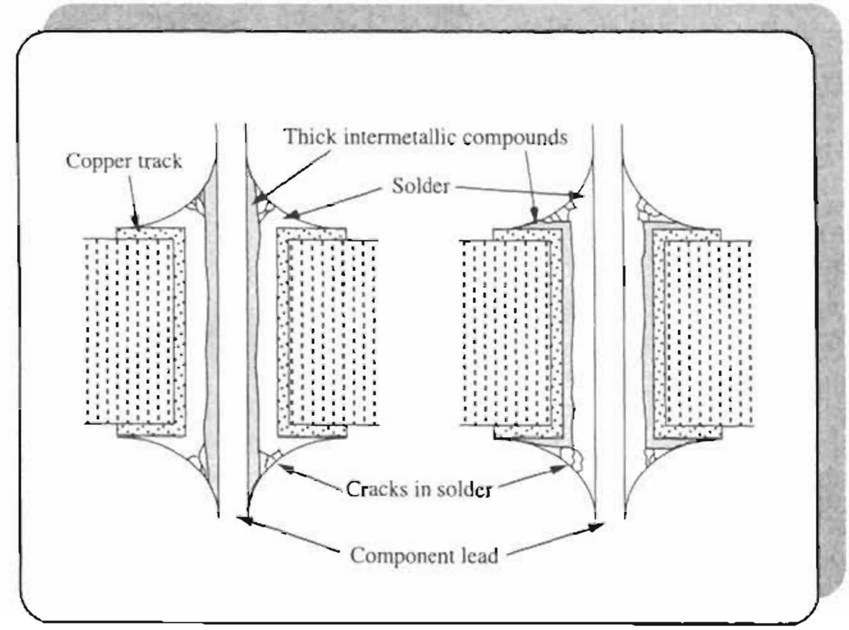


Figure 3.9 *If thick intermetallic layers exist between either component lead and solder (left) or copper track and solder (right), solder may crack*

Figure 3.10a, b and c show stages in the solder process by which a plated through-hole joint is soldered. Under ideal conditions — and with the help of flux — solder first wets the lower surface of the hole (Figure 3.10a), then begins to wick up the hole due to capillary action (Figure 3.10b).

As this takes place the solder acts as a liquid piston, forcing the flux in the hole to rise ahead of it. This prepares the track surface for wetting by the following solder. Finally, as the entire hole approaches soldering temperature, the solder flows out of the top of the hole, wetting the top surface to form a solder fillet (Figure 3.10c).

In contrast Figure 3.11 shows a condition where cracks in the knees of hole plating prevent heat flow through the joint. In this case, a correct top solder fillet is not formed.

Solderability

One of the most important terms in theoretical study of soldering is **solderability** — a measure of a part's ability to be soldered. In other words, solderability gives us an idea how wettable a part is, by solder.

Now solderability is a metallurgical function of a metal surface and, fortunately, it is not really necessary these days to study it in any great depth. Components and printed circuit boards are generally assembled from parts of known and guaranteed solderability so, as far as the soldering process in

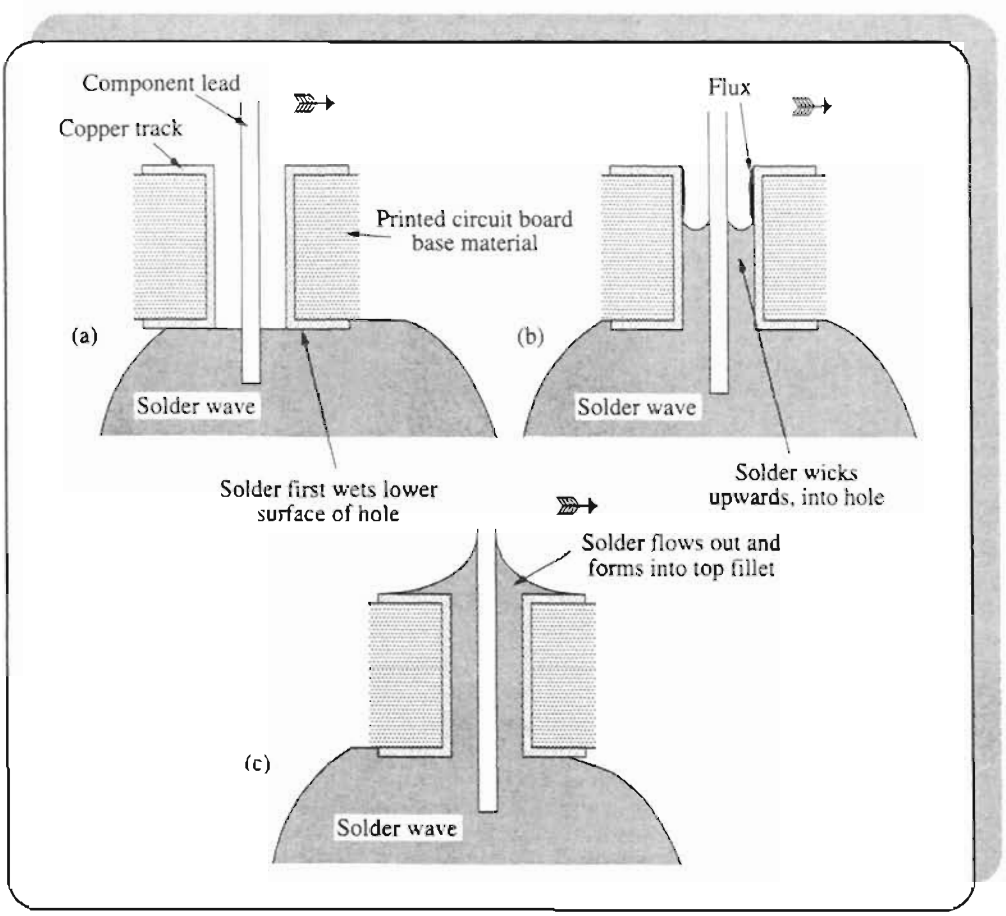


Figure 3.10 *Stages in a CS soldering process, where (a) solder first wets the underside of a plated through-hole (b) solder wicks upward through the hole, pushing flux ahead of it (c) solder flows out of the top of the hole, to wet the top surface*

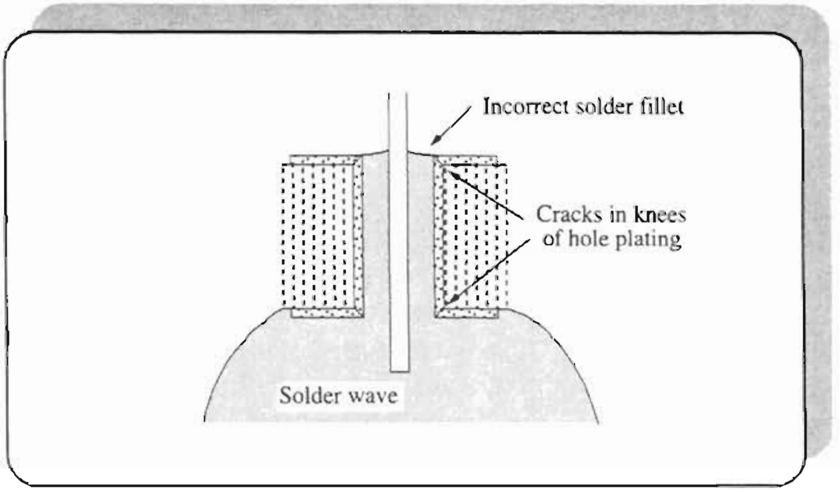


Figure 3.11 *Cracks in the knees of plated through-holes may prevent solder flowing out of the top of a hole*

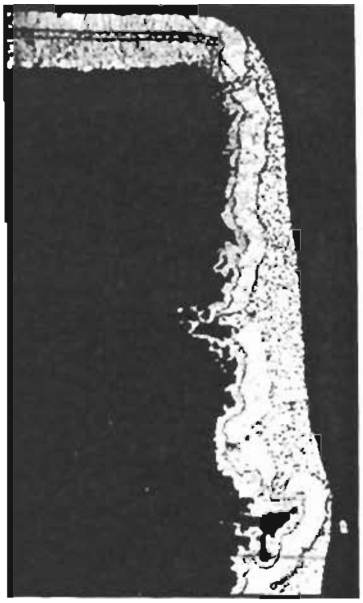


Photo 3.8 *Upper knee of a plated through-hole, with cracks (Alpha Metals)*

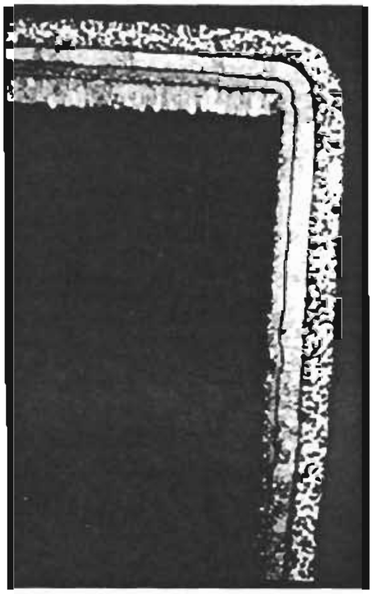


Photo 3.9 *Upper knee of a plated through-hole, without cracks (Alpha Metals)*

electronics assemblies is concerned, solderability is largely irrelevant. For this reason interested readers are referred to more specialized texts which cover the topic to a greater depth [Klein Wassink, #4] [Manko, #5] than our requirements, as well as relevant national and international standards.

In soldering terms, all we need to know *here* is how to measure solderability and what the results mean.

Measurement of solderability may be done in quite a number of ways which depend, basically, on what component you are measuring. For individual component parts such as resistors, leads, semiconductors and so on, one of the most common methods is the **wetting balance** method, in which a fluxed component is immersed, at a defined rate, in a bath of molten solder. After a defined dwell time it is withdrawn from the bath at the same rate. Various parts of the wetting balance method are shown in Figure 3.12, while the five stages which make up the procedure are illustrated in Figure 3.13. These stages are:

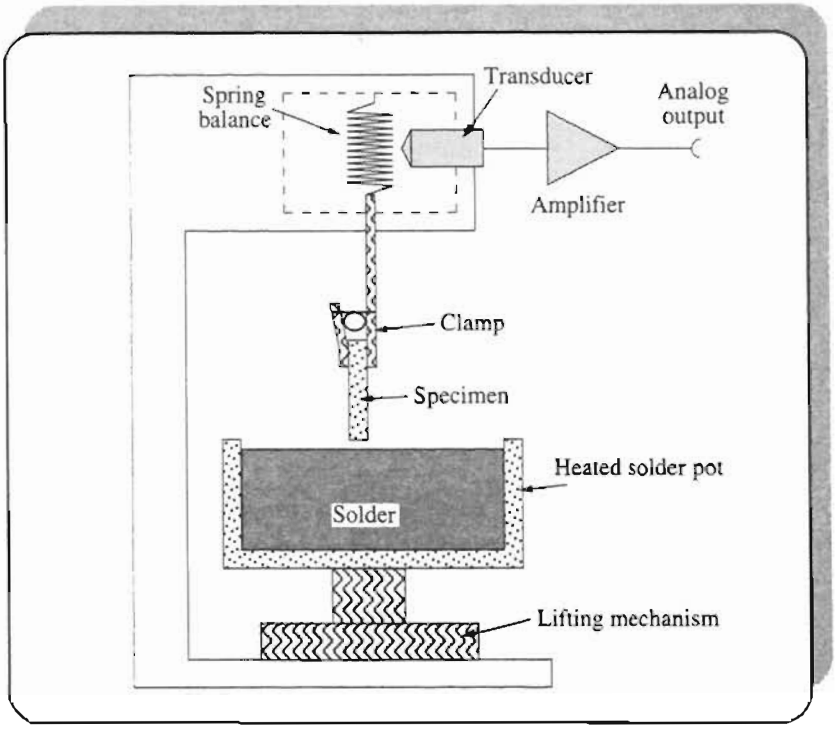


Figure 3.12 *Main parts of a wetting balance*

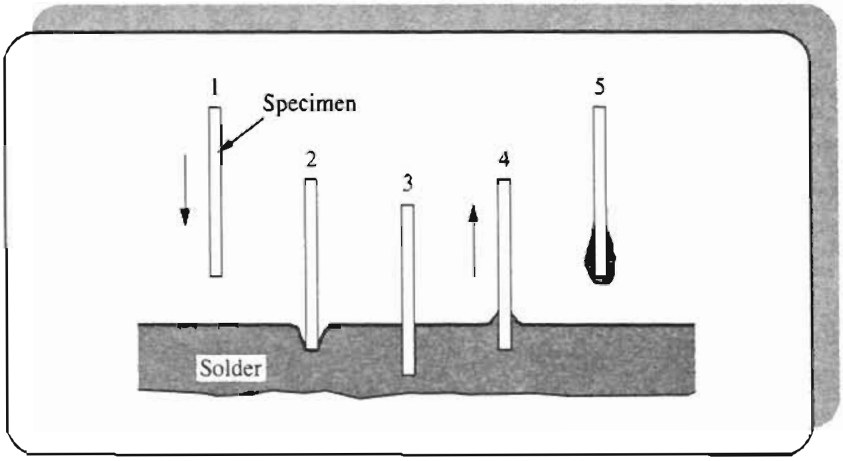


Figure 3.13 *Five stages of the wetting balance method of testing solderability*

- 1 — just before immersion
- 2 — just after immersion; when the solder's surface meniscus is still curved down, resulting in an upward force
- 3 — when wetting has reached the point where the force of surface tension is zero; so the only force remaining on the component is that of buoyancy

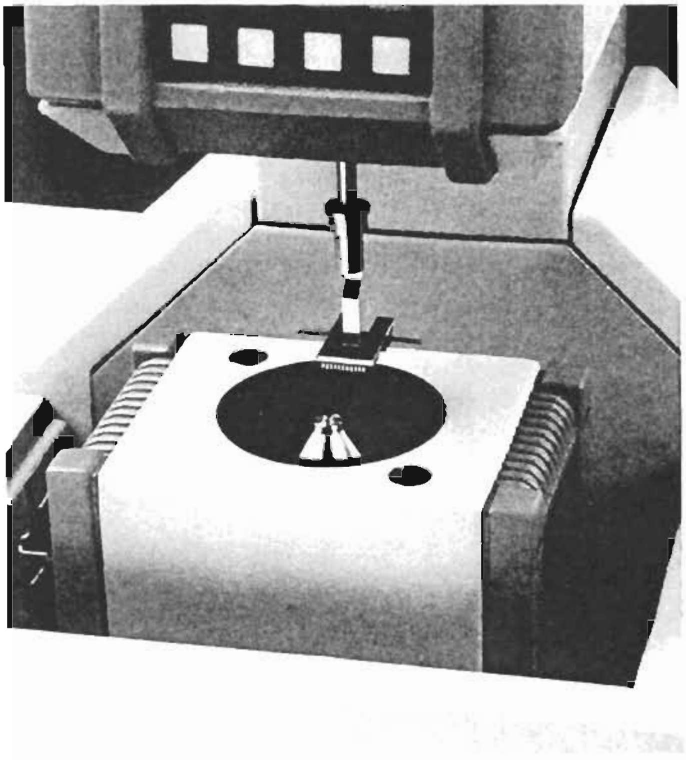


Photo 3.10 *A practical wetting balance (Multicore)*

- 4 — as the component is withdrawn the meniscus curves upwards, resulting in a downward force from surface tension
- 5 — when the component is totally withdrawn.

A transducer allows a direct reading of the resultant of the vertical forces of buoyancy and surface tension acting on the component, such that it's possible to obtain a force-time diagram, using suitable test equipment — say, chart recorder or storage oscilloscope. Such a force-time diagram is shown in Figure 3.14, marked with various points corresponding to the five stages of the procedure.

We can identify solder's wetting ability on a force-time diagram, simply because it corresponds to the rate at which force changes after wetting commences — that is, during the third stage of the procedure. Figure 3.15 shows possible graphs representing those obtained at several degrees of wetting.

Certain factors have to be accurately defined when taking and comparing measurements of solderability, otherwise results won't be accurate. Some of these factors and typical amounts are:

- type of solder (say, 60% tin/40% lead)
- solder temperature (say, 235°C)
- flux (say, pure resin, R or WW)
- immersion rate (say, 25 mm s^{-1})
- immersion depth (say, 5 mm)
- preparation of component used — say, steam aging for a period of four hours).

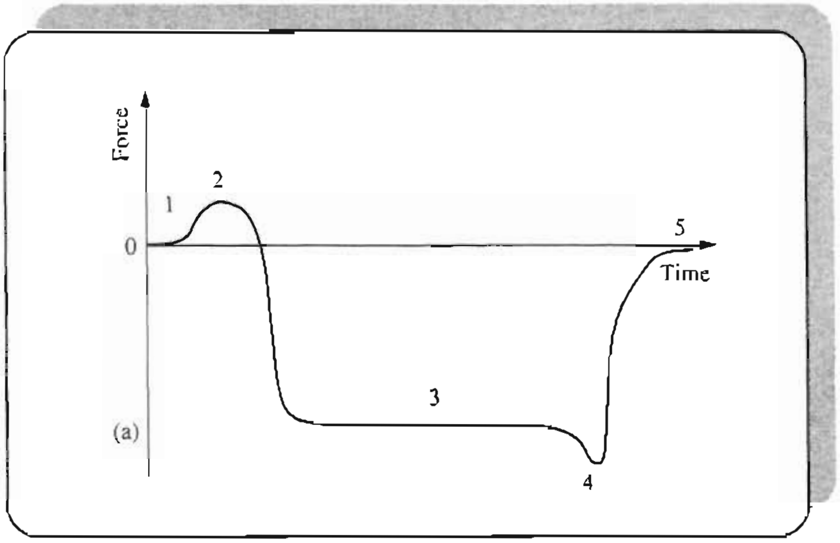


Figure 3.14 *Force-time diagram, such as would be obtained in a wetting balance method for solderability*

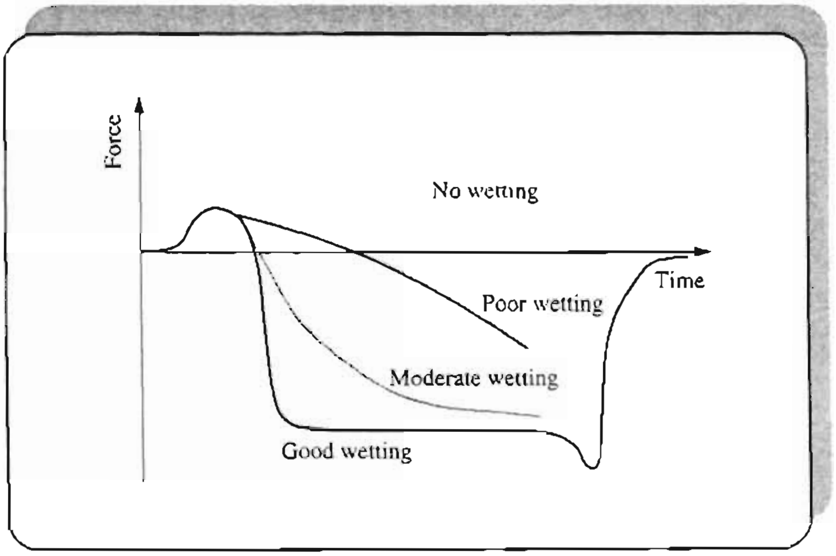


Figure 3.15 *Force-time diagrams obtained at several degrees of wetting*

Finally, it's necessary to define a suitable standard of solderability, say, when not more than 5% of terminals are dewetted, or non-wetted.

Printed circuit board solderability of conductive track and lands can't be measured easily using the wetting balance, so other methods are typically used [Bud, 1980 #6] instead. These include:

- **edge dip test** — in which a bare printed circuit board is dipped into solder. After cooling and cleaning it is inspected to ensure solder results fall within defined criteria
- **wetting time test** — [Thwaites, #7] also called the **rotary dip test**, in which several small specimens of printed circuit board are successively passed through a solder bath, gradually increasing immersion time, until a perfectly wet board results. The minimum time for good wetting is indicative of solderability
- **wave solder test** — in which a commercial wave soldering machine is used to solder a succession of boards in a similar way to the wetting time test. Note that this can be a misleading test, so must be carefully supervized and used
- **meniscometer test** — in which the rise of solder meniscus on or around a printed circuit board specimen dipped in solder is measured. From the meniscus rise it is possible to calculate the wetting angle
- **meniscus test** — in which solder menisci of defined volume are formed on the printed circuit board. Solderability is a function of solder spread, so a simple measurement of spread is representative of it.

Solderability of plated through-holes brings other test methods, including:

- **timed solder rise test** — in which a printed circuit board is immersed horizontally to a set depth. Time for solder to rise through plated through-holes is a direct indication of their solderability
- **solder globule test** — in which a printed circuit board through-hole is pressed onto a melted globule of solder. Time for solder to wick up the through-hole is a measure of solderability.

Protective coatings

Although the addition of **protective coatings** is specifically a manufacturing process, it is covered in this chapter for sake of completeness; in many cases, as we shall see soon, the protective coating is of solder form anyway and often added to printed circuit boards by conventional soldering processes.

The generic term *protective coating* refers to any coating which is applied to the printed circuit, *at any stage*, with the purpose of protecting the board from *any* form of contamination (oxide, moisture and, in some cases, solder itself). Consequently, there are three main types of protective coatings:

- pre-assembly coatings — applied to maintain solderability, therefore assuring good soldering can take place after assembly
- pre-soldering coatings — **solder resists** also called **solder masks** or **solder stop-offs** (or, if you want to be pedantic and grammatically correct; solder stops-off), which selectively protect parts of printed circuit boards from *being* soldered
- post-assembly coatings — various encapsulation methods, of which **conformal coatings** are the most common, which protect the assembled and soldered printed circuit board during its working life.

Use of the generic term *protective coating* is often used specifically to imply only pre-assembly coatings. While this, in itself, is not incorrect, it's important to remember pre-soldering and post-assembly coatings are protective coatings, too.

Pre-assembly protective coatings

Once component parts (usually bare printed circuit boards) of the electronics assembly process are known to have defined solderability, it is common to coat them with a protective substance in an attempt to maintain solderability at this level. This is only an *attempt,* note, as no coating can maintain solderability indefinitely.

In most instances pre-assembly protective coatings are of solder form in thin layers over the copper track. This is perhaps seen as advantageous in that it's solder which is to be applied at a later time anyway. In the remaining few cases, however, organic compound and precious metal coatings are used and it's here that we start.

Organic compounds

Two types of organic compounds are used:

- monomolecular lacquers
- resin-based (see Chapter 5),

giving approximate solderable lifespans of about three months (monomolecular) and six months (resin-based). Resin-based coatings give the advantage of aiding most fluxing processes, although hinder application of low-solids fluxes (see Chapter 5). Lacquers dissolve into flux as it is applied, then are dispersed by the soldering process.

Thickness is fairly important: too thin and susceptibility to damage or low shelf-life will result; too thick and coatings may crack or blister with the same result. A disadvantage is the fact they are hygroscopic, so absorbing water, which with time will reach the metal underneath, causing oxidation.

Advantage of such coatings is their relative low cost. As long as the circuit board is to be used after only a short storage period, they can prove quite economical. Many consumer application assemblies have been manufactured recently using lacquered printed circuit boards, for this reason, particularly by Japanese companies.

Metallic layers

Three forms of metallic layer are used to protectively coat circuit boards:

- precious metal plating (gold, rhodium, platinum, palladium)
- silver
- tin/lead alloy coating.

Precious metals are often used to protect edge-connection terminals of a circuit board. Their low oxidation rates and metallic softness help to ensure that push-on contacts maintain an adequate low resistance. Thicknesses of precious metal coatings used to protect terminals varies from about 2 µm (over nickel-plated copper) to about 5 µm (over bare copper).

Occasionally precious metals are used to maintain solderability of complete printed circuit boards and, in this case, thickness should be between about 0.25 µm and 0.5 µm. Shelf-life of precious metal coated boards is up to 12 months.

A coating of pure tin, or tin/lead alloy (ie, solder itself), is the normal method of protectively coating printed circuit boards to maintain solderability. Three main methods are used to coat circuit board surface:

- roller coating — using a solder-covered roller, partially immersed in a solder bath, shown in Figure 3.16. Boards coated in this way should have

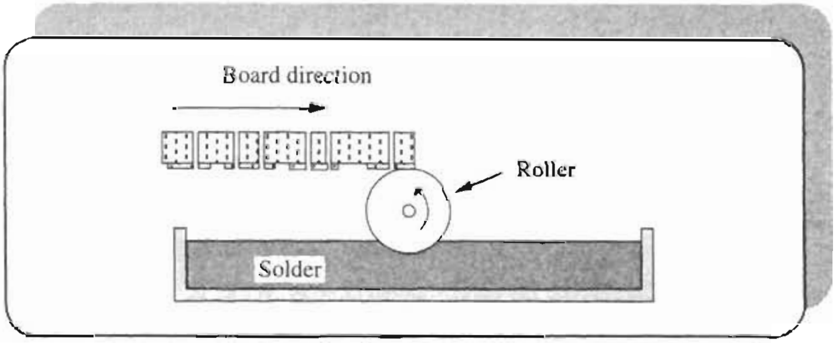


Figure 3.16 *Roller coating solder on to a printed circuit board*

a coating thickness of 0.5 µm to 1 µm, and have a limited shelf-life of no more than 6 months

- dipping — the board is fluxed and dipped into a solder bath, then levelling of the solder layer, and clearing of plated-through holes, is accomplished with a hot-air knife, as illustrated in Figure 3.17. (Hot-air knives are also found in some machine soldering processes — see Chapter 7). Using a hot-air knife to level a solder coating is commonly known as **hot-air levelling** (HAL). Boards properly coated and levelled in this way should have a coating thickness from 5 µm to 15 µm, and will have a shelf-life of at least 12 months. Hot-air levelling of boards also provides a good visual indicator of solderability

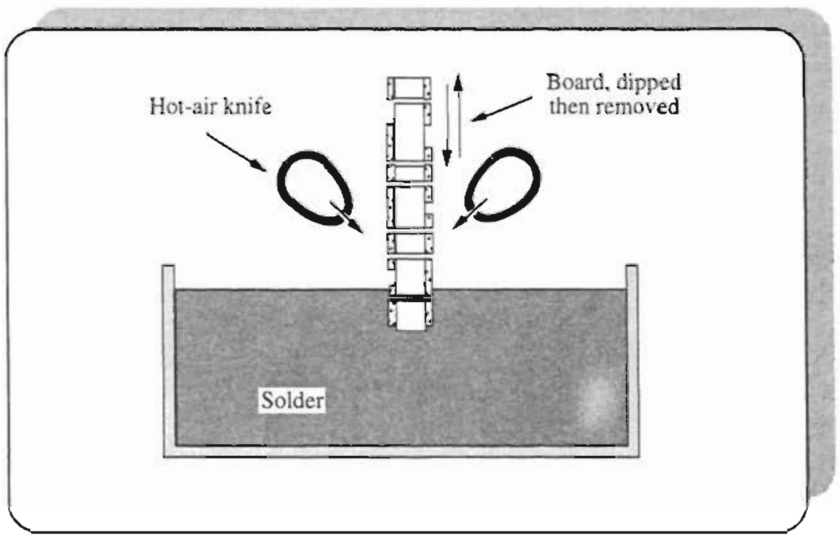


Figure 3.17 *Dipping a printed circuit board into solder*

- a variation in the dipping process with the proprietary name of AlphaLevel can offer better performance than hot-air levelling. It uses a dipped layer of silver between 0.07–0.1 µm thick, protected with an organic molecular layer. This process produces tracks and pads that are very flat in comparison to hot-air levelling
- plating — the board is plated with tin, or a tin/lead alloy, to a thickness of at least 10 µm, then copper and plated alloy layers are fused with the application of heat. Even with the initial 10 µm plated layer, thicknesses around holes or close to board edges will fall to as low as 1 µm, so hot-air levelling may be required. Shelf-life is a minimum of 12 months.

Technically, the process of **fusing** is one of heating a previously electroplated tin/lead layer to ensure an interfacing alloy bond, while **levelling** is the process of removal of much of a tin/lead layer to leave behind a thin coating. These terms are often used incorrectly, and are even sometimes interchanged.

Where surface mounted components with fine pitched lead spacings are to be placed onto printed circuit boards, plated boards have an advantage over hot-air levelled boards simply because the surface is flatter. Figure 3.18a shows a cross-section of a hot-air levelled copper track on a printed circuit board, which is quite convex.

As the termination of a fine pitched component is placed onto the track it tends to slide off the convex surface, misplacing the component. A plated track, on the other hand (Figure 3.18b), is relatively flat, so a component termination is less likely to slide off.

Manufacturing processes for circuit boards may include tin/lead plating of the copper track. In such cases, it would appear that no secondary protective coating is required. However, solderability of the original copper surface, prior to tin/lead electroplating is important here. If the electroplated layer is applied to copper which is not solderable, on heating to ensure fusing the electroplated layer will become dewetted and maybe even non-wetted — the original copper surface *must* have acceptable solderability to prevent this.

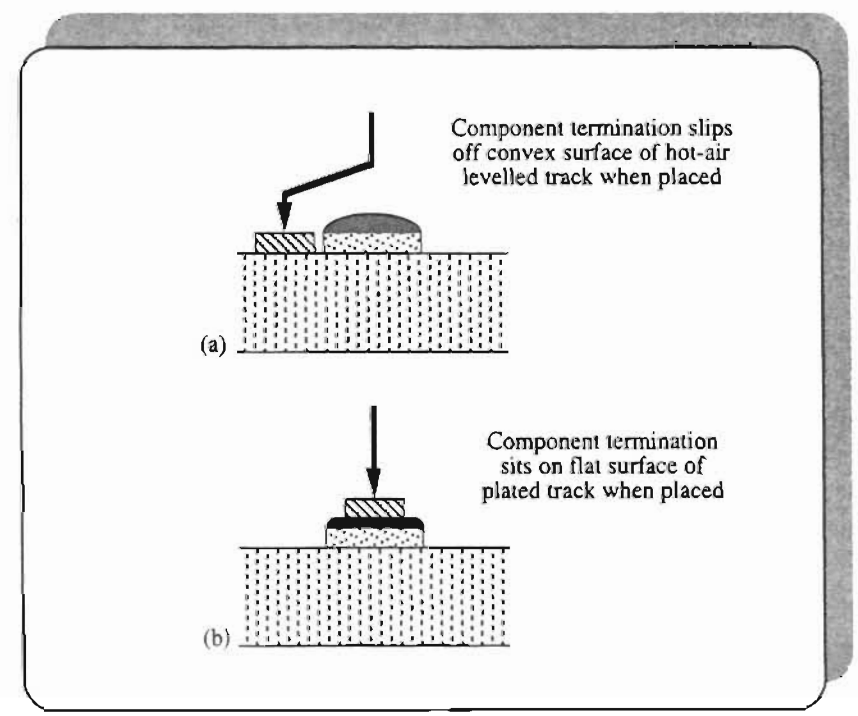


Figure 3.18 *Differences between hot-air levelled and plated track surfaces (a) component terminations with fine pitched lead spacings can slip off hot-air levelled tracks when placed (b) component terminations sit better on plated track*

Pre-soldering coatings — solder resists

It is sometimes necessary to ensure that some areas of an assembly be kept free of solder. In such cases **solder resists**, sometimes called **solder masks** or **solder stop-offs**, can be used. Fairly obviously, a solder resist must provide two functions. First, it must be heat resistant, to prevent the heat of the soldering process from breaking it down. Second, it must be non-wettable.

Solder resists can be temporary, in that they are removed after the soldering process, or permanent. In general, temporary solder resists are used to protect particular areas of a PCB during mass soldering methods such as dip, drag, and wave soldering. They are typically used to keep small areas such as plated through-holes, gold-plated contacts and so on, clear of solder for later purposes. After soldering, they are removed. Although usually of a liquid form, applied to the surface of the PCB, then left to dry before soldering, mechanical resists such as plastic or wooden plugs or inserts, and even adhesive tape are not unknown. Occasionally, protrusions from soldering machine conveyor systems are used to mask areas of assemblies from the soldering process. These are only economical, however, in large-volume production, and the area to be masked must be allied to an edge of the assembly for the protrusion to be able to cover it and no other areas.

Permanent solder resists are often used to eliminate the risk of solder bridges between closely-spaced adjacent tracks. This means that PCB designers can reduce gap sizes and have extra freedom in track layouts. Secondary advantages include: physical protection of tracks, particularly those of a fine-line nature; reduced drainage of solder from joints which may otherwise cause the joints to be poorly soldered; reduced consumption of solder overall, coupled with reduced contamination of the solder in the bath; a known dielectric present between tracks (although this *can* change with ingression of water); improved visual inspection of solder joints due to the fact that resist reflects light less than joints; good appearance.

Permanent solder resists are applied using conventional screen-printing techniques or, where high accuracy is important such as in the production of fine-line boards, they are photo-printed following liquid or dry-film application. Two main types of permanent solder resist are used:

- epoxy-based
- acrylate-based.

Post-assembly coatings and encapsulations

These are used for environmental protection of assemblies and components. Assemblies and components may be subjected to either a corrosive environment or a mechanically stressful environment. Effects of one or both of these environments may be reduced to acceptable levels (though never eliminated) by **encapsulating** assemblies. Assembly encapsulation is a generic term referring to techniques using resin-like materials to package the assembly. There are four main methods of encapsulation:

- conformal coating
- embedding
- impregnation
- potting.

Conformal coating

By far the most common method of encapsulation, **conformal coating**, sometimes called **surface coating** or **surface sealing**, uses thin (between 0.005 mm to 0.075 mm) transparent coats of materials to provide an electrically insulating protective barrier against humidity, dirt, vaporous contaminants, and foreign bodies such as metal filings. Fully assembled printed circuit boards are often conformally coated to help protect them during normal operating conditions, where hostile environments are not envisaged.

Typical coating materials include:

- acrylic
- diallyl phthalate (DAP)
- epoxy
- oleo resin
- olystyrene
- paraxylylene
- polyimide
- polyurethane
- silicone
- silicone rubber.

Of these, acrylic, diallyl phthalate, epoxy, polyimide, silicone and urethane are the most common. A summary of the main characteristics of these six conformal coating types are listed in Table 3.3, based on Concoat's data [Concoat, 1989 #8].

Table 3.3 Summarized characteristics of the six main conformal coating types

Characteristic	*Acrylic*	*Diallyl phthalate*	*Epoxy*	*Polyimide*	*Polyurethane*	*Silicone*
Abrasion resistance	3	2	1	1	2	2
Acid resistance	1	1	1	1	3	2
Alkali resistance	1	1	1	3	3	2
Application ease	1	3	3	3	2	3
Cure time	1	3	4[1]	3	3[2]	4
Humidity resistance:						
short-term	1	1	2	1	1	1
long-term	2	1	3	1	1	2
Mechanical strength	3	2	1	2	2	2
Pot-life	1	3	4	3	2	4
Removal:						
burn	1	—	3	—	2	—
chemical	1	—	5	—	3	—
Solvent resistance	5	1	1	1	2	2
Temperature resistance	5	3	5	1	5	2

Notes: characteristics are recorded in descending scale of 1 to 5, that is, 1 is good, 5 is poor.

[1] reduced to 3 if heat-cured.

[2] reduced to 2 if heat-cured.

When selecting a coating, known use and environment of the assembly must be carefully considered. Manufacturers' precautions should also be followed, and safety precautions regarding vapours and toxic materials observed.

Conformal coatings also may be applied to individual components, or sub-assemblies, in the case of, say, hybrid assemblies to be mounted on a through-hole printed circuit board. In this case, the conformal coating is to protect the sub-assembly during later processes, such as soldering, in the assembly's production.

Application of conformal coatings is usually by brushing, dipping, flow coating or spraying. Paraxylylene, is an exception, as it is applied by vapour phase deposition technique under vacuum. Note that application of a conformal coating by spraying may cause damage to electrostatically sensitive components.

It is sometimes thought that conformal coatings aid mechanical strength and thermal insulation, providing protection against stresses such as vibration or thermal shock, but this is not true, and other encapsulation methods must be used where such stresses are envisaged.

Conformal coatings do, on the other hand, allow a measure of protection against damp environments, and where occasional condensation is met conformally coated assemblies may function satisfactorily. But where constantly damp environments are encountered, conformal coatings are not suitable.

Embedding

An **embedding** process completely envelopes an assembly or component within a protective material not less than 6 mm thick, filling free space in the assembly. A mould or container is required to confine the encapsulating material while hardening, after which the embedded assembly is released from the mould. The result is a self-contained assembly module.

Usually, mould-releasing agents are used to treat a mould prior to embedding an assembly, so that once cured, the embedded assembly can be easily released. Exceptions to this are where moulds are made of materials such as polythene or PTFE; these are self-releasing. Mould release agents may be non-drying liquid, or dry-film forms. Liquid forms may migrate to areas which require bonding, so as a rule-of-thumb, dry-film forms are normally preferred.

Impregnation

Impregnation methods rely on the injection of a material into all intervening spaces or voids of components to provide environmental protection. Impregnation may be used alone, or together with other methods of encapsulation.

Potting

Potting is an embedding method where the encapsulating material bonds to the mould or container, becoming integral with the item. Release from the mould is therefore not wished for.

4 Lead-free solder

At the time of writing the debate on using lead-free solders is hotting up. At a recent meeting of the Soldering Science and Technology Club (SSTC — Autumn Conference, 22 October 1998), Nick Jolly of the UK's Department of Trade & Industry asked *Is Lead-Free Moving from a Long Term to a Medium Term Issue?* As part of the publication of the first draft of the report on Waste from Electrical & Electronic Equipment (WEEE), Article 4 proposes that lead and other hazardous materials be phased out by 1 January 2004.

The future timetable of the full draft is:

- 8 September 1998 — discussion of second draft by next meeting of national experts
- European Commission intends to present proposal to European Parliament and Council of Ministers by end of 1998 or early 1999
- expect directive to be become effective 18 months after adoption.

What's needed in the future?

If the expected lead-free directive goes through, several aspects result directly, including:

- the level of manufacturing industry's capability to handle implications
- the need to design for dis-assembly
- the need for material reclamation
- no lead
- a requirement for drop-in replacements for tin/lead solder
- organizations must prepare
- there needs to be an awareness campaign.

At the same conference, James H. Vincent of GEC-Marconi Materials Technology — Caswell, presented the paper *IDEALS — Improved Design life and Environmental Aware manufacture of electronics assemblies by Lead-free Soldering.* The programme looking at lead-free will be completed early in 1999. The consortium includes the programme coordinator: Marconi Electronic Systems GMMT — Caswell, as well as several other companies; Philips Centre for Manufacturing Technology, Siemens Corporate Logisticsolders, Multicore Solders, Witmetaal — AlphaFry Technology, NMRC — University College Cork.

The conclusions thus far are that no single drop-in alloy is suitable for all applications. Soldering temperatures are likely to be higher with lead-free alloys — it is suggested that wave soldering processes will increase by 10°C, while reflow processes will increase 20°C. This raises many issues concerning the higher temperature for boards, components, equipment, narrower temperature profile windows, board and component finishes.

In summary: lead-free soldering is a practical proposition with direct and indirect benefits. It's an opportunity for the industry, however, we have to remember that:

☐ **it's no longer a question of *if* lead-free solder is used...**

... it's *when!*

We are grateful to *Tin International*, a journal associated with **ITRI**, formerly known as the International Tin Research Institute, for permission to publish the following feature article written by its chief lead-free solder specialist *Kay Nimmo*. The authors feel this article neatly sums up the lead-free soldering position.

Lead-free soldering — now a hot topic!

There is a world-wide environmental movement away from the use of lead, towards substitute non-toxic products based on tin. There are examples of lead-free shot, ammunition, wheel weights, lamps, casting alloys for toys as well as examples of lead-free solders being used in the electronics industry. Nortel was one of the first companies to announce the production of a telephone using lead-free solder, and this product won the company an environment award in 1997 from *The Financial Post.*

Photo 4.1 *The Nortel lead-free telephone*

Just one year on has seen significant change towards a worldwide lead-free electronics industry. While anti-lead legislation was first proposed in the USA around 10 years ago with, for example, the Lead Exposure Reduction Act (S. 729), and the Lead Tax Act (H.R. 2479, S. 1347), the momentum for lead-free electronics has gradually shifted away from the USA, through Europe, to Japan, where a growing number of major OEMs have announced significant voluntary reductions in lead use within 1 or 2 years.

Examples include; *Hitachi* which will reduce its use of lead solder in 1999 by half from 1997 levels and stop using lead solder by 2001; *Matsushita (Panasonic)* which will stop using conventional lead solder in 2001; and *NEC* which will reduce lead consumption in solder by 50% by 2002.

Many other companies are in the process of preparing for the lead-free solder age including; *Toshiba* which is developing a solder for high-density

Photo 4.2 *Lead-free solder alloys now come in all forms*

cellular phone PCBs, and *Sony* which has developed its own lead-free alloy said to have a reliability five times that of tin-lead.

Finally, even those companies who do not manufacture but can specify materials to be included in products are involved. *NTT (Nippon Telegraph and Telephone)* is gearing up for 'green' material procurement by 2001, when the use of lead and cadmium-free materials safe for the environment will be specified.

The growing trend for manufacturer responsibility makes companies aware of the environmental effects of their products from manufacture to disposal, including any recycling that may be required. The use of hazard-

Photo 4.3 *Panasonic Mini-Disc system — lead-free solder production is used (signified by the green leaf icon). Thanks to Dr Kenichiro Suetsugu, manager of the process and material development department, circuits manufacturing technology division, Panasonic Osaka, Japan*

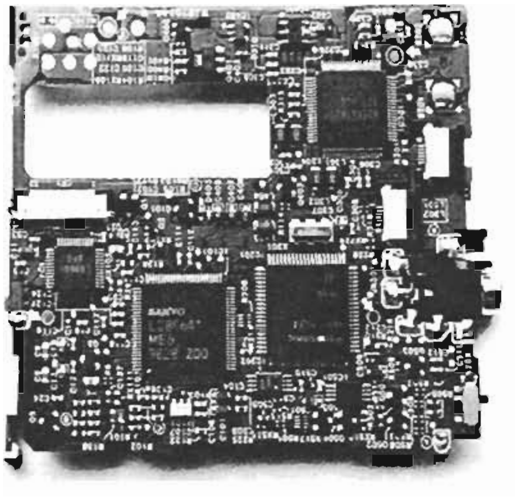


Photo 4.4 *One side of the printed circuit board used within the Panasonic lead-free Mini-Disc system*

ous materials in products which may be covered by these regulations raise concerns over public and worker safety, and waste disposal. The main driving force towards lead-free soldering is therefore through end-of-life electrical and electronic appliance legislation proposed by the European Commission and Japanese government.

Recycling legislation was pioneered by the European Parliament and Council Directive on End-of-Life Vehicles (ELVs). The draft directive proposes that producers should control the use of hazardous substances from the concept stage of new vehicles, in particular, the use of lead, PVC, mercury, cadmium and hexavalent chromium should be phased out in vehicles put on the market after 1 January 2002 (lead in batteries is exempt). Although circuit boards are also exempt from this draft they may be covered by an additional proposal covering a much wider product group.

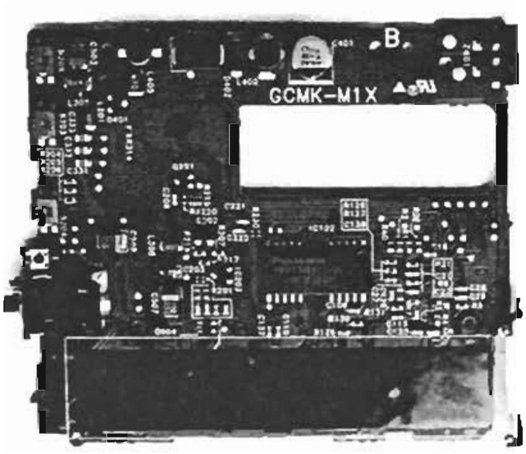


Photo 4.5 *Other side of the printed circuit board used within the Panasonic lead-free Mini-Disc*

The EC resolution on waste has named electrical and electronics equipment as one of five priority waste streams and the recent draft proposal on End-of-Life Electronic and Electrical Goods outlines action against lead. A series of equipment types are covered ranging from household appliances (white goods) to control instruments, and from medical equipment to video and sound equipment (brown goods), even watches, games, and automatic dispensers are included. The current draft wishes to:

> ensure that the use of lead, mercury, cadmium, hexavalent chromium and halogenated flame retardants contained in electrical and electronic equipment is phased out by 1 January 2004.

The Japanese ministry of trade (MITI) has drafted a similar law that will require consumer and business users of electrical appliances to return end-of-life goods to retailers or local authorities for recycling. The cost will be borne by manufacturers or importers of the product who will be required to arrange for dismantling and recycling.

It is often argued that if all electronic waste is recycled any lead content can be safely treated. However, it is an accepted fact that not all waste will be collected and, particularly with small units such as mobile phones, the collection rate will be low, even if the hazardous material content remains high. Collection of small electronic goods and the separation of lead from these products before recycling treatments would be extremely costly compared with the use of lead-free solders.

Scandinavia is particularly concerned over the effects of lead and is intending to reduce its use of the metal whether recycling can be achieved or not. A meeting of the Nordic Ministers of Environment in 1994 produced a statement that:

> in the long run the phasing out of lead is necessary to reduce risk from lead exposure on human health and the environment.

This was signed by Denmark, Sweden, Norway, Finland and Iceland and led to a proposal by the Danish Environment Protection Agency to ban import, sales and production of lead and products that contain lead.

While this is currently in draft form, and not yet approved by the European Commission, it could come into force immediately, and could even be back-dated to take effect from 1 January 1998. Lead in both the chemical and elemental form is covered and the draft includes two clauses affecting the use of solder; firstly, those used for incandescent lamps, and secondly, those used in heating, ventilation and sanitary equipment. Once accepted by the EC, it is likely that other Nordic countries will introduce similar legislation that may also extend to other solder products. Already Sweden is aiming that *all use of lead should eventually be phased out* even in lead-acid batteries despite their well established recycling network.

The age of lead-free soldering is approaching fast

While environmental reasons forcing a change away from the use of tin-lead are seen by some as a negative process, the switch to lead-free solders can bring positive advantages. The use of non-toxic materials improves the public image of product and company and brings potential technical advantages as well as possible overall cost savings. It can now be shown that the switch from tin-lead to lead-free alloys is achievable if enough information on the replacement alloys is known. A conclusion from a Brite-Euram funded pan European project on lead-free soldering is that there are no technical show-stoppers to the adoption of lead-free processes and, that the route to environmentally-friendly manufacture and more reliable soldered products seems to be open.

As part of this project GEC Marconi/Siemens joint venture GPT has reported the successful production trials of a lead-free solder. GPT has already eliminated lead from its circuit board finish and is currently securing supplies of lead-free components. Although the new alloy is slightly more expensive than tin-lead GPT expects to offset the cost with savings from the lead-free circuit boards making the total process change cost neutral. Additionally the lead-free material is twice as strong as tin-lead and therefore has an advantage in harsh conditions such as in cars.

Panasonic has already released a lead-free Mini-Disc in Japan (produced at a rate of 40,000 units a month), that is to be available in Europe shortly. A following Mini-Disc from Panasonic will also use lead-free solder. Other products are also expected from manufacturers such as Hitachi, with all Japanese OEMs selecting different solders for each product dependent on the properties required. So, while one alloy may be chosen to increase reliability over tin-lead in products seeing extreme service conditions, other alloys may be selected for a process route where lower melting temperature is of more importance.

Lead-free solders can be found with a variety of properties. When selecting which to use the easiest place to start is to consider melting temperature ranges. Low temperature alloys such as the tin-bismuth eutectic (138°C) have been in use in specialist applications for many years and higher temperature alloys, such as the tin-silver eutectic (221°C), have also been used in high reliability products. New alloys have been developed to provide further lead-free options; the tin-silver-copper eutectic (217°C) melts at a slightly lower temperature than tin-silver and can give better solderability in certain applications, a tin-bismuth-zinc alloy (189–199°C) is the closest in temperature to tin-lead but difficult to use, while the tin-copper eutectic (227°C) is a cheaper, but higher temperature option.

It is important to select the correct lead-free alloy for the job — ask advice from your supplier or ITRI — and your lead-free soldering will be a success.

ITRI

ITRI has many years of experience developing lead-free alloys and evaluating their performance.

An outline of the experimental work that ITRI is carrying out on lead-free solders can be seen on the ITRI Web site at: <http://www.itri.co.uk> and all the results from this can be obtained through its ITRA company membership scheme. The scheme also provides publications listing where to buy lead-free supplies (solders, boards, components and so on), plus information on patents and other published lead-free literature. Please contact Kay Nimmo for more details of membership tel: +44(0)1895 272406 fax: +44 (0)1895 251841 or email: <kay@itri.co.uk>.

Photo 4.6 *A selection of literature available from ITRI*

ITRI is also developing a series of lead-free fact sheets summarizing information from its research — if you would be interested in obtaining copies when ready then please fax your contact details to Shellene Peters +44 (0)1895 251841.

5 Flux

Historically, fluxes have always been thought to be a necessary prerequisite to enable soldering in electronics assembly. However, recent exciting advances in soldering machines have identified a particular ideal case (some controlled atmosphere — usually nitrogen — environments) where fluxes may no longer be required under certain conditions. Much work is continuing in soldering techniques with nitrogen atmospheres.

We have already touched on the prospect in Chapter 3, where we considered preparation of the metal surface to be soldered and stated that the only prerequisite to successful soldering is a *clean* metal surface. We'll expand on that now and stress that clean means *truly* clean ie, without oxide or contamination of any kind, with an external surface of pure metal and nothing else. Naturally, as long as the metal surface can be maintained to this level of cleanliness as solder is applied, solder wets it. Results from controlled environment processes are so encouraging it seems likely they will play a major rôle in electronics assembly soldering over the remainder of the decade and beyond, probably becoming the norm in large scale production of electronics assemblies within just a few years.

In most other soldering processes, of course (with the only other exception being ultrasonic soldering), flux is still a fundamental requirement; and will be so for a while. Consequently, much of this chapter discusses flux: its importance, its function, and its variants, as a vital part of soldering processes. We do, however, include a resumé of *no-residue* or *low-solids* fluxes; which, in reality, perform exactly the same rôle as conventional flux — as a cleaning agent in controlled environments. No-residue or low-solids fluxes will become inevitably more and more important as controlled environment processes become popular. Their popularity will probably be forced on the industry, as the current drive towards elimination of chlorofluorocarbons builds up speed.

Need for flux

Fluxes are used in the first place to clean the metal surface to be soldered, then cover it to prevent further formation of contaminants. Contaminants are anything which form a barrier between the pure metal and solder. Obviously the contaminant does not have to be an externally applied material. Commonest contaminant is simply the oxide formed by the metal on its own surface — almost all metals oxidize immediately on exposure to oxygen in the ambient air and this oxide alone is sufficient to prevent solder wetting the metal surface.

To illustrate extent of the problems in cleaning metals ready for soldering, Figure 5.1 shows a section of copper track of an assembly (obviously, not to scale) which shows three distinct layers of material. Most internal is the metal part to be soldered ie, pure metal copper. Next layer is a reaction layer, of strongly bound and so very adherent materials such as oxide, sulphide and carbonate, as well as residues from previous production steps. Finally, and most externally, an absorption layer exists, in which materials such as water, gases and residues from preceding reactions collect.

From outside in, therefore, flux must:

- dissolve materials of the absorption layer
- remove oxides, sulphides and carbonates and any other residues
- dissolve some substrate molecules, to initiate formation of intermetallic compounds when solder is applied.

Obviously this is a simplification of the job of flux, but it does highlight the process: by cleaning the metal surface then covering it, fluxes keep the surface at a stage of readiness for the solder to flow and wet the metal.

On the other hand, besides this vital cleaning and covering function, fluxes must have several secondary characteristics:

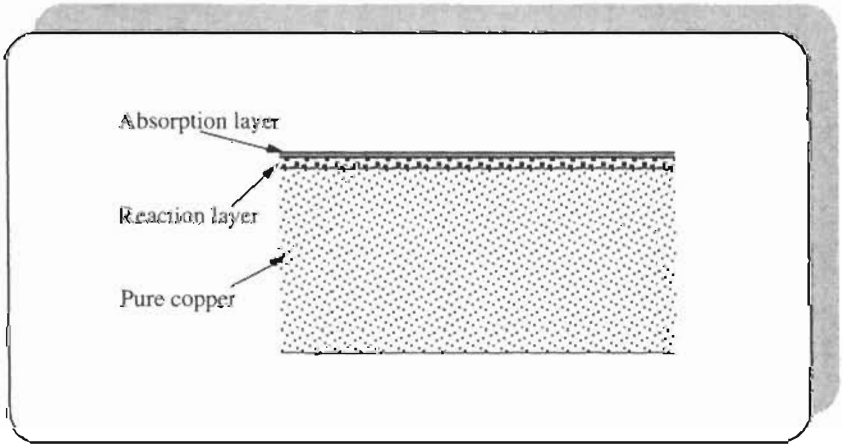


Figure 5.1 *Three layers of a copper track*

- they must be able to withstand the soldering temperature
- they must break down oxide layers formed on the surface of molten solder — this allows solder to flow and wet
- ideally they should not attack and corrode either the metal of the joint or the surrounding materials
- they and their residues after the soldering process should be easily removable.

While all flux systems perform the prime function, these secondary characteristics are variable and fluxes perform with significant differences simply because of minor characteristic variations.

How fluxes work

Figure 5.2 shows a copper sheet, covered with a layer of flux and placed on a heating plate to raise the temperature of the sheet above solder's melting-point. A ball of solid solder is placed on the sheet (Figure 5.2a) and the heating plate is turned on. As the temperature of the copper rises above solder's melting-point the solder begins to melt (Figure 5.2b), starts to flow (Figure 5.2c) then wets the copper sheet (Figure 5.2d). Note the resultant small wetting angle and feathered edge of the solder, which indicate good wetting.

A close-up view of this action is shown in Figure 5.3, at the point where solder is melting and flowing (equivalent to the situation in Figure 5.2c). Here you can see the copper sheet, a thin layer of copper oxide, flux, solder and solder oxides. In the illustrated process two things are important. First, as the copper sheet heats, it melts the flux which then becomes chemically active. As it does so it dissolves the oxides from the copper surface and the solder surface and prevents any further oxidization.

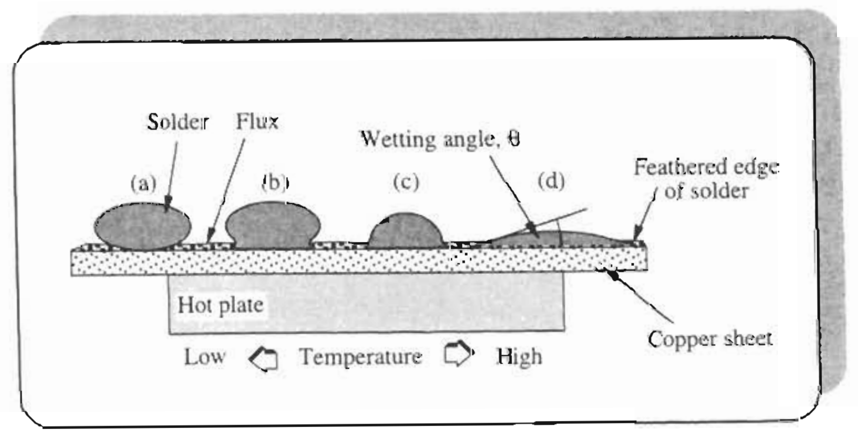


Figure 5.2 *Four stages in solder wetting a copper surface (a) solid solder (b) starting to melt (c) starting to flow (d) wetting the copper*

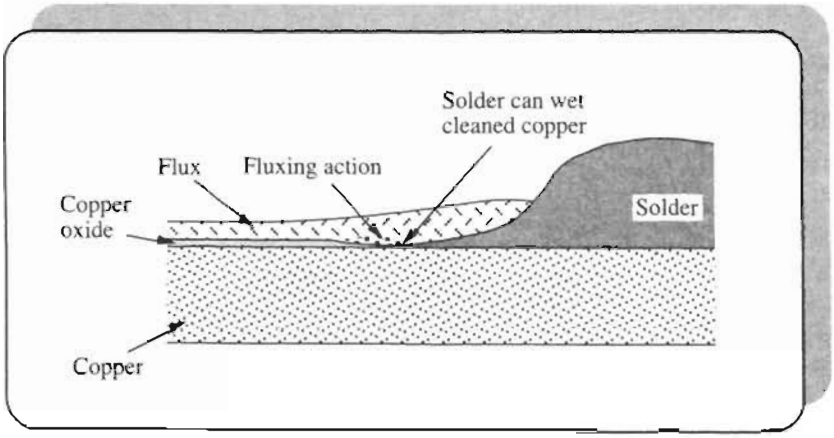


Figure 5.3 *Close-up view of the wetting action of solder on a copper surface, aided by flux*

Next, the cleaned solder wets the cleaned copper surface underneath the flux and starts to flow. As the solder flows it pushes the flux (and its resultant fluxing action) ahead of it. As the fluxing action moves forward, so does the solder to wet more copper.

Effectiveness of a flux in removing oxide and contaminants from the surface of metals is known as its **activity**. Fluxes vary in their chemical activity. Type of flux used generally depends on the oxide layers of the surfaces to be soldered. If only a thin oxide layer is present, a flux with only a low activity is required. On the other hand, surfaces with a considerable oxide layer require more highly active fluxes.

Anyone would be forgiven for thinking the best solution to solder all surfaces is to use only highly active fluxes. This way, whatever the metal surface and however thick its oxide layer, soldering is guaranteed. There is a price to be paid, however, when highly active fluxes are used — flux activity is closely allied with the corrosivity of the residues remaining after soldering has taken place. A highly active flux often leaves corrosive residues which may corrode the solder itself. Effective post-soldering cleaning without delay, usually with water, is essential.

Categorization of fluxes

Numbers of different types of flux are hard to evaluate (some 46 different low solids fluxes alone, from 12 manufacturers worldwide have been recorded (Rubin, 1990 #9]), so it's easy to see there must be hundreds if not thousands of available types. Consequently, to say the very least, it is difficult to correlate all types. What's more, fluxes have been used in one form or another for a long time — since soldering first began. Quite naturally, therefore, many different categorization methods have been used through time, depending on what the latest new flux product offered better than the rest.

We start by defining some of the many important categorization methods currently used. First is simply whether they are based on naturally occurring or synthetic materials. First flux ever used in electronics was, in fact, a natural material — gum **rosin**, also commonly called **colophony**, which is made from pine tree sap, a resin. This sap, after distillation, produces solid rosin which is dissolved in an organic solvent such as alcohol to produce flux. Most synthetic fluxes are based on organic acids, although other materials are used.

Another way of categorizing fluxes refers to the residues remaining from the flux after the soldering process. Thus, these are known as **organically soluble** fluxes, or **water soluble** fluxes. It's important to note with this categorization, however, that the term *soluble* refers purely to the residues left after soldering, and has nothing to do with whether the flux itself is soluble in organic solvents or water. Further, organically soluble flux residues can often be removed just with water and detergent, while many water soluble fluxes can be removed with some solvents. So this categorization of fluxes is not particularly logical, although is still useful bearing its limitations in mind.

Another categorization of fluxes: **non-activated** fluxes or **activated** fluxes, refers to whether chemicals have been added to increase activity. Generally, a pure rosin flux is said to be non-activated, while any other rosin-based flux is said to be activated. With this method of categorization it's particularly easy to further categorize activated fluxes into grades of activity, such as:

L = low, or no flux or flux residue activity
M = moderate flux or flux residue activity
H = high flux or flux residue activity.

These categories can be sub-divided, say, 0 and 1, to indicate absence or presence of halide in a flux.

Yet another categorization of fluxes groups them according to composition. As each compositional type of flux has its own unique properties regarding activity and residue solubility anyway, this method of categorization is perhaps one of the most useful, particularly as it is commonly used. Often abbreviations may be used following this categorization method; the abbreviations deriving from various specifications and standards, and usually referring to the type of activator added. Table 4.1 lists common flux abbreviations, abbreviation meanings, subsequent types of flux and activities according to this categorization method. However, this method gives little information regarding what activators or solvents are used.

Table 5.1 Common flux abbreviations, meanings, flux types, and levels of activity

Abbreviation	*Meaning*	*Flux type*	*Level of activity*
R	Rosin	Purest grade of rosin, no activator added	Very low
WW	Water white	Purest grade of rosin	Very low
RMA	Mildly activated rosin	Rosin, with addition of mild activators	Mildly active
OA	Organic acid	Organic acid activator	Strongly active
RA	Activated rosin	Rosin, with addition of strong activators	Strongly active
SA	Synthetic activated	Rosin, with synthetic activators	Strongly active
SRA	Superactivated rosin	Rosin, with very strong activators	Very strongly active

Such a hotch-potch of categorization methods and such a wide variety of fluxes inevitably leads to much confusion and ambiguity when users attempt to choose a flux for a given purpose. Acknowledging this, the International Standards Organization has attempted to clarify the situation, distinguishing fluxes according to four variables:

- flux type — whether resin, organic, or inorganic form
- flux basis — what the flux is based on
- flux activation — what type of activator, if any, is included
- flux form — whether liquid, solid, or paste

These are summarized in Figure 5.4 and given a number or letter for each variable. Thus, an organic flux, based on phosphoric acid, in paste form, has a classification as type 321C.

Resin fluxes

These are often, historically, based on the use of gum rosin obtained from pine tree sap although many synthetic materials are now used, too.

To clear up a potentially confusing point: it's sometimes common to hear the terms *resin* and *rosin* interchanged. Rosin is, in fact, by dictionary definition the solid residue obtained from the distillation of oil of turpentine from crude turpentine — this, by chance alone, happens to include the residue distilled from pine tree sap and used in solder fluxes; what we, ambiguously, know as *rosin*. On the other hand, *resin* is an adhesive, inflammable substance secreted by most plants and exuding naturally from fir and pine — that is, sap. Resin can also be made synthetically. So, rosin is distilled from a resin — but that doesn't mean resin *is* rosin, or indeed that *all* resins are made into the rosin used in soldering flux. On the other hand, a resin flux may be based on synthetic resin or natural rosin.

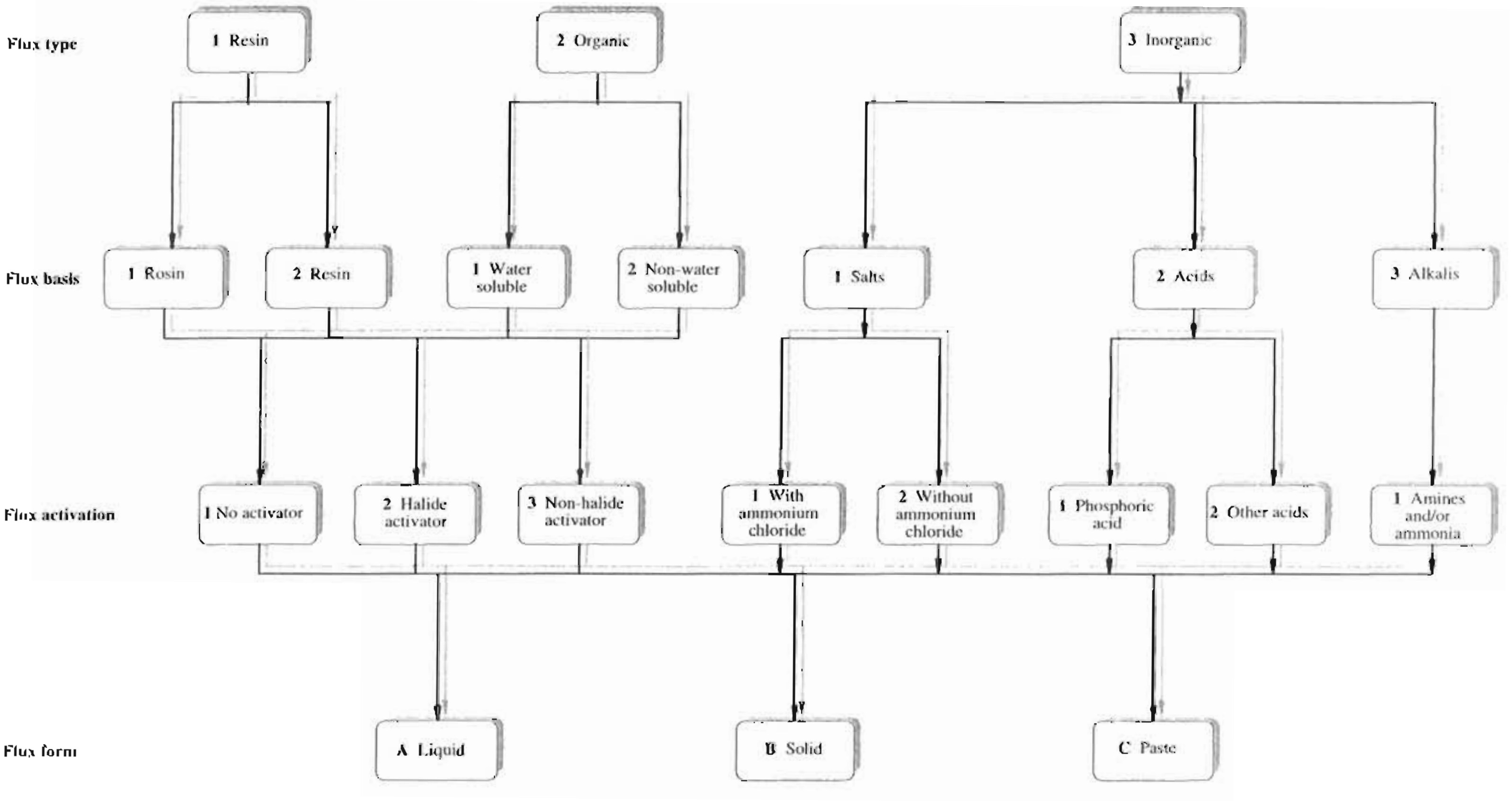


Figure 5.4 *International Standards Organization flux categorization*

Where resin is used as a flux, it is dissolved in some organic solvent. Resin flux residues, also, can be removed by dissolution with organic solvent (a fact which makes rosin-based flux the original organically soluble flux). Indeed, rosin has two excellent properties which makes its use as an electronics solder flux preferable to many others. First, as a liquid at soldering temperature it is active, being a mild organic acid, and so provides good wetting capabilities for solder on lightly tarnished metal such as copper and gold. Second, as a residue in solid form, after the soldering process and consequent evaporation of organic solvent, it is basically non-reactive, so does not corrode the completed joint, and is a good insulator.

Rosin has excellent flux properties. When heated on an oxidized copper surface it becomes active and attacks the copper oxide. Its active material is abiatic acid which converts copper oxide to a blue copper abiate. This leaves a bright metallic copper surface.

As rosin cools it forms a glossy hard layer which is totally inert and protects the copper surface from further oxidation.

In all these respects it is, therefore, a perfect flux; it cleans and covers lightly tarnished metal surfaces satisfactorily and there is no specific need to remove its residues from the printed circuit board, unless later manufacturing processes such as conformal coating require it. Unfortunately, however, basic rosin flux has quite a low activity so is only useful for removing very thin oxides from metals.

Fluxes based on synthetic resin can perform in very similar ways to rosin-based fluxes. They often have significant advantages, too, including greater consistency of quality (rosin is a natural substance and can vary considerably in quality), lower fuming, and so on.

Where metals are too tarnished for resin-based or rosin-based fluxes, resin fluxes with added activators are often used. Such activators increase the flux's cleaning activity at the soldering temperature, so improving wetting. Needless to say, such fluxes leave corrosive residues, however.

Activators include:

- certain organic halide salts such as dimethylammonium chloride (abbreviation; DMA HCl), and diethylammonium chloride (DEA HCl)
- organic mono-basic acids such as formic acid, acetic acid, propionic acid
- organic di-basic acids such as oxalic acid, malonic acid, sebacic acid.

Activators of the first variety are often called **halide activators** (as they are based on halides of one of the non-metal halogen elements such as chlorine or bromine) while those of the other two varieties are often called **non-**

halide activators. Activating agents are selected according to their activity and corrosion properties, ease of cleaning, as well as their (or their vapours') effects on humans.

Rosin production, as it is a natural substance, depends on adequate harvesting from a currently decreasing source. As such, it has fixed properties and, in future, may not be economic to produce. Synthetic resin substitutes often have superior properties and ultimately may be cheaper. While only limited resin-based fluxes are currently available, more will presumably follow.

Organic and inorganic fluxes

These fluxes are often of a type known as water soluble fluxes, as their residues after soldering are often soluble in water. They are usually produced to be highly active — taking over where rosin-based and resin-based fluxes cannot cope with high oxide amounts. So, their residues are often highly corrosive and so must be removed after soldering. However, as residues *are* basically water soluble, this eases cleaning.

Formulation is based around use of an activator for surface cleaning of the metal to be soldered, and a solvent to ease application. Often, other substances to aid wetting may also be added. Activators include:

- organic salts such as dimethylammonium chloride (DMA HCl)
- organic acids such as lactic acid
- organic amines such as urea
- inorganic salts such as zinc chloride
- inorganic acids such as hydrochloric acid
- inorganic alkalis such as ammonia,

while solvents typically include water and alcohol — of one form or another — and sometimes a mixture of these. Water, however, is not an ideal solvent, as it has a tendency to spatter on rapid application of heat.

Halide free fluxes

Certain national, international and military standards prohibit use of halides (typically chlorides and bromides) in fluxes. This is because standards authorities often believe halide activators to be more corrosive than other activators. Consequently, a category of flux has arisen known as **halide-free fluxes**. Typically these use mild activators such as organic acids and amine compounds.

No-clean fluxes

This term relates to fluxes whose residues need not be cleaned from the board after soldering. Best and most obvious example is a pure rosin flux with no activators.

No-residue or low solids fluxes

A **no-residue flux** is one which theoretically does not leave a residue. In practice, although residues of such fluxes are not visible to the naked eye, some residue — however little — remains. No-residue fluxes are one variety of no-clean fluxes and, it is claimed, are excellent choices for many flux applications [Rubin, 1990 #9].

They are formed from fluxes with a very low solid content (as low as 1%, compared with most other flux solid contents of 10 to 40%). This fact gives rise to a synonymous term; **low solids fluxes**.

Preparation fluids

One of the most recent advances in soldering machine technology is **inert atmosphere wave soldering**, in which assembly soldering takes place in a controlled environment of inert gas — usually nitrogen. Without oxygen around the solder wave, further oxides form neither on the solder nor on the metallic surfaces to be jointed.

The other flux function of cleaning surfaces in the first place, on the other hand, is still required. While conventional fluxes are usable in an inert atmosphere wave soldering machine, the process lends itself to other forms of fluxes which simply *prepare* the metal surfaces prior to soldering, leaving little or no residues at all. Such **preparation fluids** are available, typically based on an acid in an alcohol solvent. Most common to date is a 0.5 to 1% (by weight) adipic acid mixture with anhydrous 2-propanol (isopropanol). As such, of course, they are — correctly — varieties of *no residue* or *low solids* fluxes, although we treat them here as belonging to a separate category merely for descriptive purposes.

Choosing a flux

Choice of flux in any application depends on a number of factors:

- how solderable the assembly is, in other words, how clean the assembly is prior to fluxing

- whether the assembly must be cleaned after soldering
- what cleaning process is used.

Consequently, it's not hard to appreciate; flux should be chosen to suit cleaning processes, rather than the other way round.

Application of fluxes

Methods of applying flux are manifold — there are almost as many methods as there are flux types. However, methods are conveniently split into whether assemblies to be fluxed are undergoing CS or SC soldering processes. CS soldering processes imply a liquid flux, while SC soldering processes indicate flux is in paste form (in a mixture with solder particles). We consider only the main fluxing methods in both process variations.

CS soldering process flux application

As most CS soldering processes are based on wave soldering, it's here where main CS fluxing methods are considered. Usually one of six main methods is used which, in no particular order, are:

- brush fluxing (shown in Figure 5.5), in which a rotating brush dips into flux and spreads it over the bottom of the assembled printed circuit board passing overhead. Although simple, it is not easy to control amount of flux deposited on the printed circuit board, flux runs down the brush bristles, and brushes can disturb components on the board. Such a basic system has been used, however, in second stages of solder-cut-solder processes where leads have been soldered and cut, but assemblies are still hot — other fluxing systems cannot be used to flux hot assemblies

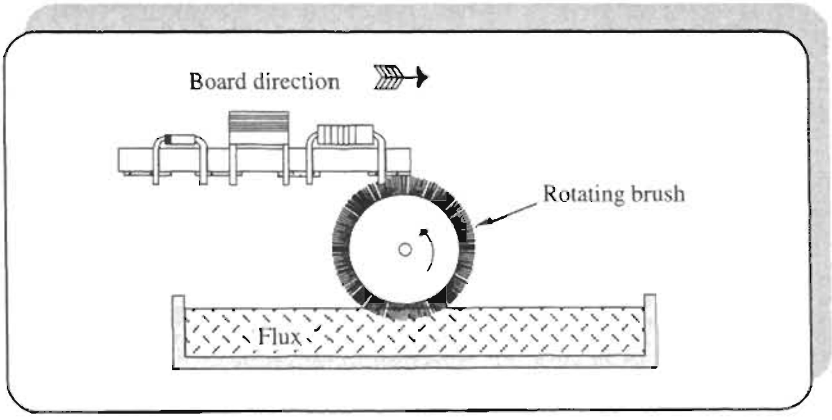


Figure 5.5 *Principle of brush fluxing*

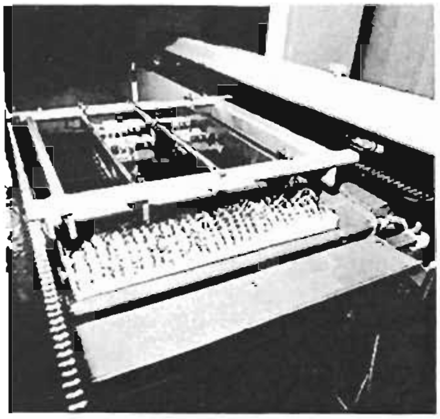


Photo 5.1 *Brush fluxer in operation (Marconi)*

- foam fluxing (shown in Figure 5.6), where air is forced though an aerator into the flux, generating a foam head of flux over which the assembled printed circuit board is conveyed. Aerators may be of porous stone or plastic tubes, or air nozzles. It is simple to operate and lower in cost than most other methods. Foam fluxing applies a reasonably thin and even coating of flux and is easily set up to give repeatable results, although *no residue* or *low solids* fluxes often only allow acceptable foaming with great difficulty. Porous tubes must be kept clean and not allowed to dry out. Foam heights are usually only around 10 mm or so, so there are restrictions on through-hole component lead lengths and where leads have not been cut prior to wave soldering, foam fluxing is usually not possible. Sometimes, side

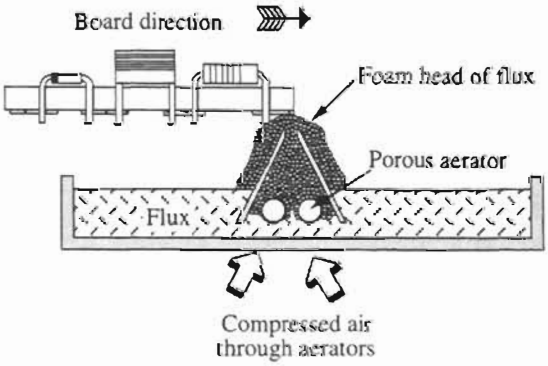


Figure 5.6 *Foam fluxing, in which air is forced through flux to create a head of foam*

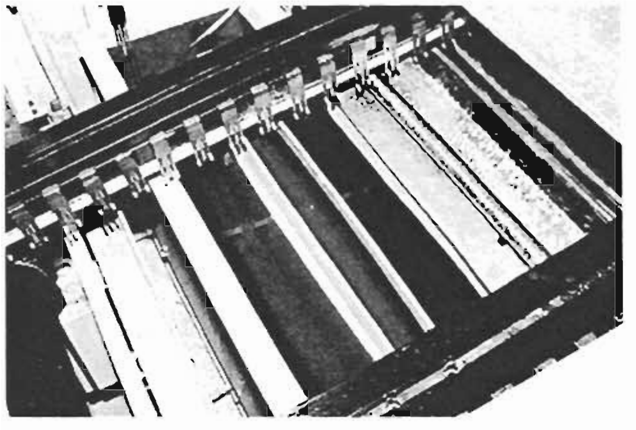


Photo 5.2 *Foam fluxer, not operating (DDL Electronics)*

brushes are incorporated which extend lead heights. Occasionally, foam fluxers are used with brush fluxers, to create a foam of flux which is then brushed on — this prevents flux running down the bristles of the brush. Hot pallets or printed circuit boards may collapse the foam head, however. Foam fluxing is the most common form, simply because it is the most economical and most easily controlled — foam quality is assured by trying to get it to look like the head of a glass of Guinness!

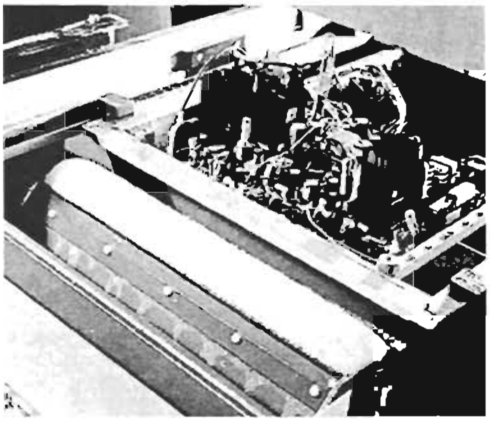


Photo 5.3 *Assembly passing over operating foam fluxer (Electrovert)*

- spray fluxing. Here, several main variants exist. One uses a finely-holed drum rotating in flux, while air from an air-knife forces flux through the drum's holes onto the printed circuit board overhead (Figure 5.7). Another uses a compressed air spray nozzle, moved backwards and forwards across the underside of the assembled printed circuit board (Figure 5.8). A third uses a compressed spray principle, comprising a bank of atomizing nozzles,

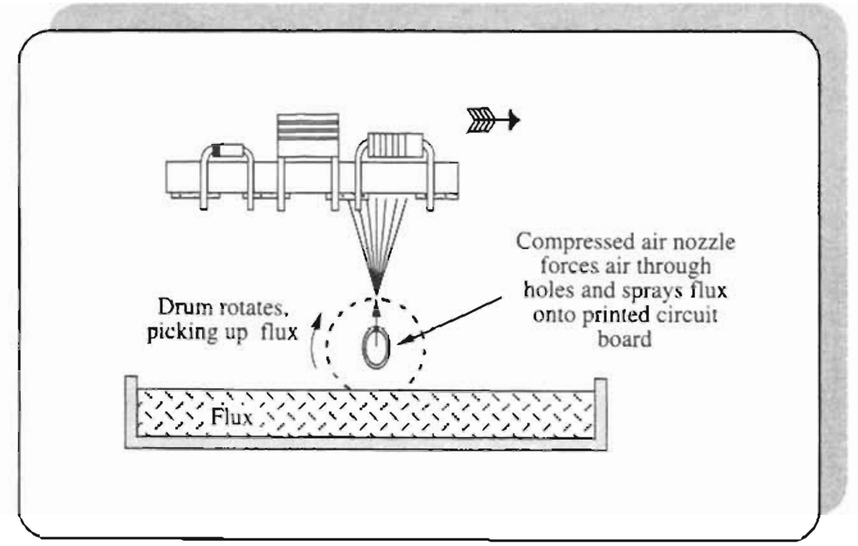


Figure 5.7 *Spray fluxing, using an air knife inside a finely-holed drum*

over which the assembled printed circuit board passes (Figure 5.9). The JeFlux is a proprietary version using this principle, comprising pulsed spray jets spaced at 0.1 inch across the conveyor width within a pressurized container. Finally, another type of spray may be used, in which a pump forces flux out through a nozzle, and an air horn blows the spray onto the underside of the assembled printed circuit board

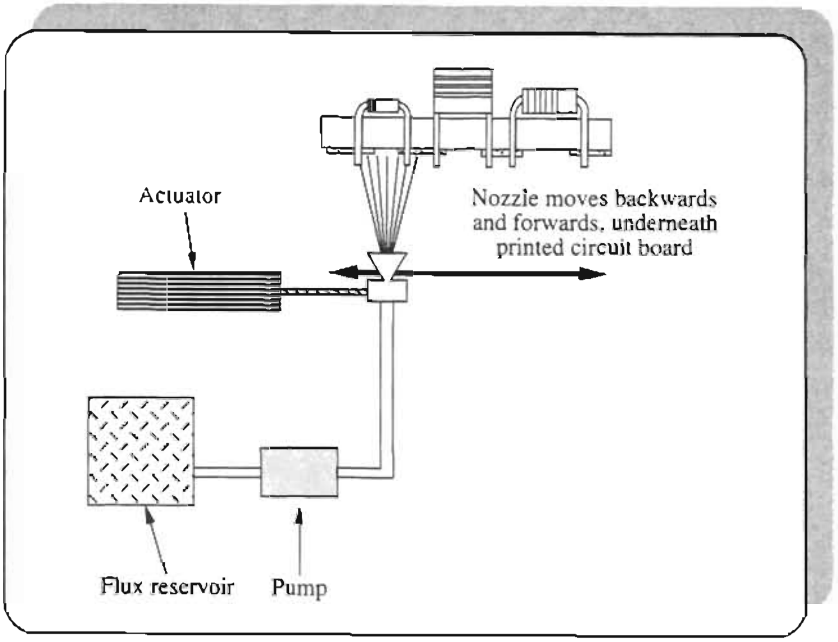


Figure 5.8 *Spray fluxing, using a single moving compressed air nozzle*

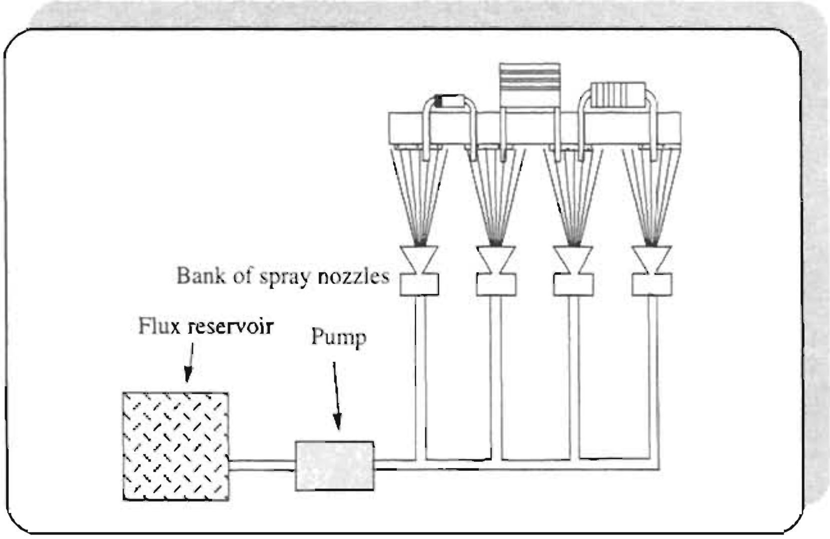


Figure 5.9 *Spray fluxing, using a bank of atomizing nozzles*

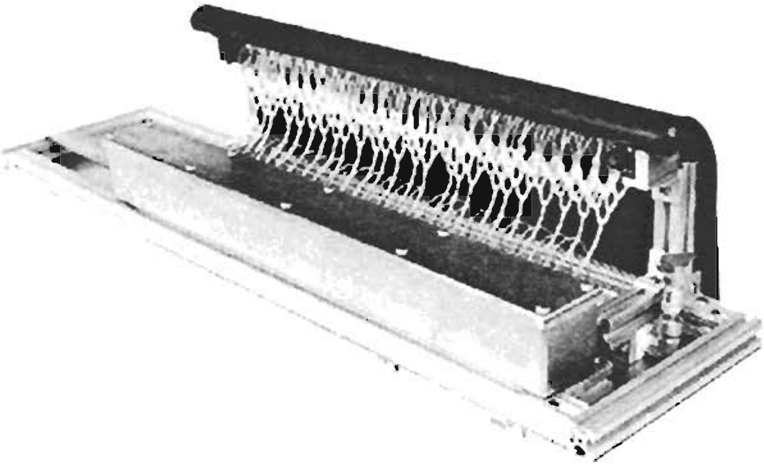


Photo 5.4 *Jetflux spray fluxer, shown with main flap up to see sprayheads (Speedline Electrovert)*

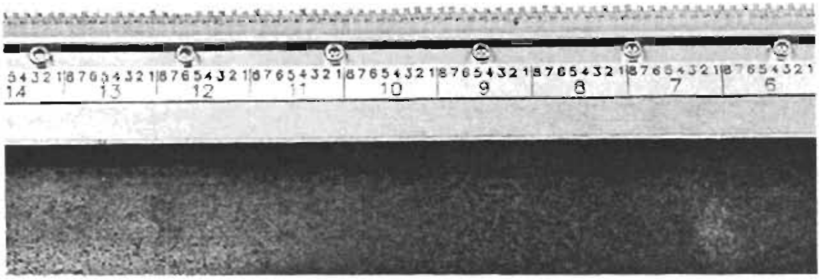


Photo 5.5 *Close-up of Jetflux spray fluxer sprayheads (Speedline Electrovert)*

- bristle spraying. Where bristles of a rotating brush catch against a peg, flicking flux on the bristles up to hit the underside of a printed circuit board conveyed overhead (Figure 5.10)

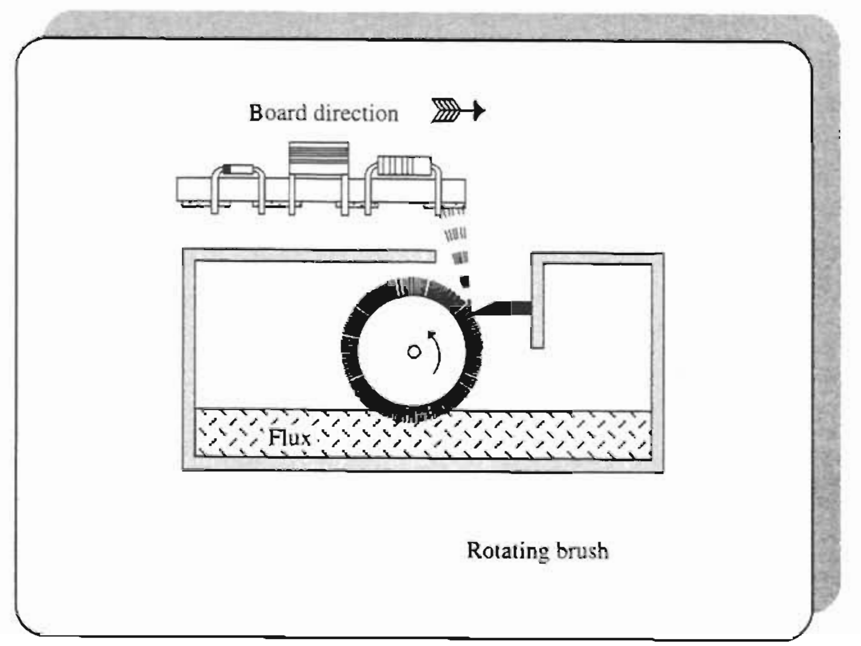


Figure 5.10 *Bristle spray fluxing, using a rotating brush — a knife edge catches on a brush to flick the flux onto the base of the assembly*

- wave fluxing (shown in Figure 5.11). This method uses a liquid wave applicator, similar in principle to the solder wave itself. This is especially successful in fluxing multi-layered printed circuit boards, but can suffer from problems of excessive flux

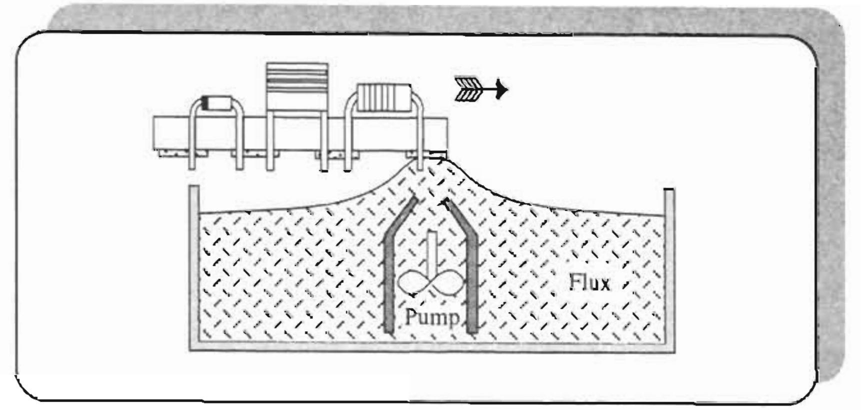


Figure 5.11 *Wave fluxing, using a wave made by pumping flux up through a nozzle*

- combination fluxing. Here, two or more of these variants are combined.

Most soldering machines using these fluxing techniques follow the fluxing process with an air knife, to reduce excess levels of flux. This prevents too much flux entering the soldering stage, and so reduces possibility of consequent fire.

Fluxer level control

In fluxers in which flux is recirculated it is usual to provide some form of automatic level maintenance, if only to alleviate the need of the machine operator to top up the flux reservoir. Flux level control is not necessary in any fluxer using a spray system.

Often used is a pumped system, where the main body of flux is contained in a large tank. A weir in the fluxer body sets flux level and, as flux is pumped from the tank, it flows into the fluxer, overflows over the weir back to the main tank (Figure 5.12).

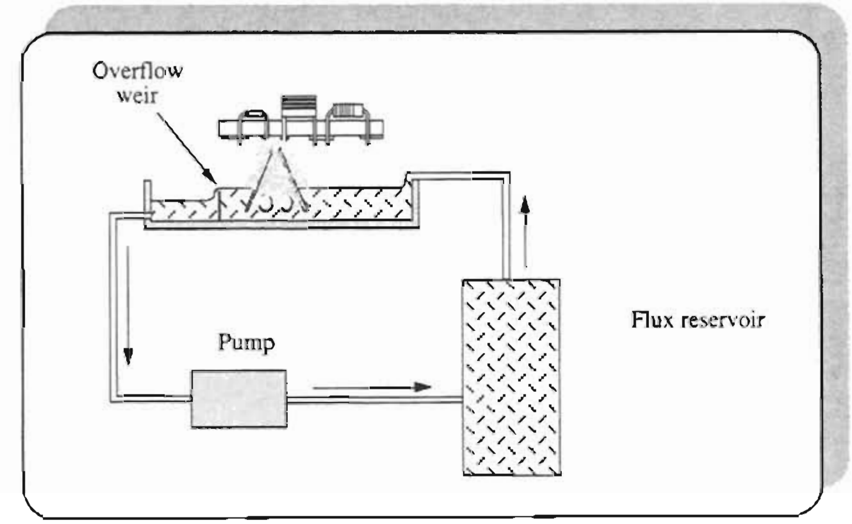


Figure 5.12 *Using an overflow weir to maintain a constant level of flux*

Flux density control

As solvents used with fluxes tend to evaporate, some form of maintenance of flux density has to be built into recirculating fluxers open to ambient environments. This is especially necessary with fluxers using low boiling-point solvents such as alcohol.

Simplest form of flux density maintenance is a hand-dipped hydrometer. Although basic this is most economical and, if performed frequently enough, is every bit as effective as automatic methods.

Quite simple electro-mechanical systems, using photo-electric detection of hydrometer position have been common in the past. Figure 5.13 shows an example where flux flows through a hydrometer sensor chamber, overflowing at its top to maintain a constant height for the hydrometer. When density changes, hydrometer height varies. A marked band on the hydrometer neck affects output of a photo-sensitive cell, indicating whether the hydrometer is low or high. This actuates a valve controlling addition of thinners to the flux.

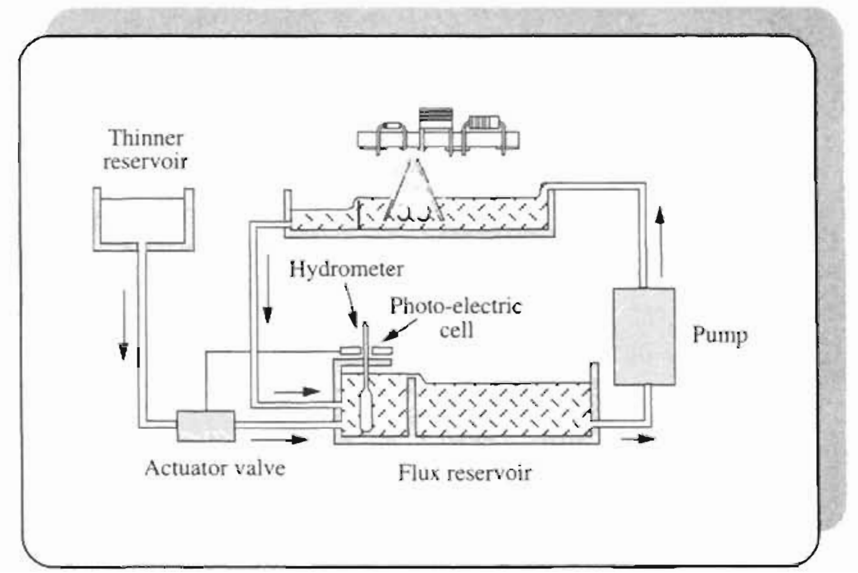


Figure 5.13 *Flux density control, using a simple hydrometer/photo-electric cell arrangement to control addition of thinners*

More common now are density float-type sensor systems which detect level and density of flux, controlling addition of both flux and thinners to the reservoir.

An exception to the requirement of flux density control is in sealed fluxer units. Here, as the whole system is enclosed, solvent evaporation is not a problem so no density control (or level control, for that matter) is needed. Flux (or preparation fluid) is not wasted, so consumption is greatly reduced.

Flux contamination

As flux washes printed circuit boards, it removes some contamination: grease from, say, fingerprints; chemicals from earlier assembly processes; dust, and so on. In all but *total loss* fluxing systems (where over-applied flux is not recirculated) such as spray fluxers, this contamination level builds up and may affect soldering performance. In addition, flux does oxidize at a slow rate, so becomes self-contaminated.

Consequently flux in recirculating systems must be dumped at intervals and all associated equipment must be thoroughly cleaned. Intervals vary from system to system depending on use, assembly throughput and extra contamination entering flux (from masks, components, tape and so on). Often the only way to specify the interval is to monitor and compare boards at the output of the system regularly — when flux contamination is a nuisance, you have passed the stage where flux should be dumped.

Preheating in CS soldering processes

Although preheating is often classed as part of the soldering process itself, it *can* be viewed as just the last stage of a flux application method. This is because preheating serves to dry the flux; evaporating away solvents in the flux to leave a pure flux form on the printed circuit board. So, the topic is included here for completeness, although actual CS soldering process preheating methods are discussed more fully in Chapter 7.

Preheating, in fact, has two main effects. First, it can reduce spattering of the flux in the solder wave. Second, and most important, as solvents do not have to be first evaporated by the heat in the solder wave, and component parts within the assembly do not have to be heated to soldering temperature by just the solder wave, there is a resultant speeding up of the soldering process itself. So, while preheating is a distinct process in its own right, it is integral to both fluxing *and* soldering operations.

SC soldering process flux

Flux in SC soldering processes is applied before components in a paste form, mixed with solder powder, and known as **solder paste**. Once applied, components are added and the assembly made ready for heating. In a preheating stage (see later) the solder paste is heated till the flux becomes active, so cleaning and maintaining the printed circuit board track surface. Following this, further heating turns the solder powder into molten solder to complete the soldering process.

SC soldering processes therefore have quite specific requirements — which must be monitored and maintained in order that successful soldering can be undertaken.

SC soldering process flux application

Application of solder paste is performed before components are placed onto the board (as opposed to CS soldering processes, where components are inserted before application of flux). This is quite an important distinction, because the presence of solder paste means that components can be later assembled onto the paste (that is, the paste itself can hold the components in place during the rest of the process).

There's a number of ways to apply solder paste, including:

- screen-printing, in which a nylon screen or metal mask stencil is held on a frame above the bare printed circuit board, while solder paste is wiped across and so pushed through the stencil with a squeegee
- syringe-type dispensing nozzles, connected with tubing to a pump which forces solder paste from a reservoir out through the nozzles onto the bare printed circuit board
- pin transfer, where pins are first dropped into a reservoir of solder paste, then lowered onto the bare printed circuit board surface.

These three methods are covered in detail in Chapter 6.

SC soldering process flux classification

There are several ways in which SC soldering process flux is classified in solder paste form:

- alloy type
- powder particle size and shape
- metal content
- flux type
- viscosity.

These parameters are covered in depth in Chapter 6.

Preheating of solder paste in SC soldering processes

Unlike CS soldering processes, where preheating may be considered just the final stage in flux application, preheating of SC soldered assemblies is a distinctly separate step. After solder paste is applied in an SC soldering process components must then be placed in a completely separate operation. Only after the assembly is fully loaded with surface mounted components can it be preheated. Chapter 8 covers SC soldering process preheating in greater detail.

6 Solder paste

In typical SC soldering processes — and in a very few CS or mixed soldering processes — solder paste is applied to the printed circuit board first. Following this, components are added, then the assembly is preheated and heated to soldering temperature. Obviously, in such processes the key to successful soldering depends (among other things) on the solder paste itself. Solder paste is a mixture of solder particles together with flux. As the printed circuit board is preheated the flux cleans the board tracks, further heating turns the solder particles into molten solder.

This chapter first details how the solder paste is applied to a board in the first place. In some instances, adhesive is used to hold components onto a board (say, if the board is to be inverted prior to adding further components). The application methods for adhesive and solder paste are similar, and in many cases are identical. For this reason this chapter refers to adhesive application also.

Finally, the chapter looks at solder paste itself, its special requirements and its main variables.

Solder paste or adhesive application

Solder paste or adhesive is applied to the surface of a printed circuit board by three main methods:

- screen-printing
- dispensing
- pin transfer.

Each has its advantages.

Screen printing

This description of screen printing of solder paste and adhesive owes thanks to Alan Hobby's article *Practical aspects of printing solder paste* [Hobby #26]. The authors are grateful for permission to refer closely.

Two variations of screen-printing of solder paste or adhesive exist, both relying on the principle of using a stencil positioned above the printed circuit board, through which solder paste or adhesive is forced. Printed circuit boards are positioned and held in place during the process normally by a vacuum pump arrangement. Process is illustrated generally in Figure 6.1. Both manual and machine screen-printing are common although manual methods tend to give less accurate results, for obvious reasons.

In the first variation, a nylon (or other similar material) screen is held on a frame a small distance above the bare printed circuit board. Holes between screen fibres are selectively filled with lacquer emulsion or a similar substance prior to printing with a negative of the image of adhesive to be printed. This is generally done in a photographic way, developing and fixing the image in the emulsion which hardens, leaving the selected areas soft. After washing to remove soft emulsion areas the screen stencil is ready for use. Solder paste is applied to the top of the screen and a squeegee is used to push the screen down onto the board at the same time forcing the solder paste through the holes in the screen onto the board. Figure 6.2 shows close-ups of the contact points between squeegee and printed circuit board, as the squeegee starts its stroke (Figure 6.2a) and as it nears the stroke end (Figure 6.2b). Ideally, the solder paste or adhesive rolls in front of the squeegee as it travels across the screen. This shows it is entering the cavities in the screen to pass through it and give a complete print.

Note the screen is supported above the printed circuit board such that a **print gap** is well-defined. This print gap allows the screen to peel away from the printed circuit board as the squeegee travels over the surface, rather than snapping away suddenly. For this reason the print gap is also known as the **snap-off** or the **screen gap**. If the screen *does* snap away from the printed circuit board, print quality is degraded, so it is a condition to be avoided. Although the print gap depends largely on particular applications, an approximation to correct setting can be found by multiplying screen width by 0.005, so a 500 mm by 500 mm screen requires a print gap of 2.5 mm or so. Ideally the gap is the minimum to allow the screen to peel away

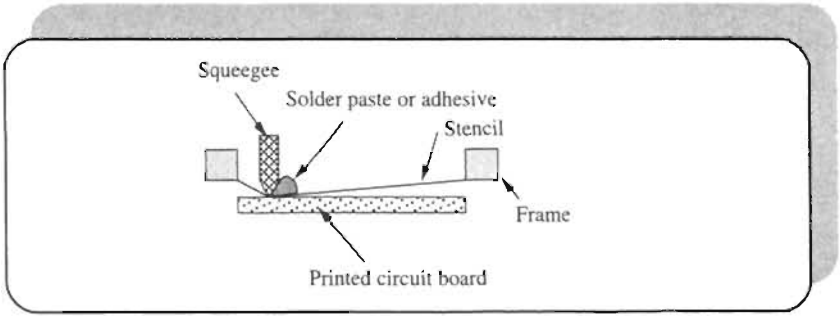


Figure 6.1 *The principle of screen-printing of solder paste or adhesive*

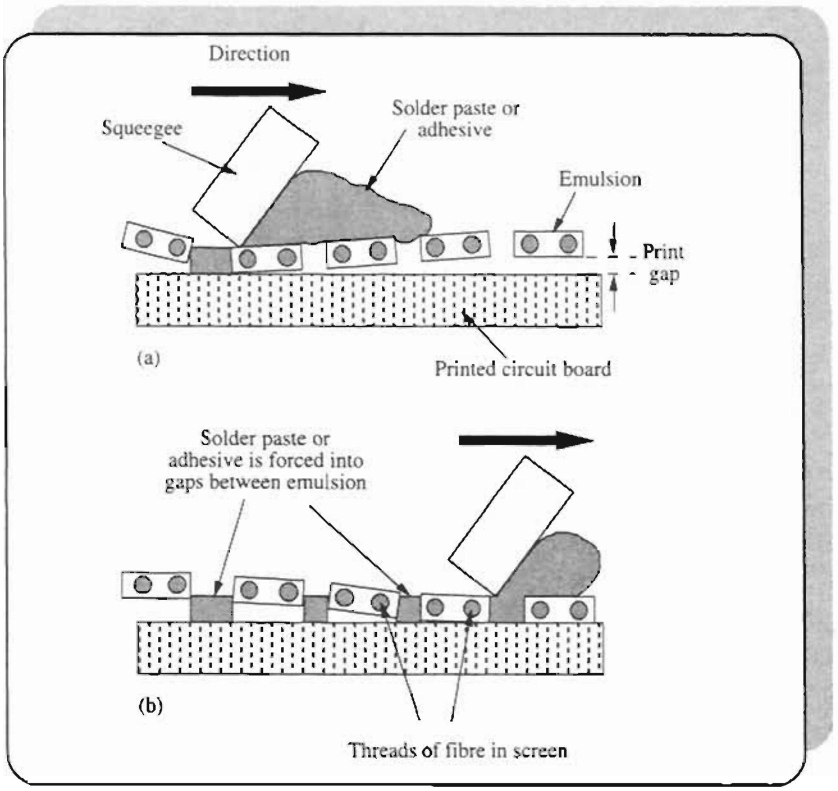


Figure 6.2 *Close-ups of the contact point between squeegee and printed circuit board, as (a) the squeegee starts its stroke and (b) it approaches the stroke end*

immediately behind the squeegee. However, it must still be large enough to break any solder paste or adhesive bridges between screen and printed circuit board when the squeegee lifts at the end of its print stroke.

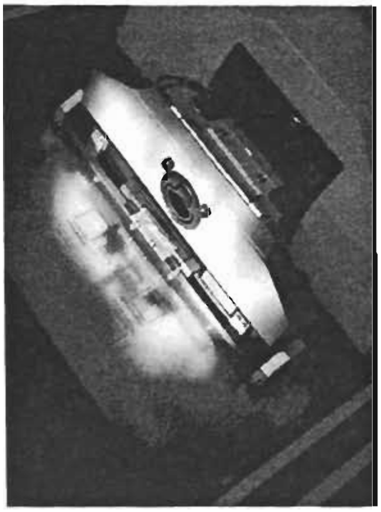


Photo 6.1 *Proflow (DEK)*

Squeegee shape and characteristics; pressure they're pushed down onto the screen; and speed they travel across, are all variable. Shape depends on the setup used. Generally, the aim is to maintain the squeegee tip at a print angle of around 45° to the screen plane, shown in Figure 6.3a. This can be achieved with a trailing edge squeegee (like that in Figure 6.3a) or a diamond-section squeegee (shown in Figure 6.3b). Figure 6.4 shows typical trailing edge and diamond point squeegees. Note that a much greater print angle gives poorer paste or adhesive transfer through the stencil, while a much shallower angle gives degraded definition. Squeegee pressure must be sufficient to wipe paste or adhesive cleanly from the stencil surface as it travels across it, though not so great as to decrease print thickness and cause spreading of the image. Low speed typically causes decreased thickness and spreading of paste or adhesive. High speed allows less time for the screen to peel away from the printed circuit board — higher speeds can often be catered for by increasing print gap, however. Actual values of pressure and speed, though, depend largely on the viscosity of the solder paste or adhesive. Generally, higher viscosity requires higher pressure and lower speed.

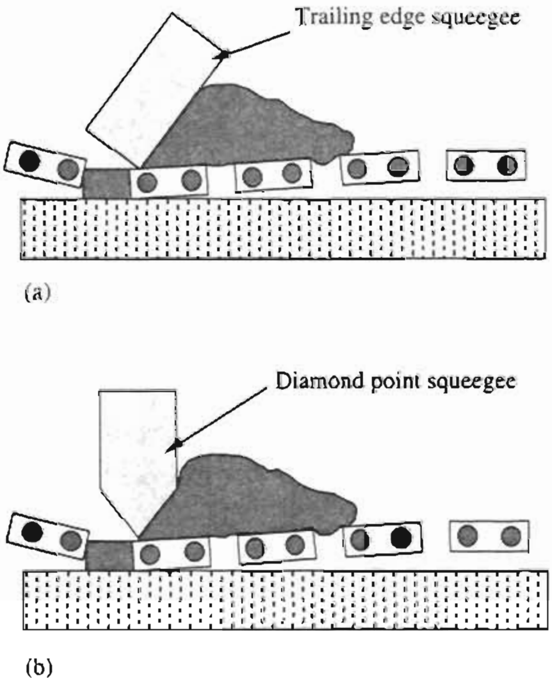


Figure 6.3 *Types of squeegee, showing angle of squeegee tip (a) trailing edge squeegee (b) diamond point squeegee*

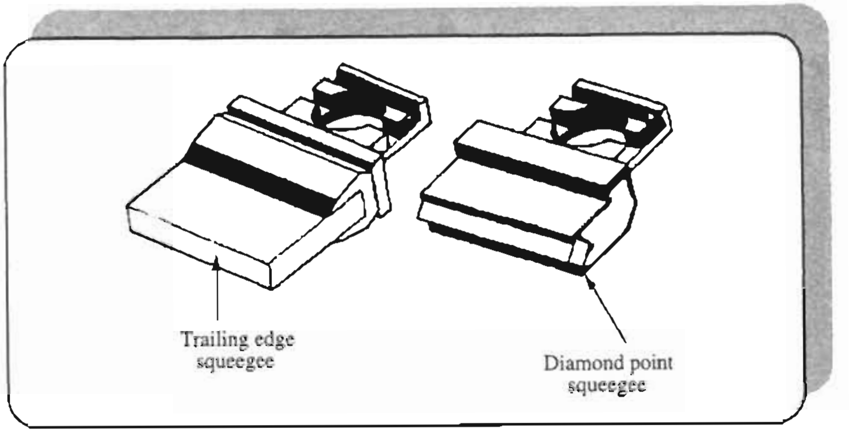


Figure 6.4 *The two main types of squeegee*

Screen life is finite and depends upon use, physical damage being the main cause of failure — not wear. Figure 6.5a shows the main culprit, where a printed circuit board is positioned underneath a screen. As the squeegee travels across the screen it forces the screen against the edge of the printed circuit board. With time — maybe only a few hundred strokes! — the screen becomes worn at these points and tears. This is understandable when you consider thread diameter of typical screens used in screen-printing processes is only around 0.05 mm. A simple surround, into which the printed circuit board fits, is sufficient to greatly extend screen life (Figure 6.5b). This ensures the squeegee does not now press the screen against the edge of the printed circuit board. Ideally the printed circuit board should be proud of the surround by only 0.1 mm, otherwise print quality and thickness control may be degraded near the edge, so careful engineering may be needed. An alternative is to restrict squeegee travel to within the printed circuit board dimensions.

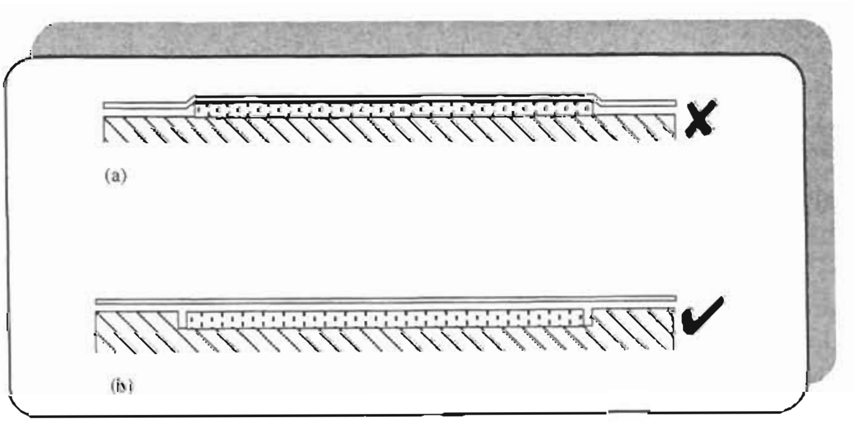


Figure 6.5 *Damage to a screen when printing (a) can be prevented by providing a surround around the printed circuit board (b)*

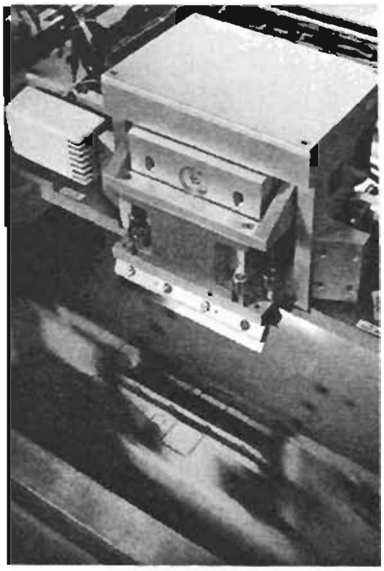


Photo 6.2 *Screen-printing machine (DEK)*

Metal stencil blades

Flexible squeegees can cause problems when screen-printing solder for surface mounted components use. The very flexing action itself causes the problems, in that they act as a pump to push paste behind the squeegee blade, which can force solder paste under the stencil and to bleed onto other areas of the board. As the squeegee passes over a hole, the flexing action can also scoop out solder paste so the final result is a thin pad for the components to sit on (Figure 6.6a).

Metal squeegees — known as **stencil blades** to differentiate them from their flexible cousins — can be used (Figure 6.6b) to correct against both these actions. They have the added benefit that lower downward pressure (less than 50%) is required. Increased rigidity means that smaller blades can be used too.

Metal mask stencils

Where extremely fine detail of solder paste application is required, nylon screen-printing suffers from the drawback that fibres of the screen itself prevent accuracy. The second screen-printing variation sidesteps the problem by using a thin metal-plate mask stencil, suspended in a conventional nylon screen mesh surround, as shown in Figure 6.7. Production of masks is more complicated than production of nylon screens, although they are often made by a similar photographic placement of image as a resist onto the metal plate, followed by etching the areas not covered by the resist. Another

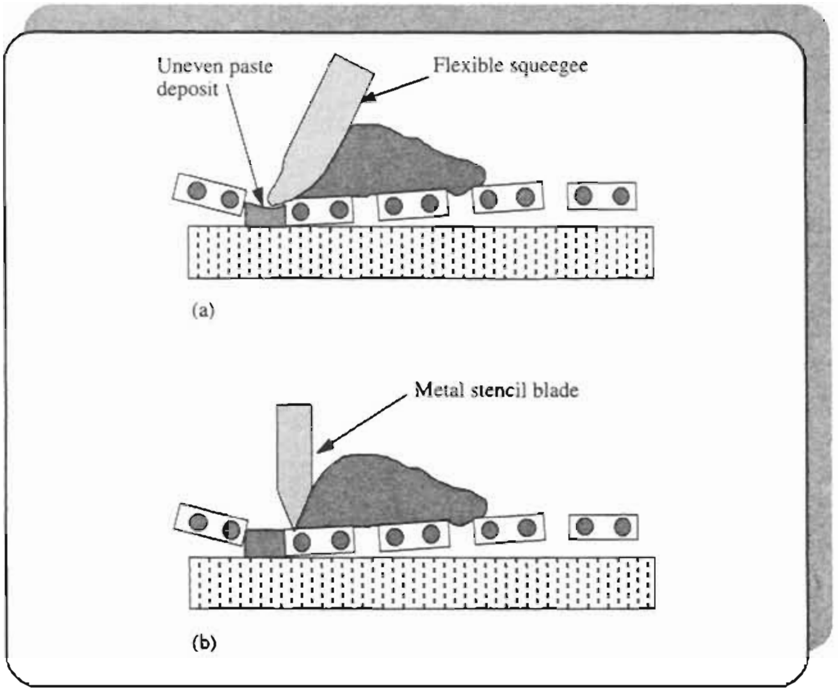


Figure 6.6 *Metal squeegees/stencil blades*

method uses laser cutting of the stencil, in a technique which allows considerable accuracy and promises great potential for the future. Mask stencils have further advantages of a much longer life than nylon screen stencils, and they allow a possibility of different thicknesses of deposits onto the printed circuit board.

Where screen stencils require a print gap, metal mask stencils are often used with no gap. This prevents solder paste or adhesive seeping through the open holes in the mask (this doesn't happen with nylon screens, because

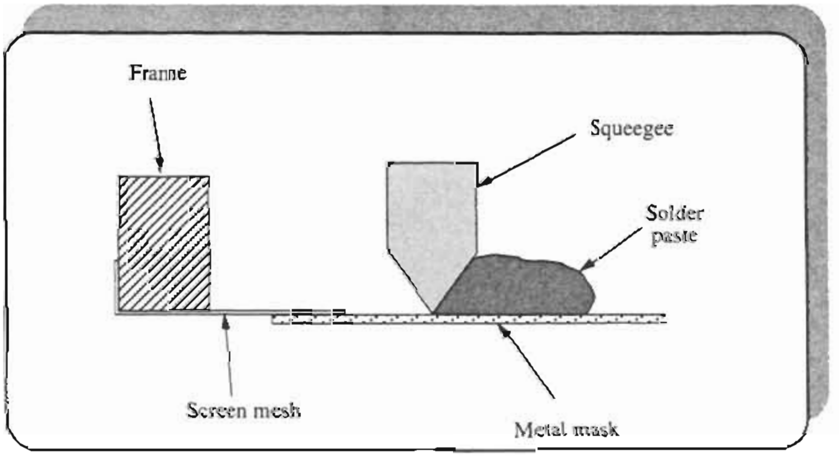


Figure 6.7 *Method of suspending a metal plate mask stencil in a surround of screen mesh*

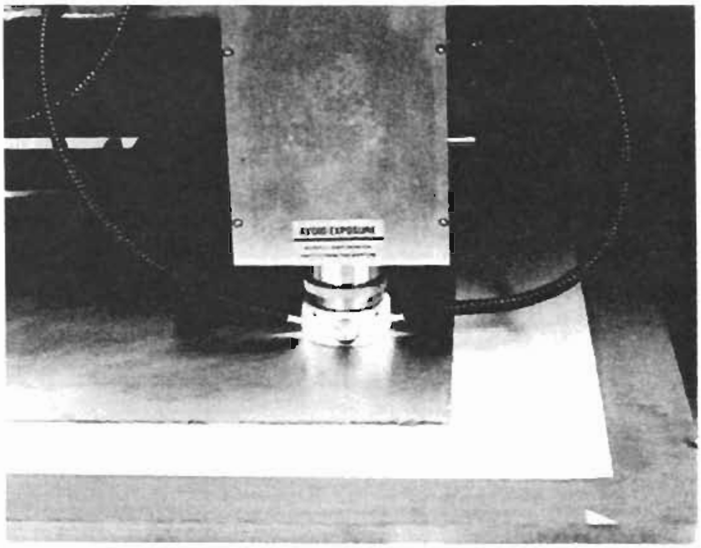


Photo 6.3 *Laser cutting metal stencil (Alpha Metals)*

fibres within the screen prevent it). However, the result is that the holding vacuum can suck solder paste or adhesive through any holes in the printed circuit board (Figure 6.8a), causing poorly defined prints. Masks can also snap quite suddenly from the printed circuit board, degrading image quality. As a result, small print gaps of around 0.002 of the mask width are used, which allow a leakage path for the vacuum (Figure 6.8b).

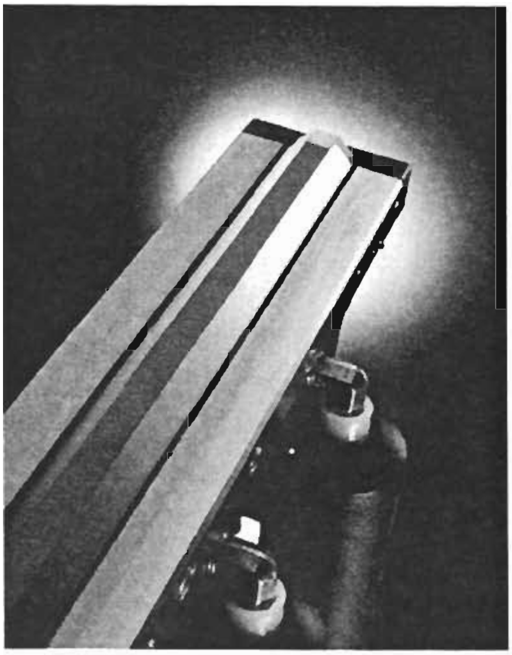


Photo 6.4 *Example of sealed print head, typical of modern print head design. It prevents paste drying out. Spring steel blade design (Speedline MPM)*

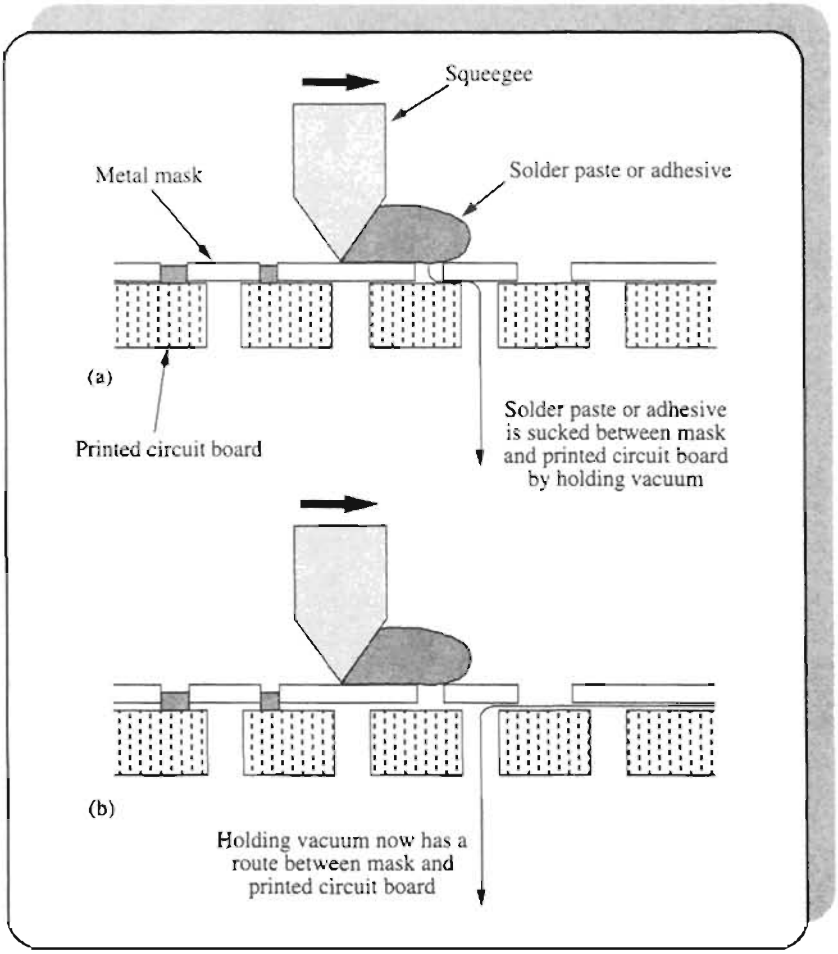


Figure 6.8 *Showing why print gaps are often still used with metal mask stencils (a) without a print gap, the holding vacuum can suck solder paste or adhesive through printed circuit board holes (b) with a print gap, the holding vacuum has an alternative route*

Photo 6.5 *Selection of metal and fabric stencils (DEK)*

Dispensing

Sometimes screen-printing is not desirable or possible. For instance, electronic assemblies with both leaded and leadless components often need solder paste or adhesive to be applied as two separate assembly processes (refer to Figures 2.25 and 2.29). Also, variants of new through-hole SC processes need solder paste to be applied in globules which screen-printing cannot fulfil (refer to Figure 2.28). Screen-printing is a technique suited to reasonably large batches, too. Where only a small number of assemblies are to be produced, costs relating to screen manufacture, use and clean-up time may be excessive. In such circumstances, other methods are more appropriate.

Syringe-type dispensing nozzles (Figure 6.9) form a common method of applying solder paste or adhesive. These are computer-controlled and so programmable — such that they are relatively easily adapted to different assemblies, making small batch production viable. This situation suits itself, also, to assemblies designed with computer aid as the dispensing program can be taken direct from the computer. Nozzles are connected with tubing to a pump which forces solder paste from a reservoir out through the nozzles onto the board. Figure 6.10 shows a typical dispensing nozzle, which uses a syringe as its solder paste or adhesive reservoir. This is a rotary positive-

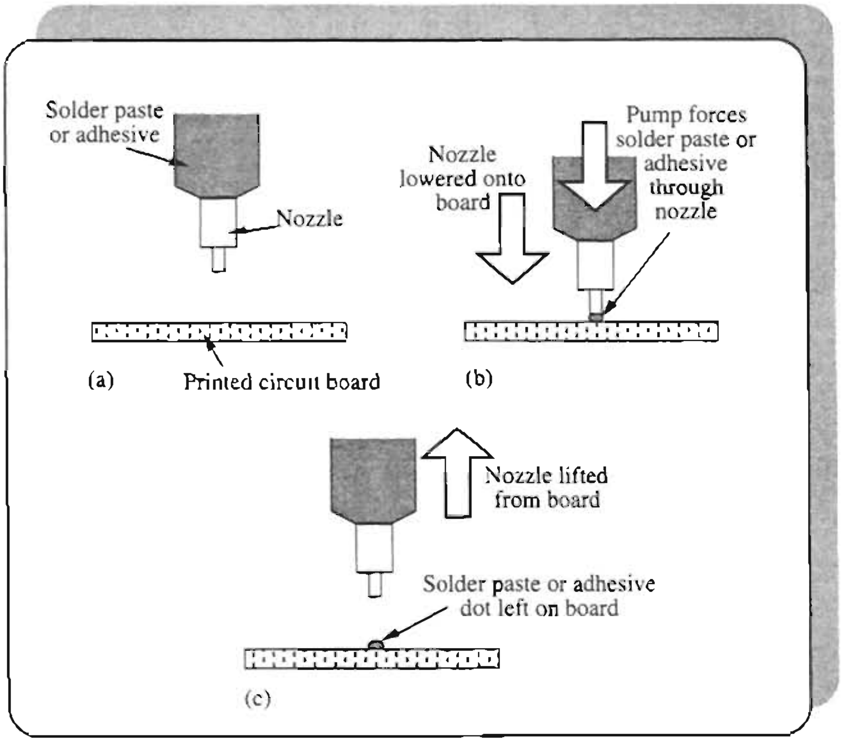


Figure 6.9 *Syringe-type dispensing is a common method used to apply solder paste or adhesive (a) the nozzle is lowered on to the printed circuit board (b) solder paste or adhesive is forced out of the nozzle (c) the nozzle is lifted clear of the printed circuit board and moved to the next application point*

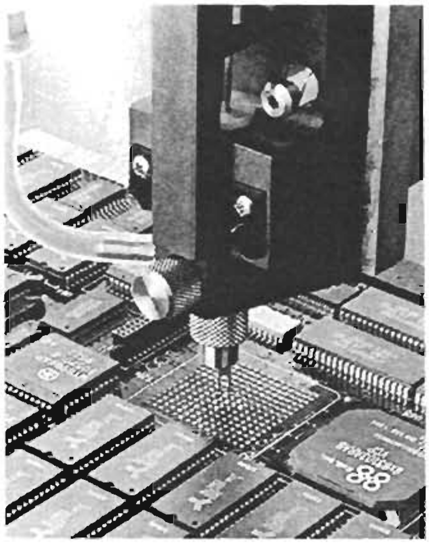


Photo 6.6 *Dispensing solder paste provides flexibility on boards with components that are already in place — such as in this BGA rework example*

displacement pump design. A syringe reservoir is often viewed as best because syringes are quite cheap, making cleaning the machine a simple matter of putting on a new syringe.

Dispensing solder paste or adhesive over a complete printed circuit board is a serial function, each dot of solder paste or adhesive is dispensed in turn and so overall dispensing times per board are long compared with screen-

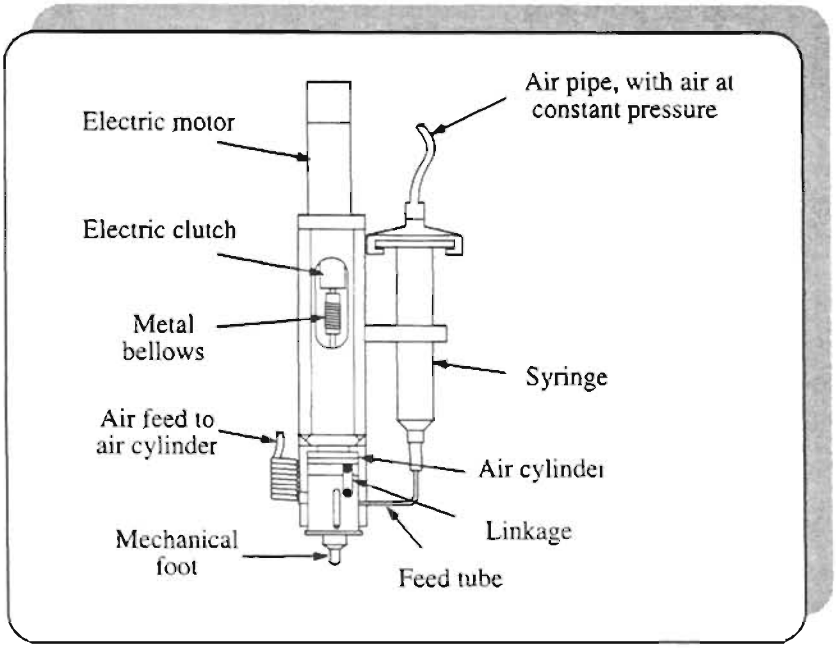


Figure 6.10 *Principle of a syringe-type dispensing nozzle, using a rotary positive-displacement pump (Speedline CAM/ALOT)*

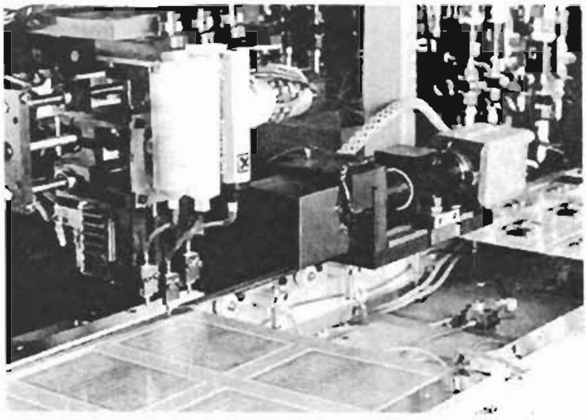


Photo 6.7 *Bank of adhesive dispensers (Dynapert)*

printing and vary with board complexity. However, rates of 45,000 dots per hour are feasible, and some machines may feature multiple dispensing heads which reduce overall dispensing times per board. In a typical pick-and-place assembly line such dispensing machines can easily keep pace with component placement.

Although such machines are quite expensive in terms of financial outlay, they are cheap to run, and especially cheap to adapt from one assembly application to another, simply by changing the software program.

Solder addition

Solder addition by dispensing allows larger amounts of solder paste to be deposited on the board. It is typically used in automotive and mobile phone applications. The method eliminates rework and avoids the use of 'stepped' stencils. With a dual dispensing pump (see Photo 6.8) both solder and adhesive may be applied to the board during a single cycle.

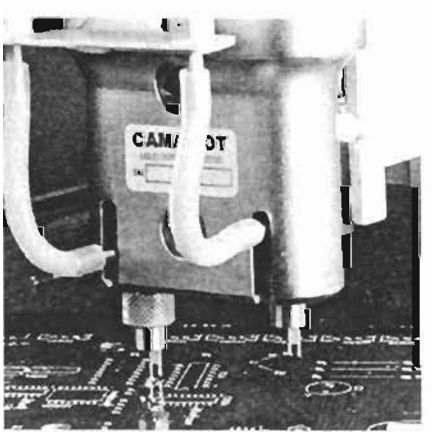


Photo 6.8 *This dual-nozzle rotary displacement pump dispenses solder paste and/or adhesive with two different sized nozzles, in the same dispensing cycle (Speedline CAM/ALOT)*

Pin-in-hole, intrusive reflow

Pin-in-hole/intrusive reflow (sometimes known as solder paste on through-hole technology — SPOTT) is mainly used on odd shaped components, connectors and large components. It eliminates the wave solder process, increases throughput and reduces rework (see Figure 6.11).

The process is quite a straightforward one — through-hole components are inserted, the solder paste is dispensed onto their leads, and the board is SC soldered. However it does rely on the accuracy of modern solder dispensing equipment.

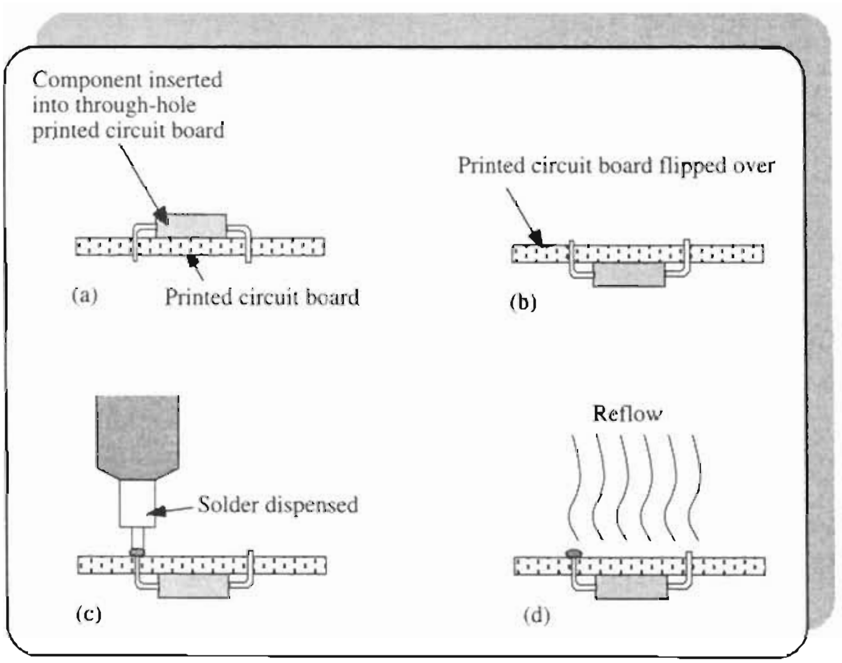


Figure 6.11 *Pin-in-hole/intrusive reflow, or solder paste on through-hole technology (SPOTT) allows odd-shaped or large components and connectors to be mounted. First, the component is inserted (a), the board is inverted (b), the solder paste is dispensed (c), finally the board is reflow soldered (d)*

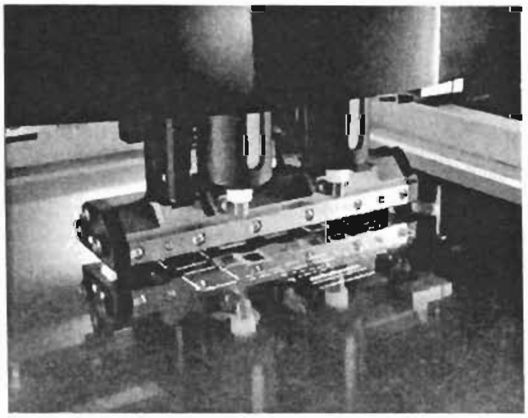


Photo 6.9 *Rheometric pump print head (Speedline MPM)*

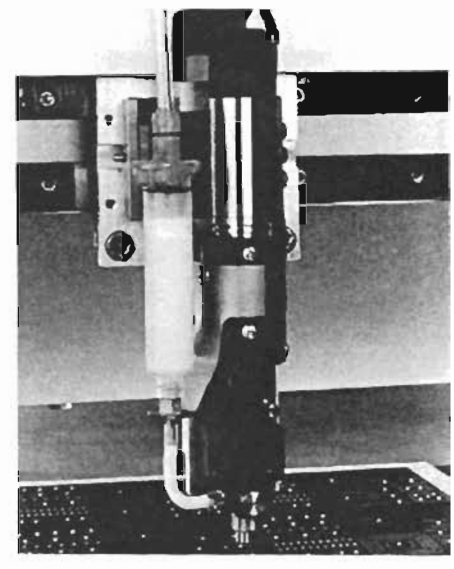


Photo 6.10 *Dispensing nozzle (Speedline CAM/ALOT)*

Pin transfer

Final method of applying solder paste or adhesive is pin transfer (Figure 6.12), where a matrix of pins is first dipped in a reservoir of solder paste, then lowered onto the printed circuit board surface. The pin matrix takes the same pattern to which components are placed. As the matrix nears the printed circuit board surface, surface tension transfers the solder paste or adhesive onto the printed circuit board.

The amount of solder paste or adhesive which is applied to any particular dispensing point on the printed circuit board depends on a number of factors, including:

- pin size
- pin shape
- depth pin is dipped into the reservoir
- closeness pin is positioned above printed circuit board
- solder paste or adhesive viscosity.

With careful design of the pin matrix, therefore, different amounts and shapes of solder paste or adhesive dots can be applied with a single pin transfer operation.

Pin transfer, like screen-printing, is an application method suited to high volume assembly production, because it is quite expensive to produce a complicated pin matrix. However it is, also like screen-printing, cheap to organize and run once the pin matrix has been produced.

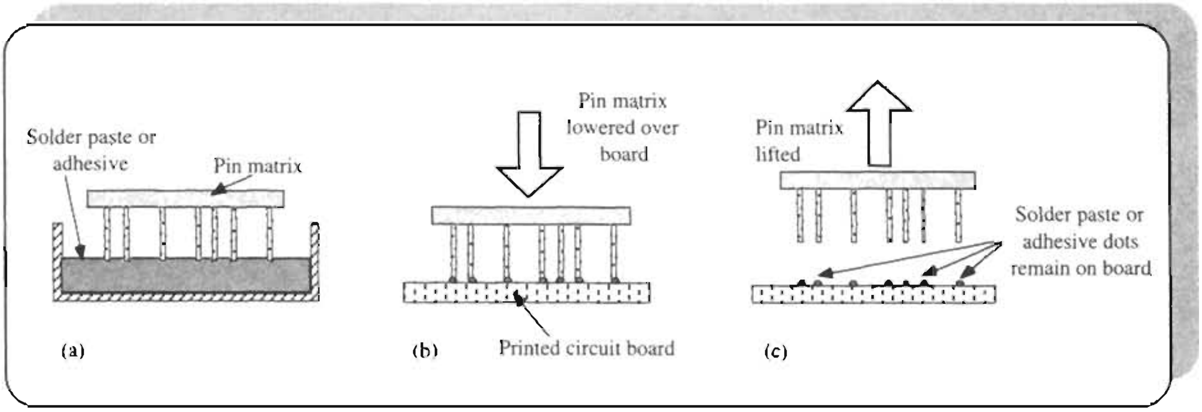


Figure 6.12 *Pin matrix application of solder paste or adhesive (a) matrix is dipped into reservoir containing solder paste or adhesive (b) matrix is lowered on to the printed circuit board (c) matrix is lifted*

Alternative methods — fine-line technology

Where printed circuit boards are to have extremely fine tracks and small component pads, these three methods of solder paste application alone are thought to be limited. Where fine-line technology in which tracks as small as 50 μm or less are required, it is often thought supplementary techniques are necessary. Some recent adaptations of pre-soldering coatings using photo-imagable solder resist (see Chapter 3 for a description of solder resists), prior to screening of solder paste or application of molten solder, report resolutions in the order of 15 μm tracks with 38 μm spacings.

Using solder paste

There are several general — though highly important — points to be noted when using solder paste:

- it's best to use pastes which avoid formation of isolated spheres of solder, remaining after SC soldering processes. Such **solder balls** may form or collect under components, form short circuits, or both
- solder paste of correct thixotropic qualities should be chosen according to application method (see later). Paste should remain on copper track lands and must not slump to other areas
- solder pastes should spread adequately, and exhibit good capillary action
- solder paste should not cause corrosion of printed circuit board and component parts prior to soldering

- there must be strict control of solder particle shapes, to minimize solder oxides forming in the paste. Figure 6.13a shows acceptable solder particle shapes (ie, those with as small a surface area as possible), while Figure 6.13b illustrates unacceptable particle shapes (ie, those with relatively large surface areas).

Solder paste is strongly hygroscopic, and because of the small solder particles and resultant large surface area, oxidizes very easily. Correct handling is therefore important, to discourage ingress of water and oxygen. Several precautions are recommended [Siemens, 1988 #20], including:

- store solder paste in a clean and dry place
- before opening refrigerated solder paste, keep it for 24 hours at room temperature to avoid water condensation on opening
- use only clean and inert tools
- close the container tightly after required solder paste is removed
- never return paste to its original container once taken out
- do not add thinners to solder paste
- if there is to be a long delay between printed circuit board application and subsequent soldering, store assemblies at room temperature in a sealed rack to retain tackiness — not in a refrigerator
- follow manufacturers' instructions.

Solder paste parameters

In simple terms solder paste is a cream which comprises powdered pre-alloyed solder, homogeneously blended with a suitably activated flux system — the active flux and solder constituents being closely related to those used in conventional soldering. The flux in this solder cream is however incorporated in a chemically stable blend of resins, chemical activators, solvents and viscosity modifiers all of which combine to give the required properties for application and reflow. The specifying parameters for solder creams — and, hence, solder paste — can be broken down into five main categories as follows.

Alloy type

Today, virtually any alloy type can be produced in a solder cream varying from low melting point (around 100°C) alloys containing Bismuth, to high lead-bearing alloys with melting points over 350°C — a range which equals the range of soft solder alloys in common practical use. For surface mounted component applications in general the eutectic 63/37 alloy melting point of

183°C is most commonly used, although until fairly recently a large proportion of applications required addition of a proportion of silver (typically 2%) to help prevent leaching of silver from the terminations of surface mounted devices during reflow. Advances such as the inclusion of nickel barriers in terminations and the growth in solder-coated components have, however, contributed to more widespread use of standard tin lead alloys with a consequential cost saving. Silver-bearing alloys are still the norm for the hybrid circuit industry, however, where the concern is of course for the leaching of silver from the fired on circuit terminations rather than the components themselves.

Powder, particle size and shape

The relative shapes of solder powder particles have formed the subject of much debate within the industry for many years and it is true to say that there are certain advantages to be gained from spherical shaped particles and others from uniformly shaped non-spherical particles. Figure 6.13 shows some typical solder particle shapes in use. The emphasis here has to be upon uniformity as variations in powder shape and particle size distribution have effects upon viscosity and application characteristics. In general terms powders today are produced as near to 100% spherical as possible and with a tight control on particle size distribution.

Typical powder sizes in common use are now between 75 microns and 50 microns and for finer printing and high resolution between 50 microns and 38 microns in diameter.

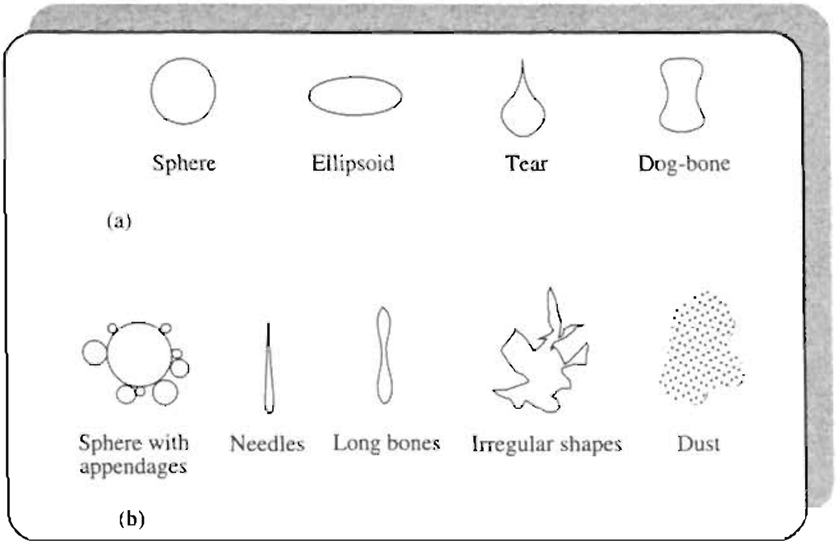


Figure 6.13 *Solder particle shapes which may occur in solder paste. Those of (a) are preferable to those of (b), because they have smaller surface areas*

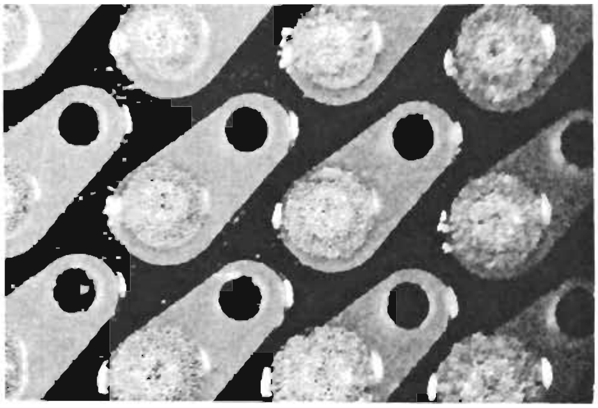


Photo 6.11 *Solder paste deposits on teardrop pads (EPS)*

Metal content

The metal content of a solder cream is usually expressed as a by-weight percentage and can vary, depending upon specification, from 75% to approximately 92%. In general terms for the surface mounted application this has been optimized at between 85 and 90%. To some extent this is due to the great difference in density between the flux vehicle and the solder powder. A solder cream with lower than 85% metal will contain a very large proportion by volume of flux and is likely to cause **slumping** during pre-heat and reflow.

Flux type

Development of flux systems for surface mounted applications has been steady and in line with application equipment requirements. In the majority of applications a mildly active flux is desired; non-corrosive and with limited halogen activators.

Use of more highly active fluxes is often mistrusted due to a fear of inadequate cleaning processes after soldering leading to long-term reliability problems.

Viscosity

Viscosity requirements for solder creams are dependent on application techniques only and can be formulated for special applications, approximate guide lines for application techniques are as follows:

Screen printing through mesh	600 k cps (centi-poise)
Stencil printing through mask	800–1000 k cps
Dispensing applications	350–600 k cps

7 CS soldering processes

All CS soldering processes involve assembly of components to the printed circuit board first, followed by application of heat and solder. CS soldering processes can be totally manual, totally automatic, or something in between the two extremes. Also, assemblies can be soldered component-by-component in serial form, or altogether in a single parallel soldering operation. Where components are assembled and joints are soldered individually in a manual way, the process is known as **hand soldering.** Parallel soldering processes, in which all (usually) components are assembled into the printed circuit board and the whole assembly's joints are soldered in one operation are often known as **mass soldering**.

Hand soldering

Hand soldering is a process in which components are mounted on a circuit board, then individually soldered, joint by joint, until the assembly is completed. Where through-hole assemblies are being soldered (that is, with components mounted using components leads inserted through holes in the board), joints are of an easily-produced reasonable size and are of strong construction. Components themselves are large and easily handled, as are the tools used. A typical assembly and soldering process by hand is shown in Figure 7.1, where components are inserted after which the assembly is held with foam padding and inverted, while soldering is undertaken. After soldering (and after rework), it is important that adequate cleaning measures are undertaken to remove flux and other contaminants.

Joint areas, defined primarily by land sizes, have typical values of around 5 mm^2. This ensures that assemblers can easily see the area to be soldered, and can manipulate the soldering iron and solder with no difficulty. Hand soldering of through-hole components into circuit boards is a well-established and well defined process.

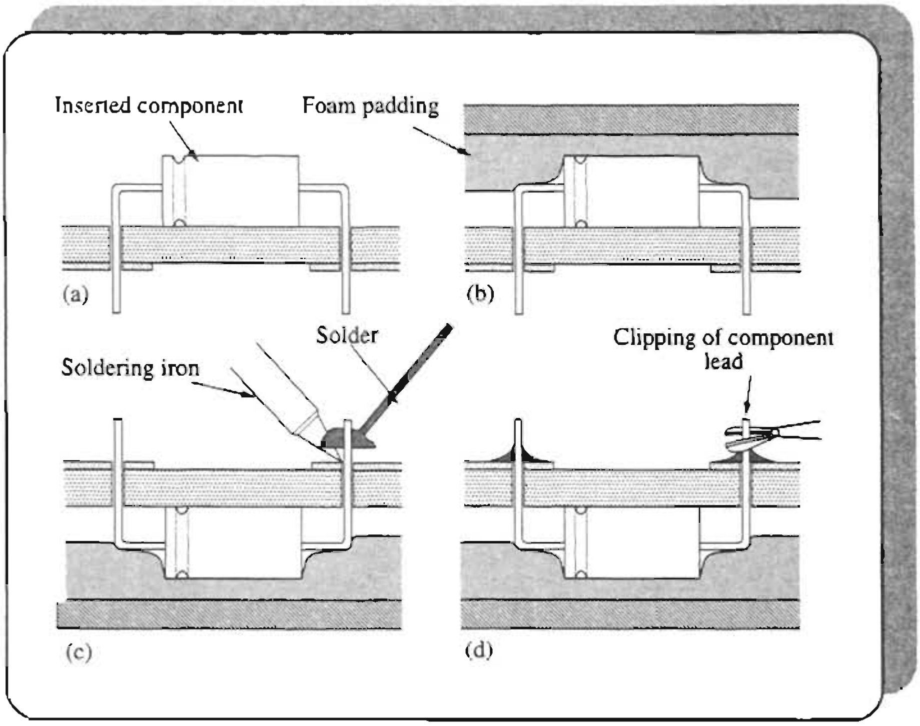


Figure 7.1 *Typical hand soldering process (a) a leaded component is inserted (b) the component is clamped in place (c) the component's leads are soldered (d) excess leads are trimmed*

Hand soldering of surface mounted assemblies, on the other hand, is much more difficult — due to the small size of components, and their corresponding small joint areas. Land areas of much less than 1 mm^2 mean that considerable strain is placed on the assembler to solder joints and, even, to see what is to be soldered. Hand soldering of surface mounted components is not, therefore, normally a process undertaken in any volume production of circuit boards.

On the other hand, where surface mounted boards are to be reworked, say, for repair after manufacture, hand soldering (and desoldering) may be desirable. So hand tools and aids *are* available.

Whatever assembly type is to be soldered, it is important to remember that final quality depends totally on the operator. Being a manual task, hand soldering quality cannot be guaranteed to any high and consistent level, unless suitably trained and motivated operators are used.

Soldering irons

Soldering irons for through-hole components are readily available. Tips are available in a large range of shapes and sizes, some are shown in Figure 7.2.

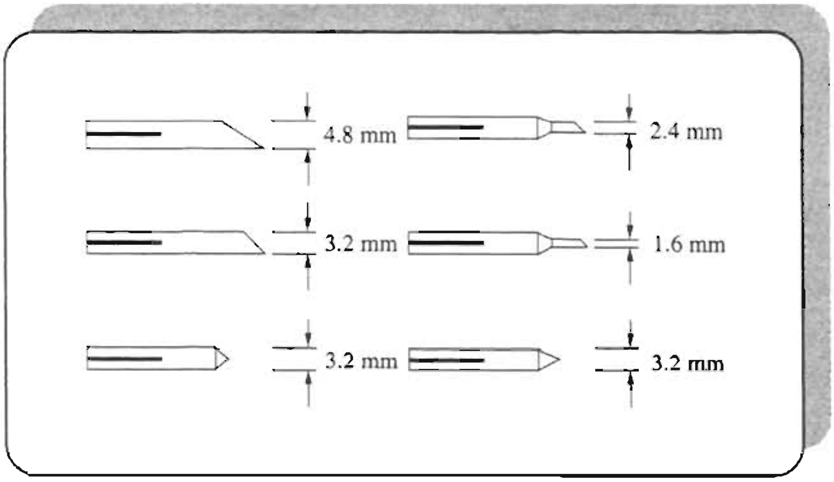


Figure 7.2 *Typical soldering iron tips for through-hole components*

Usually, a medium-sized general-purpose tip is used to solder most types of through-hole components, although some specialized components may require smaller or larger tips.

Soldering irons specifically for surface mounted component soldering are becoming increasingly more common. Unlike soldering irons tips for through-hole components, tip shape and size for surface mounted components are more critical. Many are available with tips shaped to fit specific surface mounted components. Examples of two such tips, shaped to fit common surface mounted components, are shown in Figure 7.3. Many more are available. Where a number of types of components are to be mounted, generally, an equivalent number of soldering irons would be used, eliminating the requirement to change the tip with every new component type to be soldered.

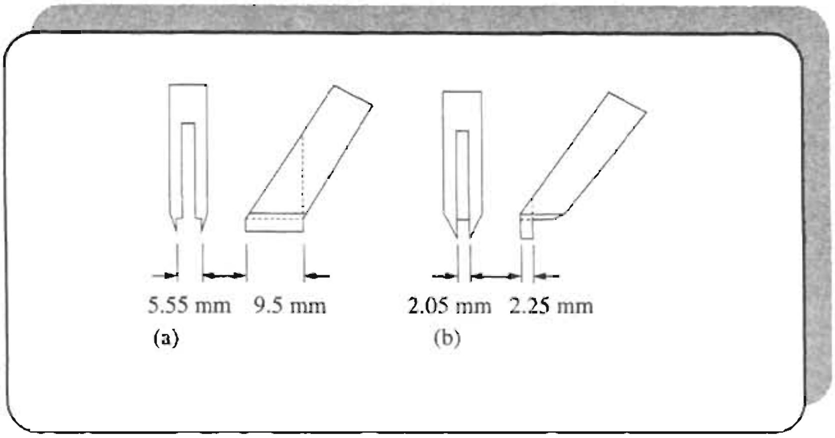


Figure 7.3 *Soldering iron tips for surface mounted components*

Soldering iron tip temperature of some irons can vary considerably during use. When idling, that is, not being used to solder components but still turned on, to the situation where it is being used consistently to solder components, temperature may easily fall from, say, 420°C to around 300°C. So an iron, after idling for a while, may be hot enough to damage temperature-sensitive components. Although less important when soldering through-hole components, this is not an ideal situation, so irons are usually electronically-controlled, to specific temperatures within the 240°C to 400°C temperature range, so that damage to temperature-sensitive components may be eliminated.

Soldering iron types

There are four main types of soldering irons:

- individual soldering irons — comprising a hand-held iron together with lead and mains plug
- soldering stations — comprising a hand-held iron, connected by lead to a control box of some form. Control boxes usually provide controls for temperature of soldering iron tip, and may contain a digital read-out of selected temperature
- cordless soldering irons — comprising a hand-held battery-powered iron (ie, with no connecting lead) and recharging station
- gas soldering irons — running on a small, rechargeable, internal cylinder of gas lighter fuel.

Work stations

In a production environment, hand soldering is undertaken at a workbench area, normally called a **work station**. Typically these will feature parts such as cupboards, drawers, lights and so on, together with several accessories:

- component carousels — typically, a tiered rotating construction, with trays to hold components
- bench racks — trays to hold components, mounted in rows
- component storage cabinets — with pull-out drawers for components
- component dispensers — as one component is removed, the next is automatically positioned ready for removal; useful when many components of the same specification are to be soldered
- cable dispensers — holders for reels of cable
- material dispensers — various peripheral materials (adhesive, solder paste, silicon grease and so on) are often required in hand printed circuit board assembly and soldering; material dispensers ensure a predefined amount of material is dispensed

- bench mats — laid on the surface of a workbench to protect printed circuit board assemblies and other equipment from damage by discarded components or rough worktops. Bench mats are generally anti-static, to protect components damageable by static charges
- printed circuit board work frames — frames to hold printed circuit boards during component assembly and subsequent soldering
- printed circuit board racks — racks to hold printed circuit boards in pre-assembled, partially assembled, or assembled states. These are often antistatic and should be able to hold printed circuit boards without components of adjacent boards touching
- various machines — small drilling machines, wire stripping machines, component lead forming machines, component lead cut-and-clinch machines and so on
- hand tools required for specific soldering job.

Ambient lighting, temperature and humidity are also maintained, typically.

Peripheral tools

A range of hand tools is normally required in hand soldering. Actual tools depend on what type of assembly is to be soldered, but normally include:

- desoldering equipment — see later
- grounded wrist-straps — these form the cheapest and most cost-effective method control over static, preventing damage to sensitive components
- heat sinks — clip-on or squeeze-fit heat-sinks, to use when temperature-sensitive components are to be soldered
- IC insertion tools — special tools which hold integrated circuit legs in correct positions to enable simple insertion into printed circuit boards
- pliers — of several forms, typically miniature snipe-nose, round-nose, flat-nose and hook-nose, as well as larger snipe-nose and combination forms
- screwdrivers — insulated-handle screwdrivers of many sizes to fit flat blade and crossed blade screws
- sidecutters — short-bladed and close-cropping
- spanners — several forms are often required, typically open-ended, box, nut spinners
- trimming knives — with changeable, or snap-off blades
- tweezers — long-nosed tweezers to hold small components and leads
- wirestrippers — many types are available including manual forms with adjustable jaws, automatic forms with interchangeable jaw sizes, and special strippers for co-axial cable.

Hand soldering aids

Where surface mounted components are being soldered, electrically-heated hot plates may help to prevent damage due to contraction. Printed circuit boards are placed on the hot plate and preheated before components are placed and soldered. In this way, boards and components are all at more-or-less the same temperature, before, during and after soldering. Hot plates can be used to cure and dry adhesive or solder paste, too, although they are not common.

Magnifying glasses, or simple microscope arrangements may be used, also, as sight aids when soldering surface mounted components.

Generally, around the work area, it is useful to have inspection aids in the forms of posters, charts and so on, illustrating good and bad points in hand assembly and soldering.

Fume extraction

From a safety point of view, solder fumes should be removed from the work area. This can be done with a fairly simple fan arrangement, or properly extracted by suction.

When extraction methods are chosen, it is common to have the extraction point in the form of a suction pipe placed immediately above the soldering iron tip. Many soldering irons are available, complete with this type of arrangement.

Flux and flux-cored solder

Soldering of any component to a printed circuit board requires that flux be added prior to, or at the same time as, the molten solder (see earlier). This

Photo 7.1 *Soldering iron with fitted solder fume extractor (Hi-Tech UK)*

is always done, when hand soldering, with flux-cored solder wire; comprising a wire of solder containing cores along its length, filled with flux. Many solder alloys are available in this form, with many types of flux, and many wired diameters. For the hand soldering of electronic components; alloy is at or close to the eutectic composition of tin and lead (around 62% tin — see Chapter 3), with four to six cores of rosin or synthetic flux (see Chapter 5), with a typical diameter of around 1 mm.

Electrostatically sensitive devices

Certain electronic components are sensitive to electrostatic discharge (see Table 7.1). When hand soldering such components it is important to use a soldering iron the tip of which is earthed, using a resistor of a minimum value of around 100 kΩ. This ensures any part of the soldering iron tip is at earth potential just a few milliseconds after coming into contact with a high electrostatic potential, but also ensures that the discharge is not sufficiently fast to damage the component at the high potential.

Table 7.1 Some components susceptible to damage by electrostatic discharge

Component type	*Electrostatic discharge range (volts)*
Bipolar transistors	over 380
CMOS integrated circuits	over 250
ECL integrated circuits	over 500
EPROM memory integrated circuits	less than 100
Film resistors	over 300
GaAsFET devices	over 200
JFET devices	over 140
MOSFET devices and integrated circuits	over 100
Op-amp integrated circuits	over 190
SAW filters	over 150
Schottky diodes	over 300
Schottky TTL integrated circuits	over 1000
SCR devices	over 680
VMOS devices	over 30

Desoldering

Occasionally, in rework or repair stages of an assembly's life, desoldering of components may be required. It is a tricky, time-consuming, operation requiring some extra tools. Operators must be skilled and fully trained.

First, the solder must be re-heated to be molten, then it must be removed, prior to component dismounting. Molten solder can be removed using implements to suck the solder away from a joint. Solder suckers can be separate tools, or form part of the soldering iron, comprising an air-bulb or plunger pump mechanism. Sometimes complete desoldering stations comprising hand-held iron-type tools and bench-mounted stations with integral pumps are used.

Alternatively, woven copper wire can be made into a braid, called solder wick, impregnated with flux, which has the effect of drawing the molten solder up the braid, away from the joint.

Mass CS soldering processes

The usual mass CS soldering process is wave soldering, sometimes called **flow soldering**; drag soldering machines are less common; dip soldering machines even less so, although there are some of both types around — if you look hard enough. One of the reasons why wave soldering machines are generally preferred over other CS processes is pretty simple — a wave soldering machine is easily included as part of a continuous electronics assembly production line, using straightforward conveyor techniques. This is, no doubt, one of the biggest advantages of the process. Other CS processes need more complicated conveyor techniques.

Wave soldering CS processes are based on one of the oldest technologies in soldering, and have been around in one form or another for more than 35 years (it was invented by Fry's Metals in the UK). Yet wave soldering is by no means an outdated process, indeed, adaptations of the basic principle of wave soldering seem able to cope with every assembly variant designers throw their way.

To date, all types of plated through-hole assemblies and all but a small handful of surface mounted assemblies are successfully soldered using wave soldering. Further, wave soldering machine manufacturers are totally committed to upgrading the technology, always making it able to cope with the newest of miniaturized components so, while it is an old technology, it still holds great promise for the future. Leaving aside any doubts about wave soldering process abilities to solder some surface mounted components, common through-hole assemblies generally can't be soldered by SC solder-

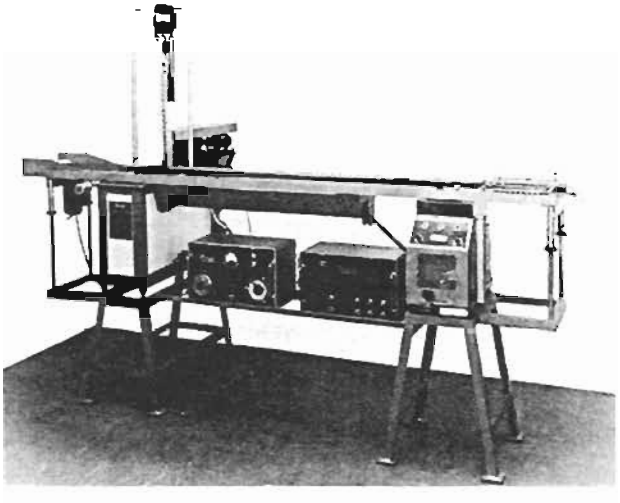


Photo 7.2 *Wave soldering machine (c1960), capable of soldering 250 mm wide assemblies. Note the modular construction popular with machine manufacturers at the time (Electrovert)*

ing processes, so for as long as through-hole components are used in assemblies wave soldering machines will be commonplace.

Nevertheless, wave soldering does have drawbacks. It is a fairly complicated process, with some nine groups of variables [Klein Wassink, #4], requiring regular maintenance both during and between operations by experienced staff. Also, running costs are high. Other considerations are the peculiarities of the soldering process which affect circuit board design for successful soldering — more so than any SC soldering process does early design affect wave soldering stages.

Wave soldering as a process

A typical wave soldering process is shown, in block diagram form, in Figure 7.4. There are three main parts, sometimes called **stations**, to the process:

- fluxing
- preheating
- soldering.

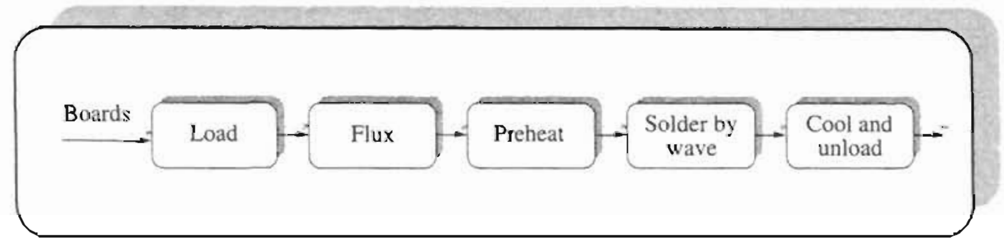


Figure 7.4 Basic wave soldering process, broken up into block parts, or stations

Other relatively minor stations, although still necessary, are loading of boards into the wave soldering machine, cooling of boards after soldering, and unloading of boards from the machine.

Inert atmosphere soldering

One recent derivative of wave soldering is the use of inert atmospheres of nitrogen, in which assemblies are soldered. This could change the way we think about soldering processes, for the very simple reason that no longer is it necessary to use a classical flux to clean and maintain the metal surfaces to be soldered. Metal in an inert atmosphere does not oxidize, therefore the surface remains as solderable as it was before entering the inert atmosphere. without any requirement of an active flux coating. Given that the metal surfaces to be soldered are sufficiently clean and solderable in the first place, much less active fluxes — which consequently leave only few residues — may be used. These fluxes have been called **preparation fluids**, though are really types of *no residue* or *low solids* fluxes.

The potential for inert atmosphere soldering applications goes even further, however. At the time of writing, it is apparent from early application trials that inert atmosphere soldering machines may, in some instances, be able to dispense with fluxes altogether [Elliott, 1991 #11]. No-flux assemblies — meaning only minute amounts of residues, hence no cleaning — are now with us. We consider inert atmosphere CS processes later.

Handling assemblies

In an automated production line loading, conveyance and unloading of printed circuit boards through soldering machines is done with **conveyors**, of which there are two main types, based on:

- pallets
- fingers.

Pallet conveyors

By placing assemblies in a frame or **pallet** (either individually, or as a combination of assemblies in a larger part-punched board — sometimes called a **biscuit board**), the whole structure can be installed on a conveying system which passes it through all solder machine parts. Typically, pallet conveyors use a roller chain moving in a slot to provide controlled movement. Pins in a pallet engage between chain links; the pallet is moved with a positive drive which provides no slippage. Conveyor drives are considered later.

Pallets are adjusted to fit assemblies with sliding bar or spring finger mechanisms. They must hold each assembly firmly and accurately, but without undue side force which might bend the printed circuit board at soldering temperature.

For solder-cut-solder processes (in which each assembly is soldered, component leads are trimmed, then assemblies are soldered again) pallet conveyors are nearly always used as they give good support from vertical movement as assemblies pass through the cutter stage.

Pallets with a fixed central bar or finger set, together with adjustable sliding mechanism either side, may be used to hold two assemblies. However, each pair of assemblies in these pallets must have similar thermal characteristics requiring identical soldering parameters.

Tooling plates

Assemblies with non-rectangular shapes, without at least two parallel sides for holding and location, must be held in pallets with tooling plates which are routed out to accept an assembly, leaving thin outside flanges for support.

Tooling plates are often designed to hold several small assemblies (with similar thermal characteristics) simultaneously.

Pallet guidelines

There are several important aspects of pallets and tooling plates:

- they must be rigid and not be distorted in handling or exposure to soldering waves
- they must be square and level — check them regularly, say, once a week
- dropped pallets must be removed from service until checked
- they must not introduce contamination into solder. Thus aluminium pallets or tooling plates must be anodized or Teflon-coated (Teflon is a trade mark of Du Pont). Steel pallets or tooling plates must have a blued oxide finish or similar
- they must allow for expansion of the laminate (0.5 mm per side is general)
- pallet and tooling plate finish should be regularly checked. Pallets and tooling plates should be replaced if their finish is damaged, scratched or worn through
- the bottom plane of a pallet should be level with the bottom of the assembly it carries, to avoid the frame depressing the solder wave.

Finger conveyors

Because **finger conveyors** use mechanical fingers to hold assemblies and not pallets, they are often known as **palletless conveyors**. Because they feature no pallet, they are easier to use and so are most common.

These fingers are part of the chain conveyor, which means three basic things about the way they work. First, to allow assemblies of different sizes to be carried, conveyor width is adjustable. Second, two sides of each assembly must be parallel. Third, assemblies of different widths cannot be soldered at one time.

A further consideration is expansion of assemblies as they experience heat from preheat and soldering stages — either conveyor mechanisms must compensate or assemblies must be a fairly loose fit when first inserted. For this reason a loading guide usually forms part of the conveyor system, into which assemblies are placed prior to being taken into the solder machine. Loading guides allow conveyors to be adjusted, initially, to suit assembly size. Thereafter, once pushed into the conveyor from the loading guide, assemblies are taken up automatically by fingers into the solder machine.

Fingers have to pass through flux and solder, so must not be affected by flux or wetted by solder. Titanium is the preferred metal for this purpose. Stainless steel is sometimes used but may become wetted with solder if highly active fluxes are used. Bent or damaged fingers should be removed as soon as they are detected, and replaced with new ones.

If large or heavy assemblies are to be soldered, finger conveyors can be used with pallets and tooling plates. This is made possible by, say, making every alternate finger L-shaped, so pallets or tooling plates are supported.

Figure 7.5 shows some of the many finger shapes used in finger conveyors.

Where large assemblies, or assemblies with heavy parts are soldered, it is often necessary for finger conveyors systems to incorporate some form of assembly support to prevent bowing as boards pass over the solder. Such **ski-bars** or **ski-chutes** can be as simple as a single roller positioned under the middle of the conveyor system, so boards are supported at the crucial time of soldering. Figure 7.6 shows such a method. Support can be included at fluxer and preheat stages, though is not so common.

Assembly design when central supports are used must take supports into account — joints must not, fairly obviously, be in the part of the board where a support is.

Finger cleaners

As fingers pass through flux and solder they inevitably pick-up residues of both — particularly if rosin flux is used. If not removed, these can build up to the extent where fingers are not able to grip assemblies correctly.

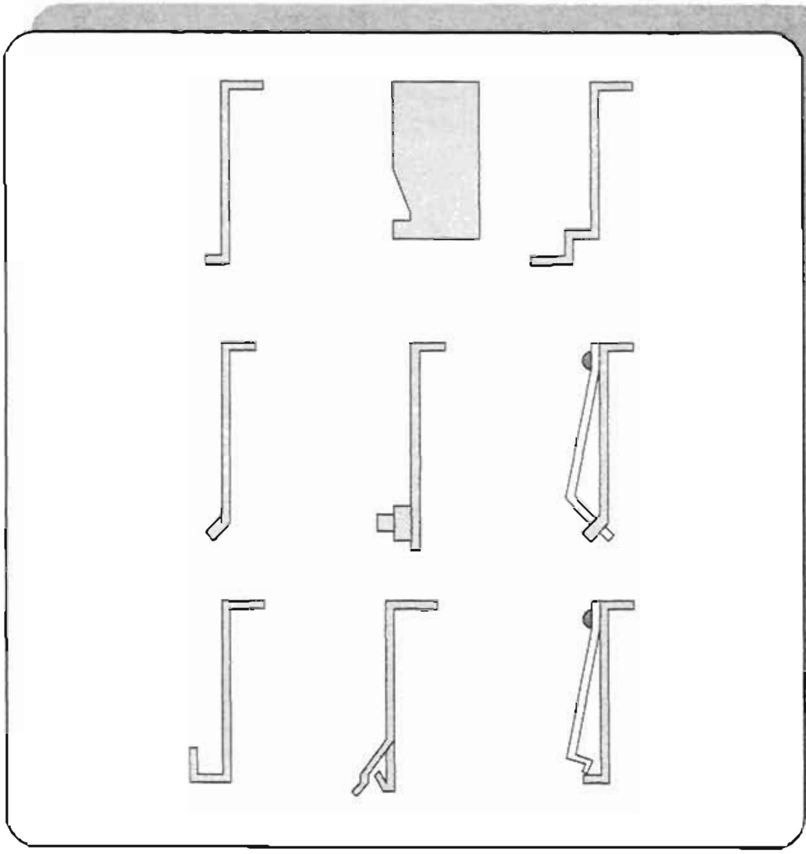


Figure 7.5 *Typical finger shapes used in finger conveyor systems*

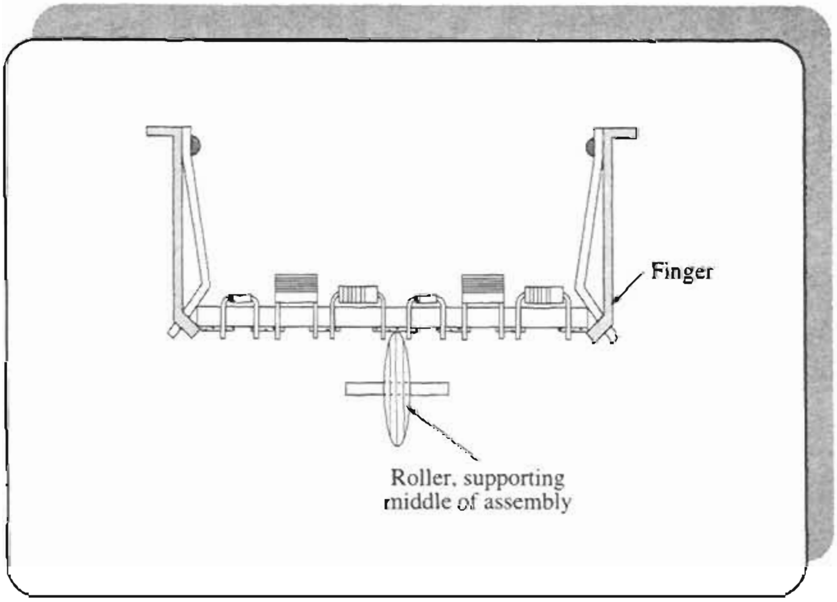


Figure 7.6 *Roller used as a ski-bar to support large assemblies as they are conveyed through a soldering machine*

Finger cleaners are fitted to finger conveyors, often comprising sprays or rotating brushes, through which fingers pass. Solvent used must not cause damage to pumps, pipes and fittings of the cleaner. Note that cleaners cannot remove hardened, dried flux which should therefore be scraped or brushed off by hand.

Cleaners must run whenever the conveyor is in operation.

Conveyor drives

Conveyor speed is varied with some combination of variable-speed motor or variable-speed mechanical drive system. Soldering speeds have to be variable from around 300 mm min^{-1} to 4.5 m min^{-1} to cope with all required assembly types and soldering variables, which is a tremendously wide range. Actual speed used depends mainly on thermal mass of assemblies being soldered and preheat amount.

Conveyors must be smooth in operation; without jerking, bumping, vibration or erratic movement. Speed must be repeatable, and constant once set, too.

Several methods of driving conveyors are used, including:

- single-speed motor, with variable mechanical drive and speed read-out
- variable speed motor, with electric speed control and voltage speed read-out
- variable speed motor, with electric speed control and tachometer speed read-out
- variable speed motor, with electronic feedback speed control and tachometer speed read-out.

While all work to a greater or lesser degree, electronic speed control and read-out gives best performance, and provides the basis for microprocessor control of conveyors.

Solder masking

Occasionally it is possible to use a conveyor mechanism in a way which allows masking of some parts of an assembly from the solder wave. This is normally done by adding fingers or plates to each pallet, such that they protrude under the assembly, simply preventing solder waves from encroaching those masked areas. While perfectly practicable, one of the problems with this type of solder masking is that it's not economically viable unless many assemblies of the same type are to be soldered at the one time.

Alternatively, snap-on titanium protectors are available, which cover assembly edges — these are typically used if, say, gold contacts for edge connectors need to be masked. These are expensive, but are re-usable.

To be masked by the mechanical means possible with conveyor systems, though, areas can only be on edges of assemblies. Couple this with their economic considerations and, rapidly, we come to the conclusion it's nearly always better to use non-mechanical means of solder masking (see Chapter 3).

Conveyor angle

Angle with which an assembly is conveyed over a solder wave has a great effect on soldering quality. An angle of about 6° from horizontal is about right, and many conveyors are fixed at this. Different wave shapes, however, may give best results with slightly different conveyor angles. Also, components may define the required conveyor angle — soldering of assemblies featuring components with long pin terminations, say, demands a shallower conveyor angle to ensure solder forms into a point on the ends of pins. Consequently, some machine conveyor angles are adjustable by either manual or motorized means.

It's important to bear in mind with adjustable conveyor angles that a conveyor acts like a simple lever and any angle change causes possible differences in input, output and solder wave heights, although which heights vary depend on where the conveyor's effective pivot point lies.

Fluxing

The flux used to coat boards in a wave soldering machine is generally in liquid form. Some consideration must be placed on the type of electronics assembly to be fluxed, because not all methods generate a sufficiently high head of flux to successfully flux through-hole boards with long component leads. Fluxing is accomplished using one of three main methods:

- foam fluxing — where air is forced through an aerator, into the flux, generating a foam of flux over which the printed circuit board is conveyed
- spray fluxing — where compressed air or pumped flux is used to spray flux through small nozzles, coating the undersides of boards passing over the spray
- wave fluxing — using a liquid wave applicator, similar, in principle, to the solder wave itself.

These are discussed in detail in Chapter 5, which describes them not as a distinct soldering process, but as an entity in their own right.

No residue or low solids flux application

No residue or *low solids fluxes* form a particular case in point regarding application. Most suppliers recommend either spray fluxing, or a combination of wave and foam fluxing application methods. Spray fluxing is most common.

Preheating

The preheating stage prepares the assembly, recently fluxed, for the soldering stage. Its main function is simply to speed up the soldering process, by heating assembly and components so that a smaller exposure time is required at the solder wave. Soldering cannot be carried out until all metallic parts of a joint are at or above melting-point of solder — where this heat comes from is irrelevant to the overall process, but is best applied as a preheating stage.

Preheating has a number of secondary functions too:

- it dries the flux — evaporating away solvents in the flux, reducing spattering of the flux in the solder wave
- it activates the flux — raising flux temperature to its activated state
- it reduces thermal shock — by slowly (comparatively) raising the board and components' temperatures (both top and bottom) to between 80° to 130°C, thermal shock when the assembly moves over the solder wave is greatly reduced. Thermal shock can have two effects. First, as its name suggests, damage to components can occur if temperature is raised too quickly. Second, considerable warpage of the board may occur as it passes over the solder wave. Warpage is due to the different temperatures on the top and on the bottom of the board producing different thermal expansions, hence bending the board.

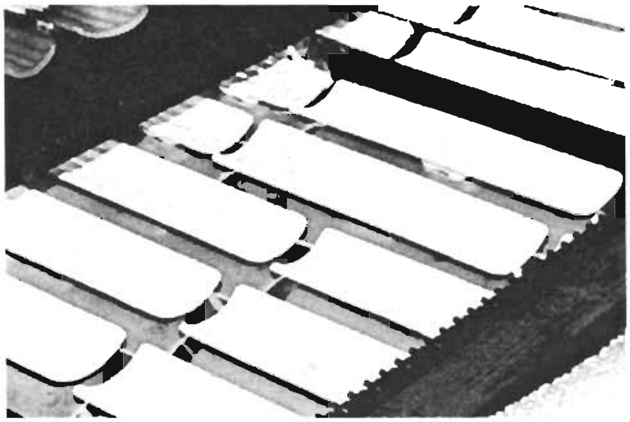


Photo 7.3 *Typical ceramic plate pre-heaters used in soldering machines (DDL Electronics)*

Preheating of different types of boards requires different preheat temperatures and times. Multi-layered boards, particularly many-layered ones, require preheat temperatures at the upper end of the range possible with preheaters and longer times, so that flux in plated through-holes is adequately dried, heated and activated. Preheat temperatures and times for multi-layered boards can be reduced by a significant amount if thought is paid to board design. Figure 7.7 shows a layer within a multi-layered board around a plated through-hole. This is designed to prevent excessive heat flow away from the hole, and so reduce required preheat temperature and time.

Preheating is accomplished, typically, by convection heating, radiation heating, or a combination of both. Whatever heat system is used, maintenance is of importance, as flux dripping from the board will accumulate, and so must be easily removable. Often, for example, on cheaper (cal-rod) preheater systems linings of aluminium foil are used as heat reflectors — these have the dual purpose of allowing easy removal and replacement for this reason.

There are several forms of preheating elements:

- plate preheaters — comprising a thick metal plate with electrical heating elements bolted on the underside, this forms perhaps the simplest methods of preheating. It is quite slow to heat, and equally slow to cool, it is not affected by flux falling on it. It is easy to clean, it is reliable and easy to maintain
- cal-rods — rod heating elements, closely spaced and usually backed by some form of heat reflector. They are quite fast acting and can run at quite high temperatures. They will burn off any dropped flux. Reflectors, how-

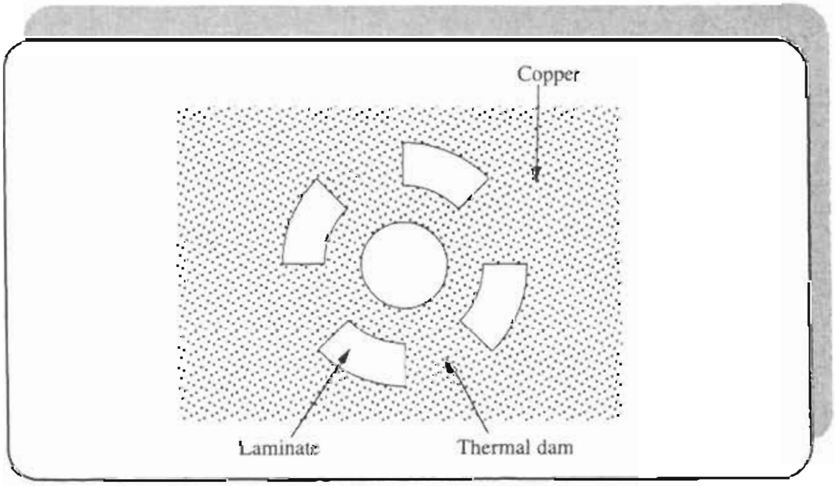


Figure 7.7 *Example of a thermal break, used to prevent excessive heat flow away from a hole*

ever, require cleaning, and are often covered with aluminium kitchen foil which is simply replaced when dirty

- quartz heaters — these are available in two forms; either plates with elements running through slots in the underside or, more popularly, tubes with elements running through. These often have internal reflectors
- hot air — although not particularly efficient as heaters for electronics assemblies, hot air heaters used to be an option in the 1960s and 1970s. They were used to disperse solvent vapours, thus preventing accumulation which could cause fire or explosion. Hot air heaters are usually, therefore, used in conjunction with other forms of preheaters.

Emissivity and wavelength

Aim of preheating is to heat metallic parts of joints, without raising temperature of base laminates too much. Energy radiated by preheaters should therefore be absorbed by metals but, ideally, reflected by the insulating base. In preheaters which emit energy of fairly short wavelengths (say, lamp types of infra-red heaters, which emit energy at wavelengths around 1.5×10^{-6} m), this can never be the case — in fact, uncontrolled, some can burn epoxy-resin glass fibre boards while leaving metal parts relatively cool. Preheaters emitting energy of longer wavelengths (say, cal-rod or plate heaters, at around 5×10^{-6} m) are less likely to cause this.

Control of board temperature

Temperature each assembly reaches immediately before reaching the solder wave should be constant. It is primarily dependent on the preheater temperature and type, and conveyor speed. However, factors such as emissivity of assembly and its constituent components, amount of flux, variations in component mountings, ambient temperature and so on, all have their effects. Generally, these are determined for each different assembly type to be soldered, under microprocessor or personal computer control, and recorded so settings are reproducible. While it is impossible to stipulate a defined temperature for all assemblies, it's possible to generalize. Table 7.2 gives approximate top-of-board temperatures which could be expected after preheat stages for four main assembly types.

Automatic control of assembly temperature by microprocessor-based preheating systems is commonplace on new soldering machines. Figure 7.8 illustrates an example system, using an infra-red temperature detector in a feedback loop, which maintains assembly top-of-board temperature within just a few degrees or less.

Table 7.2 Basic guide to top-of-board temperatures after preheating

Assembly type	*Top-of-board temperature (°C)*
Single-sided	80
Double-sided, through-hole	90 to 100
Multilayered, 4 to 6 layers	100
Double-sided, surface mounted	110

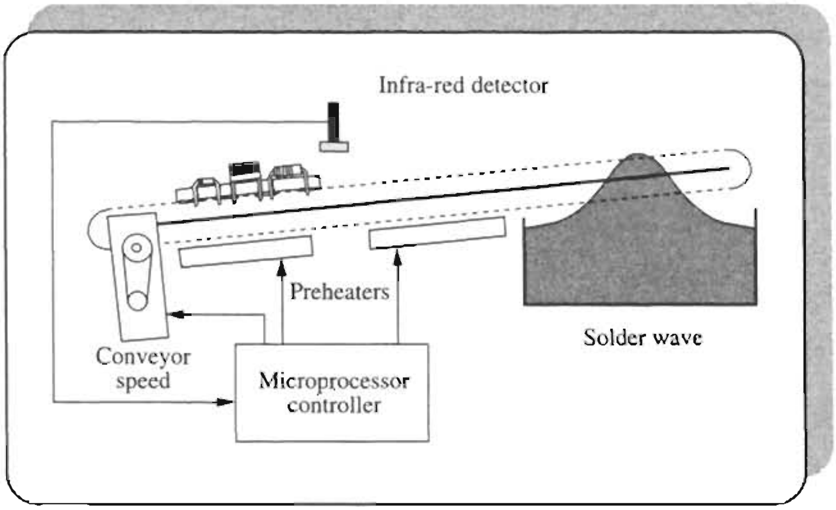


Figure 7.8 *Control of pre-heater stage, to maintain top-of-board temperatures of assemblies constant*

In this system two preheater elements are used. First element provides around 60% or so of the total heat to raise each assembly to required temperature. Assemblies pass over the first element on the conveyor, then pass under an infra-red detector which passes information regarding assembly temperature back to the microprocessor controller. In turn, the microprocessor calculates heat to be generated by the second preheater element to raise each assembly to the required temperature. Typical preheat temperatures experienced by assemblies passing through a soldering machine are illustrated in the graph of Figure 7.9. Such a graph is commonly called a **temperature profile**. Temperature profiles are discussed in detail in Chapter 9, with specific regard to SC soldering processes although of interest also to CS processes.

Note that preheaters should be positioned as close as possible to the solder wave to reduce any cooling of assemblies prior to soldering.

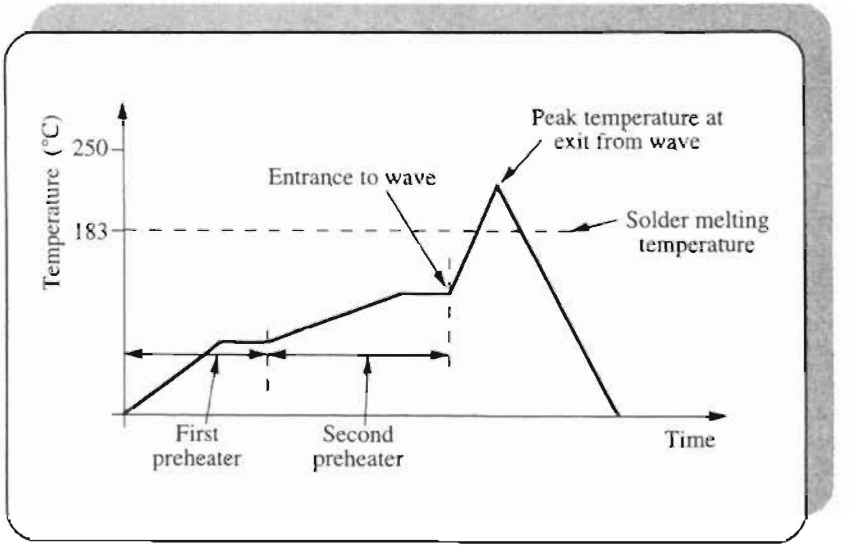


Figure 7.9 *Temperature profile, showing temperatures experienced by assemblies as they pass through a soldering machine*

Solder pots and pumps

Solder in a soldering machine of any CS soldering process is held in a container known as a **solder pot**. These must withstand high temperatures associated with molten solder — typically 230° to 260°C for eutectic or near-eutectic solder alloys, but possibly as high as 370°C or so for high lead content alloys. Solder pots must be unaffected by the solder itself, as well as being unaffected by flux or any flux residues. Solder is extremely heavy, so solder pots must be able to withstand shear bulk and weight. This is especially important when large solder pots are used. They must not bow or bend with solder weight, or warp with high temperature.

Many materials are attacked or affected by solder or flux so resultant materials which *can* be used are limited. Generally, stainless steel or cast iron are used, though some smaller soldering machines have a mild steel solder pot — however this normally requires a coating to prevent corrosion and wetting, renewable at approximately yearly intervals. Some cast iron pots have a resistant metal included in the casting alloy, to prevent wetting with the solder.

With all solder pots, though particularly mild steel, a short run-in period is advised before fully acceptable soldering is obtained. During this period pot materials build up thin oxide layers which will prevent further attack from solder. Until this is so there may be a greater than acceptable dross formation.

Two solder pot designs are common. In one, solder is pumped to a nozzle through a channel, usually an integral part of nozzle and pump arrangement. Its advantage is easy cleaning, as the whole unit is removable. On the other hand, unless the unit is very large, solder flow is not great nor is it smooth.

In the second, the solder pot is divided into two distinct sections. A pump pressurizes the lower section, forcing solder up through a nozzle. It is more difficult to clean than the previous design, but solder flow is greater. This allows large, smooth waves to be developed, which is a distinct advantage.

Solder pot heaters

Heaters used in solder pots are usually electric (in fact, no other heating methods are known to the authors), although there is no reason why other methods can't be used.

Heaters are connected to solder pots in three main ways:

- bolted on externally
- as immersion heaters, protruding directly into the solder
- positioned in internal tubes mounted into the solder pot.

Little difference in performance exists between methods. Instead, choice usually revolves around how easy they make solder pot cleaning, or how easy they are to maintain.

For instance, while external heaters allow easy cleaning of solder pots, they are often difficult to replace. Immersion heater types are usually easy to replace and leave a clear pot for cleaning, but if they fail with solid solder in place they are difficult to remove. Heaters positioned in internal tubes are easy to remove, but leave a pot which may be difficult to clean.

Solder pumps

Usually, a simple centrifugal impeller is used to pump the solder, as shown in Figure 7.10. Molten solder is somewhat inhospitable to bearings, and this method keeps all bearings above. Bearings adjacent to the solder surface are usually of graphite.

Typically, a belt drive is used to link impeller to motor, and an electric motor is most common although air motors are sometimes used. Drive method, though, has no effect on system performance, as long as speed is controllable and constant in operation.

Solder wave height is controlled in two main ways:

- adjustment of impeller position in the pumping chamber
- adjustment of pump speed.

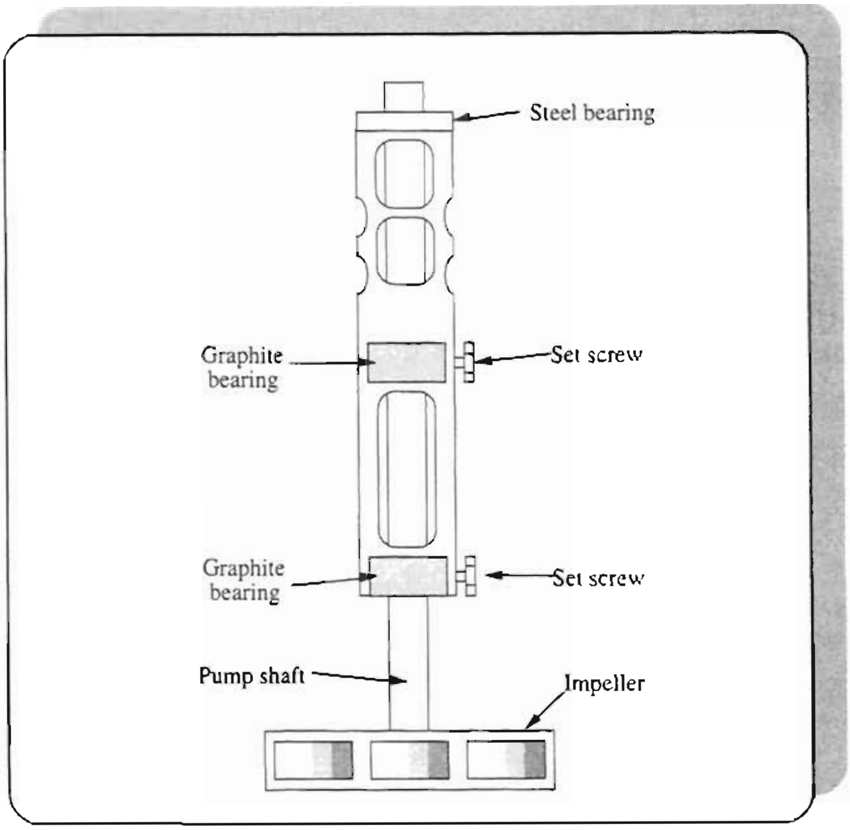


Figure 7.10 *Centrifugal impeller, used to pump solder in a typical wave soldering machine*

These are sometimes combined, with impeller position used as a coarse setting, and pump speed as fine adjustment.

Soldering

In principle, at least, assemblies are simply moved over a wave of molten solder, such that solder heat performs a number of functions. It:

- raises the area to be soldered to soldering temperature
- completes activation of the flux (started in the preheating stage)
- causes component leads or terminals, and copper track lands to be wetted by the solder.

This creates a few significant criteria which have to be considered. First, different component types have different requirements from a solder wave. A relatively smooth wave is sufficient to solder all through-hole components. Further a smooth exit between wave and assembly is essential to ensure removal of excess solder. This, in turn, ensures greatest reduction of solder bridges between closely situated components and copper tracks — of vital importance when soldering miniaturized assemblies such as surface mounted or mixed through-hole and surface mounted component assemblies.

On the other hand, closely situated surface mounted component joints are not always wetted properly in the first place by a smooth wave. In effect, a smooth wave can be diverted around some joints, if they are in the *shadow* of adjacent components or, simply, if a component joint is in the shadow of the component itself. Figure 7.11 shows how this can happen, where a component's solder wave shadow prevents a wave wetting a joint. Good surface mount assembly layout design, which takes this into account and defines component positions such that shadowing is greatly reduced, can help here. With smaller and smaller surface mounted components, though, and greater and greater miniaturization of surface mounted assemblies, together with more and more use of mixed assemblies (with through-hole *and* surface mounted components), it is often desirable to have a more turbulent wave in the first place.

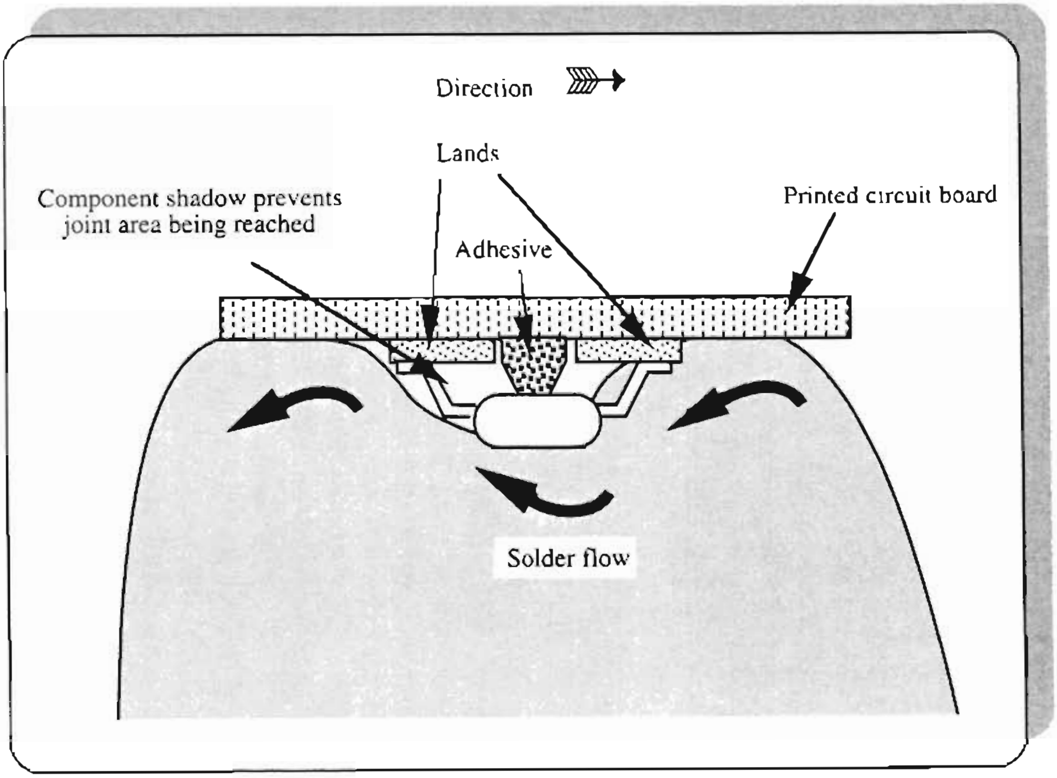


Figure 7.11 *Shadow of component prevents solder wave reaching the component's own land*

For a single soldering machine wave to be able to solder all types of assembly, and to achieve sound soldered joints throughout, it is obvious that considerable effort has to be made to get the right wave design.

Second, it takes time to do all of this. How *much* time depends on individual assemblies and their thermal attributes. To understand this it helps to consider a basic joint. Figure 7.12 (a reprint of Figure 3.10) shows a plated through-hole joint, as it is soldered. Figure 7.12 shows the situation as the joint first encounters a molten solder wave. Here, solder simply engulfs the joint area. The joint is not at soldering temperature, so solder does not yet wet the various metal surfaces.

In Figure 7.12b, lower parts of the joint have reached solder temperature, so solder begins to wet it and wick upwards through the plated hole.

A short time later, represented by Figure 7.12c, the plated through-hole joint is complete. Temperature at the top of the joint is at soldering temperature, solder has risen even further up the through-hole to form a good top fillet.

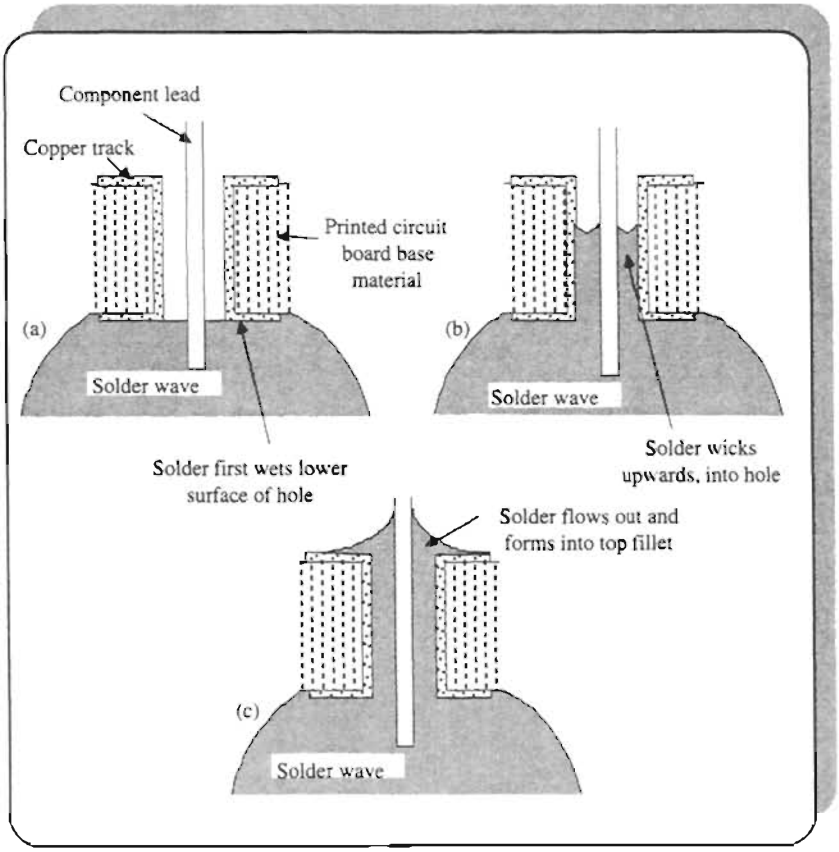


Figure 7.12 *Illustrating the fact that it takes time for each joint to be soldered (a) as an assembly first meets the solder wave (b) after a short time solder begins to wick up the through-hole (c) after further time the top fillet is completed*

All this illustrates what is known as the **critical contact time** for soldering to take place. It is the minimum time a joint must be in contact with the solder wave to ensure a good joint. As we've seen, it varies primarily according to joint type. However, two other factors influence it greatly:

- solder temperature — the hotter the solder wave, the faster the joint rises to soldering temperature
- printed circuit board type — different printed circuit board base materials and constructions have different thermal characteristics
- joint temperature prior to contact with the solder wave — the reason why preheating assemblies can greatly increase soldering speed.

Generally, this leads us on to what is called the **optimum contact time** of an assembly. This is the total time which an assembly remains in contact with the solder wave while all joints become fully wet and completely soldered. Naturally, this depends on what joint types exist on the assembly and must be *at least as long as the longest individual critical contact time.* Generally, contact times of between two to four seconds are considered ideal.

Working backwards, contact time can give us the required conveyor speed and wave dimensions. Table 7.3 lists conveyor speeds and contact widths of wave soldering machines. A suitable optimum choice can be found by taking the longest individual critical contact time of any joint on the assembly and locating the nearest time in the table. Then, conveyor speed and contact width are extrapolated.

Table 7.3 Selection of conveyor speed and contact width as a function of contact time, for wave soldering machines

Conveyor speed (cm min^{-1})	*Contact widths between assembly and solder (cm)*							
	2	2.5	4	5	6	7.5	8	10
15	8	10	16	20	24	30	32	40
30	4	5	8	10	12	15	16	20
60	–	2.5	4	5	6	7.5	8	10
90	1.32	–	2.64	3.28	3.96	4.92	5.28	6.6
120	1	1.75	–	2.5	3	3.75	4	5
150	0.8	1	1.6	–	2.4	3	3.2	4
180	0.8	0.82	1.32	1.33	–	2.46	2.64	3.2
210	0.57	0.71	1.14	1.43	1.71	–	2.79	2.36
240	0.5	0.63	1	1.26	1.5	1.89	–	2.5
270	0.46	0.55	0.89	1.1	1.36	1.67	1.78	–

Wave shape

Generally, all criteria for every assembly variant and their widely varying soldering requirements can be met and fulfilled by CS soldering processes, simply by using different wave shapes. Topic of wave shape is therefore the most important consideration in choice and use of wave soldering machines.

Solder waves are produced as molten solder is forced up through an ejection chamber, and out through a nozzle, as illustrated in Figure 7.13. After reaching a wave crest, solder falls back into the pot down one or both sides of the chamber.

To perform all soldering functions, for every type of assembly, and for as many types of components as possible, requires all assembly and component variations be taken into account. Thus, different wave soldering machines are available for different applications, varying essentially in waveshape. Waveshapes are dictated by shape of ejection chamber and nozzle.

Of particular importance to waveshape and resultant soldering performance are the following criteria:

- **exit angle** — the relative angle at which an assembly leaves contact with the solder wave
- wave smoothness — a rough wave is required at the process start ie, the first wave, to ensure all possible joint types are soldered; a smooth wave is required to ensure excess solder is removed at the end of the process

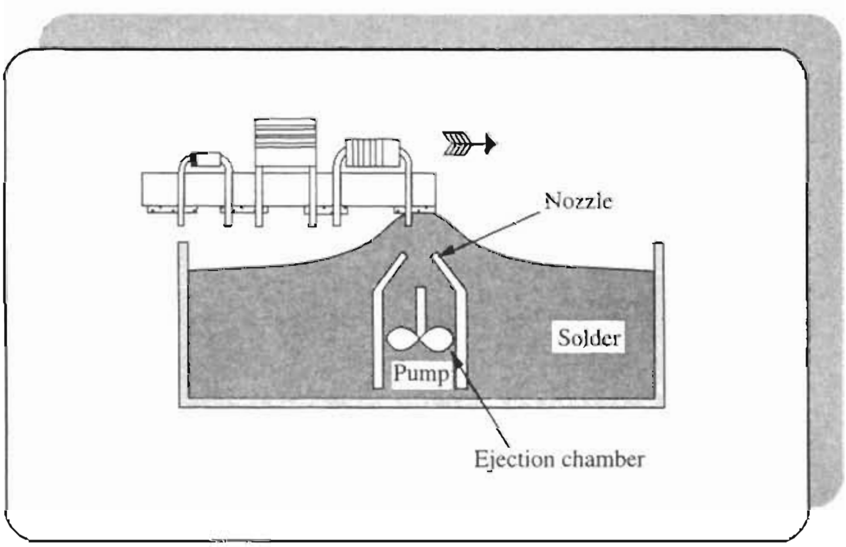


Figure 7.13 *Basic principle of wave soldering, in which molten solder is pumped up and out of an ejection chamber and nozzle*

- relative speeds of solder and assembly
- **contact area** — the area of contact between assembly and wave.

With the correct exit angle, rough wave entrance, smooth wave exit, identical assembly and solder speeds at the process end, and maximum contact area, best results are usually obtained — that is, best removal of excess solder, greatest reduction of solder bridges between closely situated components and copper tracks, and least shadowing.

Contact area effectively defines soldering time, and the larger the contact area, the faster the soldering which can take place. This is simply because an assembly has a defined contact time (explained earlier) with the solder which must be maintained to ensure all joints are properly made. With a large contact area, assemblies may be moved speedily over the solder while contact time is still guaranteed. If contact area is small, on the other hand, assemblies must pass over the solder comparatively slowly to ensure correct contact time.

Symmetrical wave

This is the basic waveshape and, chronologically, the oldest. In effect a **symmetrical wave**, also known as a **basic double-sided wave**, is formed by solder pumped out of a plain nozzle, as shown in Figure 7.14. It has a contact area with assemblies passing overhead which is, relatively, small and so requires a slow soldering speed, to maintain minimum solder contact times.

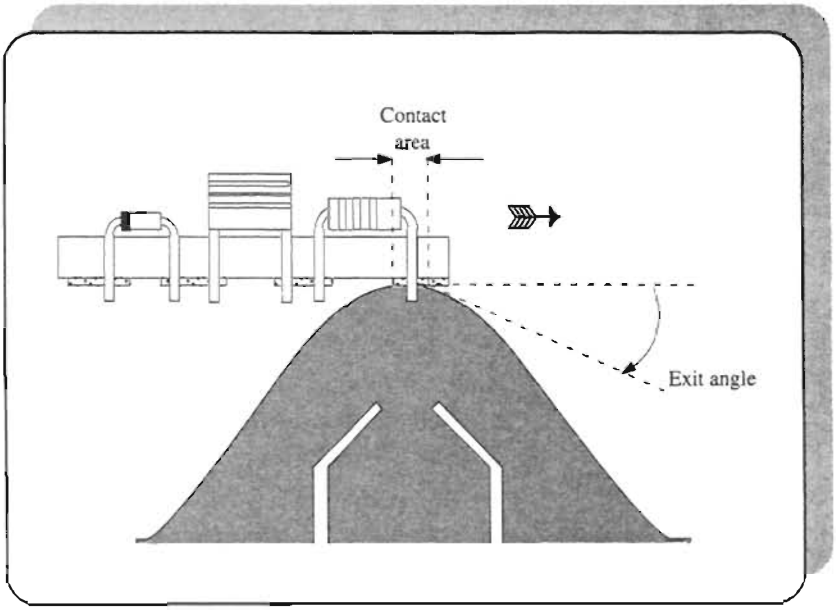


Figure 7.14 *Symmetrical, or basic double-sided solder wave*

It suffers also from production of many solder bridges between copper tracks on assemblies, because of the relatively large exit angle.

By adjusting conveyor angle so assemblies impinge at an upward slant, time in the wave is shortened, the relative exit angle where the assembly leaves the solder wave is reduced, and the contact area is increased (Figure 7.15). Assemblies also leave the wave close to the wave peak: where solder is moving much slower and more smoothly.

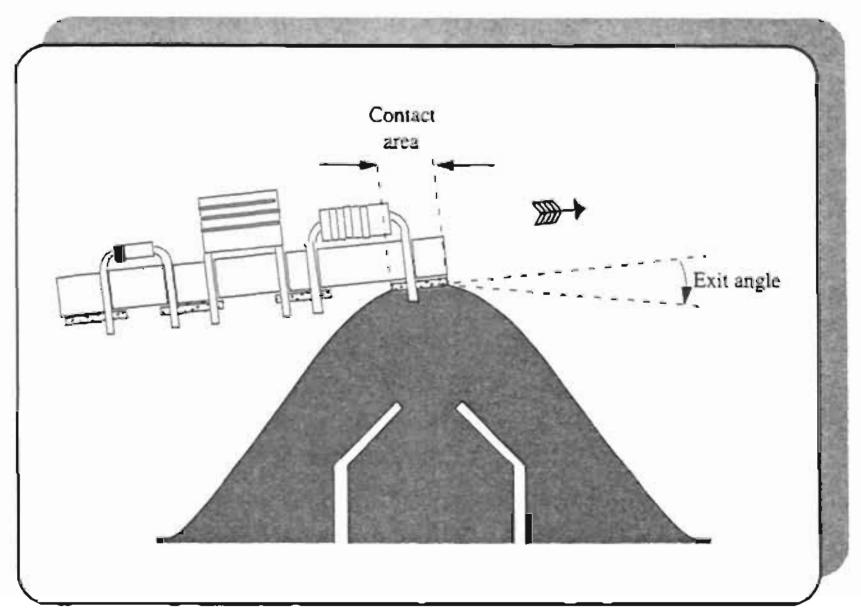


Figure 7.15 *Assemblies impinge on the solder wave at an angle, giving a decreased exit angle and greater contact area*

Symmetrical waves are further improved by making them wider with a consequent increase in contact area so soldering times are reduced and, in some cases, adjustable support plates (Figure 7.16). Such wide waves are often called **supported waves**, **extended waves**, or **adjustable wide waves**.

Angled conveyors make it apparent that exit sides of symmetrical waves are superfluous, which leads us on to second main type of waves — **asymmetrical waves**, also known as **single-sided waves** (Figure 7.17).

By combining an asymmetrical wave with an extended form, the principle of just about the ultimate waveshape is made (Figure 7.18). **Supported asymmetrical waves**, often called **lambda waves**, have very large contact areas which means soldering may be carried out very quickly — at speeds up to about 4 to 5 ms^{-1}. Further, they have well defined and controllable solder speeds at their exit points, so provide the foundation for almost perfect soldering.

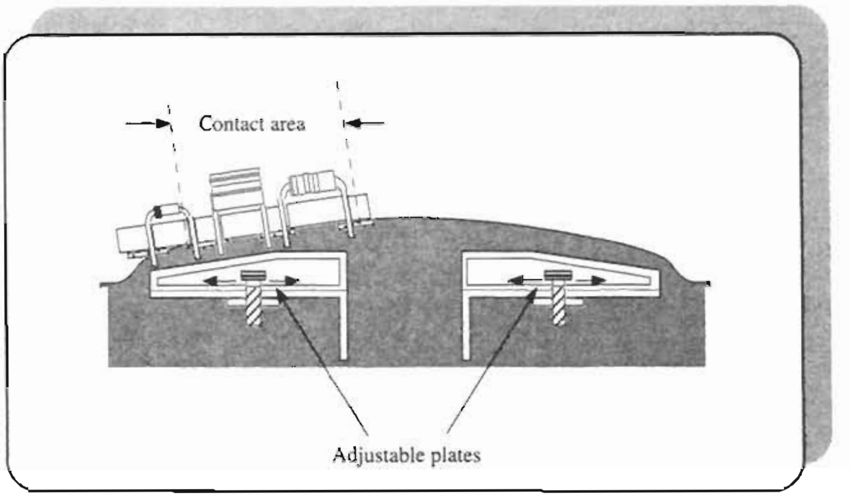


Figure 7.16 *Supported symmetrical wave*

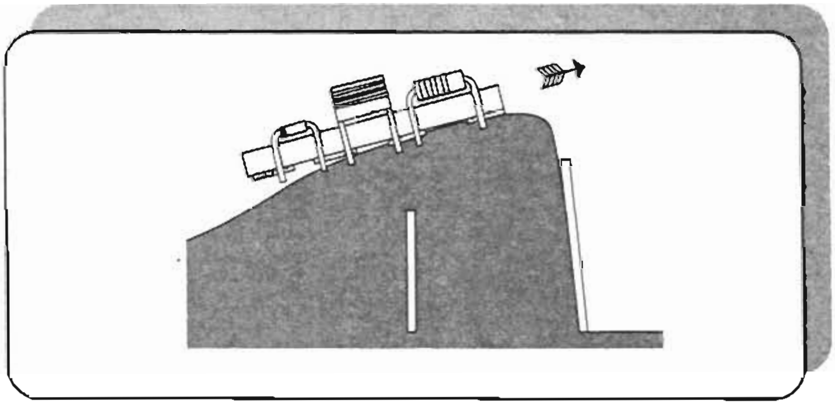


Figure 7.17 *Basic asymmetrical, or single-sided wave*

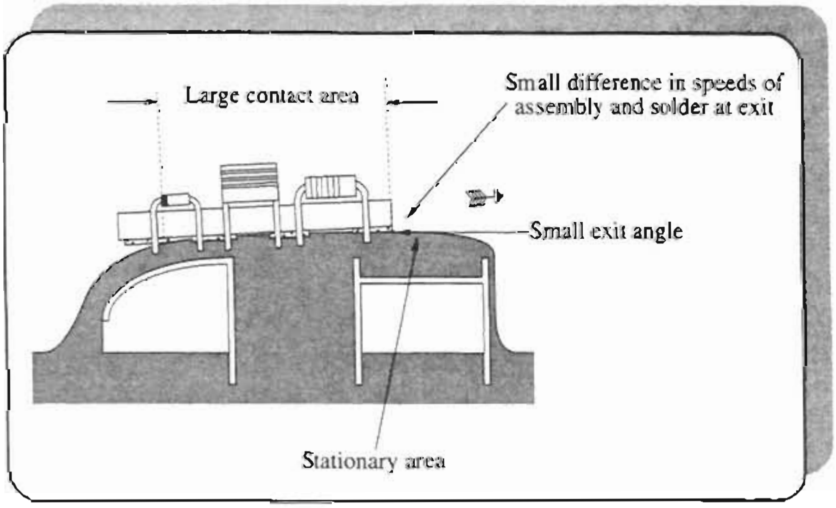


Figure 7.18 *Supported asymmetrical or lambda wave*

In the practical supported asymmetrical wave, shown in use in Figure 7.19, solder is pumped up an ever-widening nozzle — which reduces flow velocity greatly, producing an even and smooth wave surface, slowly flowing over the shaped support plate on the left. An adjustable dross chute channels solder under the surface to reduce dross formation. Around 98% of the solder flows in this direction.

On the exit side an adjustable exit wing, or dam, allows only a tiny amount of solder to flow into the second adjustable dross chute. Flow is so small that solder surface tension prevents flow at all when the wave is started — in other words, solder is stationary over the exit zone of the wave. First assembly across the wave breaks this resistance, starting flow.

Main area of interest, however, is the exit zone — as assemblies are moved over it they compress the wave surface to form a flow over the edge of the adjustable wing. Note it is the assembly which pushes solder over the wing: consequently solder flow speed is identical to assembly speed as they separate.

Solder surface in the exit zone must be level, as it is stationary. Thus exit angle between assembly and solder is determined primarily by conveyor angle. However, one factor which affects final quality is the assembly itself. Large assemblies, particularly carrying heavy components, may bend, so exit angle cannot be accurately specified unless such assemblies are adequately supported.

Three criteria of good wave soldering: control over exit angle, large contact area, and identical solder and assembly speeds on exit, are catered for in the supported asymmetrical wave. However, shadowing of some surface mounted component joints can still occur, due to its smooth wave.

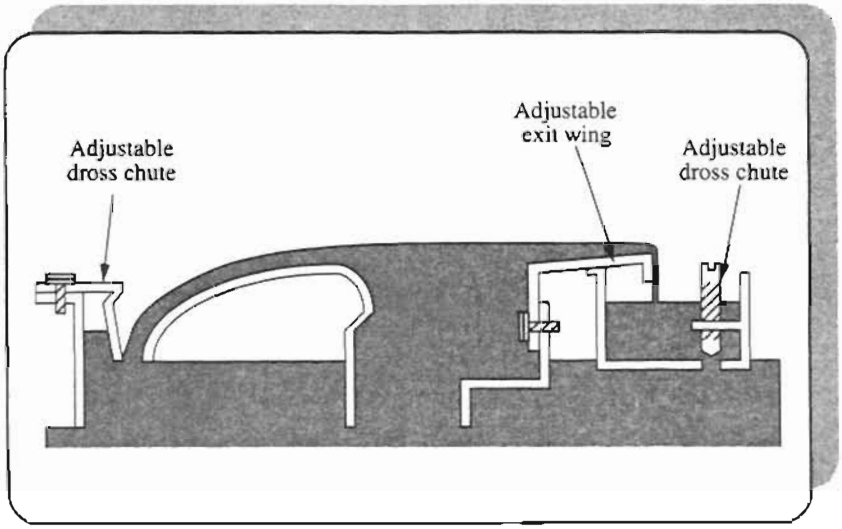


Figure 7.19 *A typical practical supported asymmetrical wave*

There are four main ways waves can be adapted to successfully solder surface mounted components:

- multi-wave soldering — by splitting criteria functions up into two or more parts, the problem can be side-stepped. Figure 7.20 shows the principle of a **double-wave** soldering principle, in which a first, turbulent wave is used to ensure all joints are wetted, followed by a second, calm supported asymmetrical wave, to remove excess solder and eliminate solder bridges. Triple-wave soldering machines may similarly be used

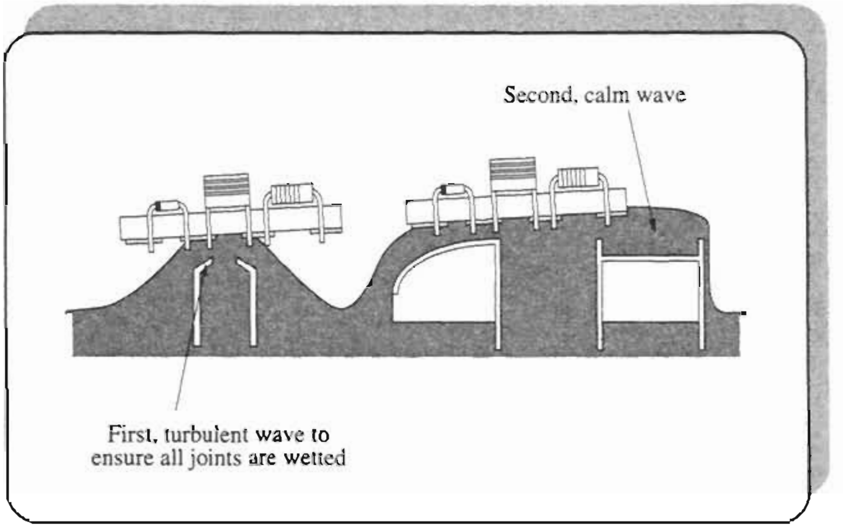


Figure 7.20 *Principle of a basic double-wave soldering machine*

- hot-air knife — a moderately turbulent wave can be followed by a hot-air knife, blowing extremely hot air across the underside of the assembly immediately after soldering (Figure 7.21). Force of the air helps to remove excess solder, thus reducing solder bridges [Scott, 1991 #17]
- using a pumped, hollow wave — instead of pumping a large mass of solder up through a wide nozzle, it is possible to eject a much lower mass from a small nozzle, so that it forms a hollow peak over which the assembly is conveyed (Figure 7.22). Such an arrangement is commonly called a **jet wave**, and the process is often called **jet soldering**. Typically an electrodynamic solder pump is used which has no moving mechanical parts. As solder flows over the wave peak underneath an assembly, the Bernoulli effect pulls the assembly down onto the wave. Further, the Bernoulli effect ensures the solder closely follows the outlines of small components and joints as it flows. Due to its operation, considerable solder oxidation takes place in a basic jet soldering process, so in most practical arrangements oil

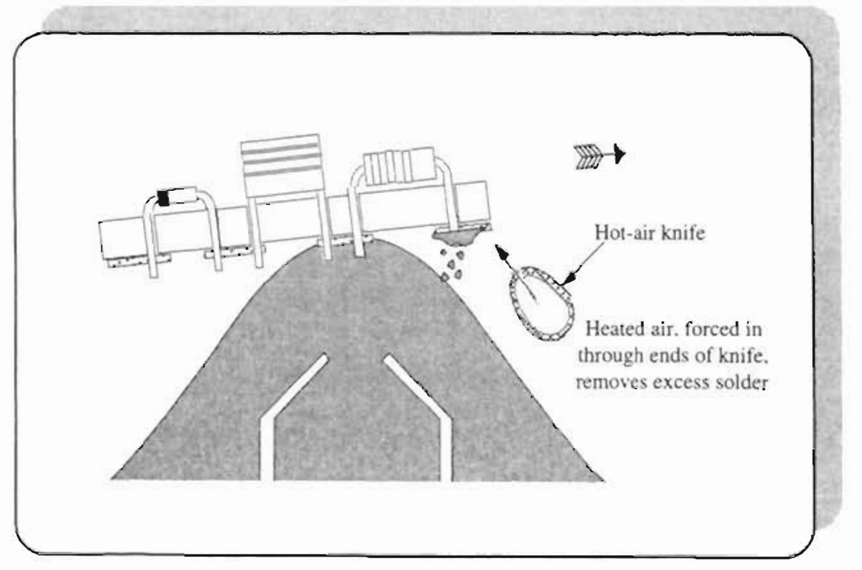


Figure 7.21 *Using a hot-air knife after a solder wave, to remove excess solder*

is added as a covering blanket, keeping air from the solder surface and reducing dross levels greatly

- using an electromagnetic transducer to impart controlled vibrations to a supported asymmetrical wave. This oscillatory wave action is commonly known as an **omega wave**.

In a typical oscillatory supported asymmetrical wave the electromagnetic transducer controls an element located in the nozzle of the solder ejection chamber (Figure 7.23). The element oscillates in a direction parallel to printed circuit board travel, at a frequency around 50 or 60 Hz. Amount of vibration is controlled for optimum performance by adjusting the oscillating element's amplitude.

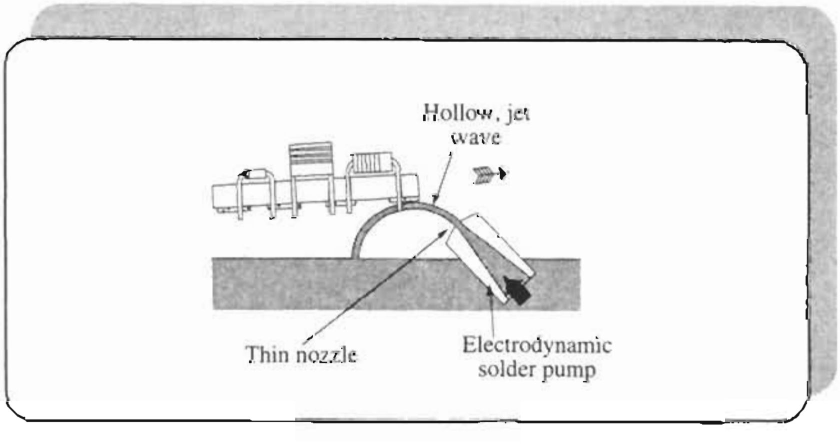


Figure 7.22 *Showing the principle of jet soldering, where a jet wave is directed at the underside of an assembly*

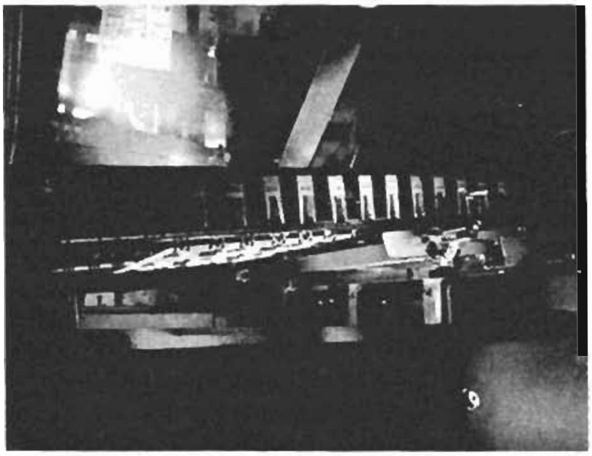


Photo 7.4 *A hot-air knife fitted to a wave soldering machine. The solder bath has been retracted to show a surface mounted printed circuit board about to pass over the knife (Speedline Electrovert)*

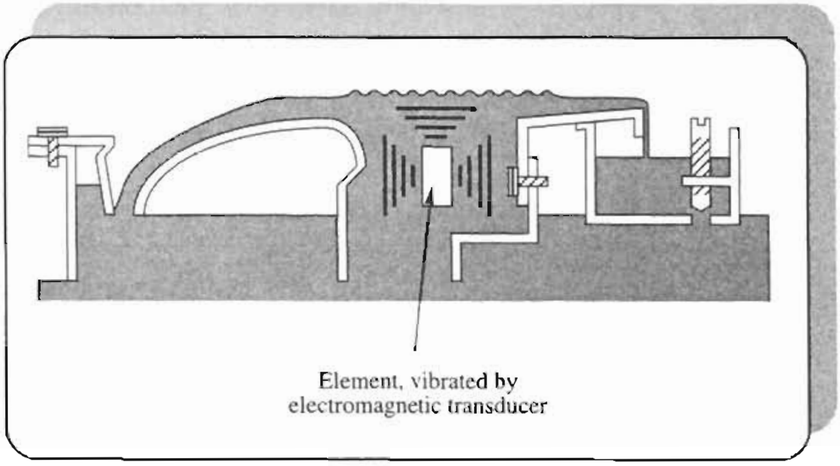


Figure 7.23 *Principle of the oscillatory supported asymmetrical or omega wave*

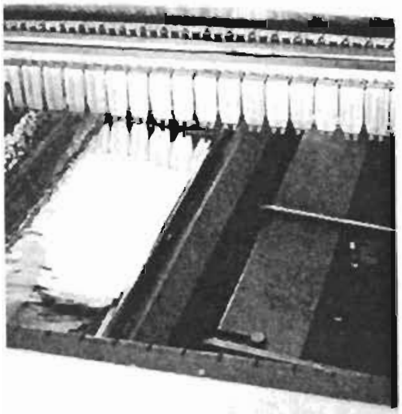


Photo 7.5 *Oscillatory action, supported asymmetrical or omega wave soldering machine, showing molten solder flowing (Speedline Electrovert)*

Inert atmosphere soldering

By encasing the wave soldering machine in an oxygen-free atmosphere (using an inert gas such as nitrogen in a tunnel built around the solder wave), several benefits are gained. First, no oxygen means no oxides formed on the surface of the molten solder. This in turn means a great reduction in dross formation, indeed it is reported [Robert Crothers, 1991 #10] that dross removal is not required in such a process during production. Naturally, this means solder consumption is reduced — to an extent which almost pays for equipment to provide the oxygen-free atmosphere. There are further benefits in that maintenance of solder pots is greatly reduced — from once every 40 hours, to around once every 1400.

An inert atmosphere prevents oxides from reforming on the copper track surface, once removed by flux. This ensures a high level of joint solderability and considerably fewer defects [Robert Crothers, 1991 #10], [Walsh, 1991 #12], [Schouten, 1991 #14].

An almost total lack of oxidization on both copper and solder surfaces means solderability of circuit track is at a premium, with resultant improved solder joint formation. Plated through-hole wicking from bottom to top surfaces of assemblies is improved, and a general reduction in joint shadowing are just two typical advantages [Robert Crothers, 1991 #10].

Because of all this fluxes with extremely low solids contents can be used, which simply prepare the track surfaces by removing oxides. After track preparation these materials are no longer required — a fact which, coupled with the process misnomer, has led to a presumption that absolutely no residues remain after soldering. However, this is not the case. Small amounts of residues always exist, as long as any chemical at all is used for copper preparation [Elliott, 1991 #11].

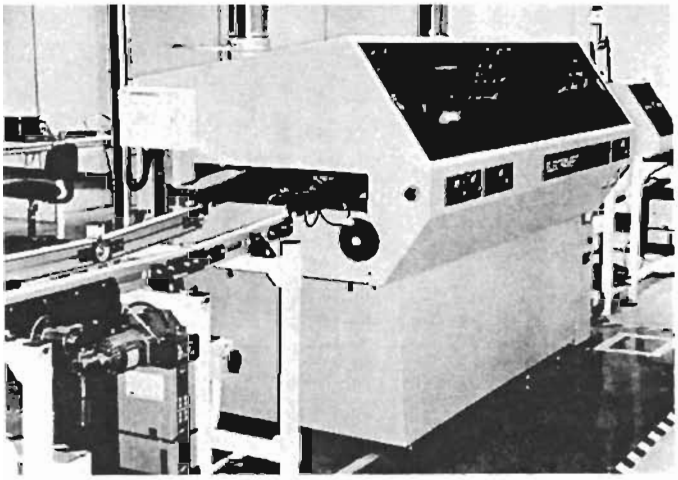


Photo 7.6 *A modern medium-volume wave soldering system — AstraPak, at Pace Microtechnology (Speedline Electrovert)*

Fortunately these residue amounts can be minute, and low enough to mean assemblies meet many worldwide standards which call for extremely low residue amounts — even without assembly cleaning. In effect, inert atmosphere wavesoldering can help to eliminate the need to clean assemblies at all, in many applications. This has benefits environmentally and in cost reduction to the manufacturer.

While it is rumoured totally fluxless cleaning (without low-solids fluxes) can be obtained with inert atmosphere wave soldering, the only way this truly seems to be obtainable is with hot-air levelled printed circuit boards [Elliott, 1991 #11] — simply because hot-air levelled boards can give a guarantee of solderability unobtainable with other techniques. While assemblies using such printed circuit boards *can* be soldered without low-solids flux or preparation fluid, it has to be remembered the bare boards must have been originally coated in an environment using at least those materials. Further, because at least *some* components on any assembly have poor solderability, a flux is most likely to be needed in practice.

How inert is inert?

Atmospheres within inert atmosphere wave soldering machines must be well controlled, in order that oxides don't form on metal surfaces. Oxygen levels below 15 parts per million ensure no oxide layer is formed on the surface of the solder wave. If the atmosphere around solder has an oxygen content above this, solder oxides are present as a permanent skin on the surface of the solder, under which the liquid solder flows [Schouten, 1991 #14]. Figure 7.24 is a graph which shows how a solder oxide film occurs at oxygen levels of 15 parts per million and above, but not below.

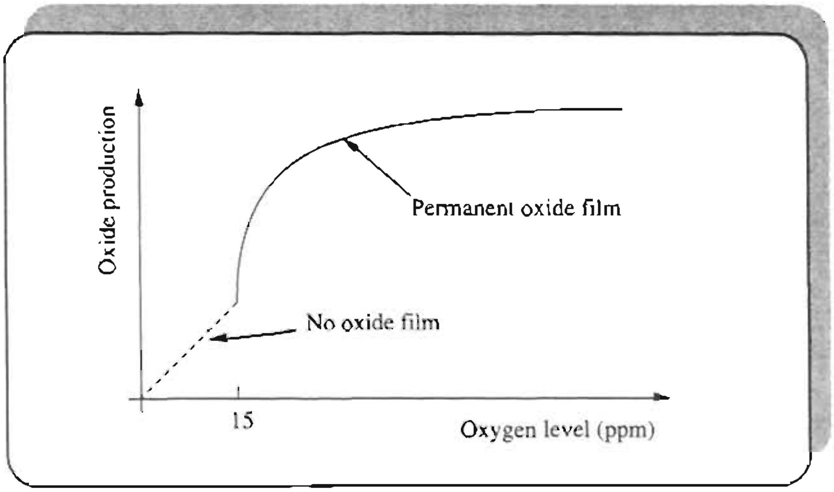


Figure 7.24 *Solder oxide film on the surface of molten solder only occurs when in an atmosphere with more than 15 ppm of oxygen*

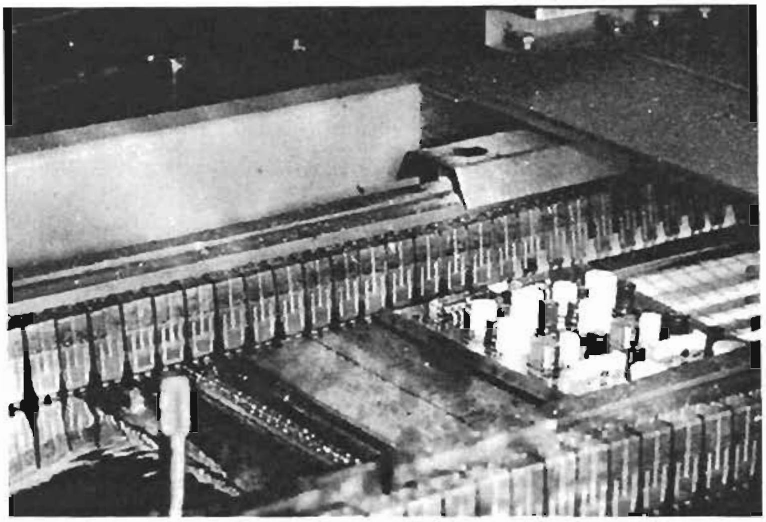


Photo 7.7 *Assembly moving from right to left, has just been pre-heated and is about to be soldered in a wave soldering machine (Motorola European Cellular Infrastructure Division)*

Consequently, at oxygen levels above 15 parts per million, solderability of joints is only possible when copper surfaces are prepared *and* solder oxide is removed, thus conventional fluxes are required albeit at relatively low strengths. Below this level preparation of copper surfaces is the only task to ensure solderability, so conventional fluxes are not a necessity and low-solids fluxes are perfectly suitable.

Maintenance of such a low oxygen content requires careful design. By purging the enclosed atmosphere of air it is possible to exclude oxygen at the commencement of a process, but each assembly entering the wave soldering machine brings with it minute amounts of air, trapped underneath components. This air comes free during soldering, and can cause an oxygen build-up with time. There are four solutions to this:

- use a more conventional flux
- dope the inert atmosphere with an acid (typically formic acid is used in nitrogen inert atmosphere soldering machines) — which reduces oxides to removable solid acid salts. This entails care in acid handling
- use a totally closed system with entrance and exit vacuum locks — so assemblies pass through vacuums up to 5 mBar, which remove trapped air prior to soldering
- use nitrogen diffusers located close to the solder wave. Nitrogen is then pumped into the system, forcing oxygen away from the solder wave to the machine's entry and exit points, where an extraction system extracts fumes, oxygen and excess nitrogen.

Higher oxygen levels (say 200 parts per million) may still be useful, however, to maintain a low dross formation. This is necessary in some applications.

Soldering process monitoring

Increasingly, computer control of soldering processes is becoming the norm. This is generally in one of two ways:

- soldering machines have computers fitted internally, to monitor and control the equipment
- separate monitoring equipment is used, which traverses the soldering machine as a standard printed circuit board would. The data from the equipment is then used to determine machine parameters.

Many soldering machines are now supplied with computer control. Where processes are automated to the point that printed circuit boards are numbered with a bar code, the computer can set machine parameters according to incoming printed circuit boards. When correctly set up, each board can then achieve optimum machine settings.

Photo 7.8 *An example of computer-controlled CS soldering, the Neupak wave soldering system uses a computer to monitor and control machine parameters. Barcode reading of each incoming printed circuit board ensures that parameters are set for that board by the time it reaches the solder wave (ATF Germany/Electrovert)*

Photo 7.9 *Another example of computer-controlled wave soldering machines, the Electra uses a Microsoft Windows NT computer to control its operation (Speedline Electrovert)*

Soldering machines which are not computer controlled this way can still achieve highly accurate parameter setting if separate monitoring equipment is used. While this is not a real-time measurement — and the machine is only as accurate as the last time the equipment was used — machine parameters can be set with reasonable accuracy.

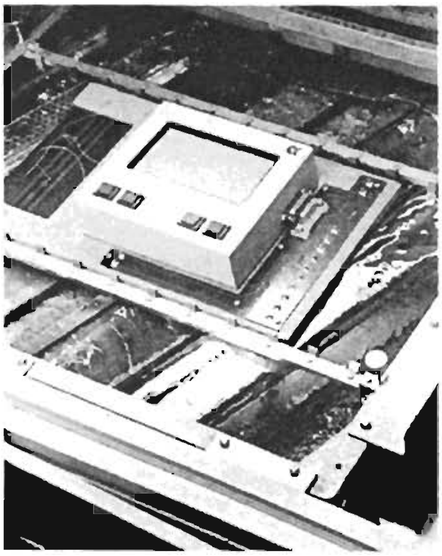


Photo 7.10 *The Alpha Solder Wave Optimiser is a board-sized tool that is passed through a wave soldering machine in general operation. Results of the whole process are recorded within, for later analysis*

Photo 7.11 *The WaveRIDER is a board sized tool, passed through a wave soldering machine in general operation. Process results can then be downloaded from the device to a computer running the associated WaveRIDER software for later analysis*

8 SC soldering processes

In SC soldering processes, the component is placed on the printed circuit board at a later stage than solder and flux. At a later stage still, heat is applied. In a nutshell, then, SC soldering processes involve three distinct stages:

- applying solder and flux as a solder paste
- placing components
- applying heat.

This separation of solder application from the application of heat (both go together in CS soldering processes — and cannot be split because molten solder in a CS process itself supplies the required heat) effectively means that application of solder, in practice, becomes an assembly process rather than a soldering process. Readers are referred to Chapter 6 for a discussion on methods of solder paste application.

Heat application

There are, of course, only three basic ways heat can be transferred and these broadly help us to categorize the various SC processes:

- conduction — hot liquid, hot belt, heated collet
- convection — hot air, hot gas, hot vapour
- radiation — infra-red, laser, light beam.

Processes may, however, be a combination of two or all three heat transfer methods.

Of the various SC soldering processes available, only three (infra-red, hot air convection and hot vapour) are used to any great extent. Figure 8.1 shows all SC soldering processes, as heat transfer types.

These three machine types have been developed to such an extent there is really very little to choose between them. All processes (at least their state-of-the-art variants) are capable of soldering densely-populated printed circuit assemblies to a high level of performance, and with few defects.

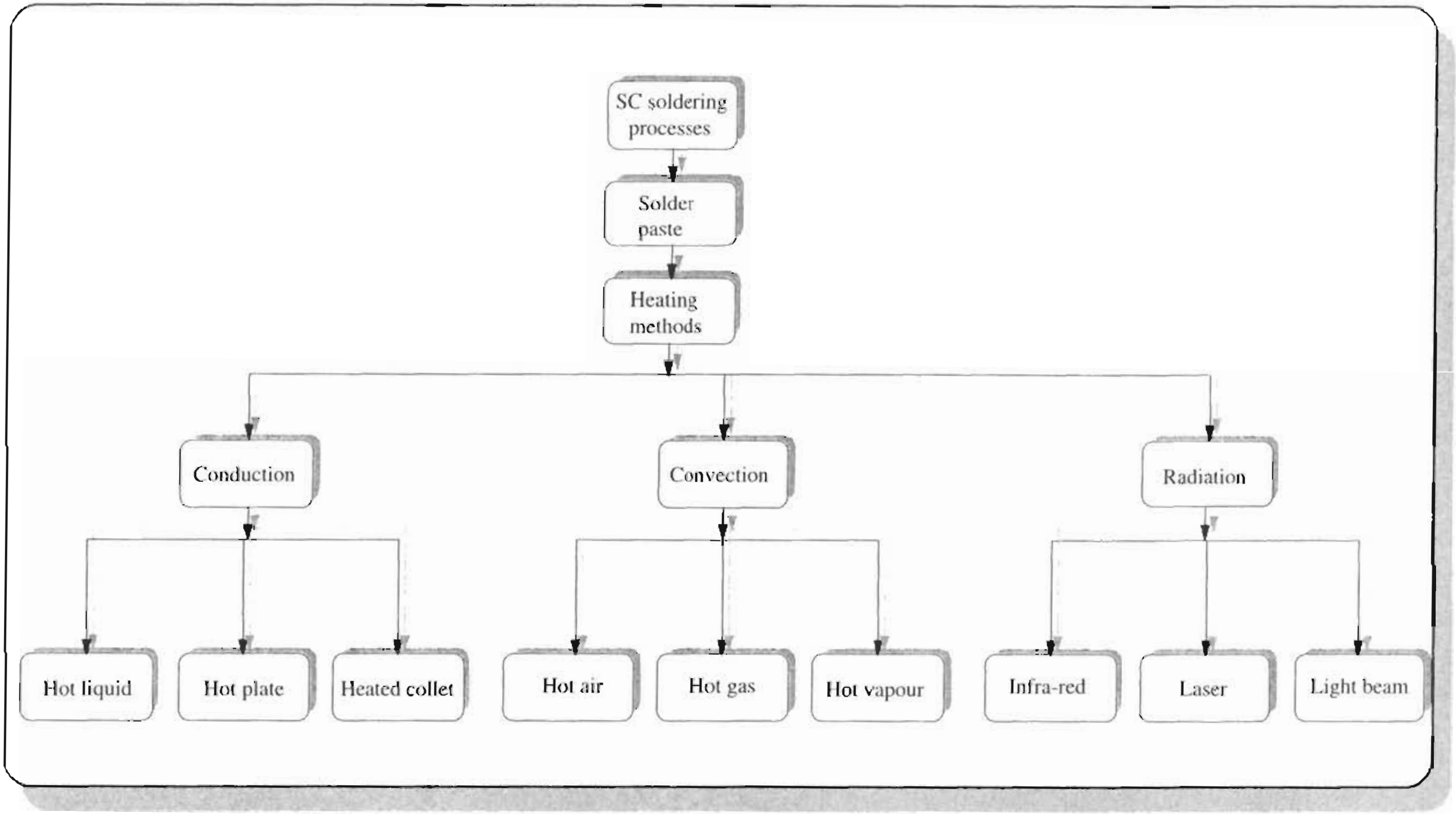


Figure 8.1 *SC soldering processes, listed by method of heat transfer*

Laser soldering is currently in late developmental stages, and shows great promise for specialized SC soldering of surface mounted components. At present it is more costly than infra-red and hot vapour soldering processes, but it may find a niche market for soldering individual components which cannot easily be soldered by other mass means.

Infra-red soldering

Infra-red (IR) soldering processes have developed rapidly in recent years since their first introduction. Main developments of infra-red soldering machine processes with time are:

- focussed lamps — near infra-red — fusing tin/lead electroplate
- diffuse lamps
- diffuse infra-red lamps and secondary reflector/emitters
- diffuse vitreous flat panels — far infra-red (black)
- metal-faced flat black panels — far infra-red — natural convection
- metal-faced panels and interstage recirculated convection
- metal panels with holes for uniform forced convection
- metal panels with holes and zoned forced convection
- metal panels and higher volume zoned forced convection
- metal panels and higher volume zoned forced convection of nitrogen.

From this list it's easy to see what the main trends in infra-red processes have been. Goal of all developments is to produce repeatable results of high quality, under wide variances of load and temperature.

Generally, infra-red soldering machines direct infra-red heat onto the board from above and below, as shown in Figure 8.2. Radiating elements have built-in thermocouples to allow temperature control. Heat transferred onto the assembly and so temperature of the joints to be soldered, however, depends on the materials and shapes of the board and components as well as wavelength of the infra-red radiation. For this reason, in such a basic infra-red machine it is difficult to be sure that all joints reach the same temperature at the same time. The effect of different joint temperatures is known as the **shadow effect** (see later discussion on temperature differentials across an assembly).

Wavelengths of between about 1 to 7 μm are generally used, with those in the range 1 to 2.5 μm classed (for soldering purposes) as short wave radiation, while those above 4 μm are classed as medium or long wave. (Infra-red wavelengths actually range from 0.73 to 1000 μm.) Short wave infra-red radiating elements are, typically, tungsten lamps, while long wave elements are usually panel elements.

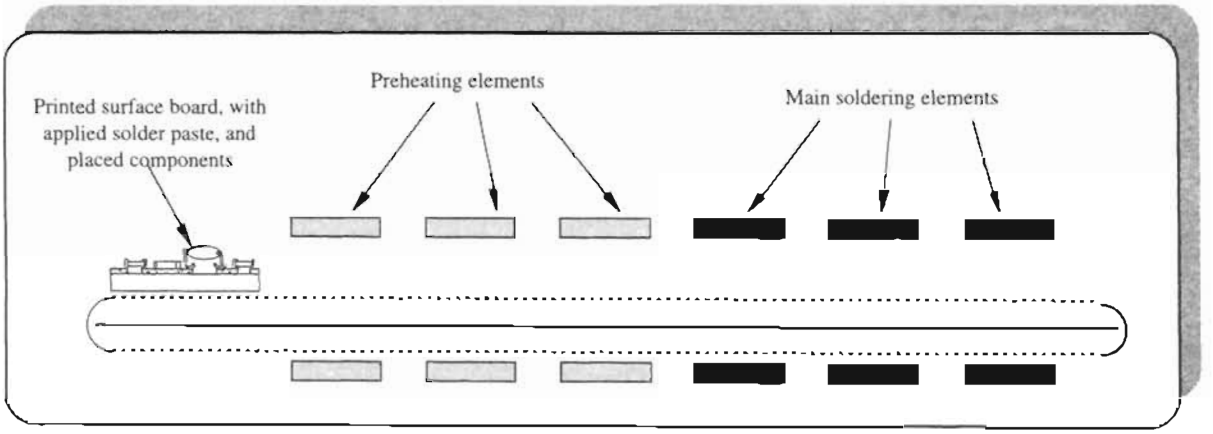


Figure 8.2 *Heating elements in infra-red soldering machines are positioned above and below assemblies*

In operating terms, the shorter the wavelength of the infra-red element the more likely are boards and small components to suffer from overheating. On the other hand, more uniform heating of solder paste is obtained with short wavelengths.

Longer wavelength elements have an advantage in that air around them is heated. This hot air provides heat to assemblies by convection means. If hot air is allowed to aid heating of assemblies naturally the process is known as infra-red radiation with **natural convection heating**. The addition of convection heating to infra-red radiant heat soldering machines tends to give more uniform heating and reduce temperature differences between joints on assemblies.

This principle of using convection heating to reduce joint temperature differentials is extended by forcefully circulating warmed air, to provide **forced convection heating**, illustrated in Figure 8.3. It can be extended further, by forcing air through perforations in each infra-red panel emitter, such that it is distributed evenly over the assembly surface. In this way, high volumes of airflow can be generated at quite low velocities. In general, the higher the volume of forced airflow the smaller the difference between joint temperatures across an assembly (see the later discussion about temperature differentials). A further advantage of forced convection is the lower infra-red emitter temperatures required.

By dividing the infra-red soldering machine into distinct and isolated zones, each of which use forced convection, greater control over assembly joint temperatures is available. Typically, air is taken into a zone from the assembly area, recirculated then diffused through heater elements back to the air intake, as shown in Figure 8.4. This effectively segregates each zone from its neighbours and gives a high degree of temperature isolation and

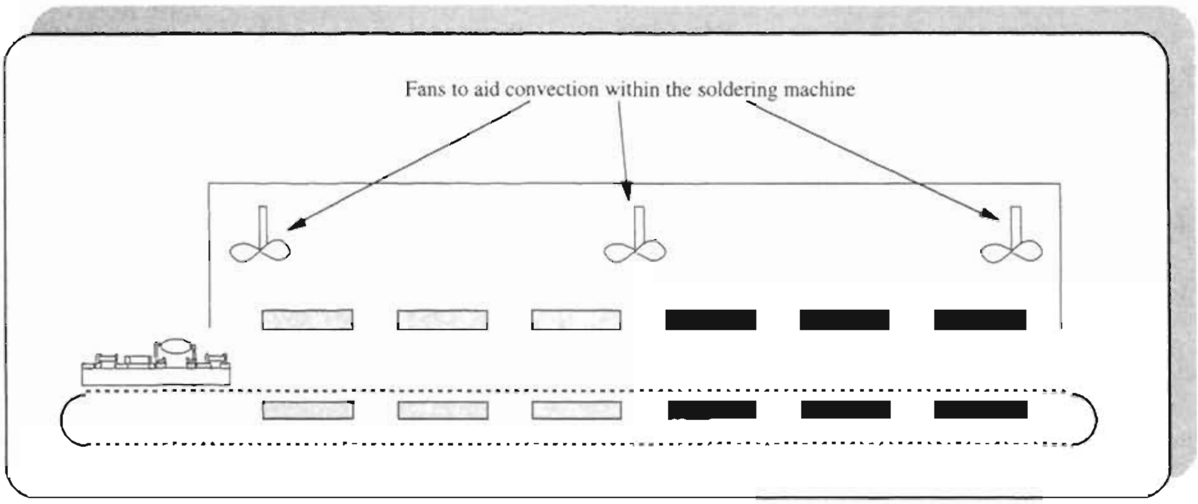


Figure 8.3 *Forced convection infra-red soldering*

controllability. Control of assembly temperature within such a soldering machine is achieved simply by standard computer and electronic closed-loop control principles, and these allow high degrees of accuracy and adjustment.

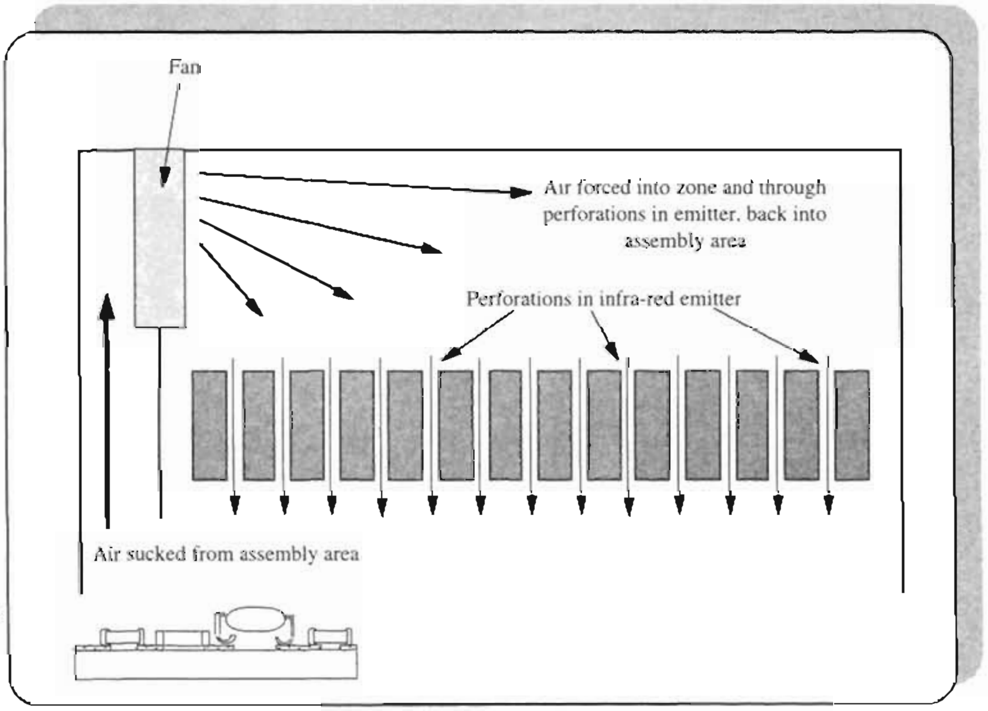


Figure 8.4 *Principle of a typical zoned, forced convection heating element*

A total soldering machine using forced convection zones is illustrated in Figure 8.5. After initial preheat stages an exhaust outlet allows flux volatiles and other products to be extracted from the machine.

Inert atmosphere soldering

Air isn't the only gas which can be used in convection infra-red SC processes. An inert gas, say, nitrogen, can easily be incorporated into the system instead. This provides similar advantages of improvements in solderability to those found in CS soldering processes using inert atmospheres (Chapter 7).

Activated inert gas can also be used, which reduces or even eliminates requirement for separate flux addition.

New solder pastes are being offered specifically for use in inert SC soldering processes. Many more are in active development and will follow shortly.

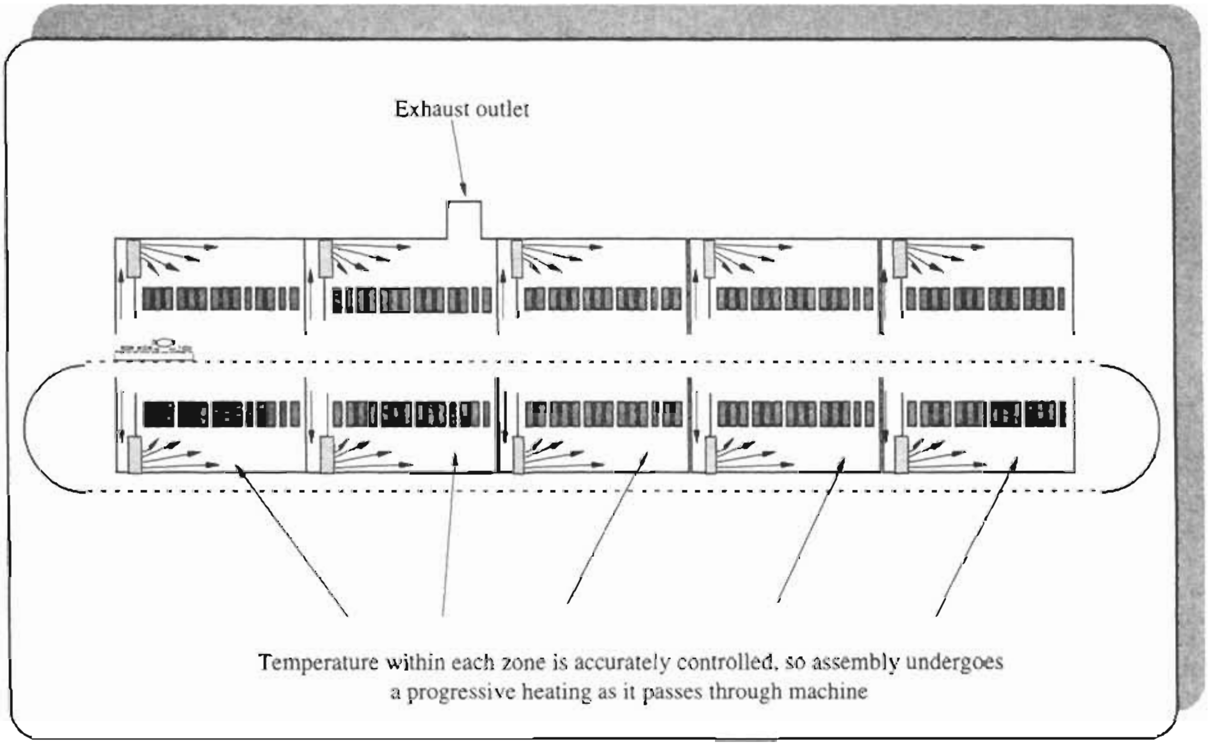


Figure 8.5 *Infra-red soldering using zoned, forced convection*

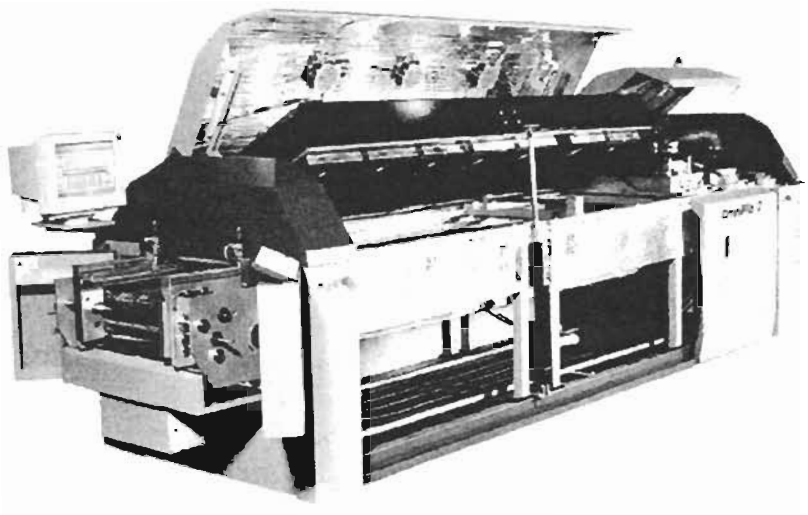


Photo 8.1 *Exploded view of an infra-red SC soldering machine. (Speedline Electrovert)*

Preheating

Sometimes, natural convection and forced convection techniques are used only in preheating stages of an infra-red soldering machine, although they are best used throughout. As all stages use infra-red elements anyway, it's not always possible to define where preheating stages end and main heating stages start.

Infra-red machines are easily adapted to in-line processing of surface mounted assemblies.

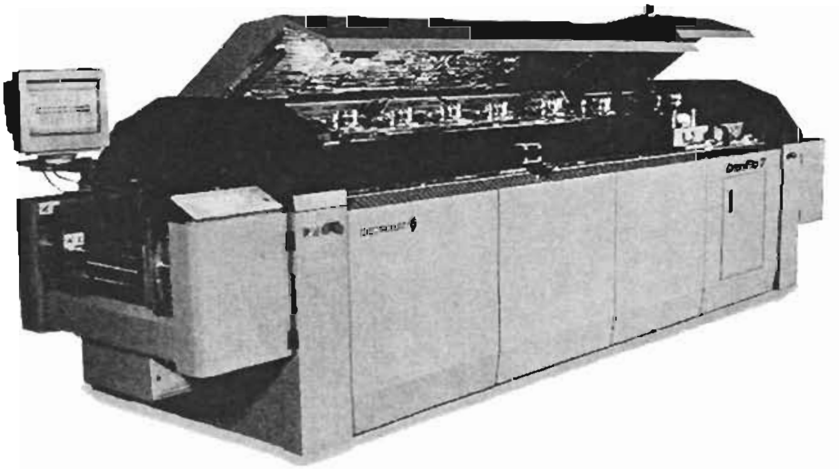


Photo 8.2 *Omniflow forced convection reflow system with an optional nitrogen purge system (Speedline Electrovert)*

Temperature differentials

The ability of an infra-red soldering machine to produce perfectly soldered assemblies depends on temperature uniformity over all joints to be soldered. As an assembly passes through a soldering machine, the ideal is to maintain a constant temperature at all joints across the assembly; in other words there should be no difference in temperature between any two points on the printed circuit board.

This elimination of temperature differential is often known as a **zero dt**. The loose term **delta** is also often used to refer to temperature differential, derived from the Greek letter used in the expression.

Temperature differentials between joints can be caused by a number of factors, including:

- assembly variations — board size, component densities, component masses and so on
- heating elements — some infra-red heaters do not dissipate heat uniformly onto the assembly surface
- conveyor systems — which extract heat from an assembly local to the conveyor supporting arms.

Any attempt to ensure thermal uniformity must mean that different assemblies require different heating characteristics as they pass through zones in an infra-red soldering machine. This causes a problem in that different zones in a machine must be at different temperatures and, further, different assembly types mean that different temperatures must be accurately maintained. This problem is confronted by measuring the different temperatures within a machine and controlling them within set limits, with closed-loop control between thermocouple sensors and heater elements.

Position of thermocouples sensors within each zone is important. Although particular machines require particular consideration, there are pointers which can optimize sensor position. First, embedded within an element a sensor may not adequately respond to temperature actually experienced by an assembly. Mounted away from the element, on the other hand, a sensor may not give an adequate indication of element temperature, causing hunting around the temperature required. Often, mounting a sensor on the surface of the element provides an optimum position, at which the sensor can form a sort of mean between both element and assembly temperature.

Hot air convection

The Whirlwind forced convection machine is a small footprint system, employing only two zones (whereas traditional SC systems have between four and 10 zones), one for preheat and one for final reflow. Laminar streams of hot air are directed along the heater tunnel.

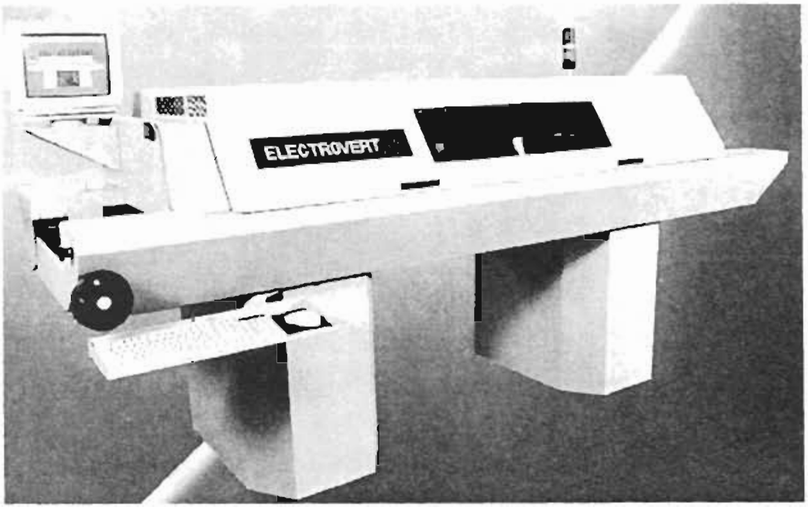


Photo 8.3 *Whirlwind computer-controlled SC soldering system (Speedline Electrovert)*

Results achieved used Whirlwind can be seen in the following microsection photographs.

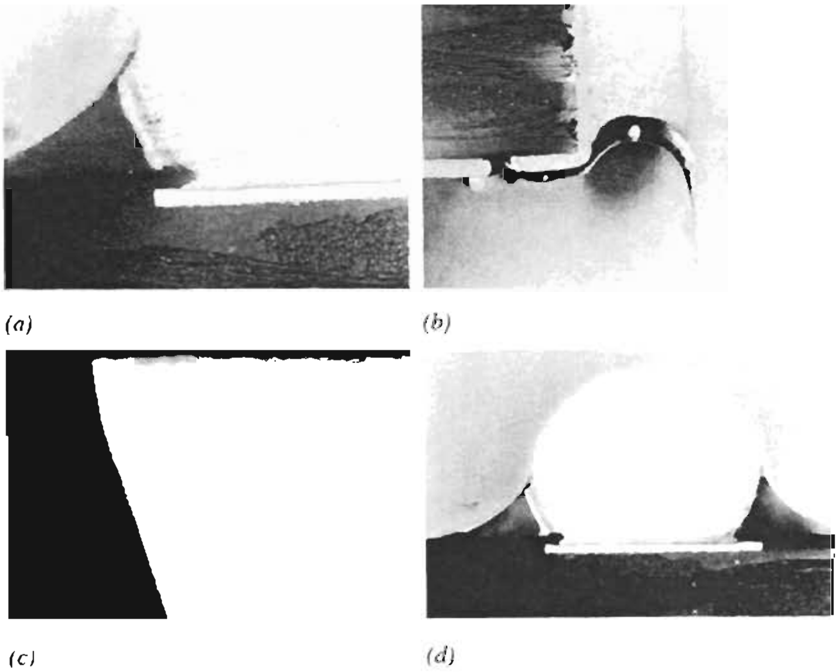


Photo 8.4 *Microsection of a BGA joint taken from a 361 termination device (a); a through-hole connector termination, soldered using solder paste in a plated through-hole (b); fine pitch gull-wing termination, showing satisfactory wetting (c); showing a termination on a SMART Group BGA package (d)*

Hot vapour soldering

Hot vapour soldering processes are sometimes called **saturated vapour**, **condensation**, or most commonly **vapour phase** (VPS) soldering processes. (The term *vapour phase* is rather loose, originating from the fact that the board is heated in a liquid which happens to be in its saturated vapour phase.)

Although classed here as a convection form of heating, heat transfer in a hot vapour soldering process takes place when a saturated vapour condenses on the board, and is thus a product of the liquid's latent heat of evaporation. If a liquid is selected with a boiling point of that required to convert the solder paste into molten solder (around 215°C to 230°C), then once that temperature has been reached, no further condensation can take place so no further temperature rise can occur. Upper temperature control in the process is therefore simply not required—a significant advantage over other SC soldering processes, particularly those using infra-red heating elements.

In turn the equipment, in principle at least, is extremely simple (Figure 8.6). An element heats the liquid to boiling point, while the assembly is positioned in the resultant vapour above the liquid. Liquid used is a perfluorocarbon (that is, *not* a chlorofluorocarbon, and possesses no environmental threat). Times to reach soldering temperature range from as little as just 5 or 6 s for small joints, to around 50 s for large joints. The vapour also removes flux and flux residues, in a washing action after soldering has taken place, reducing the requirement for post-assembly cleaning.

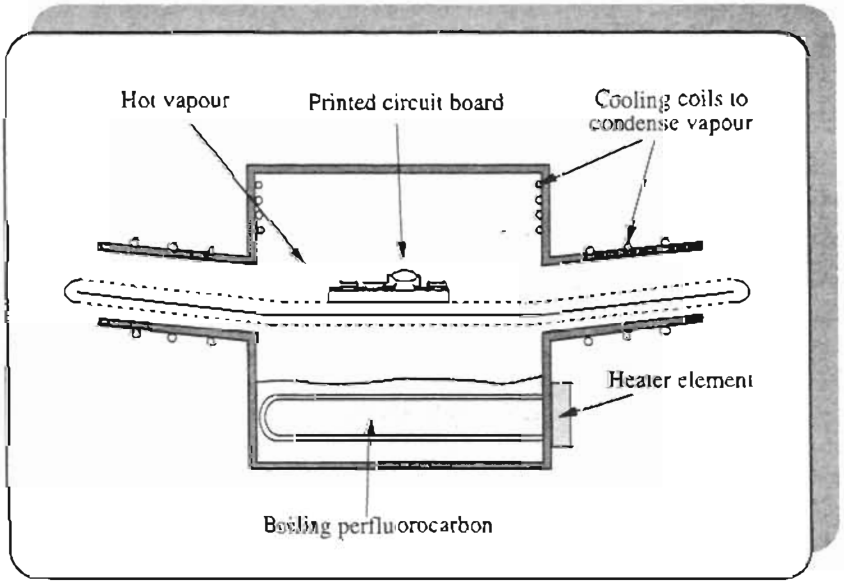


Figure 8.6 *Principle of a hot vapour soldering process, in which assemblies are soldered in a liquid in its saturated vapour phase*

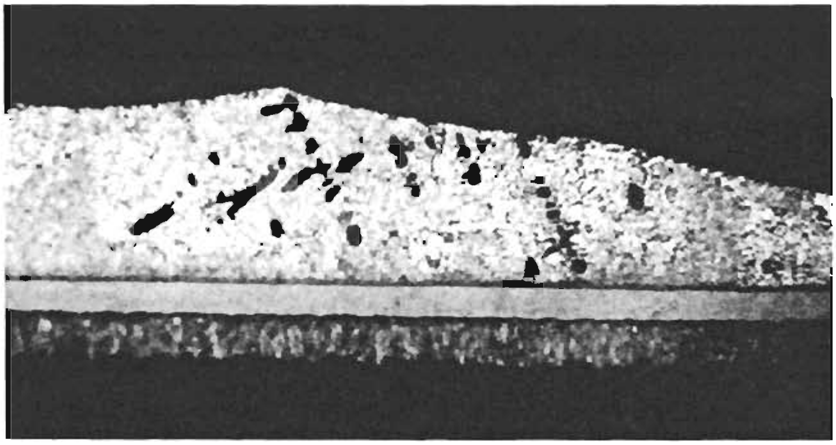


Photo 8.5 *Cross-section of an assembly track, soldered by SC soldering process (Alpha Metals)*

In practice, on the other hand, there is a fundamental problem in this simplicity, in that small joints entering the vapour undergo extremely rapid heating and consequent temperature rise (as much as 40°C¾s in some cases). In a similar way to infra-red soldering processes, if heating of an assembly previously at ambient temperature is too rapid temperature differentials between joints of an assembly occur and poor soldering can result. However, where infra-red soldering processes can suffer from shadowing effects if not adequately controlled, hot vapour soldering processes encounter other problems, mainly:

- **mis-alignment** — where two-terminal components move during the soldering process (Figure 8.7a), due to the different times that lands at opposite ends of the component reach soldering temperature. Different surface tensions may therefore be present at opposite component terminals resulting in a force which can move the component out of alignment (Figure 8.7b). If lands can be controlled to reach soldering temperature at the same time, on the other hand, the exact opposite of mis-alignment can occur — the components actually align themselves more properly on the lands than they were originally placed (Figure 8.7c)
- **drawbridging** and **tombstoning** — more severe forms of mis-alignment, where the different surface tensions at each end of a two-terminal component lift the component into an angled position resembling a drawbridge, or a vertical position resembling a tombstone (Figures 8.8a and 8.8b)
- **solder wicking** — where the solder joint itself opens up, causing some solder to be drawn up the component lead, while the remainder stays on the land. Solder wicking can occur on any leaded part, such as on the J-shaped leads of leaded chip carriers (Figure 8.9). It is due to the fact that the component lead reaches soldering temperature some time before the land.

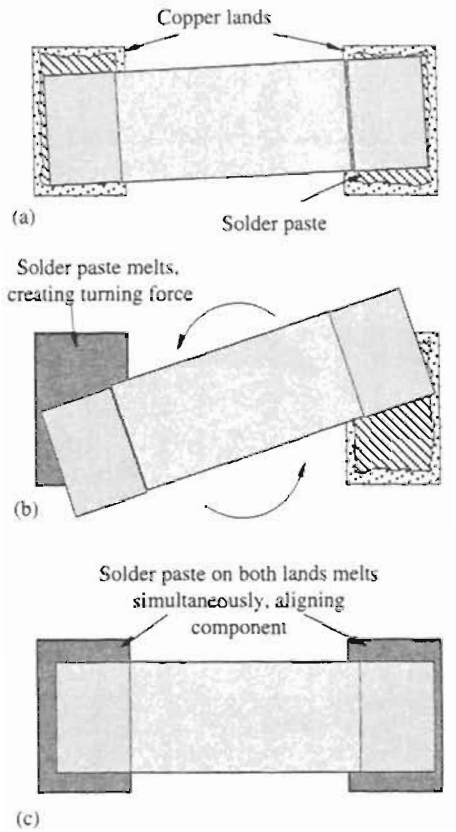


Figure 8.7 *Illustrating effects on a two-terminal component (a) component is placed on solder paste-covered lands (b) if solder paste on one land melts before that on the other, the component becomes mis-aligned (c) if solder paste on both lands melts simultaneously, the component aligns itself*

These problems can be eliminated by preheating assemblies prior to them entering the hot vapour. Many hot vapour soldering machines incorporate infra-red elements for this function, for either natural or forced convection. As a result, practical differences between modern infra-red and hot vapour process soldering machines are minimal. Only real mechanical differences stem from the method used to bring assemblies to soldering temperatures.

To date, hot vapour soldering machines have proved themselves beyond doubt in the soldering of surface mounted assemblies. The fact that in-line systems are available ensures their use in automated electronics assembly production lines.

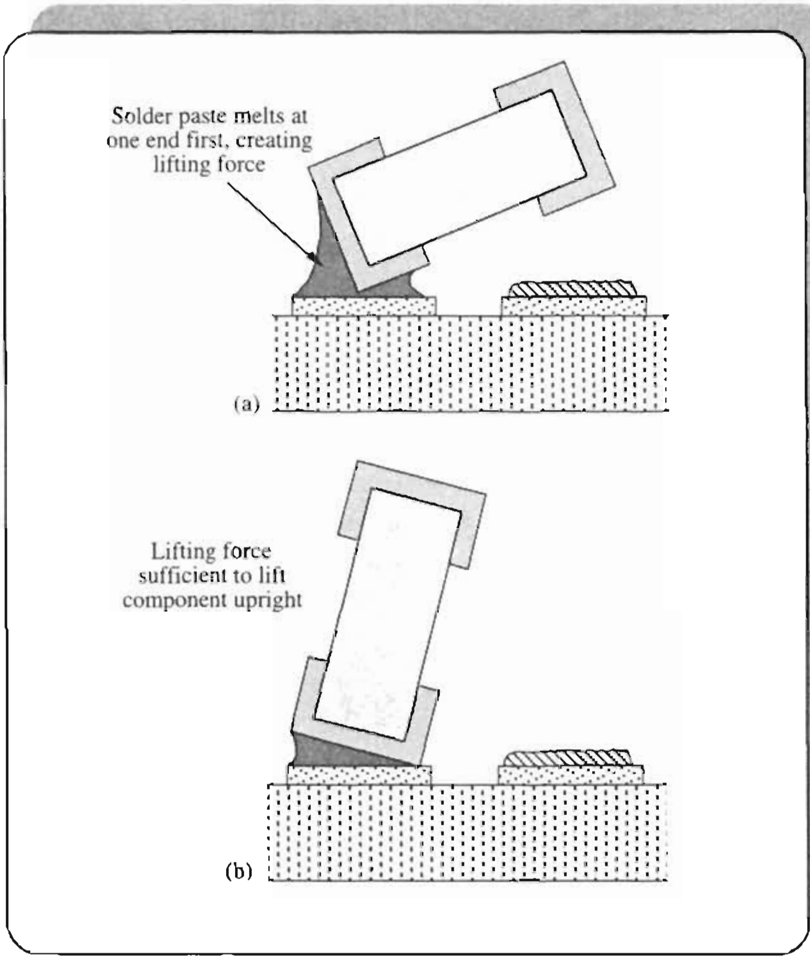


Figure 8.8 *More severe forms of mis-alignment (a) drawbridging (b) tombstoning*

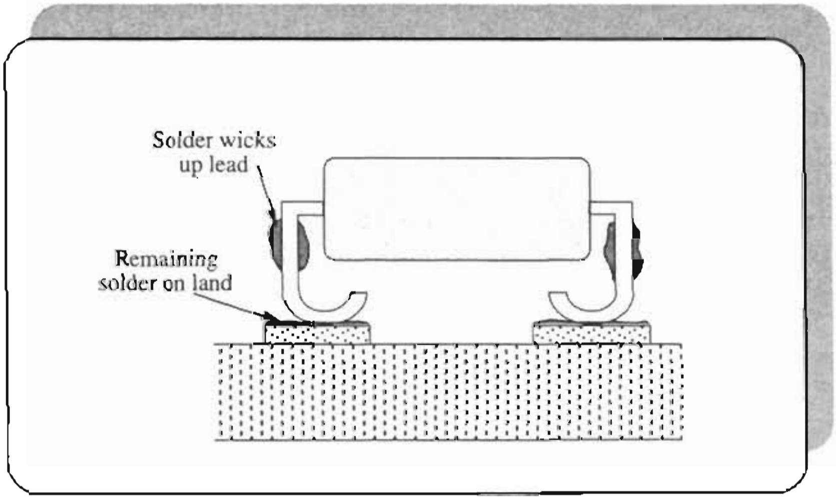


Figure 8.9 *If a component lead reaches soldering temperature before its land, solder wicking can occur*

Laser soldering

Laser soldering systems form one of the latest SC soldering processes. Until recently, the possible advantages of a laser soldering process were known, but development had not reached a satisfactory conclusion. Three main types of lasers have been found to give best results:

- neo-dymium yttrium aluminium garnet (Nd/YAG). This type of laser has a wavelength of 1.06 µm, which allows propagation through optical fibres and is strongly absorbed by metal surfaces
- carbon dioxide (CO_2). Lasers of this type have a wavelength of 10.6 µm, which is almost totally reflected from metal surfaces but is absorbed strongly by flux. Heated flux then, in turn, transfers heat to solder and metal in the joint. CO_2 laser beams are not efficiently passed through optical fibres, however
- semiconductor diode. These have wavelengths of around 800 to 900 nm, so are similar in characteristics to Nd/YAG lasers. They are also much more compact than other types and more efficient, though less powerful.

Simply, laser soldering of joints requires that a low intensity laser beam is accurately directed and focussed onto each joint, for a small **dwell time** of around 200 to 500 ms. During this dwell time, the laser beam heats the joint area above soldering temperature, the solder melts and so wets the joint area. Then, the laser beam is re-directed to another joint. In practice, things are not that simple.

Problems are five-fold. First, joints have to be soldered sequentially. The laser beam is directed and focussed on each joint in a serial manner. This means soldering times for complex assemblies are necessarily long.

Second, there is a control problem in positioning individual joints of the assembly beneath the laser beam. This can only be done in two ways: by moving the assembly or by moving the laser beam. In most cases movement is controlled using a computer-numerically-controlled XY table, which gives required accuracy and programmability.

Third, laser beam direction depends on components being soldered. Figure 8.10 shows a gull-wing leaded component joint being soldered by a laser beam at an angle (Figure 8.10a) and on the normal (Figure 8.10b). Although most laser light is absorbed by the joint some is reflected. Where the laser beam is on the normal this is of little consequence. However, where the laser beam is at a small angle, reflected laser light may strike the component body (or other objects) causing potential damage by charring.

On the other hand, J-lead components cannot be laser soldered with a laser beam on the normal. Figure 8.11a shows how the component shape

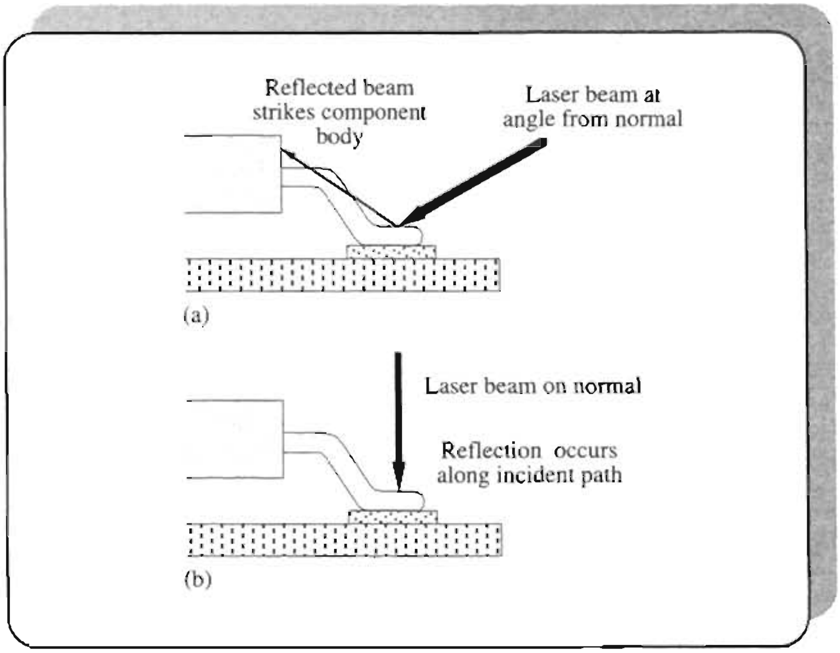


Figure 8.10 *For a gull-winged component (a) a laser beam at an angle may be reflected and damage the component (b) a laser beam on the normal doesn't*

prevents beam access to the joint area. In this case, the laser beam *must* be at an angle to allow proper joint formation (Figure 8.11b).

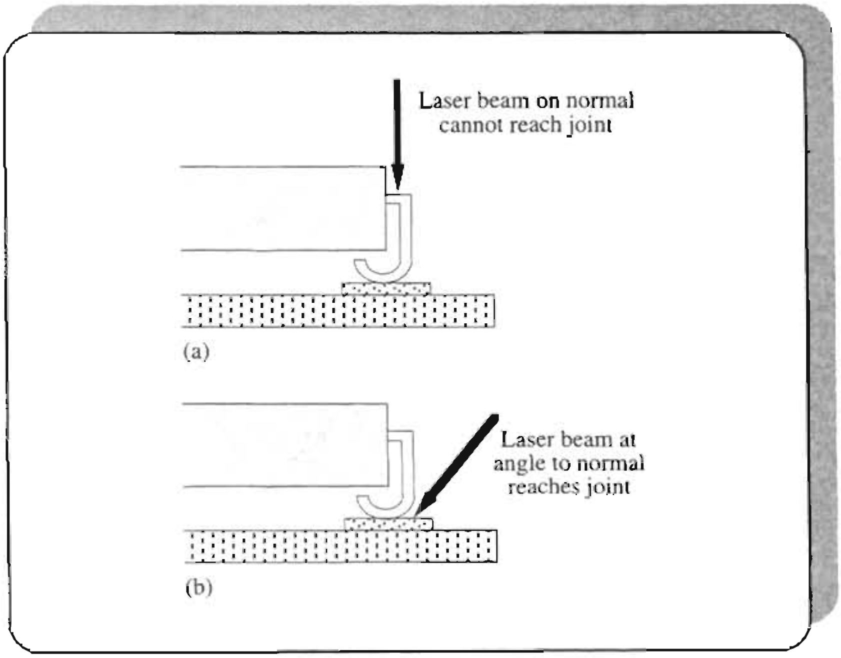


Figure 8.11 *For a J-leaded component (a) a laser beam on the normal is of no use (b) an angled laser beam is best*

Fourth, laser beam intensity and dwell time depends on the component, the substrate and, specifically, the joint being made. For example, solder paste at the inside end of the track pad of a J-leaded component is obscured from the laser beam by the component lead itself — even if the laser beam is at angle from the normal. This is shown in Figure 8.12. To ensure all solder paste is melted and an adequate joint is formed, either laser intensity has to be increased or dwell time must be longer. Soldering of all varieties of joints, components and substrates can only be carried out if intensity and dwell time can be varied to suit each joint.

Fifth, joint formation depends very much on the type of laser being used. This has a direct influence in the design of joints. Figure 8.13 shows two possible joints of a gull-wing component. In Figure 8.13a the component lead is full-on the track pad and the laser is directed at the lead centre. Figure 8.13b shows the situation where the lead is half-on the track pad, while the laser is directed at the pad centre. Nd/YAG lasers produce best joints when used in the arrangement of Figure 8.13a, as their wavelength of 1.06 µm is strongly absorbed by the lead metal. CO_2 lasers, on the other hand, have a wavelength of 10.6 µm, which is reflected off metal but absorbed by solder flux so are best in arrangements like Figure 8.13b where the beam is aimed at the track pad (which is covered in solder paste).

Figure 8.14 shows a typical Nd/YAG laser soldering machine. Laser light is directed by a tiltable optics head, which allows reflected energy from the joint to be passed to an infra-red detector. Each joint's reflected energy corresponds to a unique thermal signature, which is passed to a computer for comparison with ideal joints. Joints which do not have a signature close to required ideals are faulty.

Laser soldering has been used for a while to solder individual joints with great accuracy. Instant and fine control over the laser means that the smallest of joints can be soldered without damage, and the largest of joints can still be guaranteed sufficient heat.

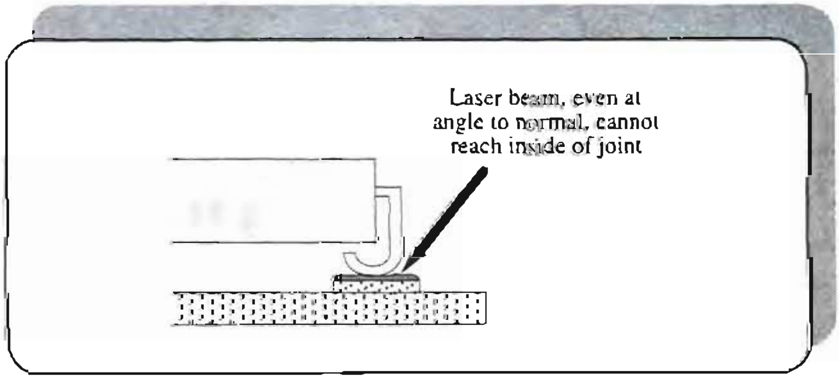


Figure 8.12 *For a J-leaded component, even an angled laser beam can't reach the inside of a joint — either laser intensity or dwell time must be increased*

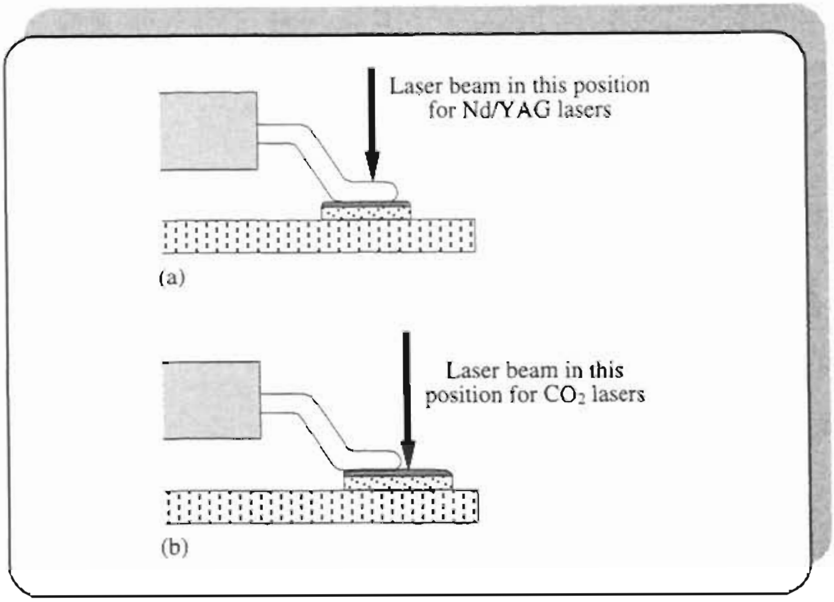


Figure 8.13 *Where the laser beam is directed depends on laser beam type (a) correct direction of Nd/YAG lasers (b) correct direction of* CO_2 *lasers*

More recently, process control has been developed such that many joints can now be automatically soldered in a sequential fashion. With joint times in the region of 250 ms, however, multi-laser systems are essential to keep overall board soldering times (with possibly thousands of joints) to acceptable lengths.

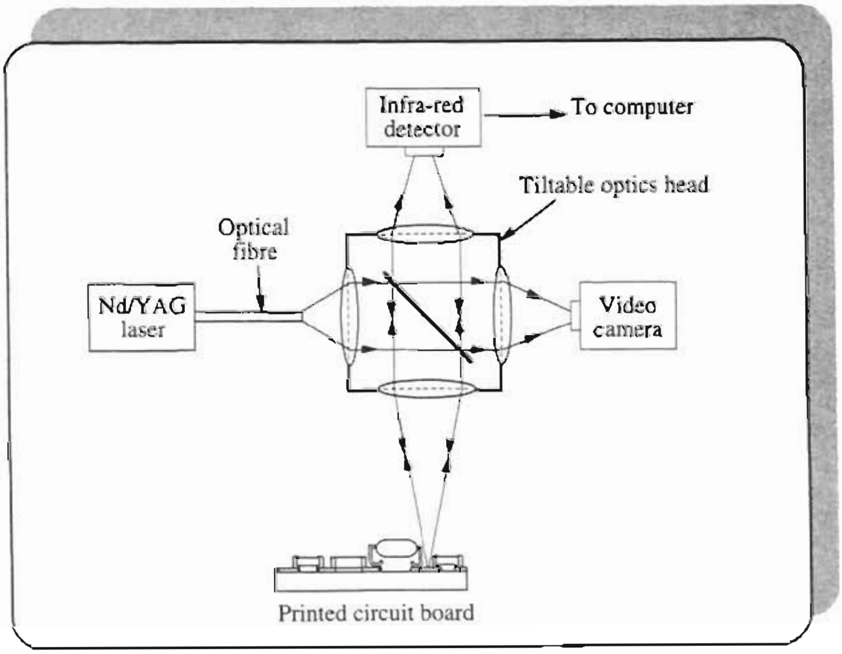


Figure 8.14 *Principle of a typical Nd/YAG laser soldering machine*

For these reasons, laser soldering promises to be an even more important process over the coming years, when high-density assemblies, micro-fine pitch tracks, chip-on-board technologies and so on become the norm rather than the exception.

Soldering machines of both CO_2 and Nd/YAG have been manufactured, but semiconductor diode machines are still in early development. Fact that shorter wavelength lasers (Nd/YAG and semiconductor) allow propagation by optical fibres means they are generally more convenient to use. On the other hand, CO_2 lasers produce joints at much lower powers and shorter dwell times than Nd/YAG lasers. This means risk of damage to components and printed circuit boards is considerably lower, and there is possibly lower intermetallic compound formation so joints are less likely to be brittle.

Low power consumption, high efficiency, small size and low voltage operation of semiconductor diode lasers means they probably have a future not only in stand-alone soldering machines but also in *integrated* automatic placement and soldering machines. This will be an exciting development with enormous prospects.

Light beam soldering

Similar in principle to laser soldering is light beam or optical beam soldering. Here, light from an infra-red lamp is focussed to a high temperature spot. While cost is significantly lower than current laser soldering processes, light beam soldering suffers from a disadvantage in that it is difficult, optically, to focus a light beam to a diameter of less than about 3 mm — too large for accurate soldering of fine pitch components.

Heated collet or hot bar

A popular SC soldering process which is not a mass method, but should be described for completeness, is the **heated collet**, sometimes called **hot bar**, **resistance bar**, or **thermode**. Here an electrically-heated collet, the shape of the surface mounted component to be soldered, is positioned over the placed component, and heated so solder under the component terminals melts. Where hot bars are used, four heated bars of required shape are brought into position and lowered onto the component's leads. In effect, the method is a simple adaptation of a conventional hand-held soldering iron, designed to solder all terminals of a surface mounted component simultaneously, and allowing semi-automated or automated soldering on a small scale.

Heated collet or hot bar techniques are often used to solder fine pitch components to printed circuit boards, without solder paste. Instead, boards are first hot air levelled with solder (see Chapter 3) or electroplated with tin/lead, to a thickness of around 0.025 mm (0.001 inch). There is a minor advantage to using electroplated tin/lead printed circuit boards, because hot air levelling leaves component mounting pads with a crowned surface of curved solder (see later). An alternative to both methods is to apply solder paste and melt it in a conventional infra-red or hot vapour soldering machine.

The component is then placed, after which it is soldered with the heated collet or hot bar. This technique eliminates any possibility of solder bridges occurring between component leads, as less solder exists at each joint. Problems of needing to ensure accurate solder paste application (see Chapter 6) are neatly sidestepped, too.

A heated collet or hot bar SC soldering process typically could be used where flat-pack or taped automated bonded integrated circuits are required to be mounted on a previously CS soldered assembly. As these components cannot be soldered by CS soldering processes, the heated collet or hot bar method gives manufacturers who already have CS soldering equipment the option of using these multi-terminal surface mounted devices, without the expense of mass SC soldering equipment.

In practice, the collet or hot bars must be non-wettable. This allows the required temperature to melt the solder paste to be reached, after which the collet or hot bar is allowed to cool (until the solder solidifies) before removal from the component's terminals. Fairly accurate control of temperature is needed to do this, so a thermocouple sensor is incorporated into or near to the thermode (either collet or bar).

Collet force

Force at which a collet or hot bar is applied is quite an important factor. It must be sufficient to hold the component in its position, yet must not be so much that the component leads are pushed off the hot air levelled crowns of solder on lead pads (Figure 8.15). Once solder melts, however, force should be typically increased to push the component lead down to contact its track pad properly.

Force profiles, which define how force is applied and varied throughout the soldering process should be followed for particular collets. An example is given in Figure 8.16 and shows how a light initial force is applied during the heatup time. During the dwell time, however, force is increased to the full reflow force. After the cooldown time, force is rapidly lowered and the collet or hot bar lifted off the joint.

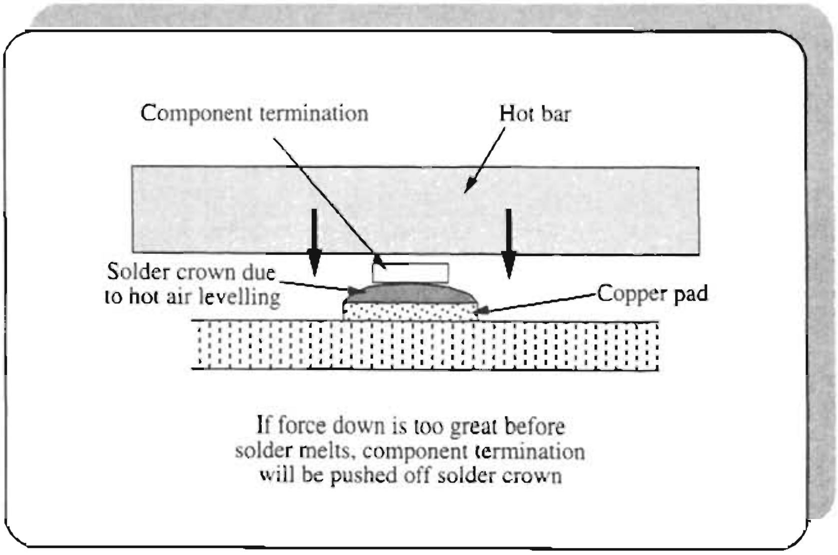


Figure 8.15 *Initial force on a component placed on a hot air levelled pad must be relatively light*

Process times

A light initial force is also a convenient method of reducing heatup rates experienced by component leads. Typical heated collets heatup to 300°C or so in around half a second; a rate which is too fast for ceramic components and substrates. If too high an initial force is used components will heatup at almost this rate and so may be damaged. With a low initial force, on the other hand, component heatup rates are slower, and damage is prevented. The overall process, though, is correspondingly longer.

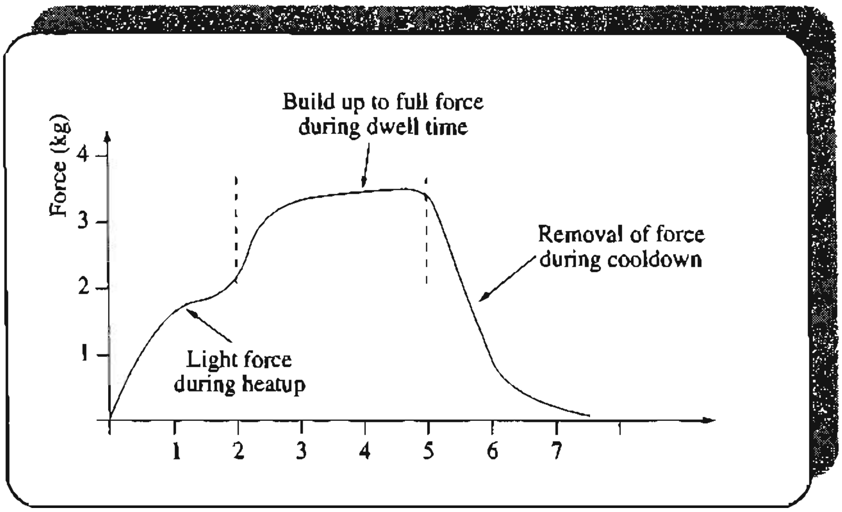


Figure 8.16 *Typical force profile in a heated collet or hot bar soldering process*

Apart from collet or hot bar force, the two main factors influencing overall process time are:

- solder volume — the greater the volume, the longer it takes to melt and wet the joint
- contact area between collet or hot bar and component lead — the greater the area, the shorter it takes to transfer heat to a lead.

Components soldered to a printed circuit board by heated collet or hot bar can be placed by hand, or automatically. Hand placement, followed by lowering a heated collet or hot bar is often used in rework or repair, but occasionally in manufacture too. Many forms of heated collet or hot bar soldering machine, though, are equipped with automatic placement systems giving placement and soldering rates of upto 200 components per hour or so.

Such systems use vacuum pipettes to pick and place components, and a camera-based vision system to ensure accurate and automatic positioning. Some systems allow automatic changes of collets or hot bars, to suit each component-type in an assembly.It is common to find heated collet or hot bar applications used where fine pitch components are placed. However, it should be remembered that by carefully controlling solder paste application (see Chapter 6), mass SC soldering processes such as infra-red and hot vapour can still be used with pitches as small as 0.5 mm (0.02 inch).

Miscellaneous SC soldering processes

There remains a small number of SC soldering processes which have fairly specific uses, but which should be mentioned. These are:

- hot air, hot gas — some techniques have been developed in which hot air or hot gas is blown from shaped nozzles onto solder joints. Though these techniques *are* used for soldering joints, they are more commonly used in repair and rework of assemblies
- hot belt — heated platens underneath an assembly line heat a belt which carries printed circuit assemblies. Heat passes through the belt to the undersides of assemblies, through the printed circuit boards, to the component joints. Typically, therefore, to reach soldering temperatures on the tops of boards, platen temperatures must be significantly higher — upto about 300°C. A variation is the beltless process, which uses pusher bars to move printed circuit boards over platens. Hot belt processes are useful in soldering of flexible printed circuit boards. By dividing these machines into zones, temperature profiles similar to those of infra-red processes can be setup

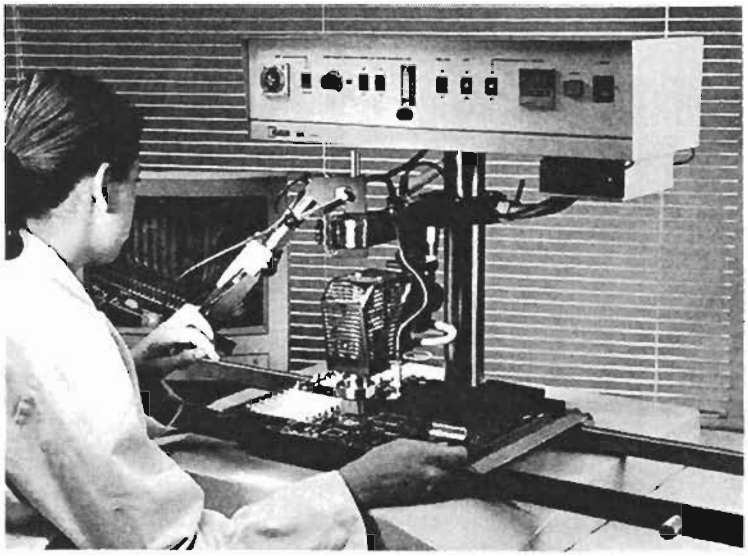


Photo 8.6 *Hot gas/air soldering machine, used typically in rework or individual component placement (Planer Industrial)*

- soldering irons — conventional soldering irons with specially shaped tips.

Comparison of soldering processes

All SC soldering processes are compared in Appendix 4, along with CS soldering processes.

9 Profiling soldering processes

Soldering processes of all types share a similar basis — their function is to solder components onto printed circuit boards. As such, the way they do this varies considerably in the practical mechanics of the task, but the actual process — in terms of heat variations — the printed circuit board itself encounters is a remarkably standard one.

Indeed, there is a sufficiently standard variation that it is possible to compare various machines and various processes in a standard way. To do this, the variations are mapped in a graph known as a **profile**.

Profiles

Typically, profiles show the zones within a soldering machine — simply because, in a physical way, it is easiest to split a process up into the various zones of a machine the printed circuit board passes through in the whole process. These different zone temperatures are mapped graphically in a form like that shown in Figure 9.1, correctly known as a machine's **temperature profile**. Temperature profiles essentially define the temperature gradients assemblies experience as they pass through the soldering machine, so provide an ideal means whereby:

- machines can be compared
- machines can be rapidly adjusted to suit each new assembly type to be soldered.

However, there is no need for a machine to have separate physical zones. A single chamber could be used (and is, in some processes) in which the printed circuit board is positioned then processed. However, the use of physical zones is a useful means in mass soldering processes to maintain a selection of ambient temperature stages for the printed circuit board to pass through.

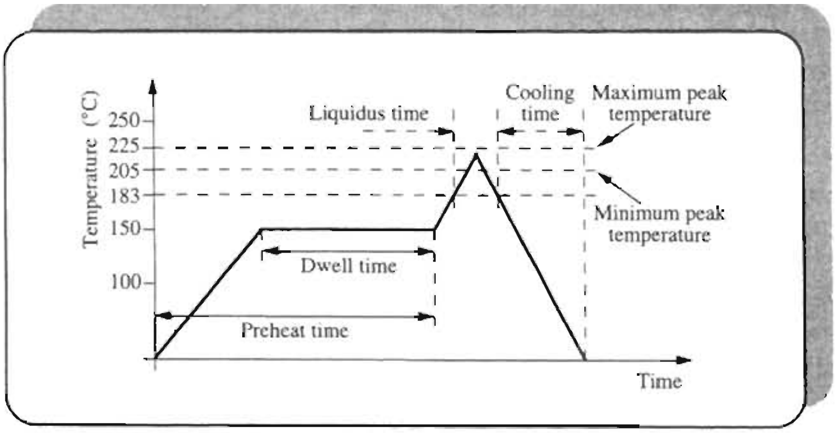


Figure 9.1 *Basic machine temperature profile, showing four main stages*

Temperature profile stages

There are four important stages and periods within a machine and its temperature profile. In the first stage an assembly is preheated, for a period known as the **preheat time**, in a controlled manner to just below soldering temperature. During this **preheat stage**, aim is merely to apply heat to assemblies as rapidly as possible within reason. Because of this, at the end of the preheat time wide temperature differentials exist between assembly joints.

In the next stage, the interior of the machine is maintained at a temperature (known as the **soak temperature** or **dwell temperature**) for a period known as the **soak time** or **dwell time**, prior to final application of heat. During soaking, main aim is ensure all joints stabilize at the dwell temperature. Smaller joints hotter than dwell temperature will cool down, while larger joints heat up. A resultant effect of this stage is to dryout and activate solder paste on the assembly, so this stage is sometimes called the **dryout stage**, or **activation stage**. At the end of the dwell time, all joints are hopefully at the same temperature.

Final application of heat in the third stage raises machine temperature above soldering temperature for a period known as the **liquidus time** — simply the time during which solder is ideally molten. Often this stage of the process is called the **reflow stage,** and its aim is to lift all joints above soldering temperature more-or-less at the same time.

Finally, temperature drops below soldering temperature during the **cooling time**.

Certain aspects within a temperature profile are important. First, all parts of a machine's temperature profile depend largely on characteristics of assemblies passing through. For example, assemblies with large components and large joints require the soldering machine to have a long dwell time to ensure all joints reach the machine's dwell temperature, before going on to soldering temperature. Further, densely populated assemblies with resultant miniature joints need a soldering machine with a relatively slow preheating rate to ensure effects such as shadowing don't occur.

It is the way different machine's temperature profiles can be controlled and varied that can define whether or not particular soldering processes can be used for particular printed circuit board variations.

Optimizing temperature profile

While a profile such as that in Figure 9.1 indicates the *ideal* temperature a soldering machine's interior must have, it is impossible to maintain in practice. More properly to indicate this, a temperature profile should be displayed as a *band* of temperatures, within which joints of an assembly must be maintained. Figure 9.2 shows such a temperature profile where the variance in actual temperature experienced by any particular joint can be seen. As long as no joint temperature actually falls outside of the profile band, it can be more-or-less safely assumed that an assembly is properly soldered. For example, a machine's **maximum peak temperature** must be carefully controlled, as must its **minimum peak temperature**. Otherwise joints on some assemblies may be overheated, while joints on others don't reach a high enough temperature for joints to be properly soldered.

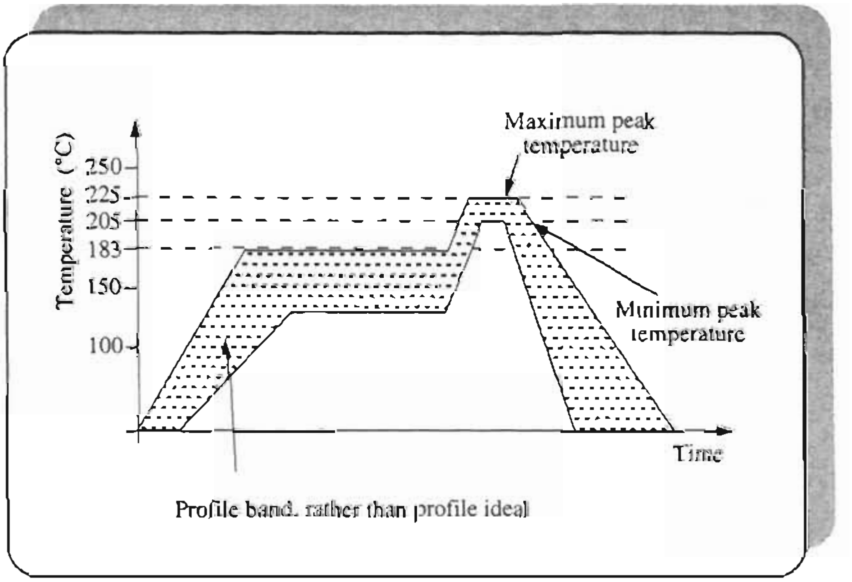


Figure 9.2 *Temperature profiles more usually follow a band of temperatures*

Temperature profile optimization has been carried out experimentally on numerous occasions and it has been found important to maintain some four criteria when using forced convection infra-red soldering machines [Anvari, Chow #23]:

- maximum rate of heating during the preheat stage should be 6°C¾s
- dwell time should be between one and three minutes, at a temperature of between130° to 170°C
- liquidus time should be 30 to 90 seconds above 200°C
- maximum temperature anywhere on the assembly at any time in the soldering process should be 235°C.

Each assembly type has a different requirement for preheat, soak and final heat so soldering machines must allow adjustable machine temperature profiles. Consequently, when changing from one assembly type to another, a new machine temperature profile has to be setup before soldering can begin. Without adequate management of machine temperature profiles, faulty joints occur.

It should be understood, machine temperature profiles as understood in a mass soldering machine are simply temperatures within the machine, which assemblies experience as they pass through. Put another way, temperatures of individual joints on an assembly are *not* necessarily the same as a machine's temperature profile. Indeed, individual joints on an assembly have temperature profiles *significantly* different from a machine's temperature profile. Figure 9.3a shows two possible temperature profiles experienced at joints of an assembly passing through an infra-red soldering machine, superimposed on the machine temperature profile ideal of Figure 9.1. Profile 1 is the sort of profile which may be obtained at a joint within

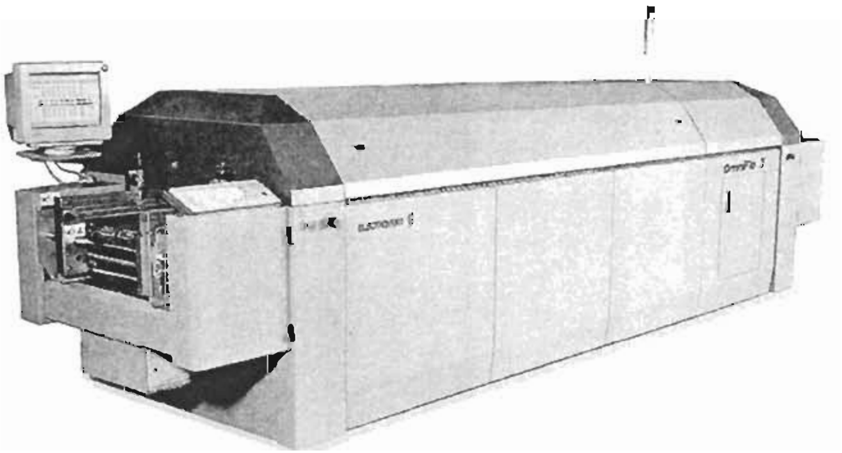


Photo 9.1 *Omniflow forced convection infra-red soldering machine — external view (Speedline Electrovert)*

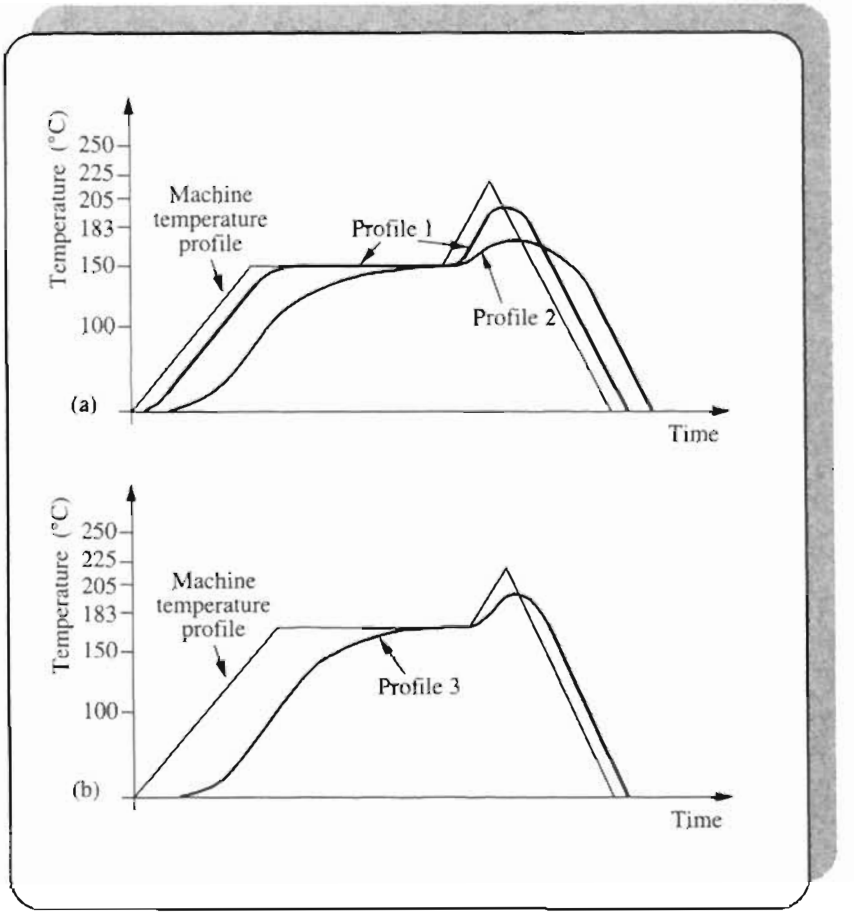


Figure 9.3 *Possible joint temperature profiles, superimposed on a machine temperature profile (a) profile 1 is of a small joint which reaches soldering temperature quickly, while profile 2 is of a larger joint so doesn't reach soldering temperature at all (b) profile 3 is of a large joint which does reach soldering temperature, because the machine temperature profile is adjusted to give a slower rise to a higher dwell temperature*

a densely populated part of an assembly, so corresponds to a small joint of a small component. Heat experienced at this joint rapidly follows machine temperature changes. Profile 2, on the other hand, shows temperatures at a large joint of a bulky component. Naturally, these lag behind machine temperature changes somewhat.

Profile 1 rises more rapidly than profile 2 whenever heat is applied, so reaches a higher temperature more quickly. Profile 2, for example reaches dwell temperature a considerable time after profile 1. On application of final heat, the joint corresponding to profile 1 has an adequate liquidus time so is properly soldered. It is doubtful, however, whether the joint corresponding to profile 2 has a liquidus time sufficient to create a good joint.

By adjusting the machine's temperature profile to create a slower but longer initial temperature rise to a higher dwell temperature (Figure 9.3b), this problem is solved and the joint is properly soldered (profile 3).

In practice, machine temperature profiles and, hence, joint temperatures aren't just as simple to control as it might seem. Infra-red soldering machine temperature profiles can never be as smooth as suggested here, simply because discrete heater elements produce discrete stepped changes in temperature throughout the machine. However, the greater the number of elements, the smaller each step between is, so the easier it is to define acceptable profiles. Similarly, wave soldering machines which rely solely on the solder to heat the printed circuit board cannot possibly achieve an ideal machine soldering temperature profile.

Infra-red soldering temperature profiles

In basic infra-red soldering machines, without convection assistance, machine temperature profiles are often difficult to adjust or maintain. Considerable time has to be allowed when changing from one profile to another, too. Even where profiles are adequately setup, however, localized temperature differentials due to heaters or conveyors may still occur.

At the other extreme, zoned forced convection soldering machines allow closely defined control of profiles, along with virtually no temperature differentials (that is, zero dt across assemblies), and rapid changeover from one profile to another. That's not to say that profiles mustn't be monitored regularly — it's just that their parameters are easier to maintain with this type of soldering machine.

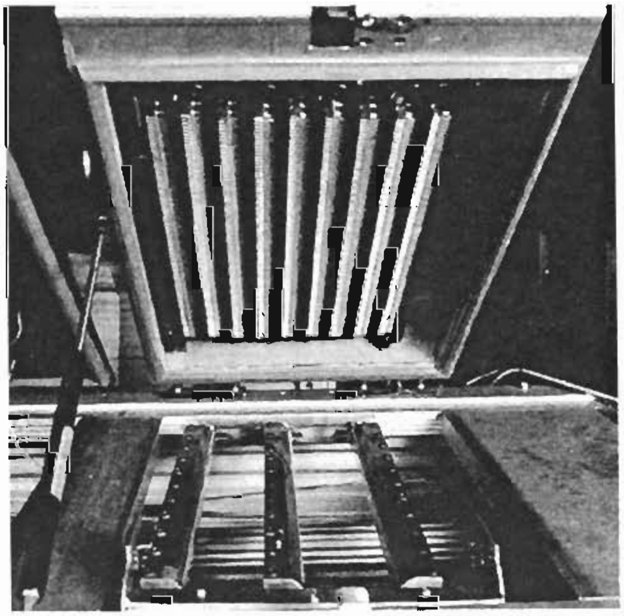


Photo 9.2 *Nitrocool™ gas knives, an Omniflo cooling option (Speedline Electrovert)*

Hot vapour soldering temperature profiles

As in infra-red soldering processes, consideration of temperature profiles of hot vapour soldering processes is useful and leads to a greater understanding of the process, coupled with consequent better soldering. Hot vapour soldering is, in principle at least, a very simple process — assemblies are SC soldered merely by inserting them in the vapour of a liquid whose boiling point happens to be above that of the melting point of solder.

Figure 9.4 shows profiles with and without preheating. Joints of assemblies soldered without preheating experience a rapid rise of temperature (some 15 to 50°C s^{-1}, or so) during the heating stage. It is this rapid rise which can cause temperature differential problems with components that were noted earlier.

With preheating, on the other hand, assemblies may be heated more slowly (as little as 2°C s^{-1}, or so) with a resultant lowering in the number of defects.

Preheating, though, is done with infra-red elements of either natural or forced convection. So practical differences between modern infra-red and hot vapour process soldering machines are minimal. Only real mechanical differences stem from the method used to bring assemblies to soldering temperatures.

To date, hot vapour soldering machines have proved themselves beyond doubt in the soldering of surface mounted assemblies. The fact that in-line systems are available ensures their use in automated electronics assembly production lines.

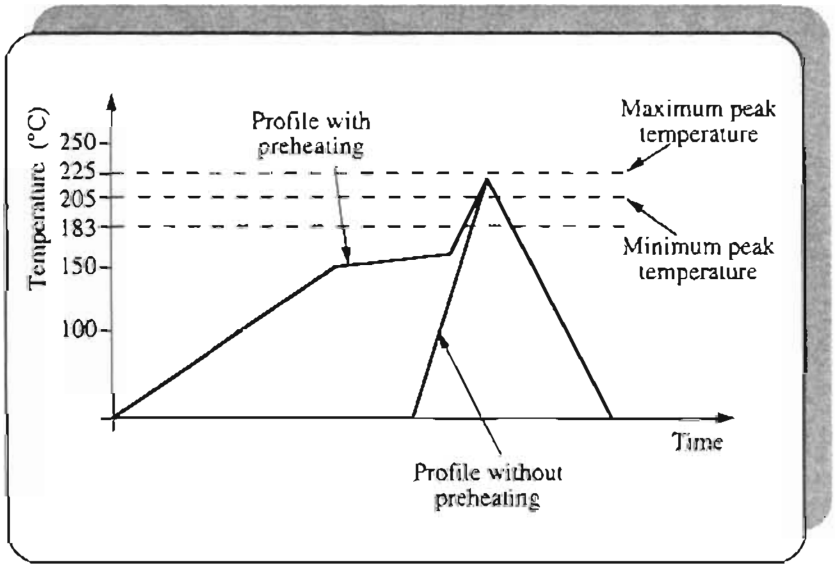


Figure 9.4 *Temperature profiles experienced in hot vapour SC soldering processes, with and without preheating*

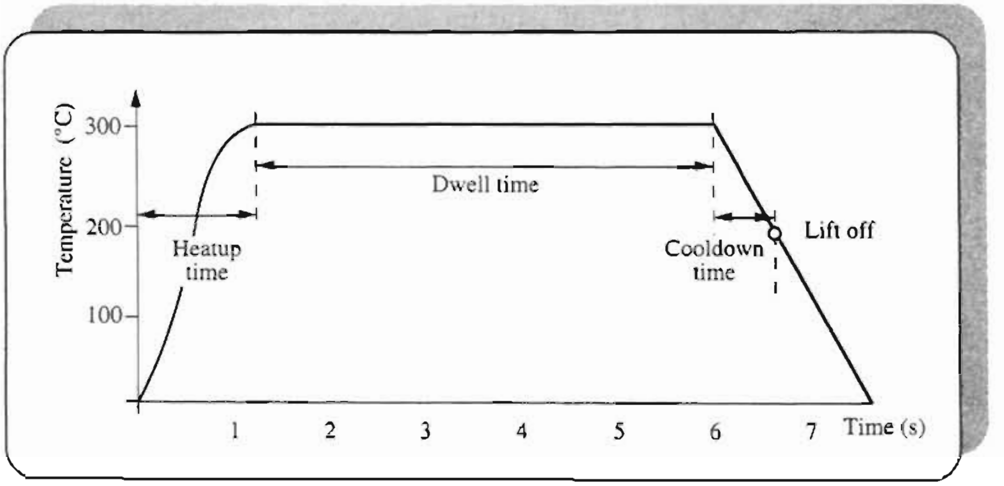


Figure 9.5 *Typical temperature profile experienced by a taped automated bonded component in a heated collet process*

Heated collet temperature profiles

Adequate control over temperature profiles of a heated collet or hot bar is important. Figure 9.5 shows a typical temperature profile when a heated collet or hot bar is used to solder a taped automated bonded component. During **heatup time**, temperature of the collet or hot bar rises as the element is excited by electrical current. When the internal thermocouple senses soldering temperature is reached, current to the collet or hot bar is regulated to maintain temperature for duration of the dwell time. On completion of dwell time, current to the collet or hot bar is switched off, and it starts to cool, during **cooldown time**. After this, when temperature falls below solder melting-point, the collet or hot bar is lifted off the joint and the joint is allowed to cool on its own.

In practice, heated collets used are typically self-regulating so operating temperature is largely independent of joint requirements. Radio-frequency excitation of the element is used and small differences in temperature cause inverse changes in resistance, used to maintain temperature constant. Overall effect is of a uniform temperature around all parts of the collet or hot bar. Such collets or hot bars are designed to operate at fixed temperatures, so users cannot adjust operating conditions. Instead, joint conditions are controlled by changing dwell times and collet or hot bar downward force.

Process times

A light initial force is also a convenient method of reducing heatup rates experienced by component leads. Typical heated collets heatup to 300°C or so in around half a second; a rate which is too fast for ceramic components and substrates. If too high an initial force is used components will heatup at almost this rate and so may be damaged. With a low initial force, on the other hand, component heatup rates are slower, and damage is prevented. The overall process, though, is correspondingly longer.

Apart from collet or hot bar force, two other factors influencing heated collet temperature profiles are:

- solder volume — the greater the volume, the longer it takes to melt and wet the joint
- contact area between collet or hot bar and component lead — the greater the area, the shorter it takes to transfer heat to a lead.

Optimizing temperature profiles

Generally speaking, profiles can be established and maintained in two ways. Either manually, or with semi-automatic aids.

Manual profile optimization

Manual profile measurement is usually undertaken by attaching thermocouples to assemblies and monitoring the temperature as assemblies pass through the soldering process.

Thermocouples should ideally be fixed to the printed board surface and component terminations directly in contact with the pad surface. If they are placed on the top of terminations themselves readings may be erroneous. After any adjustment to the oven it is necessary to wait until the oven stabilizes. Speed of stabilization and its repeatability over a number of profiles is a mark of a good reflow oven. This should be part of the initial oven evaluation and understood by production staff.

After attaching thermocouples, a test board should be passed through the oven and the temperature profile analysed. Adjustment may then be made to the zone temperatures and conveyor speed to obtain the correct profile. The desired profile is a combination of recommendations from the solder paste manufacture, the component suppliers guidelines and the printed board.

Solderable finish

All surface finishes are affected to some degree by high temperatures. The correct temperature profile can eliminate solder balls and significantly reduce flux residues on many low residue pastes.

To conduct the reflow operation correctly it is important to know what temperatures are being seen by the whole board assembly. This requires the use of thermocouples to monitor selected solder terminations. In the case of surface mount parts the thermocouple beads are soldered directly to the joint surface using high temperature solder.

With ball grid array (BGA) assemblies, thermocouple leads must be positioned under the centre of the devices. In most cases these are the last terminations to reflow during soldering. Either thin wire is used or more commonly a profile board is produced with a thermocouple wire mounted through the board into a ball termination to improve the repeatability of the temperature measurement.

All profiles should be developed on a fully populated board to guarantee that the correct conditions are achieved. If the boards are to be processed in or on support pallets then they should be used during profiling. The pallets will contribute to the mass and hence affect temperature rise on selected areas in contact with the board. It can easily affect the temperature rise by as much as 20°C.

When a profile has been established, the board should be run through the oven again monitoring the profile but load the oven in front and behind the profile board to determine the thermal loading and the degree to which the temperature drops. Final setting changes may then be made to the oven zone temperatures.

Final trials

When a profile has been established and been run in production with satisfactory soldering results the following information should be retained:

- the solder temperature in each zone
- speed of the conveyor
- extraction rates
- board loading.

A temperature profile should be run on the oven initially each day to build up a picture of the process stability. The frequency may then be adjusted depending on the repeatability of the results.

Further trials should also be run on the desired profile with the production paste to determine the degree of slumping of the paste as it will affect solder shorting. Lower the final zone to just below the reflow temperature of the paste. Pass a fully populated board through the machine and examine the board on exit. Check the amount of slumping on fine pitch, under BGA devices and chip components. This test is very useful to understand many of the causes of solder beading on chip devices.

Process trials procedures

Standard trials are often conducted on reflow ovens by production engineers during product assessment, machine approval or in process set-up. The following trials are also used by machine suppliers during equipment development.

Temperature uniformity

Measuring surface temperature on an assembly or ideally a blank laminate test board checking variations across the complete belt width. Measured using thermocouples fixed to the surface of the panel. This shows any peaks or low points between centre or near the edge of the conveyor.

Test results ideally achieve between 5–10°C

Thermal loading

First a temperature profile is produced as a reference using six probes soldered to an assembly — three probes on top, three on the bottom. The oven is then thermally loaded with products. Alternatively copper laminate or steel sheets may be substituted to fully load the oven. During loading a further profile is taken to compare the temperatures in this simulated production test.

Test results achieve ideally less than 10–15°C

Temperature stability

Measuring surface temperature on an assembly or test board checking variations across the complete belt width. Repeating this trial periodically throughout the day in production shows an ovens control system even with a varying environment. The test should be run with one set-up but may be run with different board types.

Test results achieve ideally less than 10–15°C

Throughput speed

Adjustments are made to the conveyor speed for the maximum envisaged circuit board throughput requirements. The preferred temperature profile for the most complex product is then the goal. Reference must be made to the paste or adhesive requirements when considering these tests.

Evaluating nitrogen usage must be conducted with discussions with existing users of machines for consumption and maintenance. The use of nitrogen has benefits but need to be justified. Solderability assessment of surface pads is a good measure of the benefits of nitrogen, comparing samples before and after reflow in nitrogen.

Semi-automatic profile optimization aids

A number of manufacturers make devices that can help to ensure profile optimization. These devices are generally computer-interfaced modules that attach to the assembly and are passed through the soldering process to allow profiles to be monitored.

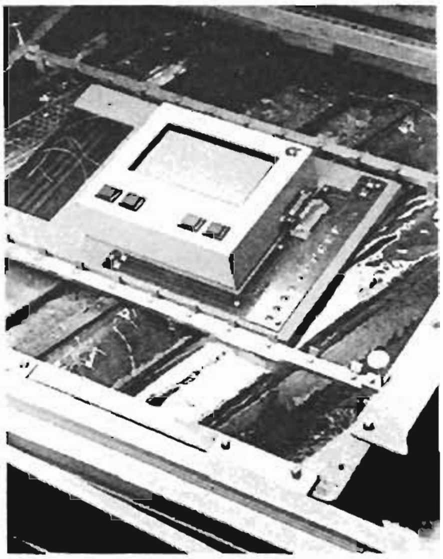


Photo 9.4 *System to monitor temperature profiles during soldering process — showing the optimizer passing through a CS wave soldering machine (Alpha)*

Photo 9.5 *System to monitor temperature profiles during soldering process — here shown by itself (ECD)*

10 Cleaning soldered assemblies

Cleanliness in the electronics assembly industry has never been particularly sought after — at least by the industry itself. Too often manufacturers have done as little as specifically requested by the customer, to produce clean assemblies. Although, externally, yesterday's appliances may have appeared as bright as new pins, internally, they could be compared to rusty nails. Cleanliness costs money, after all.

However, as modern electronics assemblies increase in complexity and packing density, so do requirements for cleanliness increase. Today's and, particularly, tomorrow's appliances have to be clean inside and out!

Where electronics manufacturers are persuaded to clean, usually just to follow specifications laid down by customers, they naturally use the cheapest method. In the past this was often a solvent cleaning method, with chlorofluorocarbons (CFCs) as the solvent.

The Montreal Protocol

Chlorofluorocarbons, in terms of cleaning ability alone, are excellent solvents. They rapidly clean printed circuit boards which have all sorts of soldering residues on them. However, chlorofluorocarbons are most definitely *not* excellent solvents in all other respects.

This is simply because chlorofluorocarbons readily vaporize into earth's atmosphere. In small quantities this is no problem, but in the large quantities manufacturing industries and their processes were discharging chlorofluorocarbon vapours (*all* manufacturing industries — not just electronics) there *is* a problem. Chlorofluorocarbons contain three particular elements: chlorine, fluorine and carbon, which are so inert they will stay in earth's atmosphere for — quite literally — hundreds of years before they can be broken down by ultra-violet energy from the sun.

In the quantities which chlorofluorocarbons were being vaporized into the atmosphere a catastrophic event began to occur — chlorine (directly attributed to vaporized chlorofluorocarbons) began to increase the rate at which ozone in the stratosphere was destroyed. In a steady state, ozone is naturally produced at the same rate at which it is destroyed by naturally occurring elements in the atmosphere. But with the chlorine produced from chlorofluorocarbons in the atmosphere, a steady state no longer exists. Ozone is destroyed at a faster rate than it is naturally produced.

Ozone has a job to do in the atmosphere. It absorbs ultra-violet and visible light from the sun, preventing it directly reaching earth. With less ozone in the stratosphere (caused by its unnatural destruction by chlorine from chlorofluorocarbons), more ultra-violet light from the sun reaches earth.

Unabated, chlorofluorocarbon vaporization will destroy ozone to the point where so much ultra-violet radiation reaches earth from the sun that life-forms are affected and, indeed, made extinct. Once this starts to happen, life-forms further up the food chain are affected.

Such was the concern globally that, in 1987 in Montreal, the Montreal Protocol had been devised, agreed upon and signed by many nations worldwide. Currently users of some 98% of all chlorofluorocarbons have signed.

The Montreal Protocol decreed that chlorofluorocarbon (and other similarly ozone-destructive materials such as halons) use should be restricted, with all nations agreeing to progressively reduce consumption. It is hoped that, eventually, it will become economically unviable to use these substances at all.

Provisions within the Protocol make additions to the restricted list of other substances possible. In this way, it is possible to ensure other substances are not seen as simple alternatives to chlorofluorocarbons and halons.

In the electronics industry, chlorofluorocarbons used to be seen as ideal cleaning agents. With global issues over-riding the use of chlorofluorocarbons, the industry is moved to find alternatives.The pressure is on to do this quickly.

Why clean at all?

Soldering, with its requirement for fluxes to aid the process, and resultant flux residues, is generally a messy business. Most fluxes and their flux residues are corrosive to a greater or lesser extent, so if they remain on the assembly, corrosion will occur. In the past, due to low packing densities and large components, corrosion may not have had an effect, if any, for years in an appliance's life.

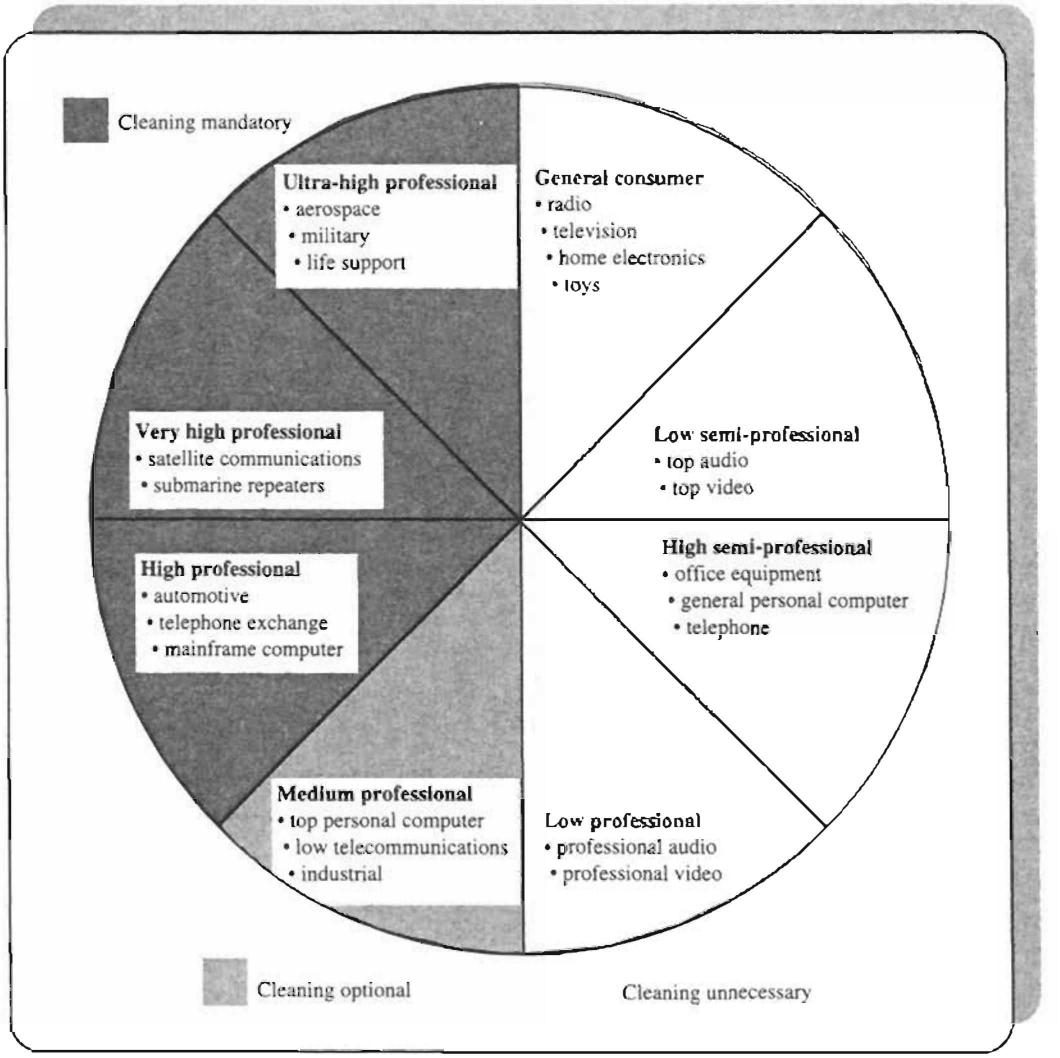


Figure 10.1 *Eight main categories of end use, showing cleaning as mandatory, optional or unnecessary*

If corrosion, even just a little on the other hand, occurs where high packing densities, extremely thin copper tracks, fragile components and so on, are present; then rapid malfunction may occur. Of necessity, therefore, manufacturers are forced to clean their products — simply to ensure a useful appliance life.

Yet there are other advantages to clean assemblies which manufacturers should see also as useful. These include:

- automatic test equipment access to test points
- easier visual inspection

- subsequent application of protective **conformal coatings** (see Chapter 3)
- ease of mechanical handling.

All these aspects help to improve quality and reliability of the product. All manufacturers, therefore, should view the clean assembly as part of the organization's defined quality assurance programme.

Nevertheless, there are many instances when cleaning is neither necessary nor specified. Grouping electronics assemblies into eight categories of end-use [Ellis, 1990 #25] and giving each category a quality rating, it is possible to see which products are cleaned mandatorily, optionally or not at all (Figure 10.1). Interestingly, the trend is to clean less and less, presumably as soldering processes improve and contamination of assemblies becomes less and less.

Contamination

Aim of cleaning is simply to remove contamination. To do this effectively and choose the best cleaning agent, therefore, knowledge of contaminants involved is vital. In other words, what is on the assembly which needs to be removed by a cleaning process?

There are three main sources of contaminant:

- printed circuit boards used in assembly manufacture
- components mounted in or on the printed circuit board
- soldering processes used.

While it is commonly accepted that contaminants from soldering processes — that is, flux and flux residues — form the main contributory factor why assemblies must be clean, the other two contamination sources are often forgotten or purposefully ignored. This is a mistake: all contamination sources should be considered.

Printed circuit board contaminants

These contaminants are generally introduced during manufacture of boards, so depend largely on specific processes used. Typical contaminants include:

- grease, from handling
- food
- tobacco
- epoxy resins
- glass fibres
- internal contamination of copper.

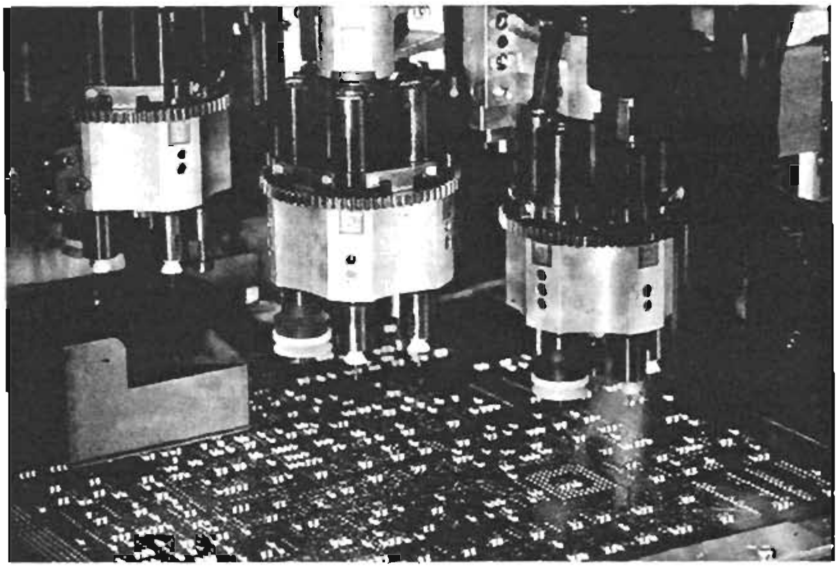


Photo 10.1 *Surface mount assembly manufacturing processes (Motorola European Cellular Infrastructure Division)*

Component contaminants

Like printed circuit board contaminants, most contaminants on components are due to residues of manufacturing processes. Typical contaminants include:

- grease, from handling
- food
- tobacco
- material defects
- internal contamination of component leads.

Soldering process contaminants

Contaminants here are more readily defined. They still, however, depend on process used. Typical contaminants are:

- flux
- flux residues
- solder balls
- internal contamination of solder
- internal contamination of solder paste
- grease, from handling
- food
- tobacco.

Quantities and exact forms of contaminants are impossible to predict — it all depends on processes used and working procedures followed. Consequently, any cleaning process used should, ideally, be sufficient to remove *all* possible contaminants. Further, contaminants of the first two types may have a deleterious effect on the soldering process. So it can be an advantage to clean *before* soldering as well as after. Such **pre-soldering cleaning** can drastically improve overall performance and yield, and mean lower activity fluxes can be used. This, of course, has a natural conclusion in the pre-cleaning of printed circuit boards, components and assemblies; followed by maintenance of clean conditions in, say, an inert atmosphere, prior to soldering (also in an inert atmosphere). Under such conditions — see Chapters 7 and 8, and later — there becomes no need for post-soldering cleaning processes.

Classifications of cleaner

Cleaning agents are classified in many ways. One of the most important classifications refers electro-chemically to what type of contaminant is to be removed. Often, contaminants are classed as ionic (sometimes called **polar**), or **non-ionic** (sometimes called **non-polar**) such as rosin flux residues and grease, referring to whether the materials' molecules are permanently polarized and dissociate to form ions in water, or not. This classification derives from military standards [Defense, 1975 #21; Defence, 1986 #22] for electronics assemblies, which have been used to determine contaminant amounts on soldered printed circuit boards by defining test procedures (detailed later, along with other test procedures). Many other standards follow these test procedures. A further classification of contaminants refers to particulates — debris from earlier processes of assembly. Table 10.1 lists typical contaminants within all three of these classifications.

A general rule-of-thumb is that where contaminants are ionic; clean the assembly with an ionic solution. Further, where contaminants are non-ionic; either convert them to ionic form and clean with an ionic solution, or clean with a non-ionic solution. Most particulates are typically removed in whatever cleaning process is used — the main exception being residues of solid solder, known as solder balls.

Ionic contaminants pose the most serious problem, as any atmospheric moisture during operational life will cause them to dissolve, maybe forming chemical reactions and carrying electric currents. It is *essential* they are removed. Non-ionic contaminants, although not so important to remove for atmospheric moisture reasons, may prevent correct circuit operation by

Table 10.1 Contaminants of soldered electronics assemblies

Ionic	*Non-ionic*	*Particulate*
Flux activators	Rosin	Dust
Plating salts	Grease	Solder balls
Fingerprints	Metal oxides	Fibreglass
Water	Mould release agent	Metal
Perspiration		Plastic
Etch residues		

forming insulating films on connectors and the like. It is *preferable* they are removed, therefore, from most assemblies. In certain cases, customer specifications may call for their removal, too.

Ionic solutions are usually based on water, sometimes de-ionized, sometimes with addition of alcohol or detergent. Non-ionic solutions, on the other hand, are usually solvents of some form. Obviously, water-based cleaning methods are generally preferable, being easier to handle and less likely to damage the environment, but the chosen cleaning method depends primarily on the contaminant.

Another common classification method for cleaning agents, groups them simply by chemical type. These include:

- chlorofluorocarbons
- halogenated chlorofluorocarbons (HCFCs)
- organic solvents
- semi-aqueous solvents
- water.

Chlorofluorocarbon cleaning agents

All things equal, a natural choice for a cleaning agent is simply the one which cleans to a desired level easily and cheaply. To this end, chlorofluorocarbon (CFC) solvents have been most popular to date. Chlorofluorocarbons are reasonably cheap in strict monetary terms and do an efficient job in removing most forms of contamination from assemblies, with a minimum of fuss within the production facility. Indeed, from their introduction to the finding that they damage ozone in the stratosphere, chlorofluorocarbons seemed to provide a more-or-less physically optimum cleaning method. For example, chlorofluorocarbon cleaning processes have several advantages over alternatives, including:

- cleaned assemblies come out of the cleaning machine dry
- low toxicity
- non-flammability.

This being said, alternatives must now be considered — if not immediately, then in the very near future. By the end of the century there will be no economic reason why chlorofluorocarbon usage should be maintained. Most manufacturers should wish to eliminate chlorofluorocarbon usage long before then, though. In effect, chlorofluorocarbons already are not considered an option in cleaning processes.

Halogenated chlorofluorocarbons

Although halogenated chlorofluorocarbons can be virtual replacements for chlorofluorocarbons (some can be used in unmodified equipment originally designed for chlorofluorocarbon use) they are also known to destroy ozone in the stratosphere. This is to a lesser extent, however, as they have a shorter lifetime in the stratosphere before being broken down by ultraviolet light. Nevertheless, they still do destroy ozone, merely less than longer-lasting chlorofluorocarbons. Consequently, long term use is not suggested, and most types of halogenated chlorofluorocarbons can be expected to be phased out under governmental command in the medium term.

On the other hand, for a short while (say, 15 to 20 years) halogenated chlorofluorocarbon solvents will be used by some assembly manufacturers as a stop-gap cleaning process. Halogenated chlorofluorocarbon processes have the same primary benefits as chlorofluorocarbon processes.

Organic cleaning agents

Cleaning agents in this group are those alcohols, ketones and esters which dissolve contamination present on soldered printed circuit boards. These products have been used for assembly cleaning for many years — long before adoption of chlorofluorocarbons, in fact. Iso-propyl alcohol, for example, is a well-known and effective solvent for cleaning rosin flux residues.

Organic cleaning agents are quite inexpensive and they do not harm the environment. On the other hand, their cleaning potential is not so great as chlorofluorocarbons and halogenated chlorofluorocarbons, and they are flammable. Nevertheless, now that ozone-destroying chemicals are to be phased out, organic solvents once again become more important. Cleaning techniques and processes can overcome these solvents' lower cleaning abilities, and safer handling and usage procedures can counteract their flammability.

Semi-aqueous cleaning agents

Despite their name, cleaning agents in this group aren't mixed with water in any way. The name merely refers to the method in which they are used: a solvent is first used to dissolve contaminants into a mixture on the surface of the assembly, then water is used to wash off this mixture.

Solvents used in semi-aqueous cleaning processes are typically based on the range of biodegradable hydrocarbon chemicals known as terpenes. While they have reasonably effective cleaning properties, they are quite flammable and are considered volatile organic compounds (VOCs) so features have to be built into semi-aqueous cleaning machines to closely limit emissions. Newer chemicals under development will improve both cleaning and combustion characteristics.

Semi-aqueous cleaning solvents contain no chlorine so pose little threat to the environment in the way chlorofluorocarbons and halogenated chlorofluorocarbons do. Further, they tend to have quite low vapour pressures so atmospheric emissions are minimal.

Current aim of semi-aqueous cleaning machine manufacturers is to develop a process in which both solvent and water are totally recycled. Such closed-loop systems naturally prevent volatile organic compound emission.

Water

Depending on contaminants to be cleaned from soldered assemblies, water (or water with added chemicals) can form a satisfactory cleaning agent. Water is, quite naturally of course, an ideal solvent for ionic contaminants and for those fluxes whose residues are water soluble.

In addition, some non-ionic contaminants such as rosin flux residues can be successfully removed by a water and chemical mixture. Here, alkaline is added to the water and used to remove contaminants by converting rosin to a water-soluble, or at least water-washable, material called a **rosin soap**. This rosin soap can then be removed with water. The reaction required to convert rosin to rosin soap is known as **saponification**. This method is becoming increasingly popular, due to its environmentally friendly nature.

Similarly, a detergent or a **surfactant** can be added to water to aid removal of contaminants. Surfactants (*surfactant* is a contraction of the term *surface active agent*) have the effect of lowering water's surface tension, so allowing it to remove non-saponified contamination as well.

A simple technique to perform water cleaning is the use of a household dishwasher. Generally, a dishwasher provides adequate heating and agitation to do the job, at a reasonable cost. Time for a cleaning programme, however, and batch operation prevents use in high-volume production lines.

Despite the advantages of relative simplicity that water (and semi-aqueous, for that matter) cleaning processes offer, manufacturers must be aware of the damage water itself can do to assemblies. Salts in water, even at extremely low concentrations such as found in tap water, produce the very effects of ionic dissociation the cleaning is intended to remove. Further, water intake by capillary means may take these contaminants inside components. A final rinse in deionized water (which may not, incidentally, be capable of removing capillary-ingressed contaminants), followed by thorough drying is essential. Drying (usually in the form of air knives to blow off excess water, followed by baking) is an energy-consuming operation, which may be a bottleneck in the production process.

Water treatment

Currently, there is a move towards restrictions on amount and type of water effluent. For this reason, manufacturers offer water treatment systems. These have the function of removing as much effluent as possible from the water used in a water cleaning system.

Cleaning processes

For all the many types of cleaning agents used in electronics assembly cleaning, there is only a limited number of processes used to create the cleaning action. Many of these processes can be used or adapted for use with several cleaning agents.

Cold cleaning

The term cold cleaning refers to processes which clean soldered assemblies with a liquid. The liquid can, however, be hot or cold — just not a vapour. There are six main cold cleaning methods:

- dip cleaning
- wave cleaning
- brush cleaning
- spray cleaning
- centrifugal cleaning
- ultrasonic cleaning.

These are now considered.

Dip cleaning

This method of cleaning immerses the soldered electronics assembly into successively cleaner baths of the cleaning agent. It is a quite inefficient method of removing contamination, though has its functions in certain cases.

Wave cleaning

This is a similar operation to wave fluxing and wave soldering, in that soldered assemblies are conveyed through a wave of cleaning agent. Due to the nature of the process, only solvents which do not evaporate greatly can be used. Also, assemblies are in contact with the cleaning agent for just a small time, so aggressive solvents are required.

Brush cleaning

There are two methods of brush cleaning. In the first, known as underbrush cleaning, two or three rotating brushes are partially immersed in cleaning agent, as shown in Figure 10.2. They rotate (usually in opposing directions) while the assembly is conveyed above them. The brush bristles carry the cleaning agent up to the underside of the assembly, scrubbing it and dissolving contaminants simultaneously. Typically separate tanks of cleaning agent are used for each brush, so the assembly is cleaned by progressively cleaner agent.

In the second type of brush cleaning (Figure 10.3), the brush is positioned in a wave of cleaning agent, so simply adds a scrubbing action to the wave cleaning action.

Spray cleaning

Spray cleaning is a method whereby solvent is effectively agitated to aid the cleaning function. Typically, solvents are sprayed onto the assembly from

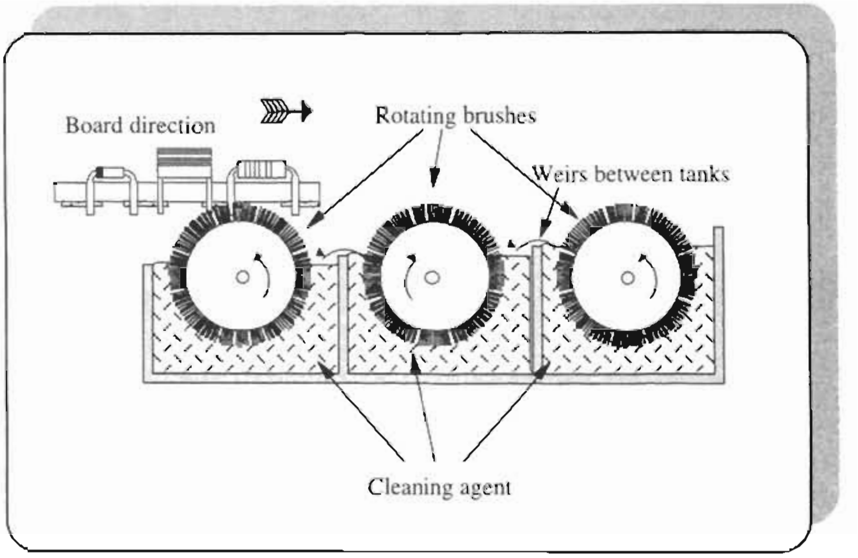


Figure 10.2 *Underbrush cleaning*

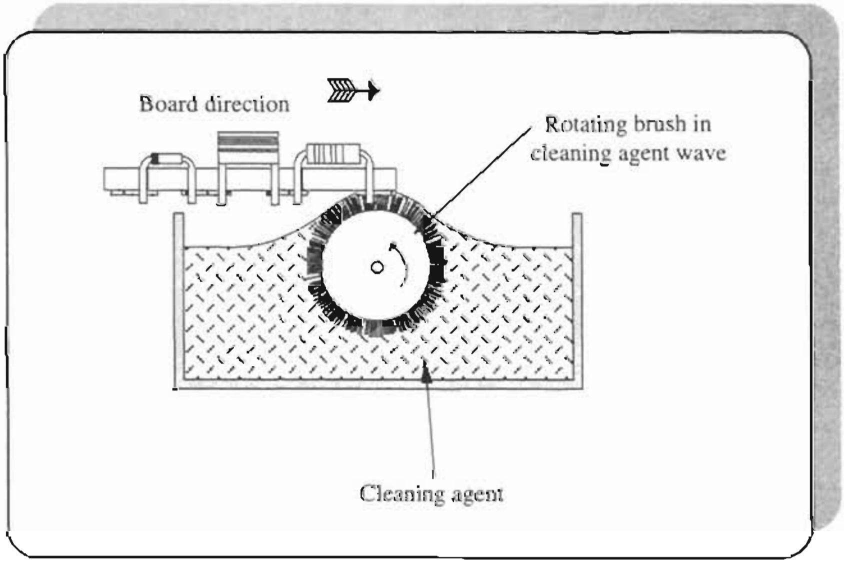


Figure 10.3 *Brush cleaning in wave of cleaning agent*

high-pressure spray nozzles. Assemblies can be above level of solvent in the solvent bath, or immersed in solvent. Where assemblies are over the level of solvent (Figure 10.4a) processes are called **spray-over-immersion** processes, while if assemblies are immersed (Figure 10.4b) they are known as **spray-under-immersion** processes.

Spray-under-immersion systems produce much less solvent mist than spray-over-immersion. Solvent mist is a problem associated particularly with semi-aqueous processes (although it can be a problem with organic

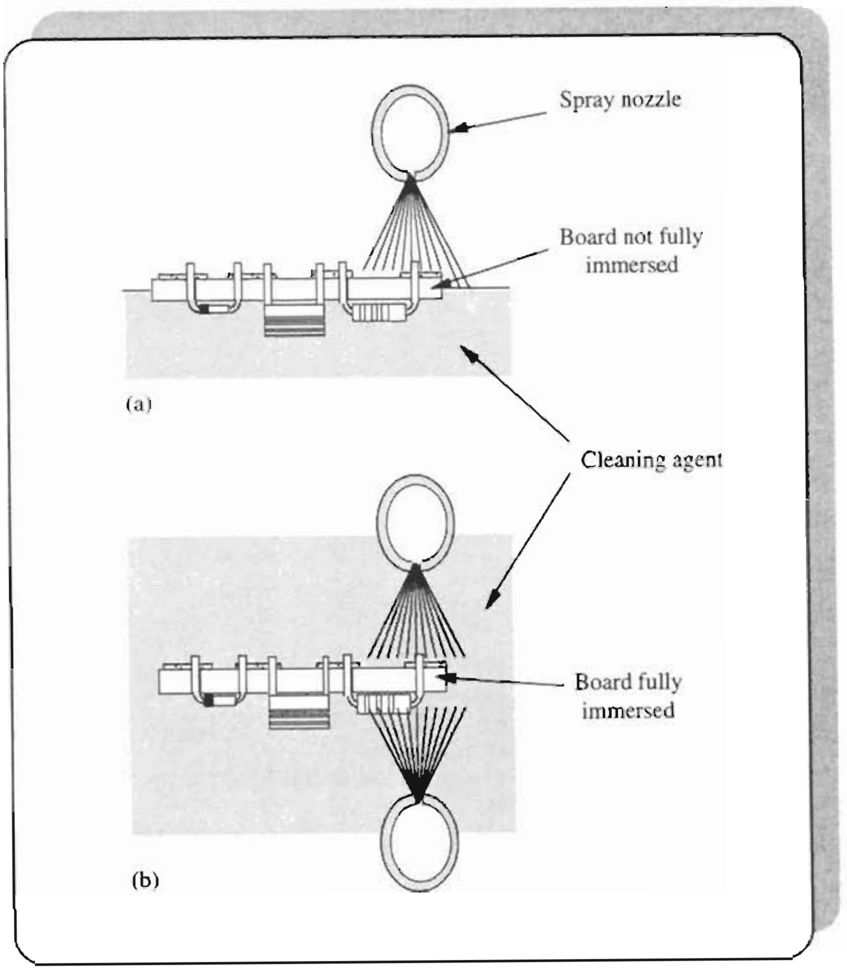


Figure 10.4 *Spray cleaning (a) spray-over-immersion (b) spray-under-immersion*

solvents and chlorofluorocarbons, too). First, it creates an increased flammability risk which must be counteracted somehow. Second, it implies more solvent vapour is released into the atmosphere and creates an odour. Some semi-aqueous solvent odours can be quite overpowering — smelling, say, of pine or oranges. Spray-under-immersion processes maintain good agitation to force solvent under and around even the finest pitch components while keeping odour levels to a minimum.

Shape of the sprayed cleaning agent is important. By careful design, spray nozzles can direct the spray in a controlled manner onto the soldered assembly. One type of nozzle, called a **coherent jet**, directs cleaning agent vertically onto the printed circuit board surface (Figure 10.5a). Here the cleaning agent is then forced out radially from the point of impact. This occurs with great turbulence, forcing the agent underneath components and allowing it to clean even densely populated surface mounted assemblies.

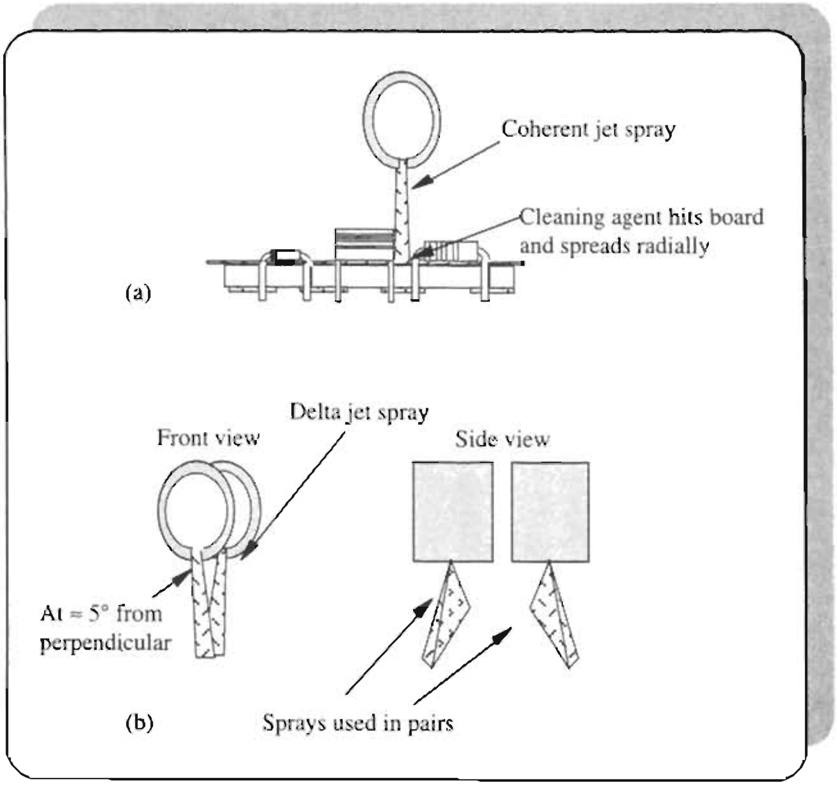


Figure 10.5 *Spray design (a) coherent jet spray (b) delta jet spray, normally used in pairs of jets*

Another nozzle type produces a **delta jet** of cleaning agent, where a narrow, flat spray results, usually at a small angle (around 5°) from perpendicular. Delta jet nozzles are often paired so that alternate nozzles direct cleaning agent in opposing ways (Figure 10.5b).

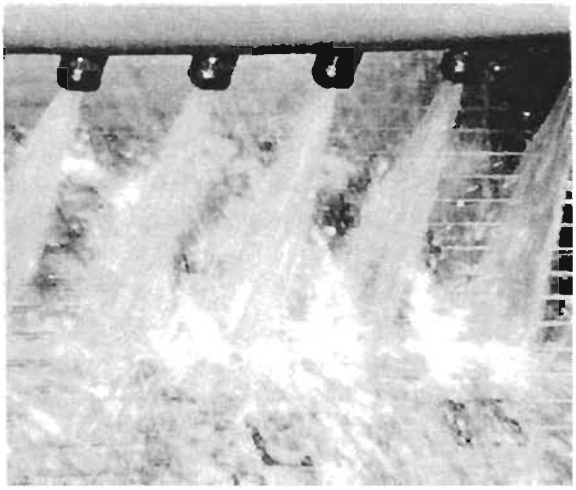


Photo 10.2 *Aqueous cleaning, using jet sprays (Speedline Electrovert)*

Volume of cleaning agent sprayed onto an assembly, and pressure this occurs at can usually be varied to suit applications. A high enough volume is required to ensure flux residues are removed, but a high enough pressure is also critical to ensure pentration under small, surface mounted components.

Typically, a mixture of jet types, volumes and pressures are used within a single spray cleaning machine.

One adaptation of spray cleaning commonly used is **emulsion cleaning** — in which water with another cleaning agent is used to wash off contaminants. A decant tank typically allows solvent to be separated and returned to the solvent stage tank. Simultaneously, water may be recycled back to the emulsion stage tank. A final one or two rinses of plain water or a vapour stage (see later), may follow the emulsion stage.

Centrifugal cleaning

Like spray cleaning, centrifugal cleaning is an agitation process, simply to aid the cleaning function. There are two main methods: **spin-under-immersion** — in which assemblies are spun under the surface of the cleaning agent — and **spin-under-spray** — in which assemblies are spun while cleaning agent is sprayed on them from a high-pressure spray nozzle. Those processes which create significant solvent mist typically reduce flammability hazards by using an inert atmosphere of, say, nitrogen, around the agitation process.

Ultrasonic cleaning

Ultrasonic cleaning methods form yet more ways in which solvents are agitated to aid the cleaning function. There are three basic ultrasonic approaches. In the first, the cleaning agent is agitated by application of ultrasonic energy to the liquid, creating a mechanical oscillation of an amplitude and frequency which the liquid is unable to follow. This creates periodic pressure variations within the liquid which generate cavities in the form of bubbles at low pressure points, then consequent implosions of these bubbles at high pressure points. Energy from these implosions acts as shock waves on the surface of the assembly passing through the cleaning agent. These shock waves are very effective in dislodging contaminants.

Second ultrasonic cleaning method imparts ultrasonic energy into a cleaning agent at or near its boiling point. At these temperatures the ultrasonic energy doesn't create imploding cavities. Instead it simply creates waves on the surface of the liquid which are used to force the liquid into small spaces beneath components, so aiding cleaning.

Ultrasonic energy is imparted into a spray of cleaning agent, in the third method of ultrasonic cleaning. The ultrasonic energy aids the cleaning process by reducing the cleaning agent's surface tension, so allowing it to get underneath small components.

Vapour-liquid solvent cleaning

This, the main alternative to cold cleaning, uses a cleaning agent heated to boiling point to form a layer of vapour through which the soldered electronics assembly passes. Typically, the assembly is immersed alternately in a bath of liquid. Figure 10.6 shows a typical vapour-liquid solvent cleaning machine, in which three main sections exist. First section is a vapour stage, followed by a second section immersion in liquid, followed by a third section vapour stage.

An advantage of vapour-liquid solvent cleaning is the lack of requirement to dry assemblies — they emerge dry from the final vapour stage.

An alternative to simple vapour-liquid solvent cleaning (Figure 10.7) uses a multi-stage process, incorporating vapour pre-wash and rinse-dry stages at entry and exit. These are coupled with two immersion in liquid stages, joined with a central spray cleaning stage.

Ancillary processes

Allied with these main processes in cleaning electronics assemblies, there are some related processes which either aid the cleaning function, or are necessary in completing it.

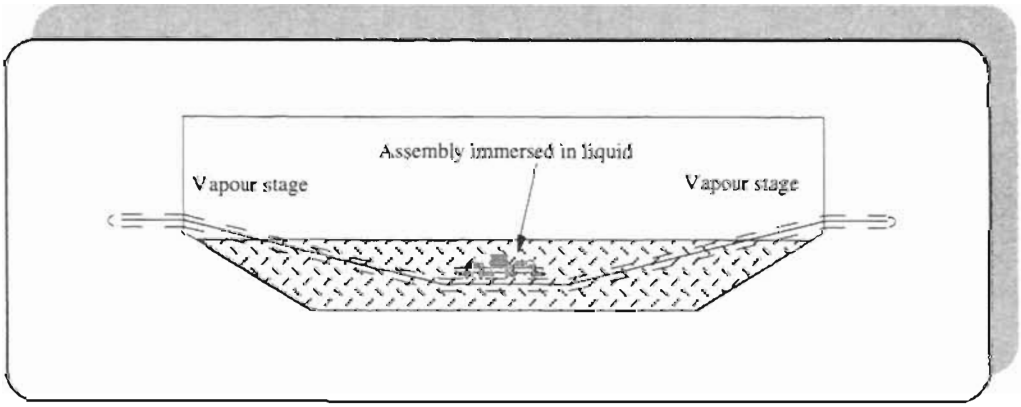


Figure 10.6 *Principle of a vapour-liquid solvent cleaning machine*

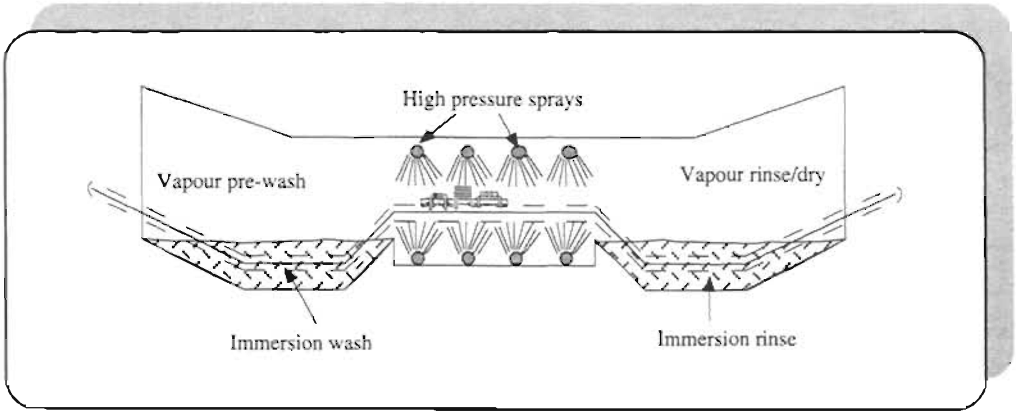


Figure 10.7 *Principle of a multi-stage vapour-liquid solvent cleaning machine, where vapour pre-wash and vapour rinse-dry stages are included at entrance to and exit from the machine*

Drying stages

After water or semi-aqueous cleaning processes, there must be some form of drying stage, to ensure that all traces of water are removed from assemblies.

A basic process is illustrated in Figure 10.8, which shows how the two cleaning stages of a possible semi-aqueous cleaning machine are followed by an integral drying stage. Infra-red heater panels are typically used as heating elements. Temperatures of upto about 260°C are common in drying stages.

Air knives

Some manufacturers use air knives at the exit of the first stage of semi-aqueous cleaning machines, to help prevent contaminants and solvent being dragged out on assemblies to subsequent stages. However, air knives tend to create a degree of solvent mist which is extracted by the machine exhaust system, out of the machine. Machines with air knives are usually fitted with some form of filter in the exhaust system, for this reason.

Drag-out of contaminants from the solvent cleaning stage is an important topic in semi-aqueous cleaning processes. If no drag-out occurs — say, air knives are used to *totally* eliminate it — concentration of contaminants in the solvent bath build-up to the point where the solvent no longer functions and must be replaced. Cleaning performance consequently varies with time from last replenishment.

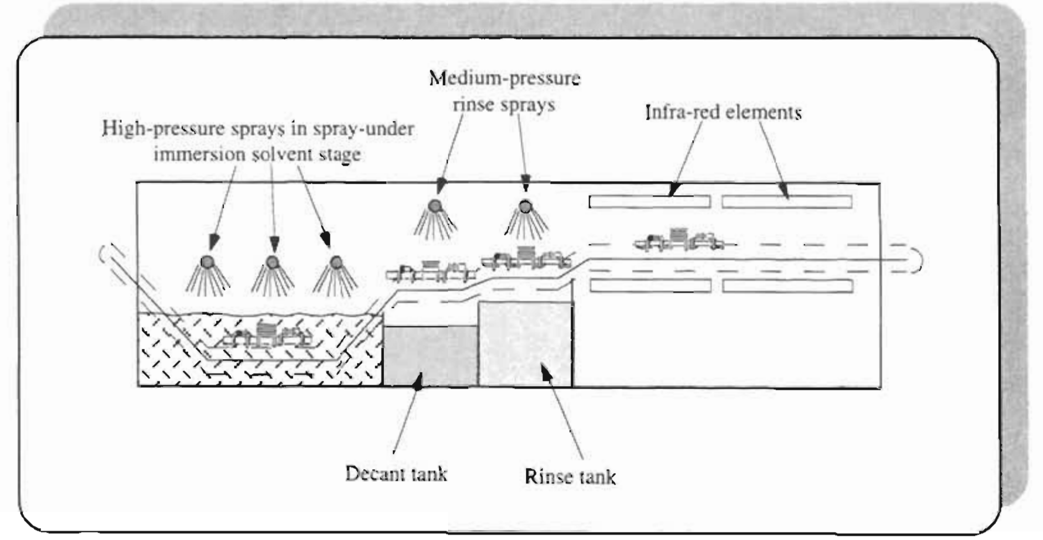


Figure 10.8 *Semi-aqueous cleaning machine, showing spray-under-immersion solvent stage, followed by medium-pressure spray rinsing stages, and a final drying stage*

Instead, some degree of drag-out of contamination is best, to ensure cleaning performance of the solvent stage continues unaffected with time. Effectively, the system reaches a steady-state, where level of contaminants on assemblies cleaned equals level of contaminants dragged out of the solvent stage. Contamination dragged out from the solvent stage is then removed in one or more following washing stages. Typically, this is done in an emulsion cleaning stage.

Photo 10.3 *Aquastorm 100 aqueous cleaning machine (Speedline Electrovert)*

Photo 10.4 *Aquastorm 100 aqueous cleaning machine in action (Speedline Electrovert)*

Air knives are almost universally used in the drying stage of semi-aqueous cleaning machines. Here they provide one of the best methods of removing excess water from the water washing stage.

No-clean options

While cleaning of electronics assemblies is necessary for many types of soldering processes and fluxes, for completeness here we must consider those soldering processes which do not need to be followed by cleaning stages. They are covered eleswhere in the book in greater depth but a general description here is worthwhile.

No-clean fluxes

These are considered in Chapter 5, as flux types. A no-clean flux is simply one which can be left on the electronics assembly, after soldering. While there are many new fluxes specifically designated no-clean, it should be remembered that basic rosin fluxes have allowed a complete lack of cleaning in certain applications for many years. These new fluxes, however, ensure that assemblies with dense populations of components can still be manufactured without cleaning.

No-clean fluxes, though, still leave residues, albeit in minute amounts. While residues are non-corrosive and do not affect an assembly's electrical performance, they can still cause problems in test stages, where test probes become gummed up with the no-clean flux residue.

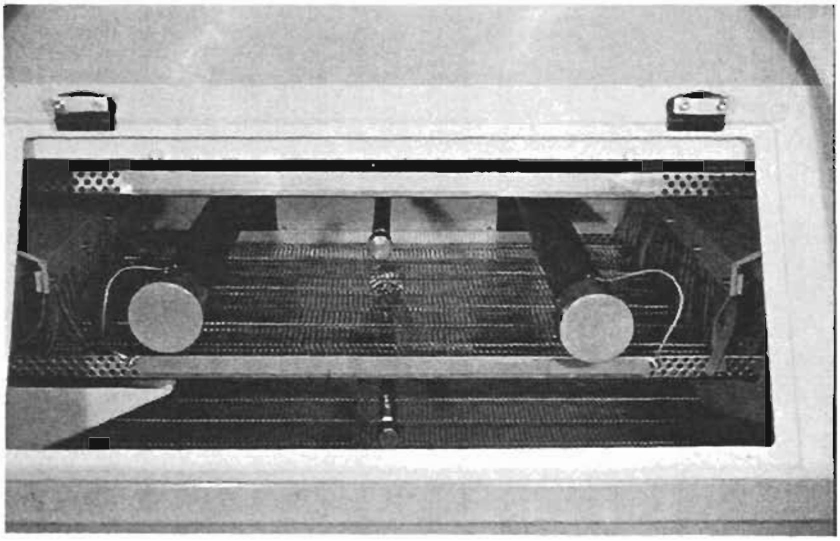


Photo 10.5 *Looking through the inspection window of an Aquastorm 100 aqueous cleaning machine (Speedline Electrovert)*

Inert atmosphere soldering

Chapters 7 and 8 consider inert atmosphere CS and SC soldering processes, in which assemblies are soldered in an atmosphere of almost pure nitrogen. Lack of oxygen in the immediate atmosphere around an assembly as it is soldered ensures solderability of metals is high. This means fluxes used can be only marginally (if at all) active and so residues may not need to be cleaned off after soldering. Indeed, in certain instances, it might be that — to all practical purposes — no residues are left at all.

Contamination testing

After soldering an assembly, it is often necessary to measure any contamination present. There are many methods of detecting levels of contamination including, in order of popularity:

- ionic contamination testing
- surface insulation resistance testing
- acetonitrile testing
- atomic evaporation contamination testing.

There are also tests which detect specific contaminants such as rosin, or polymeric organic materials. Generally, though, only the first two in the list are used.

Ionic contamination testing

Although practical procedures exist to allow ionic contamination testing, it's more usual to use proprietary instruments which allow measurements both simply and accurately. In all available instruments a pure solution of alcohol in water is used to dissolve contamination on the soldered assembly. This causes the solution's conductivity to rise, which gives an indication of contamination amount. There are differences in interpretation of what the measured conductivity actually means in terms of contamination amount, however, varying between instrument manufacturers. There is no standard interpretation, although the International Technical Commission is currently defining a method to calibrate instruments for inclusion into national standards; so at least all calibrated instruments will give equatable results.

Often instruments spray heated solution onto assemblies, in an effort to dissolve contaminants underneath components with a low stand-off; such as some surface mounted components. Other instruments use no agitation or heat, but extrapolate results mathematically. Extrapolation often leads to reduced test times.

Surface insulation resistance testing

This testing method relies on the resistance between two probes being a product of leakage paths through contaminants on the surface of an assembly. To carry out a surface insulation test, resistance is usually

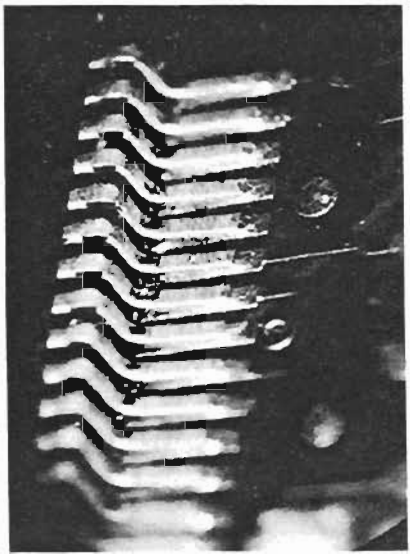


Photo 10.6 *Close-up of gull-winged surface mounted component, soldered to a printed circuit board (Vision Engineering)*

measured under environmental conditions beyond those of normal working, for lengthy test-times; in an attempt to induce worst-case conditions.

Results for surface insulation resistance tests are often varied and, thus, inconclusive. Despite many standards existing on procedures, no single method is available which accurately and repeatedly allows reliable contamination measurement.

Visual examination

While not allowing any exact assessment of amounts or types of contaminants ie, it is only a qualitative test, visual inspection — particularly with magnification and video display — is a common option used in the electronics assembly industry. It proves useful in many cases.

Typical contaminants which can be directly seen, or whose effects can be seen, include:

- white residues — thin contamination films, typically resulting from poor soldering process control
- flux and solder spatter — remaining after CS soldering processes
- solder balls — remaining after SC soldering processes
- abrasive particles from mechanical cleaning processes
- corrosion products or salts remaining from plating processes
- fingerprints — likely to prove existence of grease
- dust.

Photo 10.7 shows a comprehensive visual inspection system, while Photo 10.8 shows a system with hand-held microscope.

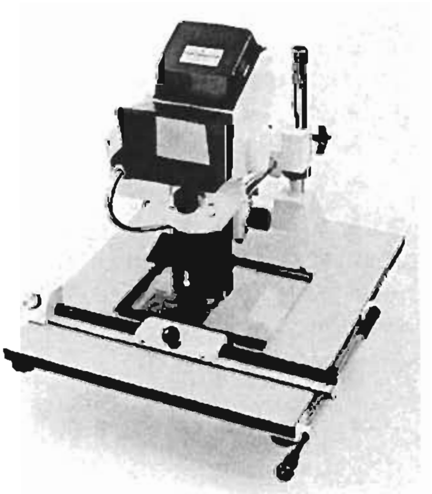


Photo 10.7 *Visual inspection system, for close-up examination of electronics assemblies (Vision Engineering)*

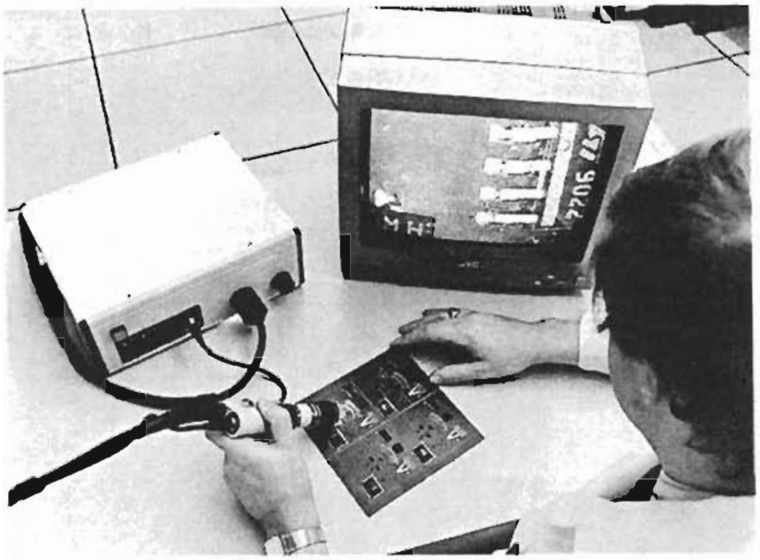


Photo 10.8 *Visual inspection system incorporating a hand-held microscope (Leica UK)*

Comparing the cleaning options

Figure 10.9 (over) lists main advantages and disadvantages of the various cleaning agent groups. It also takes into consideration options of using no-clean fluxes (see Chapter 5) and inert atmosphere soldering (see Chapters 7 and 8) which reduce or even negate requirements to clean assemblies separately. In this light, Figure 10.9 summarizes all the post-soldering cleaning options now available to the electonics assembly industry. It is based quite closely on Dr Colin Lea's authoritative quantification of the options [Lea, 1992 #24]. Readers wishing a more in-depth understanding of the environmental and cleaning issues involved are advised to consult his book.

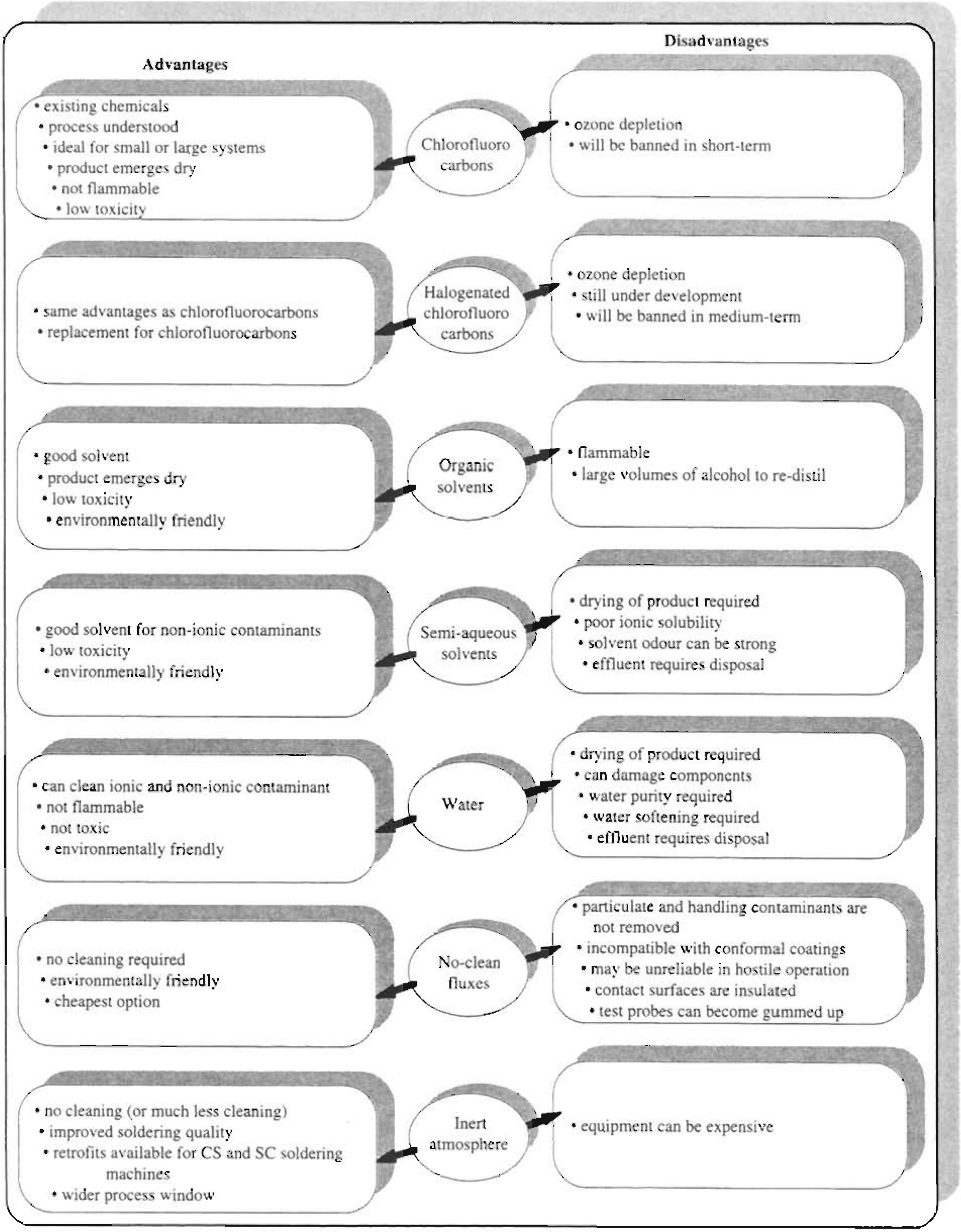


Figure 10.9 *Post-cleaning options available to electronics assembly manufacturers (after Dr Colin Lea)*

11 Avoiding problems — soldering quality

Problems in soldering of electronics assemblies are legion. Processes are necessarily complex and variable. Assemblies vary considerably in requirements. New component types or assembly methods place new emphases on processes which, in turn, create new problems.

Problems cause defects. Whether these defects cause total failure of an assembly immediately — such that it doesn't work at all — or whether they cause partial failure after a product is in service for many years, should be largely irrelevant to the manufacturer. Product failure of any type implies poor reliability and manufacturing goal must be high reliability.

Problems can occur at any stage within the manufacturing process. Design, fabrication, assembly or soldering stages are all susceptible to problems, and these varied problems often cause defects which may be very similar and so make isolation of individual problems difficult. Consequently, isolation of problems is of great concern in electronics assembly manufacture. To reiterate: maintaining high reliability of appliances depends on there being no problems.

This leads us to three stages to consider. First thing we need to look at is — what defects are likely to occur? Then we need to consider — how do we determine what problems have occurred to cause those defects? Finally — how do we determine solutions to problems? If we can do this, a logical step-by-step approach can be constructed, which allows reasonably simple identification and correction of defects.

Of course, the ideal situation is one in which manufacturers control their manufacturing processes to an extent where problems do not happen. In turn, no defects occur and products are totally reliable. In other words: a zero defects scenario. In practice, this situation rarely exists — though must be our aim.

With any defect it's important to remember that problems which cause it can occur in any of the manufacturing stages: design, fabrication, assembly or soldering. Defects which, on the face of it, look like soldering defects may be caused by an entirely separate though not unrelated problem.

Have problems occurred?

Manufacturers control quality of their products by some method of **process control**. In the minimum, process control is exercised simply by looking at finished products and saying *yes, it works* or *no, it doesn't*. If the product doesn't work, this has to be qualified with identification of defects. Then, problems which cause the defects must be isolated and corrected.

In effect, even in this simplest of manufacturing process control operations, products are measured against an acceptable quality standard. If they are as good as or better than the standard the manufacturing process can be called **in-control**. If products are not as good as the standard, on the other hand, the manufacturing process is **out-of-control**.

Statistical process control

When manufacturers turn to a mathematical model to describe manufacturing process control operations, it is termed **statistical process control** (SPC). Then, product variables and attributes are mapped as distributions. What those variables and attributes are depends on what the manufacturer perceives as important. Typically, variables are characteristics which take the form of real values such as assembly size, weight and so on. Attributes are either/or characteristics, such as good/bad, there/not there, pass/fail and so on. Standard values for all variables and attributes must be first determined.

By measuring variables and attributes for each product as it is manufactured, distribution curves for a particular batch of products can be built up. A distribution occurs simply because measurement of any product's characteristics always shows some variation from the quality standard, no matter how small the variation is. Then, **acceptable limits** for variations must be determined.

Variation from standard — often known as a **tolerance** — is the result of one or more causes. There are two main types of cause:

- **common causes** — random variations which always occur to some extent in all processes. They are not usually cost-effective to eliminate, but as long as they can be maintained sufficiently low in number or effect are usually ignored

- **assignable causes** — large, unpredictable variations which must be identified and rectified.

If only common causes of variation occur, manufacturing processes are in-control and future quality is predictable. This is shown in Figure 11.1.

On the other hand, where assignable causes of variation occur, processes are out-of-control and future product quality is unpredictable (Figure 11.2).

Where a process is in-control and quality tolerances are within acceptable limits the process is known as a **capable process**. This is shown in Figure 11.3a. A situation can arise, on the other hand, where processes are predictable so are in-control, but still having quality tolerances outside acceptable limits (Figure 11.3b). Such a process is called an **incapable process**.

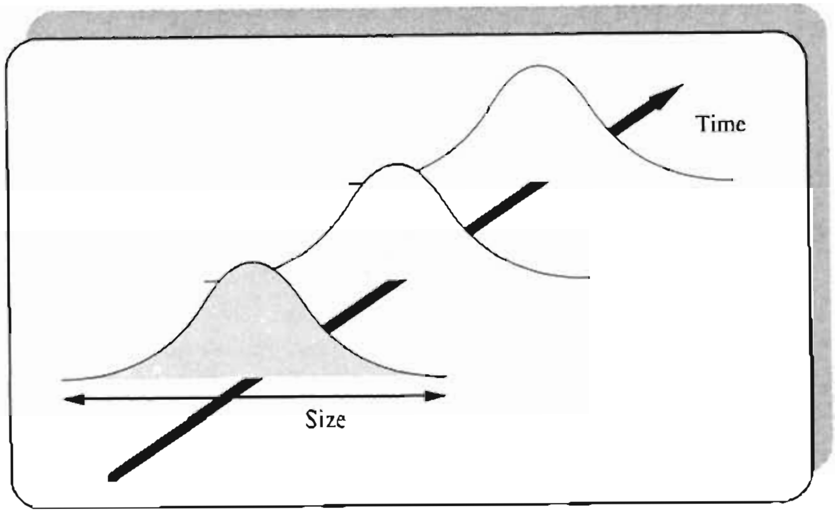


Figure 11.1 *A process which is in-control produces only random variations falling within acceptable limits*

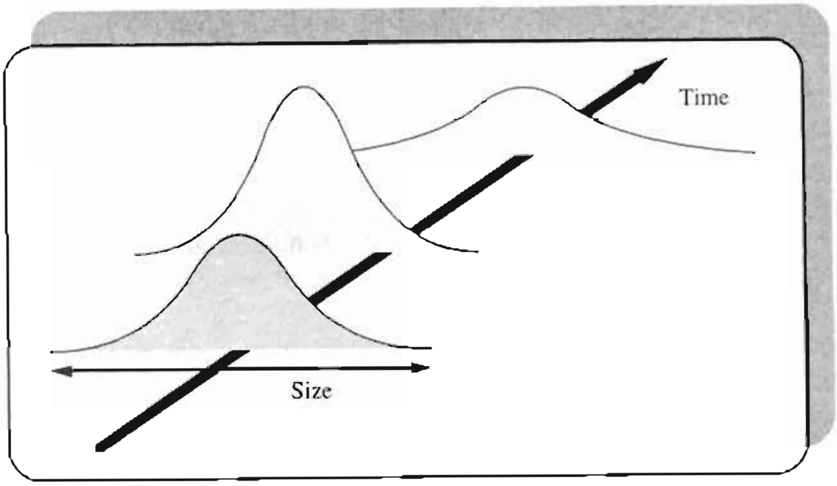


Figure 11.2 *A process is out-of-control when assignable causes of variations occur which produce unpredictable, unacceptable results*

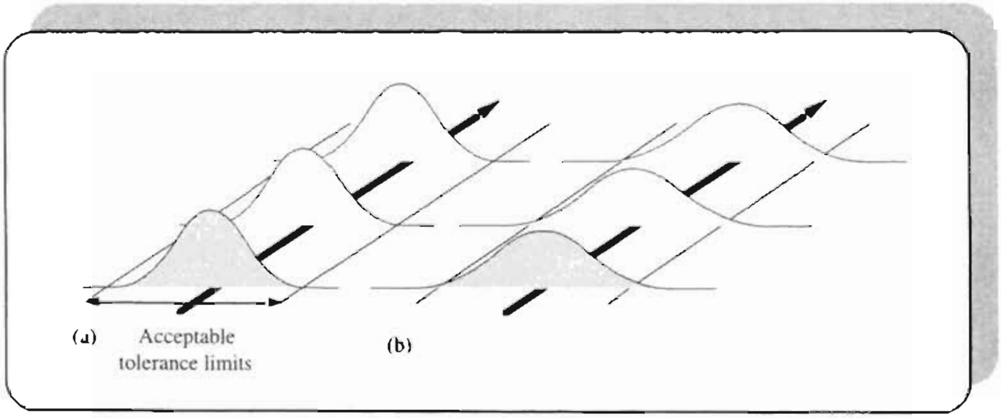


Figure 11.3 *A process may be (a) capable; in-control and within acceptable limits, or (b) incapable; in-control and outside acceptable limits*

Defining acceptable quality tolerance limits

Product quality is totally defined by how much margin exists between the *ideal* quality standard of variables and attributes and the product's *actual* values of variables and attributes.

Size of this quality margin depends basically on product design. A poorly designed product has a small margin; a well-designed product has a large margin. If only a small quality margin exists, more products can be expected to fall outside the acceptable limits and to have defects.

Margins are expressed as a number of standard deviations from the mean of a distribution curve. A **normal distribution**, for example, is expressed as being between $\pm 3\sigma$ (plus-or-minus three sigma) about the mean. Consequently, a process having a normal distribution produces around 997,300 parts per million within the normal distribution limits. However, the remainder (around 2700 parts per million) fall outside the limits and so are unacceptable in terms of quality.

So, for an electronic product with, say, 1000 parts, some 2.7 defects per product can be expected. Not good enough!

For this reason, a good choice for variation of acceptable limits is $\pm 6\sigma$. Then, only around 3.4 parts per million can be expected to be defective. With a product having 1000 parts, only 0.0034 defects can be expected in each product. Put another way, for 1000 products, less than 4 will not function correctly. Processes following these limits are called **six sigma** processes. Products manufactured in six sigma processes must be designed to operate acceptably as long as they fall within the limits.

Solutions to problems

Calculating mathematically whether a problem exists is one thing; finding the assignable cause — hence determining the problem — is another. Mathematically, this can be done if sufficient experience exists within the automating process. More often, though, problems are isolated in a much more ad hoc manner. With this in mind, Appendix 2 lists common problems of electronics assembly soldering and some possible solutions. Note not all problems are related specifically to soldering processes. Design, fabrication and assembly processes can also create problems, which manifest themselves as apparently soldering-related defects.

Assessment of quality

Assessment of soldered joints, till just a few years ago, usually involved little more than a careful visual inspection. Joint sizes of, then current, through-hole assemblies were often sufficient to warrant only an inspection with the naked eye. Further, incorrect joints of this type are easy to detect, having vastly different characteristics to good joints. Often, it's a simple matter of glancing at joints to make sure they all have smooth and shiny concave surfaces — any without these attributes are faulty.

These days, on the other hand, large through-hole joints are becoming less the norm, more the exception; as miniature surface mounted components find their ways onto more and more printed circuit assemblies. Further, solder finish of surface mount joints is not generally smooth and shiny; so what would appear to be a faulty joint when compared with through-hole joints, may well be a perfect surface mounted joint. Couple this with the fact that visual inspection, at least by naked eye, is not generally sufficient to detect most faulty surface mount joints, simply because they are so small. Aided by optical magnifiers, though, it is still possible to isolate many faults, albeit in a time-consuming process.

Successful soldering depends, to a large degree, on a number of individual contributing factors, eg solder alloy, paste type, flux, wave form, soldering iron tip, reflow temperature, design of soldering lands, the shape and material of component leads, materials and finishes.

The method used to produce soldered joints, without affecting the reliability, may affect the visual appearance. In this respect hand soldered joints may vary from machine soldered joints, as will the appearance when using other production processes. This should be taken into consideration when assessing soldering quality.

Criteria for the assessment of soldered joints

Several aspects of soldered joints need to be assessed.

Solderability

Solderability is the ability of a surface or surfaces to be wetted with molten solder resulting in the formation of a smooth, continuous solder film or fillet.

Good solderability of all surfaces to be joined should be a pre-requisite for the production of good quality soldered joints.

Poor solderability results when surfaces to be joined are not in the correct combination. This results in non-wetting, de-wetting or a combination of both and gives rise to poor quality soldered joints.

Inspection of soldered joints should be conducted under conditions of adequate lighting with use of approximately x5 magnification. If required, a maximum of x10 magnification may be used in cases where the joint standard cannot be judged, at x5.

An acceptable joint can be judged by the wetting produced between the component and the board. Limited penetration of solder on boards containing plated through-holes, provided it is not widespread, is acceptable but the process, components and board should be investigated to assess the cause.

Non-wetting

Non-wetting is the incomplete wetting of the base metal or metals and surfaces to be joined which results in the formation of discontinuous solder fillets.

In non-wetted areas, colour of surfaces to be joined is visible. Hence, where the base metal is copper, non-wetting is clearly distinguished. However, on plated through-hole printed circuit boards with a tin/lead coating on the conductor and lands, non-wetting may not always be clearly visible.

De-wetting

De-wetting of a solder coating presents an appearance similar to that of water lying on a grease-contaminated surface. It arises when molten solder, after initially wetting a surface, retracts into discrete globules and ridges which exhibit high contact angles. The areas between globules and ridges retain a solder colour, even when the base metal is copper, but solder coating in these areas is extremely thin.

Characteristics of soldered joints

Good and bad characteristics of soldered joints appear in many combinations and to various degrees. Assessment of soldered joints is subjective and evidence of some poor characteristics does not necessarily indicate a faulty joint.

Good characteristics

There are several common aspects of good soldered joints:

- good solder wetting of the component lead or termination and PWB land
- formation of a solder-cone with a concave fillet, the solder cone tapering off evenly towards the tip of the component lead
- evidence of capillary action in plated through-holes on mixed technology boards (viewed from the components side of the printed circuit board)
- sufficient quantity of solder on the soldered join with the profile of the component lead or wire visible
- smooth and shiny appearance, generally. High temperature solders may have a dull appearance.

Poor characteristics

As there are common aspects of good soldered joints, so there are common aspects of poor soldered joints:

- incomplete wetting of component lead or termination or printed circuit board land
- insufficient solder leaving the component connection exposed
- insufficient penetration of solder in plated through-holes
- excess solder, where it appears widespread
- voids and surface contamination both metallic and non metallic
- solder spikes and bridges on the component lead or printed circuit board land.

When examining solder joint wetting angles, consideration should be given to the board design and land areas as this may affect the shape of the joint. Depending on the process used for assembly this will also affect the appearance. In cases where too much solder has been applied this may give the appearance of a bad wetting angle. Where this is evident, the process of assembly shall be examined.

Classification of soldered joints

During assessment of soldered joints by Inspectors or operators the following classifications are useful:

- satisfactory — preferred condition which should be achieved and used as the standard for manufacture
- acceptable — this condition represents the maximum acceptable departure from the 'satisfactory' condition. Joints within this limit of deviation will not require reworking. Individual clarification accompanies each illustration
- unacceptable — applies to an unacceptable joint condition which should not be reworked without the causes of the fault being established. Rework may be possible after the assessment of the fault
- investigation of soldering process — the production department should examine the soldering process and the condition of the component termination points when the joint quality falls and remains within the standards of acceptability. It should not, however, be cause for rejection
- criteria for reworking joints — as referred to above, reworking is normally only considered on joints judged to be unacceptable. The reason why a joint is unacceptable should be established prior to commencing rework as this may well have a bearing on whether successful reworking is achievable.

Features of solder joints on surface mounted boards

It should be noted that with surface mounted technology the solder joint may be the only means of attachment between the component and the board. Consideration must be given to this point during design to ensure the ability to manufacture, test and inspect the board.

Visual appearance of solder joints of surface mounted components may vary due to the type of process used to assemble and solder the components. Surface mounted components must all meet the standard for solderability contained within company specifications.

Inspection of solder joints should be conducted under conditions of adequate lighting with use of approximately x5 magnification, if required. A maximum of x10 magnification may be used in cases where the standard cannot be judged, at x5.

There should be no evidence of solder balls or slivers on the board. If present, the process must be investigated to determine the cause.

Components which are soldered in place using waves oldering will be glued to the board. Minimal adhesive on components terminal points is acceptable, provided that it does not reduce the minimal solder fillet.

Evidence of terminal contamination by adhesive must be examined and corrective action taken before further production.

Any evidence of poor solderability or leaching must be investigated and tests for solderability on remaining stocks conducted. Repair work on boards containing surface mounted components need special consideration. Reference should be made to relevant section repair manuals.

Resistor and capacitors with metallized terminations

Solder joints should exhibit a visible solder fillet between pad and component termination. Fillet should rise to a minimum of 25% of the terminal, with evidence of good wetting. A continuous fillet should be visible around 75% of the metallized area and termination.

Evidence of leaching on metallized components is unacceptable. This is an indication that a problem exists with the components or the process. Both should be examined for possible correction. If leaching has occurred, it will generally be visible on the corners or edges of the metallization. Due to their construction capacitors may delaminate or crack and evidence of this will require removal and investigation of components and process.

No more than 25% of the component termination should overhang the pad, provided that the minimum clearance between conductors is maintained. Components should ideally be flat to the surface of the pad.

Melf resistors and round leads

Solder joints on round contacts should exhibit a visible fillet between the pad and component termination. The fillet should rise to a minimum of 25% of the terminal, with evidence of good wetting. The outline of the termination should ideally be visible in the solder fillet. A continuous solder fillet should be visible around 75% of the termination.

SO and SOT Packages

Leaded chip carriers solder joints on flat leads should exhibit a visible fillet between pad and component. The fillet should rise to the top of the lead with the outline of the component lead ideally visible in the joint. In the case of flow soldered joints the lead form is not generally visible. A continuous solder fillet shall be visible around 75% of the lead.

Minimal marks left by probes used to hold components in position during reflow are acceptable. The heel fillet should be continuous between the heel of the lead and the pad, wetting should extend to a midpoint between upper and lower bend as a maximum. A solder fillet should be visible to a minimum of half the lead thickness.

Any sign of non-wetting or de-wetting should require examination of boards and components for satisfactory solderability.

Leads may be raised off the pad surface provided this does not exceed two lead thicknesses, however a good solder fillet must still be visible.

Leads may have a side overhang provided that it does not exceed 25% of the lead width and the minimum clearance between conductors is maintained. Any machine misplacement found or damaged leads must be investigated for correction on future production.

Gull wing chip carriers should exhibit the same soldering requirements as other leaded devices. Leads, not having wettable areas by design are not required to have fillets, however, the joints should permit easy inspection of all wettable surfaces.

Inspection consideration should be given to the condition of all lead frames and their correct plane height. Any excessive variation should be investigated for causes of damage whether it be assembly or poor packing.

Leadless chip carriers

Solder joints should exhibit a visible solder fillet between pad and termination. A joint is not required where no pad is present.

The solder fillet should rise to a minimum of 25% of the metallized termination with evidence of wetting between casterlation terminal and pad.

Overhang of the terminal is allowable to a maximum of 25% provided the minimal joint is present.

All termination points should ideally have a tin/lead finish prior to processing. Components should be obtained in this condition from the supplier.

X-ray inspection

Use of X-ray inspection is becoming popular due to the increased use of small components — particularly those of ball grid array (BGA) technology. Indeed, where ball grid array components are used it is simply impossible to inspect the termination points after component placement and soldering without use of X-ray. This inspection technique can also be used for inspection of other surface mount solder joints and fine pitch leads which are difficult to fully examine.

Real time X-ray is achieved by placing a board assembly between an X-ray tube and a camera. As the X-rays are transmitted some are absorbed and some pass through the sample and are picked up by the X-ray sensitive camera. The video signal is then passed through an image enhancer to allow inspection and interpretation of results. The resulting output will display a grey scale image that represents differences in either density or thickness of the material.

If there is an increase in density the image appears darker. If there is an increase in thickness the image again appears darker. X-ray inspection may be used to confirm correct solder joint formation after reflow soldering on all visible and invisible joints; it may also detect voiding. The techniques also allow alignment of component terminations to be assessed.

As with conventional assessment the use of different size pads on the same part can affect solder joint assessment and should be avoided. Inspection on all components other than ball grid array types should be conducted using normal inspection techniques prior to X-ray evaluation.

X-ray inspection procedure

A sample of two boards should be examined from each batch being produced during normal in process inspection. This should also be done when changing temperature profiles or when setting up new product profiles. Voiding is the most common fault detected using X-ray inspection. Voiding is normally a fault of the profile peak temperature or the time above liquidus temperature of the solder paste alloy.

Some solder paste formulations are more likely to void than others and may require specific profile conditions. Double sided reflow products often exhibit voiding on second side reflow if the same profile is used for both sides.

Inspection of ball grid array components

Inspection of solder joints should start at the centre of the component. This area is the most likely to be the last point to reflow during soldering. It is the most likely area to exhibit voids, non reflow or component delamination. If X-ray is being used *after* rework the whole area beneath the part should be scanned.

All ball grid array termination points should be circular in appearance and consistent in size. Measurement of a centre ball location and four outer row positions will allow confirmation of complete reflow. BGA termination pads may include a wetting indicator. If this is the case it will make solder joint inspection easier to assess. A wetting indicator is a minor change to all pad shapes or a track from the mounting pad which is left exposed. In each case the solder paste can wet away from the main pad in a controlled manner, wetting may then be confirmed by X-ray.

The maximum void size in any one termination will be less than 10% of the minimum joint dimension. In the case of multiple voids the maximum area will be less than 10%.

Fine pitch quad flat pack and plastic leaded chip carrier

Inspection should commence from one corner of the device and scan around all four sides. Attention should be paid to the presence of heel fillets, side fillets and possible toe fillets on gull wing leads.

Toe fillets are not always visible during inspection due to the lack of wettable area on the lead tip. The heel fillets should be consistent in size. The heel fillet is the area which will be subjected to stress during any mechanical or thermal cycling. Voiding may also be present under the lead. Toe and heel fillets should be viable on all J-leaded devices.

Maximum void size in any one termination should be less than 10% of the minimum joint dimension. In the case of multiple voids the maximum area should be less than 10%.

Passive components

X-ray inspection of passive components should be left until last as they will normally be satisfactory if all other parts are confirmed as completely reflowed. Due to their small mass they are likely to reflow before any other component and less likely to exhibit voids. They may exhibit voiding on second side reflow operations.

When a chip component has successfully soldered it will have evidence of a fillet on the end terminations and possibly on the side terminations. The solder joint area under the chip termination should also be assessed.

The maximum void size in any one termination will be less than 10% of the minimum solder joint dimension. In the case of multiple voids the maximum area will be less than 10%.

Small active components

Small active components like SOT23, SOT89 and SOIC devices are not likely to exhibit poor reflow. Their low mass makes complete reflow of these devices relatively easy. It is possible to see voiding on SOT89 components on the centre paddle termination.

The maximum void size in any one termination will be less than 10% of the minimum joint dimension. In the case of multiple voids the maximum area will be less than 10%.

Visual inspection standards

Any company manufacturing, assembling and soldering printed circuit boards must define an internal standard which is to be maintained. Part of this standard must be a visual definition of soldered joint quality. Unfortunately, appearance of faults in both surface mounted and through-hole assemblies, is not generally well documented elsewhere. For this reason, we include here a selection of photographs of typical soldering-related faults in joints and components on electronics assemblies. The remainder of this chapter is effectively a guide to visual detection of soldering defects. Included in the chapter are soldering defects detected by X-ray inspection.

Photographic guide to defects

Typical defects are, listed in alphabetical order:

- adhesive contamination — where adhesive used to mount surface mounted components affects the later soldering process or final product

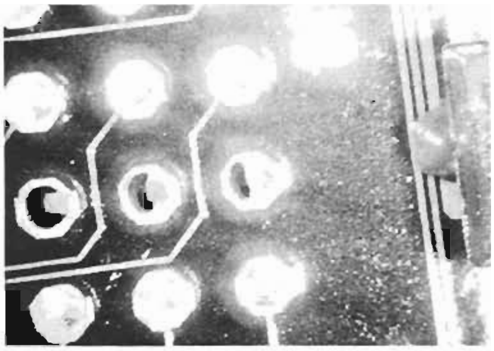


Photo 11.1 *Adhesive contamination prevents complete fillets (EPS)*

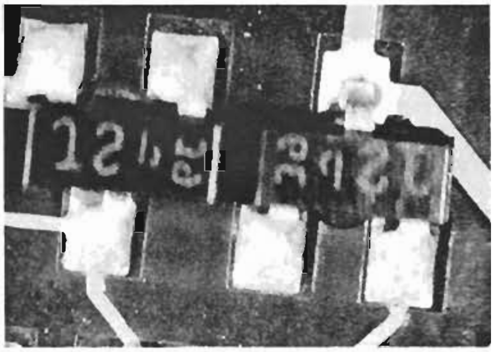


Photo 11.2 *Adhesive contamination affects joints (EPS)*

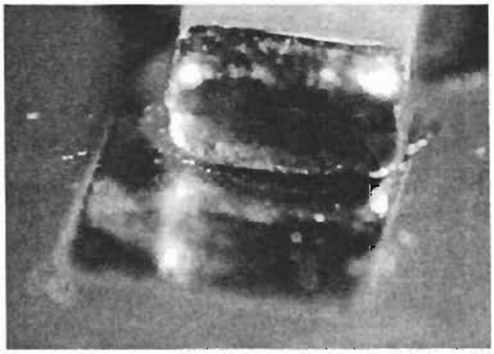


Photo 11.3 *Adhesive contamination prevents complete fillets (EPS)*

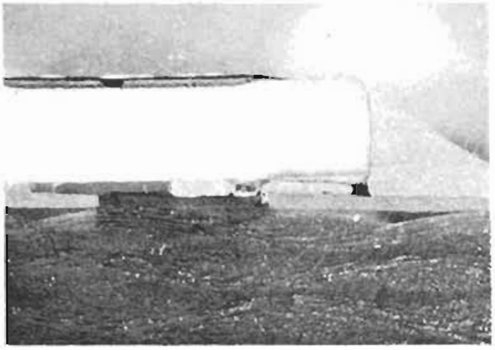


Photo 11.4 *Adhesive voids under component causing solder shorts (EPS)*

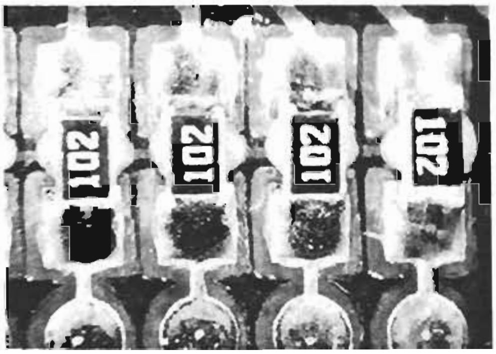


Photo 11.5 *Excessive adhesive deposit (EPS)*

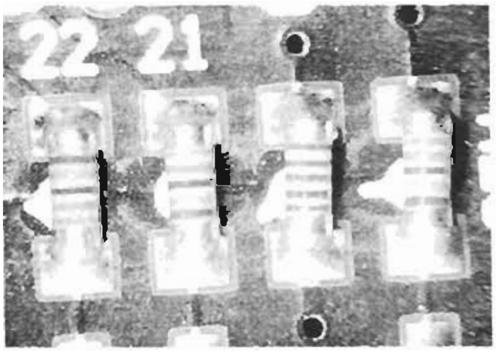


Photo 11.6 *Adhesive stringing under two-terminal components (EPS)*

- blistering or lifting — where copper track lifts from a board surface

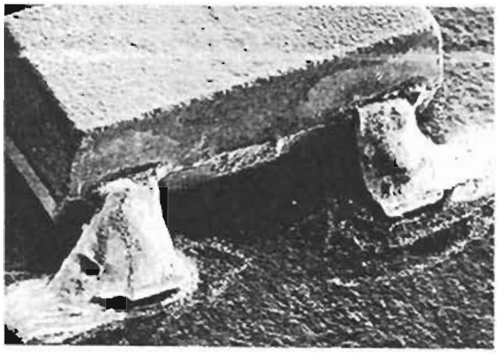


Photo 11.7 *Poor solderability of component terminations (Siemens Aktiengesellschaft)*

Photo 11.8 *Lifted pads on surface mount printed circuit boards (EPS)*

Photo 11.9 *Lifted pads on single-sided printed circuit board (EPS)*

- blow holes — defects in plated through-hole solder joints, where gases burst through solder as it solidifies, usually at the bottom of a fillet. Cavities are often deep and not washable. Caused by poor through-hole plating. Compare with pin holes

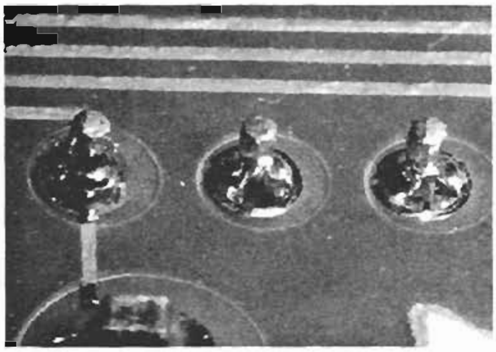


Photo 11.10 *(EPS)*

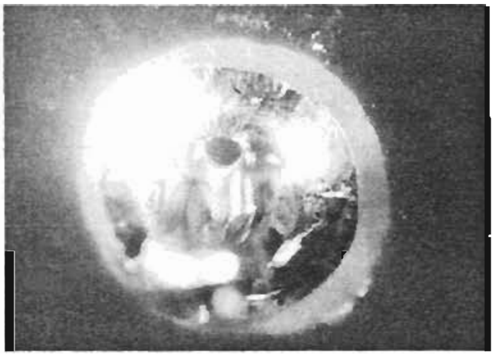


Photo 11.11 *(EPS)*

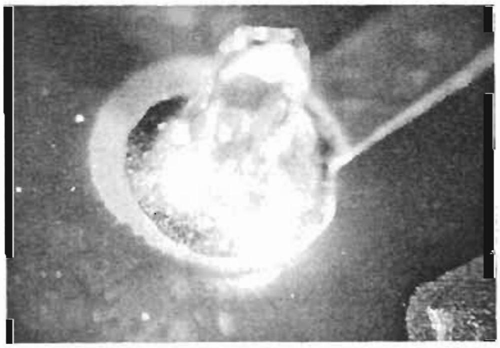


Photo 11.12 *(EPS)*

- blow holes (continued)

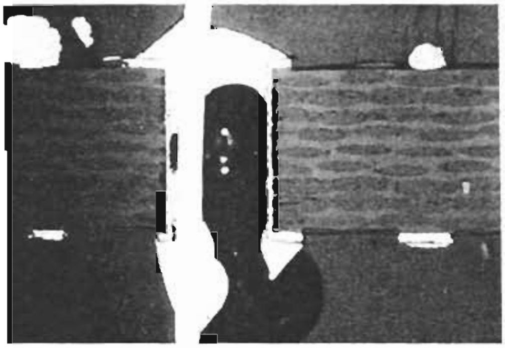


Photo 11.13 *(Alpha Metals)*

- bridging or shorts — where solder joins two or more conductive parts which are not meant to be connected

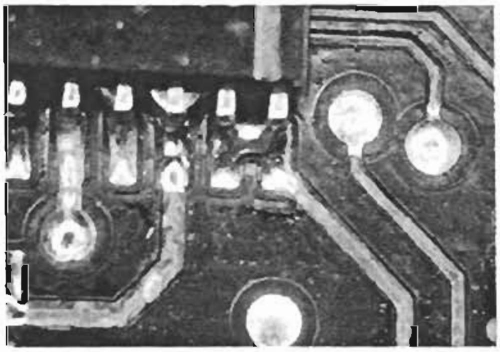


Photo 11.14 *(EPS)*

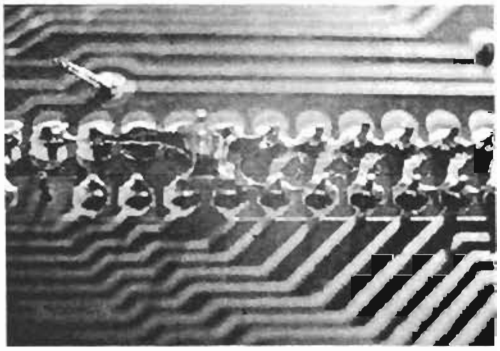


Photo 11.15 *(EPS)*

Photo 11.16 *(EPS)*

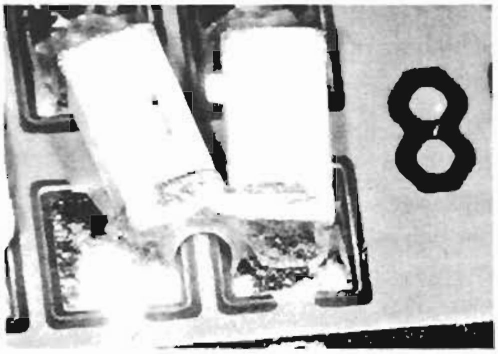


Photo 11.17 *(EPS)*

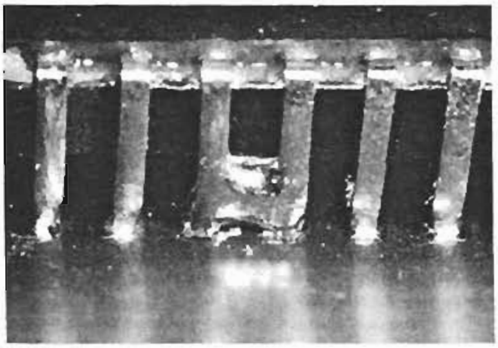


Photo 11.18 *(EPS)*

❑ bridging or shorts (continued)

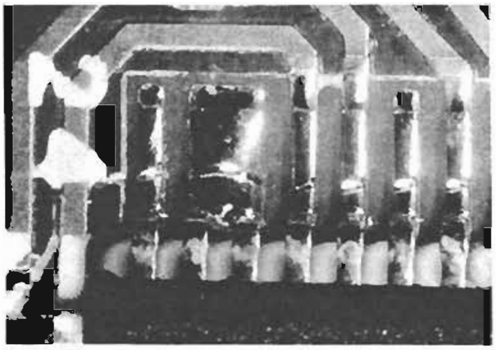


Photo 11.19 *(EPS)*

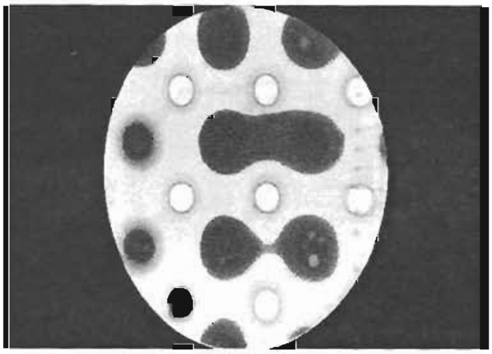


Photo 11.20 *X-ray of BGA, showing shorts (EPS)*

● components lifted

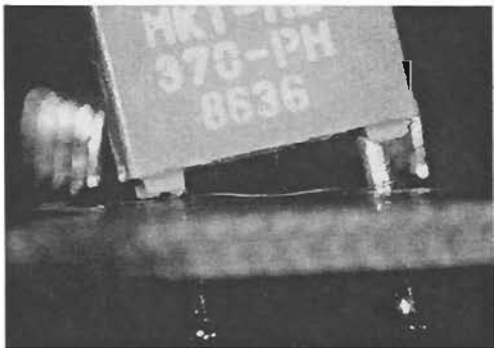


Photo 11.21 *(EPS)*

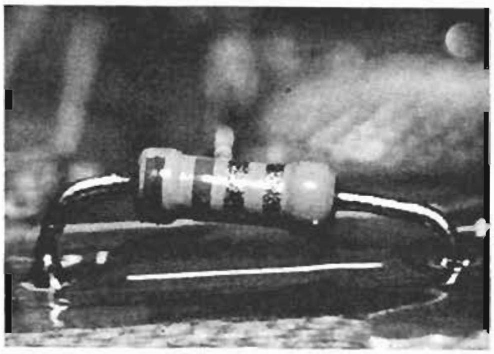


Photo 11.22 *(EPS)*

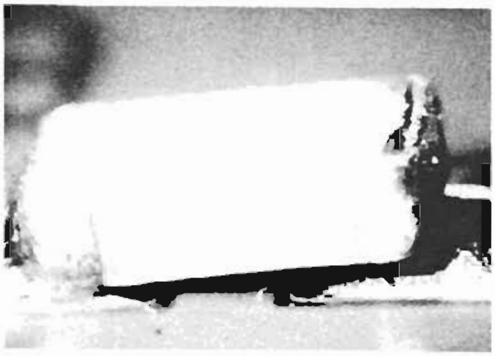


Photo 11.23 *(EPS)*

Photo 11.24 *(EPS)*

- ☐ components lifted (continued)

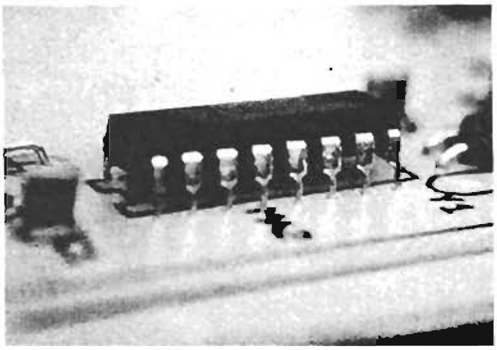


Photo 11.25 *(EPS)*

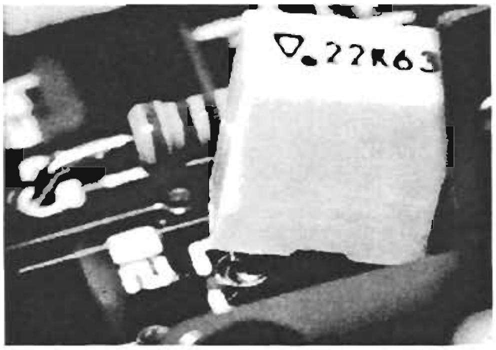


Photo 11.26 *(EPS)*

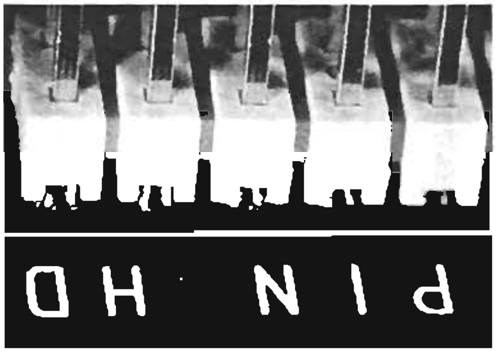


Photo 11.27 *Lifted pin-in-hole-reflow header (EPS)*

- contamination

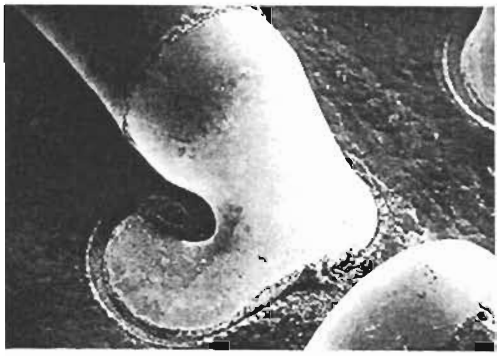


Photo 11.28 *(Siemens Aktiengesellschaft)*

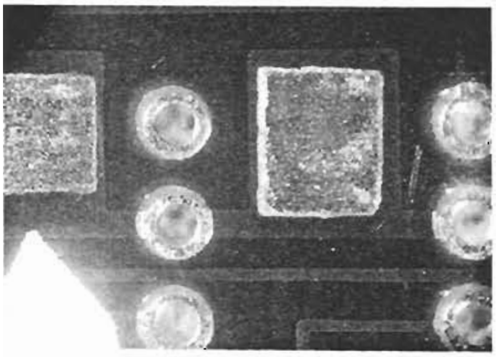


Photo 11.29 *Tin/lead contamination (EPS)*

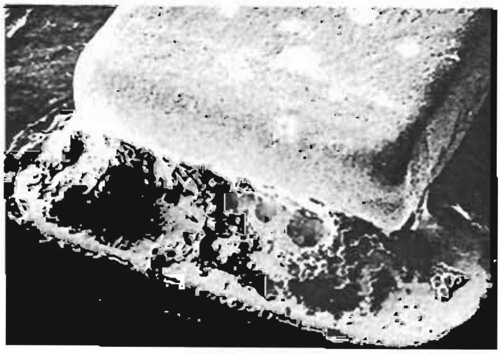


Photo 11.30 *(Siemens Aktiengesellschaft)*

- corrosion

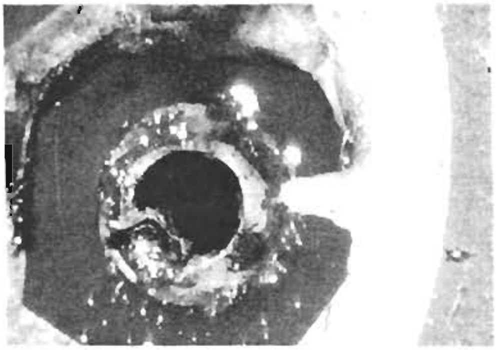


Photo 11.31 *(EPS)*

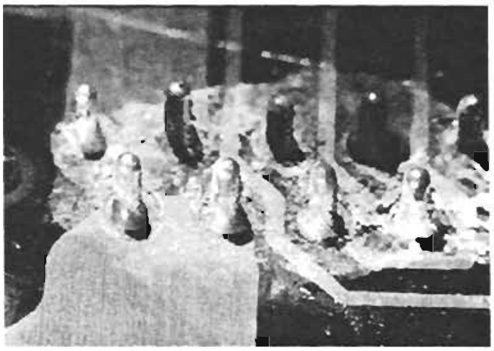


Photo 11.32 *(EPS)*

Photo 11.33 *(EPS)*

Photo 11.34 *Flux corrosion (EPS)*

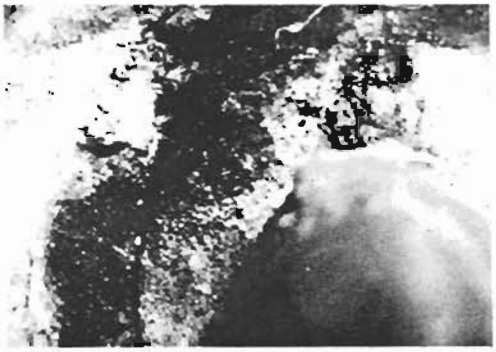


Photo 11.35 *Dendritic corrosion (EPS)*

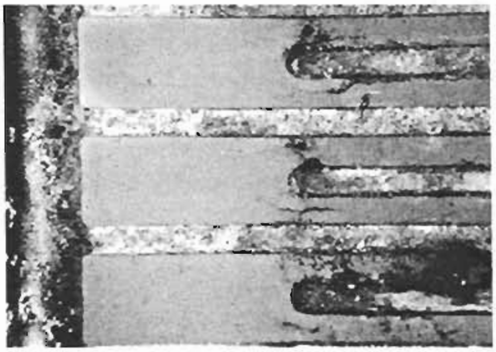


Photo 11.36 *Dendritic corrosion (EPS)*

❑ corrosion (continued)

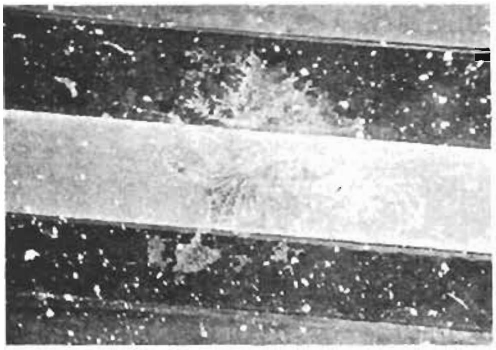


Photo 11.37 *Dendritic corrosion across resist (EPS)*

● cracked joint

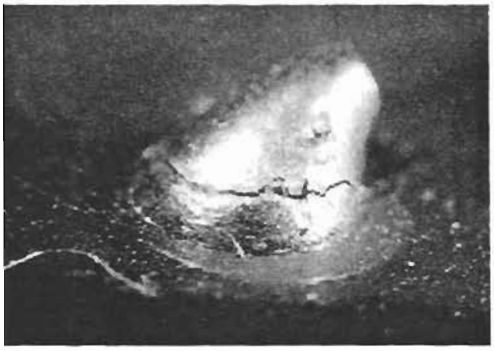


Photo 11.38 *(EPS)*

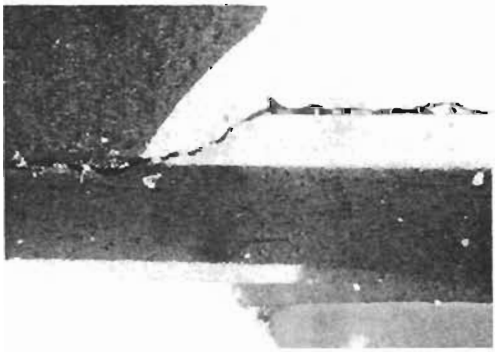


Photo 11.39 *Microsection of cracking in plastic ball grid array (PBGA) (EPS)*

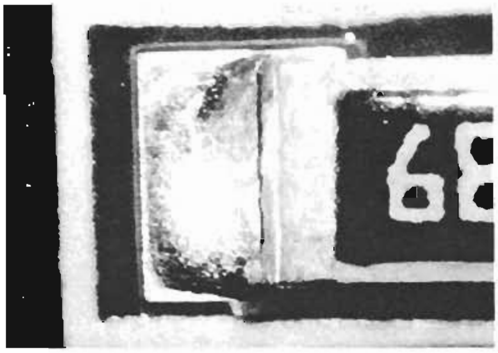


Photo 11.40 *Cracked surface mounted component joint (EPS)*

Photo 11.41 *Cracked through-hole component joint (EPS)*

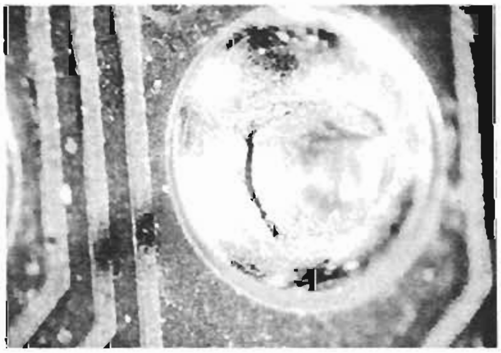


Photo 11.42 *Cracked solder fillet (EPS)*

☐ cracked joint (continued)

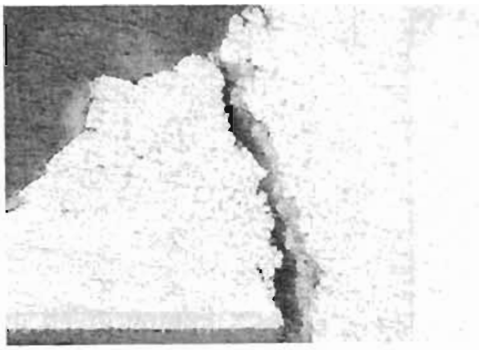


Photo 11.43 *Microsection of cracked solder joint (EPS)*

- delamination

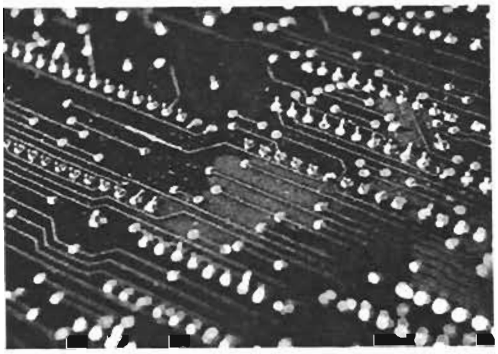


Photo 11.44 *Delamination caused by poor multilayer lamination (EPS)*

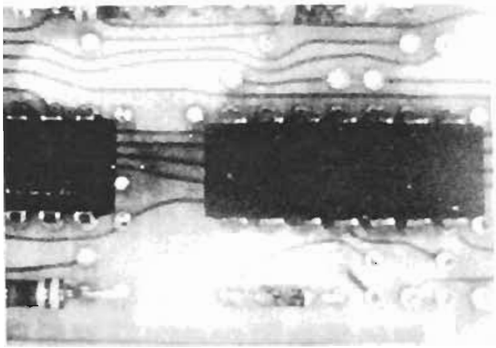


Photo 11.45 *Delamination caused by poor multilayer lamination (EPS)*

- dewetting — where an initial bond is formed during soldering, followed by a withdrawal of solder from the joint, leaving irregularly shaped mounds of solder separated by areas covered with a thin solder film. Base metal is not exposed

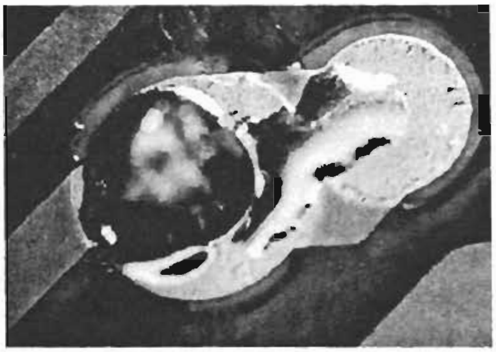


Photo 11.46

- drawbridging — form of surface mount component mis-alignment where chip components lift off their pads at one end to resemble a drawbridge. *See also* mis-alignment, tombstoning

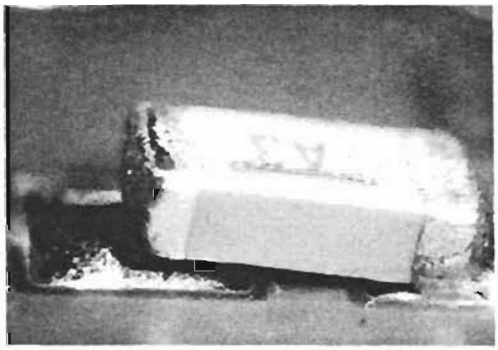


Photo 11.47 *(EPS)*

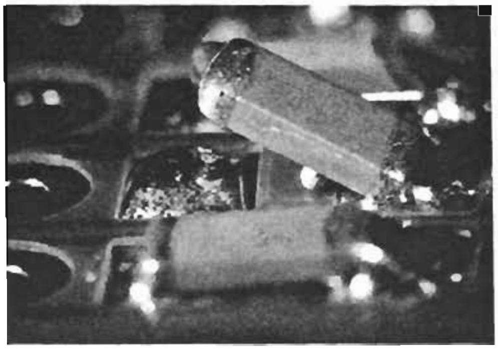


Photo 11.48 *(EPS)*

- excessive solder (solder side) — too much solder on just the solder side of a through-hole printed circuit board

Photo 11.49 *(EPS)*

- excessive solder — too much solder on an SC soldered printed circuit board

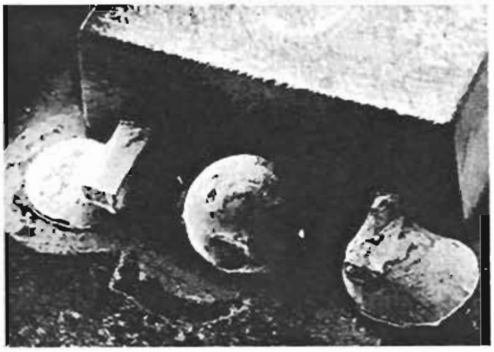


Photo 11.50 *(Siemens Aktiengesellschaft)*

- flooding

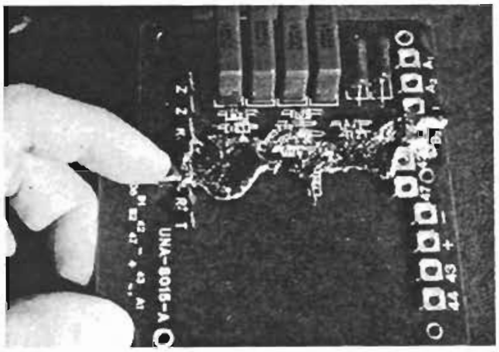


Photo 11.51 *(Speedline Electrovert)*

- flux residues

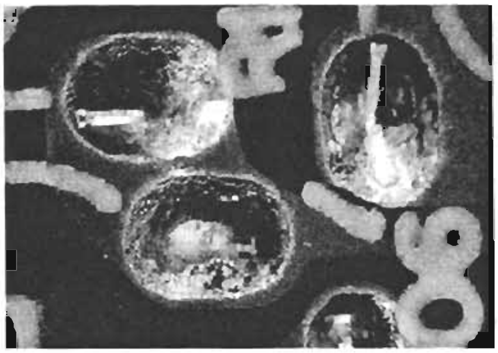


Photo 11.52 *(EPS)*

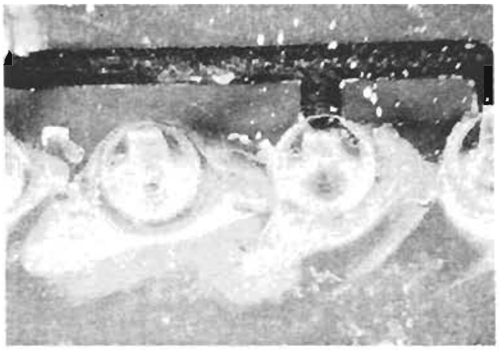


Photo 11.53 *(EPS)*

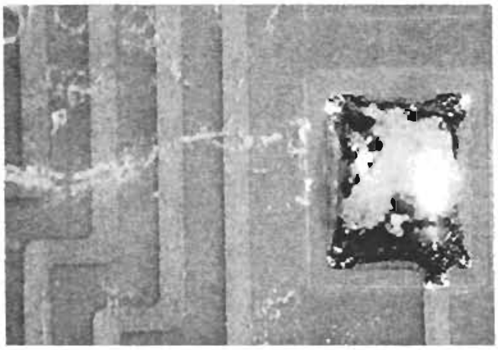


Photo 11.54 *(EPS)*

- incomplete fillet — where insufficient solder is present in a fillet

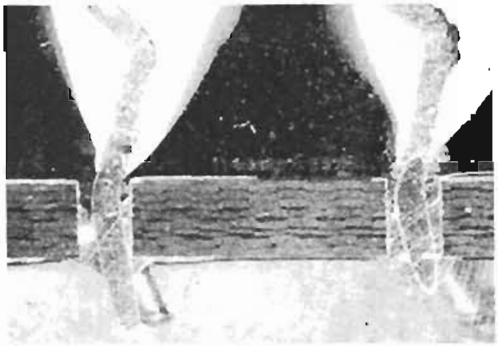


Photo 11.55 *Microsection of through-hole fillet showing poor fillet (EPS)*

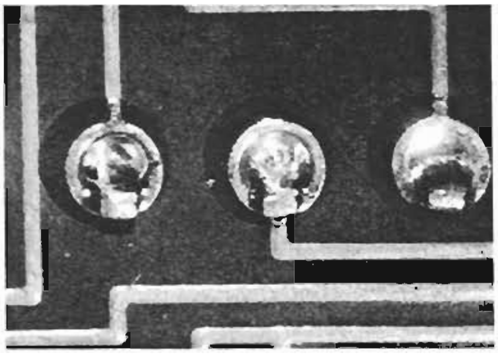


Photo 11.56 *(EPS)*

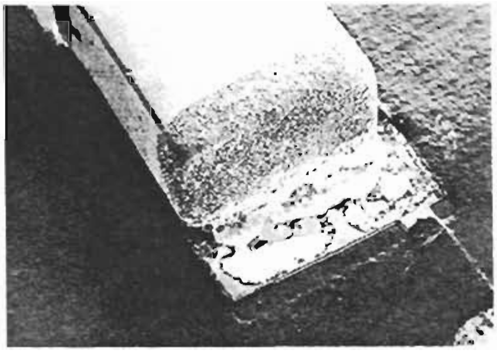


Photo 11.57 *(Siemens Aktiengesellschaft)*

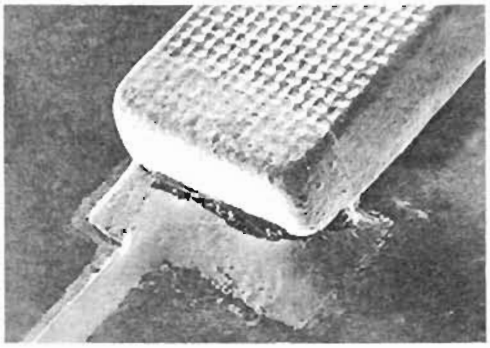


Photo 11.58 *(Siemens Aktiengesellschaft)*

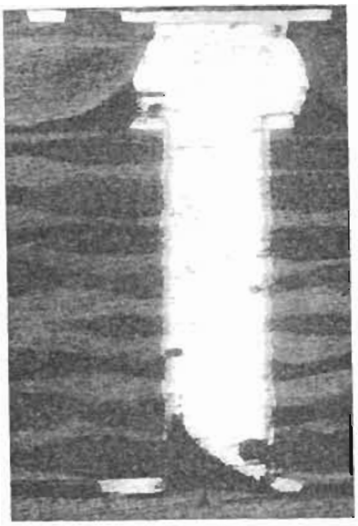


Photo 11.59 *Via mounted BGA with incomplete fillet (EPS)*

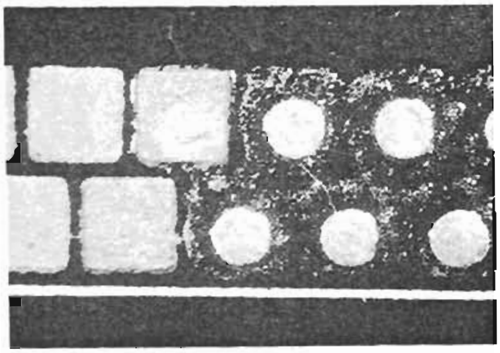


Photo 11.60 *Incomplete paste reflow on pin-in-hole-reflow board (EPS)*

❑ incomplete fillet (continued)

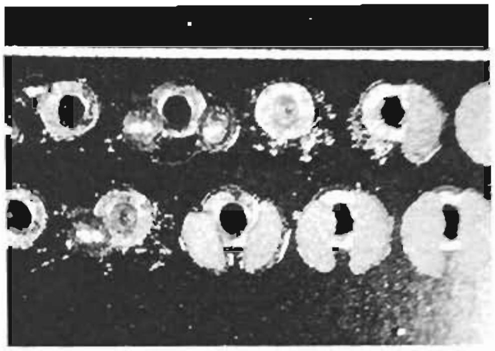


Photo 11.61 *Incomplete pin-in-hole-reflow process (EPS)*

- insufficient solder flow-through — where insufficient solder flows through through-holes in plated through-holes of printed circuit boards

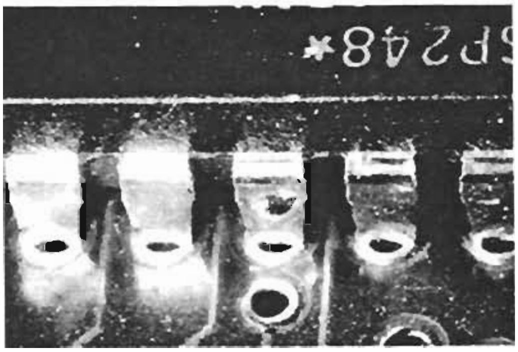


Photo 11.62 *(EPS)*

- leaching — removal of thin layers of component end terminations by solution into solder. *Syn:* scavenging

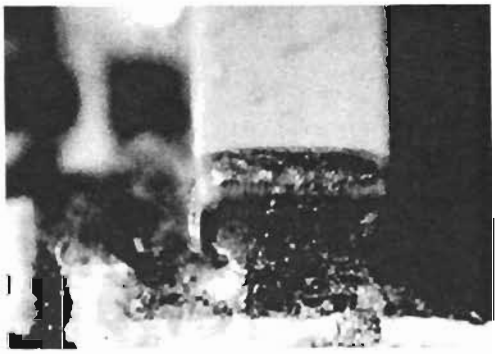


Photo 11.63 *(EPS)*

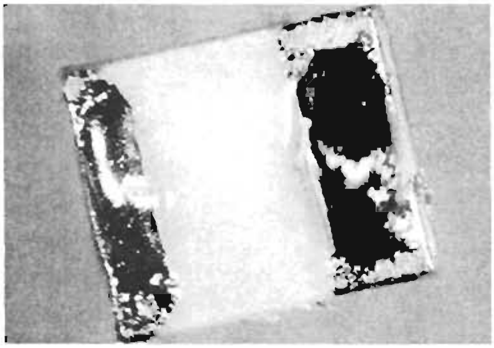


Photo 11.64 *Chip capacitor leaching (EPS)*

- misalignment or misplacement — where two-terminal surface mounted components move during the soldering process, due to the different times that lands at opposite ends of the component reach soldering temperature. *See also* drawbridging, tombstoning

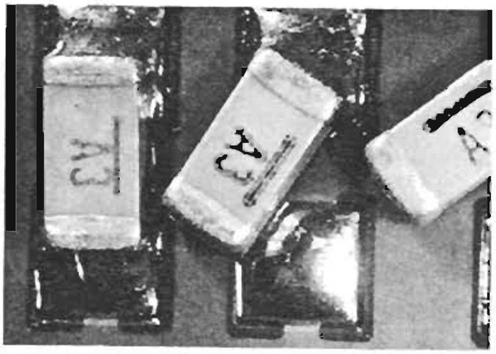


Photo 11.65 *(EPS)*

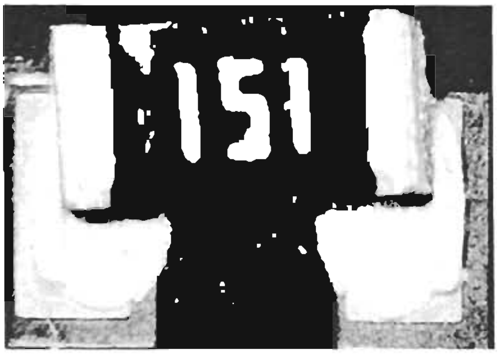


Photo 11.66 *(EPS)*

- misalignment or misplacement (continued)

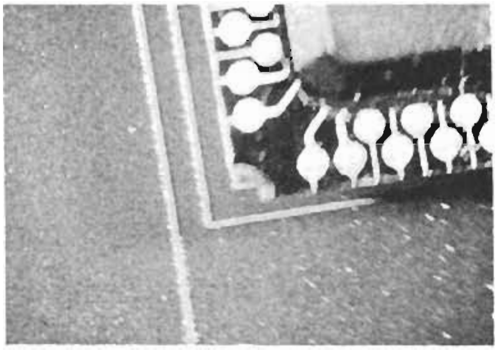


Photo 11.67 *Misplaced BGA device (EPS)*

- non-wetting — condition where part or all of a surface does not wet during soldering. Non-wetting is evident because base metal is visible

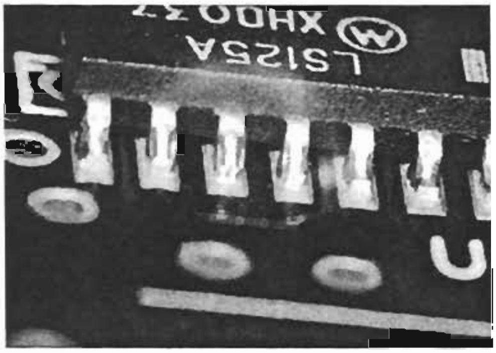


Photo 11.68 *(EPS)*

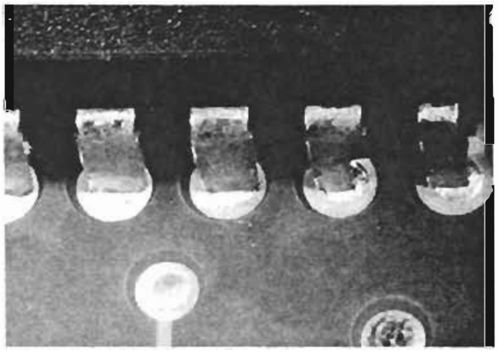


Photo 11.69 *(EPS)*

- outgassing — emission of gas or water vapour from a printed circuit board or joint, as the board is soldered

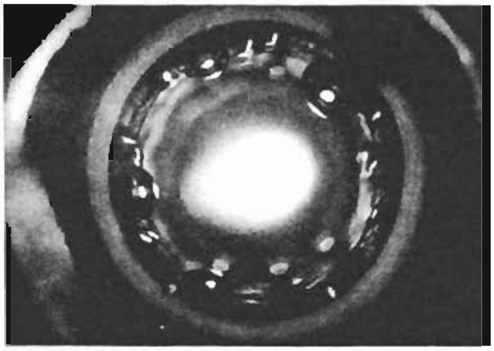


Photo 11.70 *(EPS)*

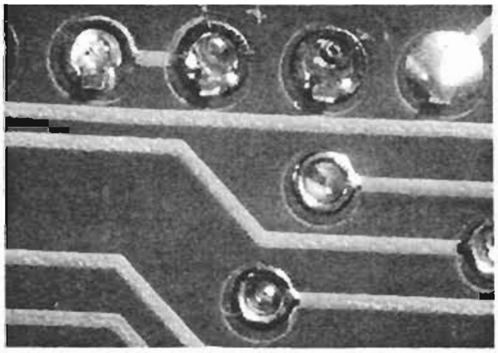


Photo 11.71 *Sunken solder fillets due to outgassing (EPS)*

- paste displacement/misalignment — where solder paste is applied slightly out of place across a printed circuit board

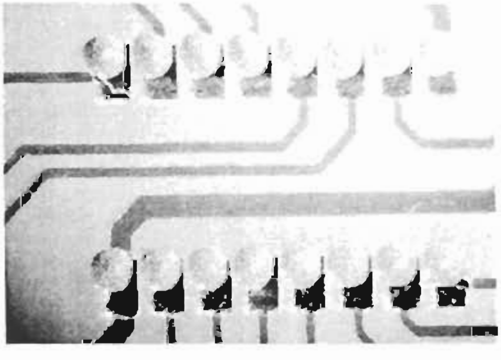


Photo 11.72 *Paste displacement on surface mounted pads (EPS)*

- paste displacement/misalignment (continued)

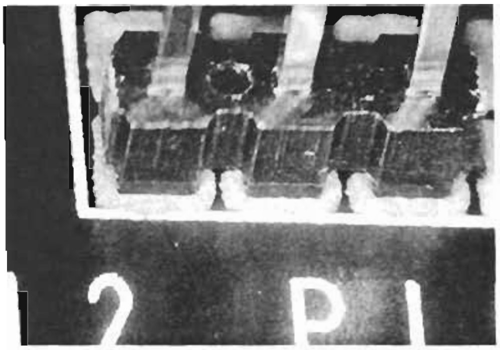


Photo 11.73 *Showing results of displaced paste after connector insertion (EPS)*

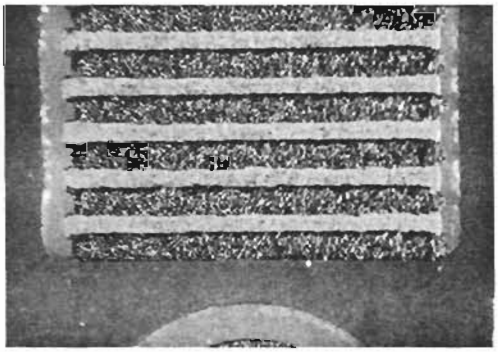


Photo 11.74 *Misaligned solder paste print (EPS)*

- paste slump — where excessive solder paste produces over-sized solder areas. These can merely be undesirable, but can cause shorts between adjacent pads

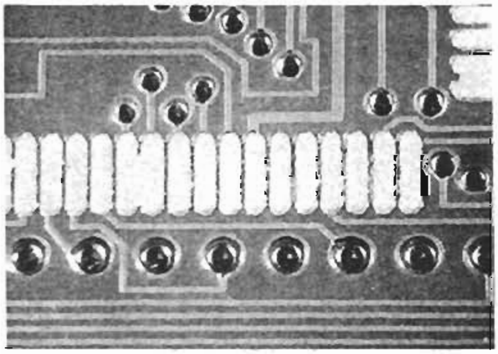


Photo 11.75 *Paste slump on surface mount board pads (EPS)*

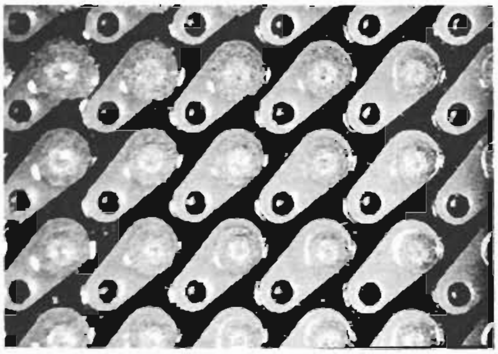


Photo 11.76 *Paste slump on BGA teardrop pads (EPS)*

- paste smear/paste smudging

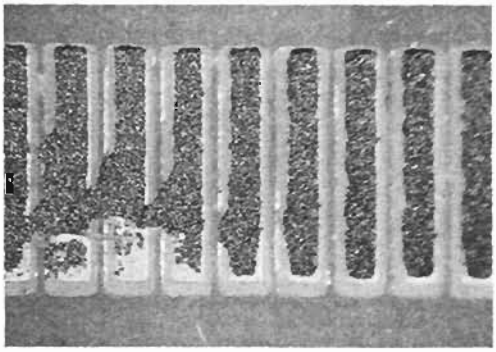


Photo 11.77 *Pbô-˜smear on surface mounted board pads (EPS)*

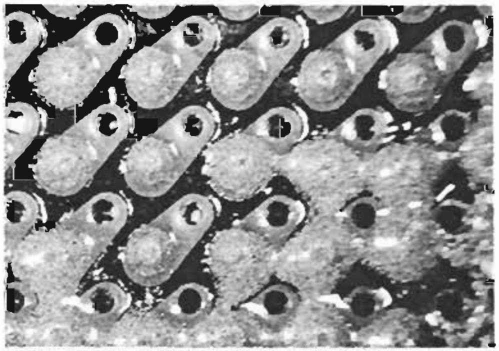


Photo 11.78 *Paste smear on BGA teardrop pads(EPS)*

- poor solderability

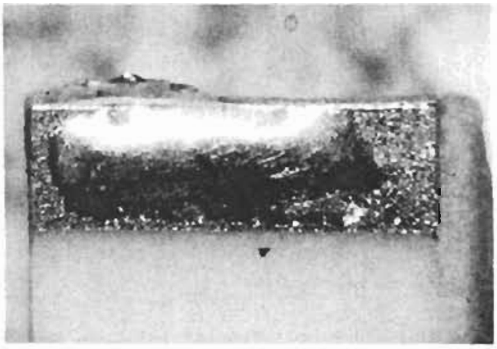


Photo 11.79 *(EPS)*

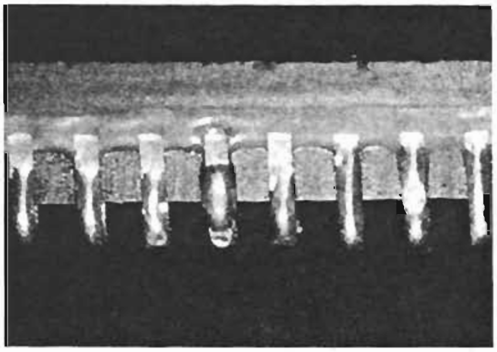


Photo 11.80 *(EPS)*

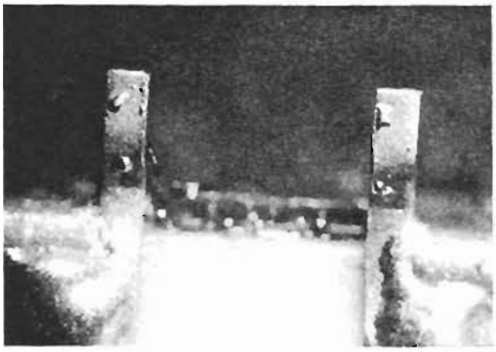


Photo 11.81 *(EPS)*

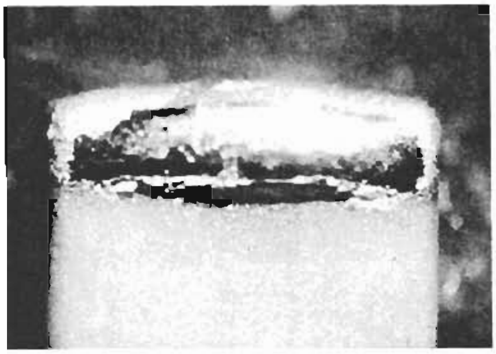


Photo 11.82 *(EPS)*

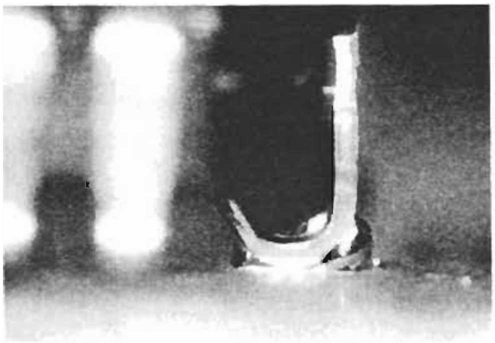


Photo 11.83 *(EPS)*

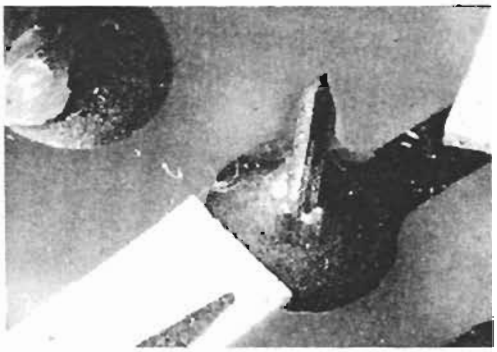


Photo 11.84 *(EPS)*

❏ poor solderability (continued)

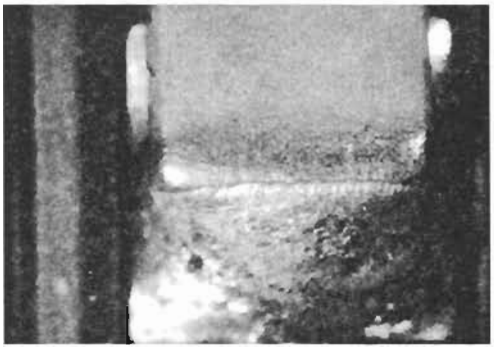


Photo 11.85 *(EPS)*

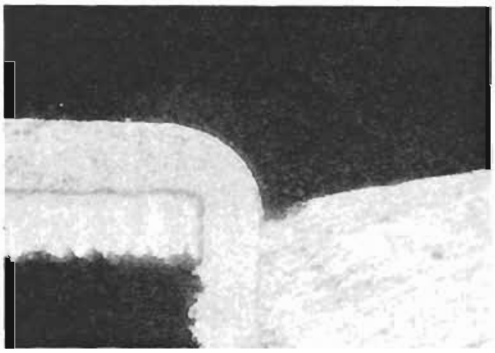


Photo 11.86 *Microsection of poor plated through-hole solderability — a weak knee (EPS)*

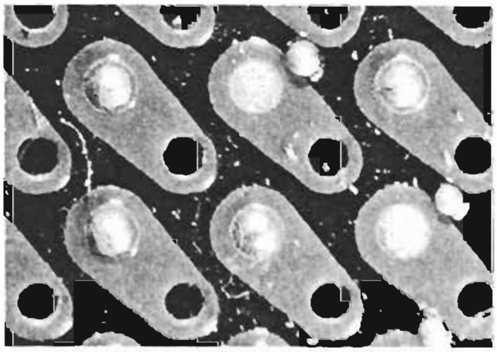


Photo 11.87 *Poor solderability of BGA pads (EPS)*

- resist contamination

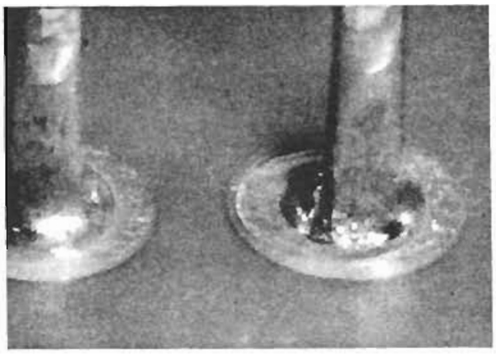


Photo 11.88 *(EPS)*

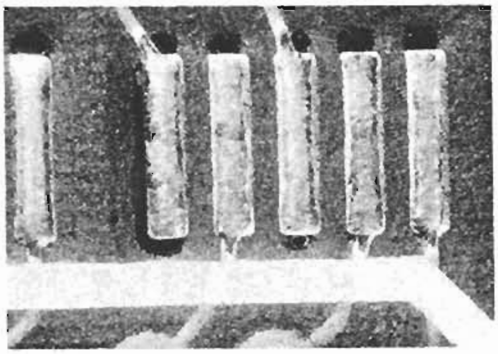


Photo 11.89 *(EPS)*

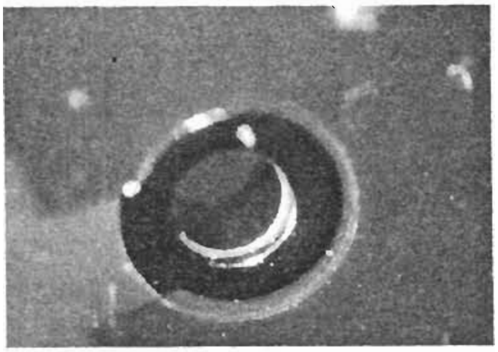


Photo 11.90 *(EPS)*

- resist lifting

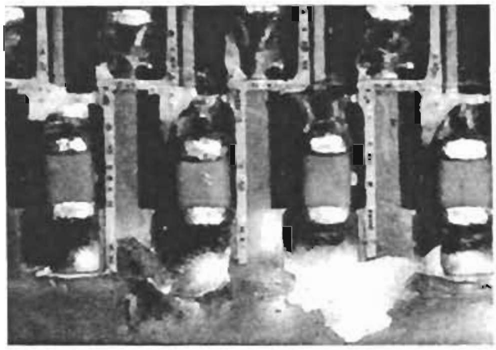


Photo 11.91 *(EPS)*

- skipped solder (or omitted solder)

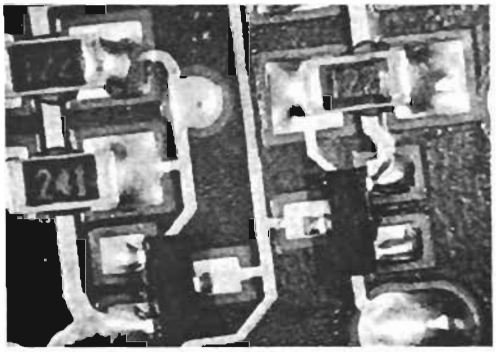


Photo 11.92 *(EPS)*

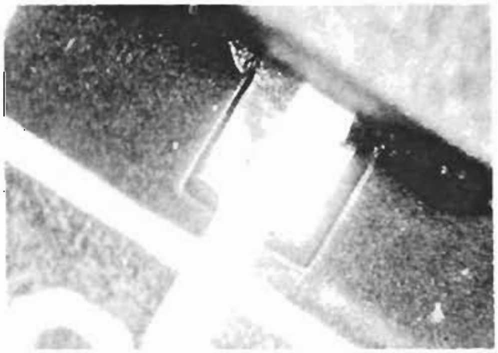


Photo 11.93 *(EPS)*

- solder balls — undesired small balls of solder remaining on printed circuit board after soldering processes

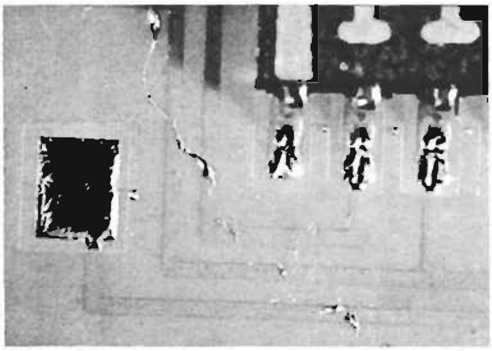


Photo 11.94 *Solder balling 'snail trails' after CS soldering (EPS)*

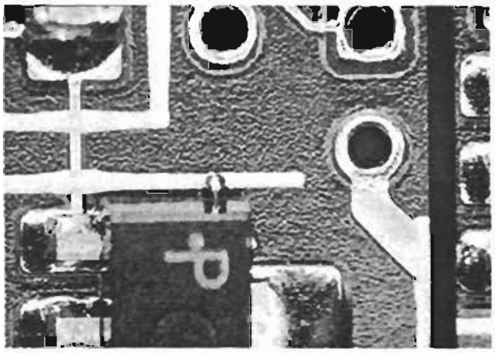


Photo 11.95 *Solder beads during SC process (EPS)*

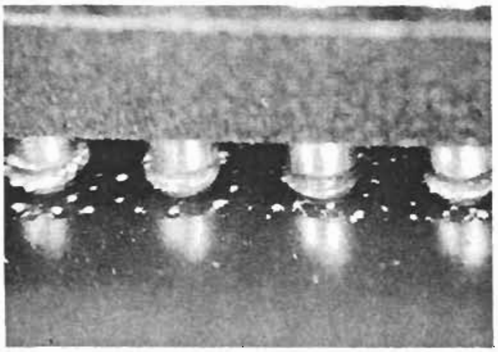


Photo 11.96 *Solder balling on resist with pin-in-hole-reflow (EPS)*

❑ solder balls (continued)

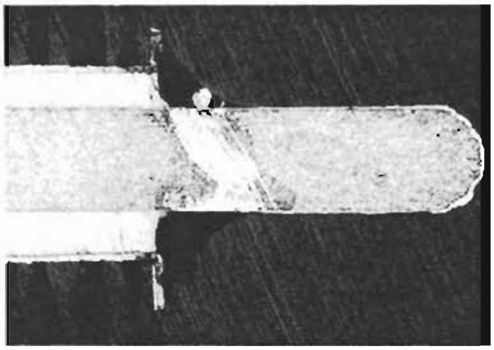


Photo 11.97 *Microsection showing solder ball after pin-in-hole-reflow (EPS)*

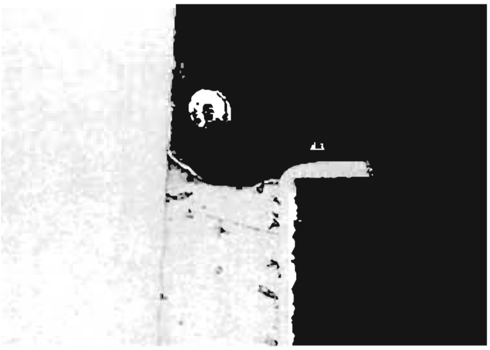


Photo 11.98 *Microsection showing solder ball after pin-in-hole-reflow (EPS)*

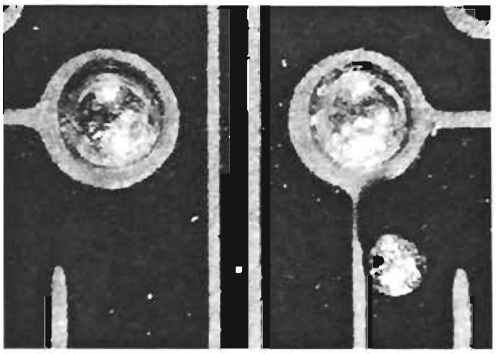


Photo 11.99 *Solder balls on BGA footprint (EPS)*

- solder bridging — see bridging

- solder mask damaged

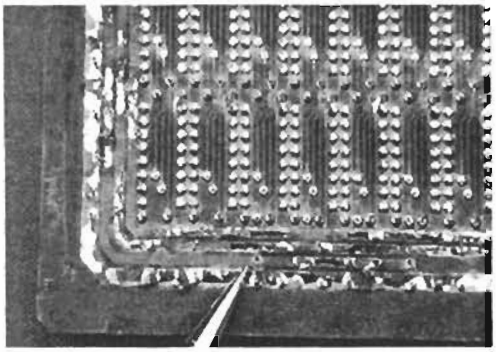


Photo 11.100 *(EPS)*

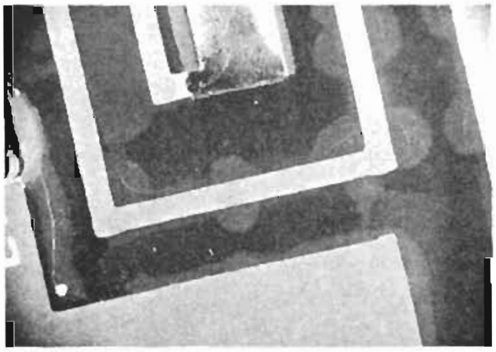


Photo 11.101 *Poor adhesion of solder mask (EPS)*

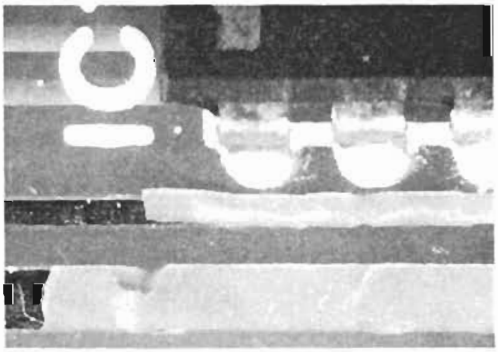


Photo 11.102 *Solder mask lifting (EPS)*

- solder spikes

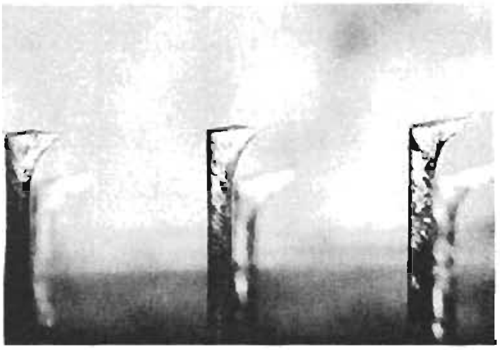


Photo 11.103 *(EPS)*

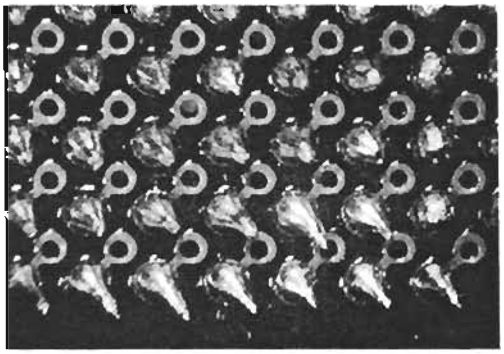


Photo 11.104 *Solder spikes after rework (EPS)*

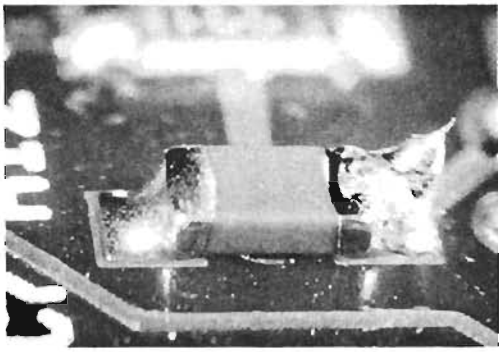


Photo 11.105 *Solder spikes on surface mounted component (EPS)*

- solder voids — *see also* outgassing

Photo 11.106 *(EPS)*

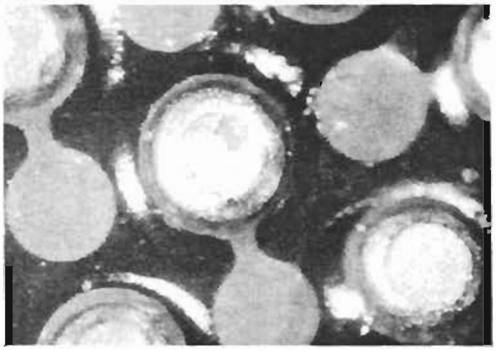


Photo 11.107 *(EPS)*

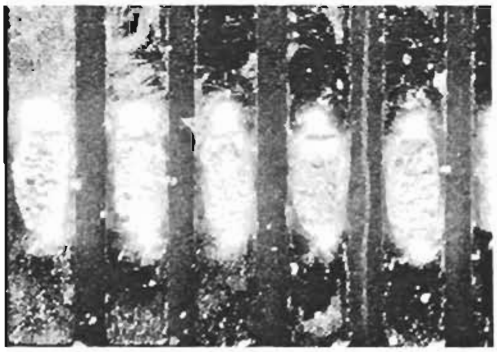


Photo 11.108 *SC solder joint voiding (EPS)*

❑ solder voids (continued)

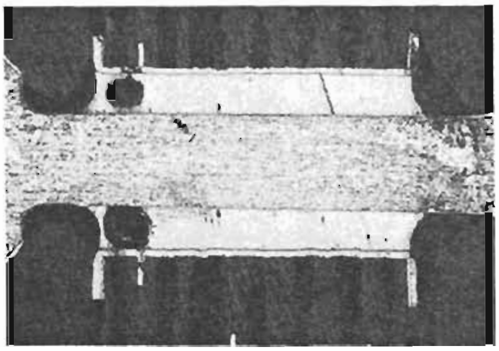


Photo 11.109 *Microsection showing voids in pin-in-hole-reflow joint (EPS)*

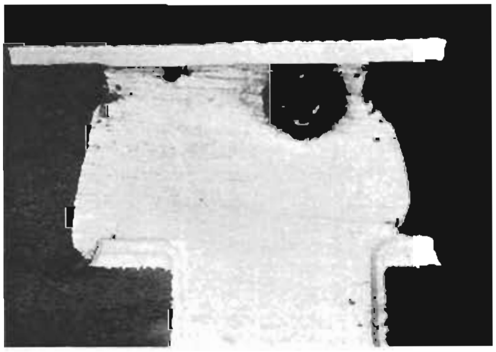


Photo 11.110 *Microsection of via-mounted BGA joint, with voiding (EPS)*

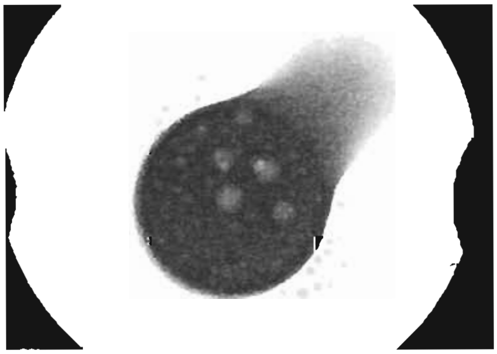


Photo 11.111 *X-ray of BGA joint, with voids (EPS)*

● splatter (see solder balls)

- solder wicking

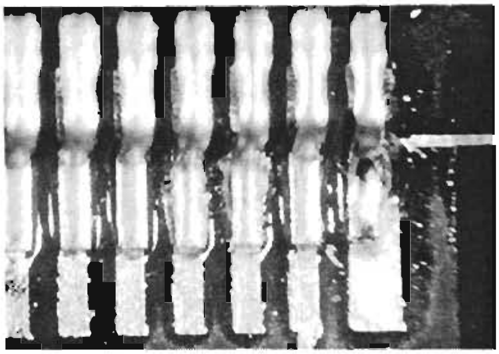


Photo 11.112 *Solder wicking along terminals of surface mounted component (EPS)*

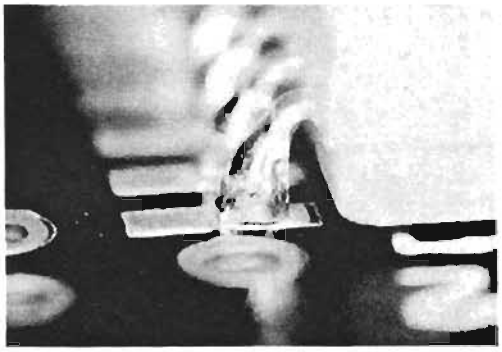


Photo 11.113 *Solder wicking up components terminals (EPS)*

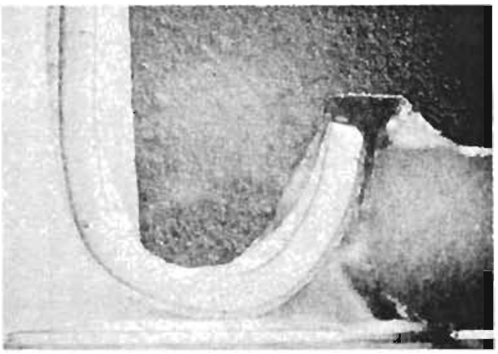


Photo 11.114 *Showing how solder wicks up a J-leaded component terminal (Texas Instruments)*

- tombstoning — severe form of mis-alignment, where a two-terminal component lifts into a vertical position during soldering

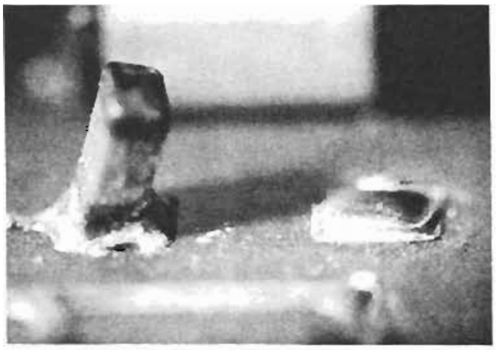


Photo 11.115 *(EPS)*

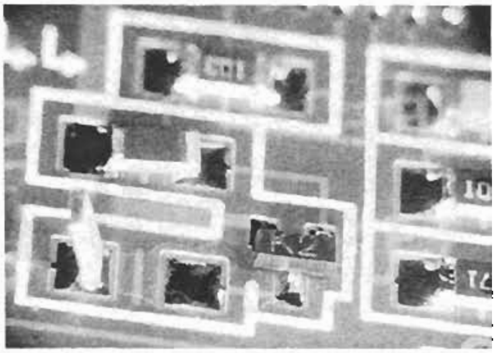


Photo 11.116 *Mis-alignment of components, including tombstoning (EPS)*

- white residues

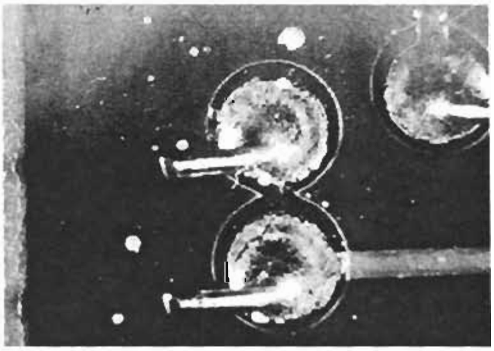


Photo 11.117 *(EPS)*

Note: photographs supplied by EPS (Electronic Presentation Services) are used in the training courses offered by EPS worldwide.

12 Standards & specifications

The aims of standards and of standardization, stated in the British Standards Institution's guide to standards (BS 0: Part 1, 1981), are simple. By providing technical criteria which are accepted by consensus, standards:

- promote consistent quality
- promote economic production
- allow rationalization of processes and methods of operation
- help confidence in manufacturers and users alike
- provide a means of communication among interested parties
- promote economy in effort, materials and energy
- protect consumer interests
- promote the quality of life — safety, health and the environment
- promote trade.

Standards, however, are not legally binding regulations. There is no law which demands standards must be used. Compliance with standards is left to the individual, company or organization.

Why comply with standards?

Standardization, itself, is defined by BSI, as:

> the discipline of using the minimum number of parts for the maximum number of purposes, produced by the most economical manufacturing processes, of the appropriate quality to give reliable and acceptable performance at minimum (whole life) cost.
>
> [PD6470: 1981]

In short, standardization and the use of standards in product manufacture brings economies at the end of the day, while ensuring quality and reliability in the manufactured product.

Reference to standards

There are three ways in which standards are usually referred to:

- by exact identification — a strict reference to a standard and its date of issue (eg, *BS 0 part 1: 1981*). Thus, any updates of the standard is not to be incorporated as a matter of course
- by undated reference — referring to the standard, but not the date (eg, *BS 0part1*). Thus any update of the standard is to be incorporated as a matter of course
- general reference — referring to a standard in non-specific terms (eg, as in *BS 0*).

Levels of standards

National standards

National standards can be, and often are, incorporated into standards of a higher level. A good example of this can be seen in the American standard EIA232 (often known as RS232) which defines, among other things, the signals of the interface between data circuit-terminating equipment such as computer and connecting cables. The International Telegraph and Telephone Consultative Committee (CCITT) recommendation V24 adopts that part of the EIA232 standard with little modification. Thus the EIA232 national standard has become, to all intents and purposes, the V24 international standard.

In the UK, the national standards organization is the British Standards Institution (BSI). It is, incidentally, the oldest national standards organization in the world, starting life in 1901. Now over 80 similar national standards organizations exist all over the world.

Regional standards

The European regional standards organization for general standards is the Comité Européen Normalisation (CEN), of which the European national standards organizations, like BSI, are a part. The electrotechnical counterpart of CEN is CENELEC. Together CEN and CENELEC form the Joint European Standards Institution.

International standards

Internationally, general standards are organized by ISO, while electrotechnical standards are organized by the International Electrotechnical Commission (IEC).

One of the best examples of the way in which national, regional and international standards interact can be seen in the series of standards, at all three levels, aimed at rationalizing quality assurance of electronic components (although dealt with briefly here, it is covered in detail later).

In the UK, the national series is known as the *BS9000* series. Standards numbered from *BS9000* through to *BS9999* refer to the UK national standard system for components of assessed quality. In Europe, and the UK, the regional series for assessed quality components is known as the CECC (Electronic Components Committee of CENELEC — the European Committee for Electrotechnical Standardization) series. Finally, in the UK, and worldwide, the equivalent international series is known as the International Electrotechnical Committee Quality Assessment System.

Standards organizations and bodies

Which standards to comply with

Starting from the assumption that the product is some form of electronics assembly, the question of which standards to comply with really depends on where the product is to be sold, and who the customer is. In the UK, for example, four bodies must be considered. These, and the main types of standards relevant to electronics assembly are:

- BSI — the national organization for standards relevant to electrotechnical (and non-electrotechnical) industrial and commercial aspects. BSI represents UK viewpoints in regional and international organizations, too. Most UK standards are formed by the general BS series, and many relevant standards fall in this series. All aspects of component standards, from specification and manufacture, to distribution and test, make up the BS9000 series. Many publications, referenced by prefix, are also produced by BSI, including; harmonized series of component quality assessment (*BS CECC*), codes of practice (*CP*), published documents (*PD*) and handbooks. The work of BSI and some of the services it offers are detailed later in this chapter
- CENELEC — the regional standards organization for Europe. Together with CEN, as the Joint European Standards Institution, work is undertaken towards the harmonization of national standards into regional standards (see BS CECC, earlier), and the production of regional standards (the CECC series)
- IEC — the international, worldwide, standards organization, working towards the harmonization of regional standards into international standards. These international standards are to form the *CQ* series of standards in the International Electrotechnical Committee Quality Assessment System,

for component quality assurance. More general work by the IEC is carried out by technical committees and their sub-committees, each responsible for a well-defined area in electrotechnical subjects. Four special committees also exist: the advisory committee on electronics and telecommunications (ACET); the advisory committee on safety (ACOS); the international special committee on radio interference (CISPR); the information technology co-ordinating group (ITCG). With the exception of CISPR, committees produce standards with the general prefix IEC. International CISPR standards are prefixed CISPR

- Ministry of Defence — standards are produced, for armed services purposes, by the Ministry of Defence (MoD). These standards, generally with the prefix Def Stan, must be met by any manufacturer of components or assemblies proposing to sell to the MoD. Originally, defence standards were completely different from BSI standards although, increasingly, they now conform to BS9000 series or BS CECC series standards. Increasingly, therefore, manufacturers will follow normal standards, rather than pure defence standards. Main reason for this rationalized changeover is that, wherever possible in recent years, the MoD has offered draft defence standards to BSI to publish as UK standards. Only where absolutely necessary, in fact, does the MoD publish separate defence standards.

Throughout Europe, member countries have their own national standards organizations, including:

- France — Association Française de Normalisation (AFNOR) which uses the main prefixes of *NF* or *UT*
- Germany — Deutches Institut für Normung (DIN) which uses, among others, the *DIN* prefix.

In North America, things start to get complicated. The USA has no governmentally appointed national standards organization; instead many specific bodies have been formed, largely by concerned industrial groups to generate standards and other publications. Important bodies include:

- ANSI — American National Standards Institute (formerly the American Standards Association; before that, the American Engineering Standards Committee), was set up in 1918. Now comprising over 250 professional societies, trade associations, universities, utility organizations, government agencies and corporations, ANSI coordinates production of the majority of American standards. Note that ANSI does not produce standards itself, instead acting as a national clearing house for standards produced by the other organizations. Around 4000 standards have been coordinated by ANSI, to date. ANSI also forms the American representative in IEC production of international standards

- EIA — Electronic Industries Association. A national association of electronics manufacturers, issuing many standards and publications helpful in promoting component interchangeability. Many of these, although not to national standard level, are issued and known as Joint Electron Device Engineering Council (JEDEC) publications
- IEEE — Institute of Electrical and Electronics Engineers. Only a few standards relevant to the manufacture of electronics assemblies are produced by the IEEE
- IPC — Institute for Interconnecting and Packaging Electronic Circuits (formerly the Institute of Printed Circuits). Started in 1957, the IPC produces a wide range of relevant standards and other useful publications regarding the manufacture of electronics assemblies
- ISA — Instrument Society of America. Although producing its own standards too, the ISA coordinates US governmental, Canadian and UK standards, relevant to instrumentation, some of which are relevant to manufacture of electronics assemblies
- NEMA — National Electrical Manufacturers Association. NEMA produces standards for electrical and consumer products.

Products intended for sale to the US Department of Defense must comply with military standards and specifications although, since 1986 when a US presidential commission advised the Department of Defense to adopt ANSI standards wherever possible, a rationalization of defense standards (similar to the defence standards rationalization in the UK) is currently underway. A number of military standardization groups which affect electronic products, exist. Groups, with their prefixing letters, include:

- DOD — Department of Defense. Where a standard is prefixed DOD, it indicates metric standardization. Thus new (and revised non-metric) military standards have the prefix
- MS — military specifications. Developed by air force, army and navy departments to cover details of components used in electronic assemblies
- Mil — military standards. Developed by air force, army and navy departments to cover details of circuits, codes, designations, drawing practices, procedures, test methods and so on relating to manufacture of electronic assemblies
- Mil Std — military standard specifications. Developed by air force, army and navy departments to specify particular requirements.

Three national standards bodies exist in Canada:

- Canadian General Standards Board (CGSB)
- Canadian Standards Association (CSA)
- Underwriters' Laboratories of Canada (ULC).

Standards for electronics assembly manufacture

The following lists give standards and specifications which are important in the manufacture of electronics assemblies. The lists are simply guides and are in no way binding — manufacturers should check for themselves what current standards and specifications are for particular applications.

Should local, federal, national or other laws, regulations or recommendations exist, they shall take priority over those suggested standards and specifications in this book.

UK standards

UK standards and publications are simply prefixed *BS*. Following letters may be used to categorize further. Letters used include:

- *C* — relating to CECC quality assurance standards (referred to in BSI literature as BS CECC standards
- *CP* — code of practice
- *DD* — draft for development
- *E* — general-purpose standard
- *EN* — European standard
- *G* — aerospace standard
- *PD* — published document.

UK defence standards

Defence standards published by the MoD are prefixed *Def Stan*. A number of other publications may be used by the MoD, however, to specify standard requirements. Other prefixes denoting these publications include:

- *AQAP* — allied quality assurance publication; NATO quality assurance publications
- *BR* — book of reference; handbook for service equipment and procedures
- *DEF* — defence specification
- *Def Con* — defence conditions, specified in contracts
- *Def Con guide* — guides to defence conditions
- *DTD* — aircraft materials, components and processes publication
- *NES* — naval engineering standard
- *NWS* — naval weapon specification
- *SC* — standard conditions, specified in contracts.

A hierarchical system of preference is used by the MoD to select standards for defence use. The system currently follows the order:

- relevant British standards (ie, with the prefix *BS*)
- defence standards
- defence specifications, lists or guides
- MoD department standards or specifications
- other Government department standards
- recognized industry standards.

IEC standards

IEC standards and publications are usually prefixed *IEC*, unless otherwise specified. Other prefixes are:

- *CISPR* — referring to standards produced by CISPR committees
- *QC* — referring to standards in the IECQ quality assurance system.

ANSI standards

ANSI is responsible for the publication of many standards (although not for production of the standards). A complicated prefixing arrangement is used for American standards which requires some explaining. For standards directly published by ANSI itself, prefixes are used for classification purposes: usually a single letter or pair of letters (for example *PH7*).

Other prefixes, denoting the standards publishing bodies or organizations within the ANSI banner, are:

- *ASQC* — American Society for Quality Control
- *EIA* — Electronic Industries Association
- *ICEA* — Insulated Cable Engineers Association
- *IEEE* — Institute of Electrical and Electronic Engineers
- *IPC* — Institute for Interconnecting and Packaging Electronic Circuits (formerly the Institute of Printed Circuits)
- *ISA* — Instrument Society of America
- *NEMA* — National Electrical Manufacturers Association
- *NFPA* — National Fire Protection Association
- *UL* — Underwriters Laboratories.

So, standards are known by their *ANSI* prefix, followed by the initial letters of the individual standards organization, and the reference number (for example, *ANSI/EIA208*).

Sometimes, individual standards organizations choose to issue a further prefix, often the initial letter or letters of the standard's title (for example, *ANSI/IPCFC240*). Generally, though not always, within each individual organization's standards, a numerical order system operates, such that the standard may be located in the list simply by the standard number, thus making these further initial letter prefixes irrelevant in any case.

USA defense standards

USA defense standards and publications are prefixed in one of two main ways:

- *DOD* — Department of Defense standards. Where a standard is prefixed *DOD*, metric standardization is indicated. Thus new (and revised non-metric) military standards have this prefix
- *Mil* — military standards.

USA defense standards will thus have either a *DOD* or a *Mil* prefix. Sometimes a further prefix, often the initial letter or letters of the title, is used, too. Standards and publications are in numerical order so, regardless of prefix, a standard may be located simply by the standard number.

DIN

Deutsches Institut für Normung, the main German standards organization, produces standards and publications prefixed *DIN*. Other standards organizations produce standards which are incorporated and published by DIN, referenced with a further prefix. These further prefixes include:

- *IEC* — International Electrotechnical Commission
- *ISO* — International Organization for Standardization
- *LN* — Deutsches Luft und Raumfahrt Norm
- *VDE* — Verband Deutscher Elektrotechniker
- *VG* — Verteidigungsgerte Norm.

Where DIN standards have been harmonized with CECC and ISO9000 standards, DIN standards are usually given the same reference number, either directly or as a suffix.

In the DIN catalogue of standards, individual standards are organized into subject groups. This is a useful method of referencing standards. Many DIN standards are available translated into English — a separate DIN catalogue is available, totally in English, which lists those standards' titles.

Miscellaneous standards organizations

Other standards and publications listed include those of a number of organizations:

- AFNOR — the Association Française de Normalisation, the French standards organization. Two prefixes are used in this appendix relating to AFNOR standards, *NF* and *UTE*. Like DIN, AFNOR divides standards into subject groups, but two levels of group categories and sub-categories are used, which makes standards identification extremely easy. First categorization (denoted by the letter immediately following the *NF* or *UTE* prefix) selects the main category, while second categorization (denoted by a two figure number) selects the sub-category. Thus, *NFC93* is the sub-category relating to electronic components (93) in the electric category (C)
- CSA — Canadian Standards Association
- JEDEC — the Joint Electron Device Engineering Council of EIA. JEDEC standards are prefixed *JESD*, while publications are prefixed *JEP*. JEDEC standards are not national American standards, however, they are recognized by most of the electronics assembly industry
- US government — Federal specifications and standards.

Guide to relevant worldwide standards

The remainder of this chapter lists standards relevant to electronics assembly by reference number for worldwide standards organizations. Generally, the index or catalogue of standards and publications is given first in each table. Note that the following tables list as many standards as we could find, but can't be taken as total. Standards come and go with time and from the time of writing to publication, readers should expect there to be some differences.

Table 12.1 lists general British standards and publications, while Table 12.2 lists BS9000 system standards and publications, and Table 12.3 lists those of the CECC system.

BS9000 system

Standards BS9000 to BS9970 relate to specifications of individual components in the BS9000 system of assessed component quality. Although individual standards should be located in the BSI catalogue, standards of particular note follow. These are mainly of generic data specifications for the component type, and include methods of test, together with rules and procedures for capability approval where necessary. Immediately after any particular component standard reference (either having the same reference number or closely following it) will be found one or more of four further types of standard:

- a sectional specification for a component variety
- rules for the preparation of detail specification for the component
- a blank detail specification for the component
- a detail specification for the component and its varieties.

CECC publications

The intention of the CECC system is to form a harmonized quality system of components, to promote trade throughout Europe.

CECC standards are prefixed *CECC.* Where they are harmonized as British standards, their prefix is usually *BS CECC.* Like BS9000 system standards CECC system standards are formed by many types of standard specifications. Also like BS9000 system standards component types and varieties are headed by a generic specification. This is then typically followed by one or more sectional specifications. Sectional specifications are then followed by one or more detail, blank detail or family specification. Numbering of CECC standards is a bit more logical than BS9000, however: generic specifications are numbered *xx000*; sectional specifications are numbered *xxy00*; while detail, blank detail or family specifications are numbered *xxyzz.*

UK defence standards and publications

Defence standards are given the prefix *Def Stan*, and are placed in groups based on the NATO supply classification system, in which subject groups are allotted group numbers varying from 10 to 99. Additionally the series 00 to 09 are used for subject groups not covered by the NATO classification. Relevant standards are listed in Table 12.4.

IEC standards

Standards and publications of IEC, including CISPR publications, are listed in Table 12.5.

IEC QC standards of particular note, meanwhile, are listed in Table 12.6. The IECQ system is intended to form an internationally harmonized quality system for components, to promote worldwide trade. Organization and numbering of standards is similar to the CECC system, in that generic specifications are numbered *xxx000*; sectional specifications are numbered *xxxy00*; while detail and blank detail specifications are numbered *xxxyzz*.

USA standards

ANSI standards and publications, incorporating those of the ASQC, EIA, IEEE, IPC, UL and others are listed in Table 12.7. USA defense standards and publications are listed in Table 12.8.

Others

DIN standard groups, with selected standards, are listed in Table 12.9, while miscellaneous standards are listed in Table 12.10.

Table 12.1 General British standards

Reference	*Part*	*Content*
Catalogue		BSI standards catalogue
0		Guide. A standard for standards
DD57		Methods of equipment reliability testing
441		Specification of purchasing requirements for flux-cored and solid soft-solder wire
558		Specifications for nickel anodes, anode nickel and nickel salts for electroplating
1468		Specification for tin anodes and tin salts for electroplating
1561		Specification for silver anodes and silver salts for electroplating
1843		Colour code for twin compensating cables for thermocouples
1872		Specification for electroplated coatings of tin
2011		Basic environmental testing procedures (multi-part)
	1.1	General and guidance
	2.1	Tests
		A cold
		B dry heat
		C damp heat, steady state
		D damp heat, cyclic
		Ea shock
		Eb bump
		Ec drop and topple
		Ed free fall
		Ee bounce
		Fc vibration (sinusoidal)
		Fd random vibration (multi-part)
		Ga acceleration
		J mould growth
		Ka salt mist
		Kb salt mist cyclic

		Kc sulphur dioxide
		Kd hydrogen sulphide
		M low air pressure
		N change of temperature
		Pz flammability
		Q sealing
		R resistance to fluids
		Sa simulated solar radiation
		T soldering
		U robustness of terminations
		XA immersion in cleaning solvents
		Z/AD combined temperature/humidity cyclic
		Z/AFc combined cold/vibration
		Z/AM combined cold/low air pressure
		Z/AMD combined sequential cold, low air pressure and damp heat
		Z/ABDM climatic sequence primarily intended for components
		Z/BFc combined dry heat/vibration
		Z/BM combined dry heat/low air pressure
	2.2	Guidance on above tests (multi-part)
	3	Background information (multi-part)
	4	Miscellaneous (multi-part)
2050		Specification for electrical resistance of conducting and antistatic products made from flexible polymeric material
3338		Method for the sampling and analysis of tin and tin alloys (multi-part)
3953		Specification for synthetic resin bonded woven glass fabric laminated sheet
4145		Specification for glass mica boards for electrical purposes
4292		Specification for electroplated coatings of gold and gold alloys
4584		Metal-clad base materials for printed wiring boards
	1	Methods of test
	2	Epoxide woven glass fabric copper clad laminated sheet, general-purpose grade: EP-GC-Cu-2
	3	Epoxide woven glass fabric copper clad laminated sheet, flame retardant grade: EP-GC-Cu-3
	5	Phenolic cellulose paper copper clad laminated sheet of medium electrical quality: PF-CP-Cu-5
	6	Phenolic cellulose paper copper clad laminated sheet of medium electrical quality, flame retardant grade: PF-CP-Cu-6
	8	Phenolic cellulose paper copper clad laminated sheet of high electrical quality, flame retardant grade: PF-CP-Cu-8
	9	Flexible copper clad polyester (PETP) film: PETP-F-Cu-9
	10	Flexible copper clad polyimide film: PI-F-Cu-10
	11	Bonding sheet material for use in the fabrication of multi-layer printed boards: EP-GC-11
	12	Thin epoxide woven glass fabric copper clad laminated sheet of defined flammability for use in the fabrication of multi-layer printed boards: EP-GC-Cu-12
	13	Silicone woven glass fabric copper clad laminated sheet: Si-GC-Cu-13
	15	Adhesive coated polymeric film: PETP-F-15 and PI-F-15
	16	Epoxide glass reinforced copper clad laminated sheet of defined flammability: EP-GCA-Cu-16
4608		Specification for copper for electrical purposes; rolled sheet, strip and foil
5102		Specification for phenolic resin bonded paper laminated sheets for electrical applications
5625		Specification of purchasing requirements and methods of test for fluxes for soft soldering
5658		Specification for gold potassium cyanide for electroplating
5772		Basic testing procedures and measuring methods for electromechanical components for electronic equipment (multi-part)

5830		Specification for grid system for printed circuits
5917		Specification for conformal coating materials for use on printed circuit assemblies
6041		Method of sampling of electrodeposited metallic coatings and related finishes: procedures for inspection by attributes
6062		Packaging of electronic components for automatic handling
	1	Specification for tape packaging of components with axial leads on continuous tapes
	2	Specification for tape packaging of components with unidirectional leads on continuous tapes
	3	Specification for packaging of leadless components on continuous tapes
6096		Marking inks and solder resist coating materials for printed circuits
	1	Methods of test
	2	Specification for marking inks
	3	Specification for solder resist inks
	4	Specification for permanent polymer (dry film solder mask) material
6137		Specification for electroplated coatings of tin/lead alloys
6221		Printed wiring boards
	2	Methods of test
	3	Guide for the design and use of printed wiring boards
	4	Method for specifying single and double sided printed wiring boards with plain holes
	5	Method for specifying single and double sided printed wiring boards with plated through-holes
	6	Method for specifying multi-layer printed wiring boards
	7	Method for specifying single and double sided flexible printed wiring boards without through connections
	8	Method for specifying single and double sided flexible printed wiring boards with through connections
	20	Guide for the assembly of printed wiring boards
	21	Guide for the repair of printed wiring boards
6236		Electrical insulating materials based on mica
6534		Method for quantitative determination of lead in tin coatings
6917		Method for corrosion testing in artificial atmospheres
6918		Glossary of terms for corrosion of metals and alloys

Table 12.2 BS9000 system standards and publications

Reference	*Part/section*	*Content*
9000		General requirements for a system for electronic components of assessed quality
	1	Specification of basic rules and procedures
	2	Specification for national implementation of CECC basic rules and rules of procedure
	3	Specification for national implementation of IECQ basic rules and rules of procedure
PD9002		BS9000, BSCECC and IECQ qualified products list
9003		Requirements for the manufacture of electronic components of assessed quality
PD9004		BS9000, CECC and IECQ UK administrative guide
9005		Specification for general procedures to be followed for the capability approval of electronic components covered by BS9000 part 1
9070		Specification for fixed capacitors
	1/2	Principles and procedures
	3	Tantalum electrolytic capacitors
	4	Polystyrene dielectric capacitors

	5	Ceramic dielectric capacitors
	6	Polycarbonate and polyethylene terephthalate dielectric capacitors
	7	Mica dielectric capacitors
	8	Aluminium electrolytic capacitors
	10	Tantalum electrolytic capacitor modules
9090		Specification for variable capacitors
9100		Specification for custom-built capacitors
9110		Specification for fixed resistors
9120		Specification for radio interference suppression filters
9125		Specification for passive radio interference suppression filter units
9130		Specification for potentiometers
9150		Specification for electrical relays
9200		Specification for reed contact units
9210		Specification for radiofrequency connectors
9215		Specification for custom-built radiofrequency connector/cable
9230		Specification for optical fibre and cable connectors
9300		Specification for semiconductor devices
9370		Specification for light emitting and infra-red diode arrays
9400		Specification for integrated electronic circuits and micro-assemblies
9450		Specification for capability approval of integrated electronic circuits
9500		Specification for sockets for electronic tubes and valves and plug-in devices
9520		Specification for electrical connectors for DC and low frequency applications
9521		Specification for removable contacts for electrical connectors
9530		Specification for cable fitting accessories for circular electrical connectors
9561		Specification for lever operated switches
9562		Specification for microswitches
9563		Specification for rotary (manual) switches
9564		Specification for push-button switches
9565		Specification for printed board mounted programming switches
9600		Specification for piezoelectric crystal filters
9610		Specification for quartz crystal units
9618		Specification for capability approval of quartz crystal units
9620		Specification for quartz crystal oscillators
9720		Specification for custom-built transformers and inductors
9750		Specification for fixed radiofrequency inductors
9760		Specification for printed circuits
9761		Sectional specification for capability approval of manufacturers of multi-layer rigid printed wiring boards of assessed quality with plated through-holes
9762		Sectional specification for capability approval of manufacturers of double-sided rigid printed wiring boards of assessed quality with plated through-holes
9763		Sectional specification for capability approval of manufacturers of single- and double-side rigid printed wiring boards of assessed quality without plated through-holes
9764		Sectional specification for capability approval of manufacturers of single- or double-sided rigid printed wiring boards of assessed quality without through-hole connections and with or without rigidizing component materials
9765		Sectional specification for capability approval of manufacturers of double-sided flexible printed wiring boards of assessed quality with through-hole connections and with or without rigidizing component materials
9766		Sectional specification for multi-layer flexi-rigid printed circuits with through-holes
9800		Specification for capability approval of modular electronic networks
9930		Harmonized system of quality assessment for electronic components: fixed capacitors

9940	Harmonized system of quality assessment for electronic components: fixed resistors
9970	Harmonized system of quality assessment for electronic components: semiconductor devices
Handbook 22	Quality assurance
Handbook 23	Quality management systems. General management
Handbook 24	Quality management systems. Quality control
Handbook 25	Quality management systems. Statistical interpretation of data

Table 12.3 CECC system standards and publications

Reference	*Content*
00007	Basic specification: sampling plans and procedures for inspection by attributes
00009	Basic specification: basic testing procedures and measuring methods for electromechanical components
00012	Basic specification: radiographic inspection of electronic components
00013	Basic specification: scanning electron microscope inspection of semiconductor dice
00014	Basic specification: CECC assessed processed average procedure
00200	Qualified products list
00800	Code of practice for the use of the ppm approach in association with the CECC system
11000	Generic specification: cathode ray tubes
12000	Generic specification: image converter and image intensifier tubes
13000	Generic specification: camera tubes
14000	Generic specification: photomultiplier tubes
16000	Generic specification: electromechanical all-or-nothing relays
17000	Generic specification: mercury wetted make contact units
18000	Generic specification: dry reed changeover contact units
19000	Generic specification: dry reed make contact units
20000	Generic specification: semiconductor optoelectronic and liquid crystal devices
22000	Generic specification: radiofrequency coaxial cables
25000	Generic specification: inductor and transformer cores for telecommunications
30000	Generic specification: fixed capacitors
30100	Sectional specification: polyethylene terephthalate film dielectric metal foil capacitors
30200	Sectional specification: tantalum capacitors
30300	Sectional specification: aluminium electrolytic capacitors
30400	Sectional specification: metallized polyethylene terephthalate film dielectric capacitors
30500	Sectional specification: metallized polycarbonate film dielectric capacitors
30600	Sectional specification: class 1 ceramic capacitors
30700	Sectional specification: class 2 ceramic capacitors
30800	Sectional specification: tantalum chip capacitors
30900	Sectional specification: polystyrene film dielectric metal foil capacitors
31100	Sectional specification: ceramic dielectric capacitors
31200	Sectional specification: polypropylene dielectric capacitors with metallized electrodes
31300	Sectional specification: mica dielectric capacitors
31400	Sectional specification: ceramic dielectric (class 1) capacitors
31500	Sectional specification: ceramic dielectric (class 2) capacitors
31700	Sectional specification: polycarbonate dielectric capacitors with thin metal foil electrodes
31800	Sectional specification: polypropylene dielectric capacitors with thin metal foil electrodes
35000	Generic specification: travelling wave amplifier tubes

36000	Generic specification: magnetrons
40000	Generic specification: fixed resistors
40100	Sectional specification: low power non-wirewound resistors
40200	Sectional specification: power resistors
40300	Sectional specification: precision resistors
41000	Generic specification: potentiometers
41100	Sectional specification: lead screw actuated and rotary preset potentiometers
41200	Sectional specification: power potentiometers
41300	Sectional specification: low power single turn rotary potentiometers
41400	Sectional specification: rotary precision potentiometers
42000	Generic specification: varistors
43000	Generic specification: negative temperature coefficient thermistors
45000	Generic specification: space-charge controlled tubes
46000	Generic specification: cold cathode indicator tubes
50000	Generic specification: discrete semiconductor devices
51000	Generic specification: mercury wetted, magnetically biased, changeover contact unit
52000	Generic specification: mercury wetted, mechanically biased, changeover contact units
63000	Generic specification: film and hybrid integrated circuits
75100	Sectional specification: two-part and edge socket connectors for printed board applications
75200	Sectional specification: circular connectors
90000	Generic specification: monolithic integrated circuits
90100	Sectional specification: digital monolithic integrated circuits
90101	Family specification: TTL circuits
90102	Family specification: TTL SCHOTTKY circuits
90103	Family specification: TTL low power SCHOTTKY circuits
90104	Family specification: CMOS circuits
90105	Blank detail specification: fusible link programmable bipolar read only memories
90106	Family specification: TTL advanced low power SCHOTTKY circuits
90107	Family specification: TTL FAST circuits
90108	Family specification: TTL advanced SCHOTTKY circuits
90109	Family specification: HCMOS circuits
90110	Blank detail specification: microprocessor circuits
90111	Blank detail specification: MOS read/write static memories
90112	Blank detail specification: MOS read/write dynamic memories
90113	Blank detail specification: MOS ultra-violet erasable electrically programmable read only memories
90200	Sectional specification: analogue monolithic integrated circuits
90201	Blank detail specification: voltage regulators
90202	Blank detail specification: operational amplifiers
90203	Blank detail specification: analogue switching circuits
90300	Sectional specification: interface monolithic integrated circuits
90301	Blank detail specification: line transmitters and receivers
90302	Blank detail specification: voltage comparators
96000	Generic specification: electromechanical switches

Table 12.4 UK defence standards

Reference	*Part*	*Content*
00-00	3	Index of standards
00-5	0	Requirements for achieving reliability and maintainability of MGO procured materiel
	1	Design criteria for reliability, maintainability and maintenance of land service materiel: general aspects
	2	Design criteria for reliability, maintainability and maintenance of land service materiel: mechanical aspects
	3	Design criteria for reliability, maintainability and maintenance of land service materiel: electrical and electronic aspects
	4	Design criteria for reliability, maintainability and maintenance of land service materiel: optical aspects
00-9		General requirements for qualification approval, capability approval and quality assurance of components for MoD use
00-10		General design and manufacturing requirements for service equipment
00-13		Guide to the achievement of testability in electronic and allied equipment
00-50		Guide to chemical environmental contaminants and corrosion affecting the design of military materiel
03-5		Electroless nickel coating of metals
03-8		Electro-deposition of tin
03-9		Electro-deposition of silver
03-10		Electro-deposition of nickel and chromium
03-13		Guide for the prevention of corrosion of metal caused by vapour from organic materials
03-15		Electro-deposition of tin-lead alloy for soldering purposes
03-17		Electro-deposition of gold
03-20		Electro-deposition of zinc
03-22		Guide to soldering and brazing
05-17		Electrotechnical terms and graphical symbols
05-21		Quality control system requirements for industry
05-24		Inspection system requirements for industry
05-26		Measurements and calibration system requirements for industry
05-29		Basic inspection system requirements for industry
05-37		Policy for procurement of electronic components
07-55	1	Environmental testing of service materiel: general requirements
	2/1	Environmental testing of service materiel: mechanical tests
	2/2	Environmental testing of service materiel: climatic tests
	2/3	Environmental testing of service materiel: chemical and biological attack tests
	2/4	Environmental testing of service materiel: penetration and immersion tests
	2/5	Environmental testing of service materiel: radiation tests
	2/6	Environmental testing of service materiel: fire and explosion tests
34-4		Fluxes for soft soldering electrical and electronic assemblies
58-95	1	Electronic assemblies: general requirements
	90	Electronic assemblies: detail
59-41	1	Electromagnetic compatibility: general requirements
	2	Electromagnetic compatibility: management and planning procedures
	3	Electromagnetic compatibility: technical requirements, test methods and limits
	4	Electromagnetic compatibility: open site testing
59-47		Conformal coatings for panels, printed circuit and panels, electronic circuit

59-48		Printed circuits of assessed quality: general requirements for the procurement of rigid and flexible printed circuits
	4	Printed circuits of assessed quality: general requirements for printed wired boards with discreetly wired layers
59-49		Solderless wrapped electrical connections
59-50		Requirements for plastics sheet laminated copper clad, epoxide resin bonded, woven glass fabric base — fire retardant (metal clad base materials for printed circuits)
DTD599		Non-corrosive flux for soft soldering
NES501		General requirements for the design of electrotechnical equipment
NES724		Packaging
NWS1000		Equipment design — design requirements

Table 12.5 IEC standards and publications

Reference	*Part*	*Content*
68		Basic environmental testing procedures
	1	General and guidance
	2	Tests
	2-1	A cold
	2-2	B dry heat
	2-3	Ca damp heat, steady state
	2-5	Sa simulated solar radiation
	2-6	Fc vibration (sinusoidal)
	2-7	Ga acceleration
	2-9	guidance for solar radiation testing
	2-10	J mould growth
	2-11	Ka salt mist
	2-13	M low air pressure
	2-14	N change of temperature
	2-17	Q sealing
	2-20	T soldering
	2-21	U robustness of terminations
	2-27	Ea shock
	2-28	guidance for damp heat tests
	2-29	Eb bump
	2-30	Db damp heat, cyclic
	2-31	Ec drop and topple
	2-32	Ed free fall
	2-33	guidance on change of temperature tests
	2-34	Fd random vibration wideband — general requirements
	2-35	Fda random vibration wideband — reproducibility high
	2-36	Fdb random vibration wideband — reproducibility medium
	2-37	Fdc random vibration wideband — reproducibility low
	2-38	Z/AD combined temperature/humidity cyclic
	2-39	Z/AMD combined sequential cold, low air pressure and damp heat
	2-40	Z/AM combined cold/low air pressure
	2-41	Z/BM combined dry heat/low air pressure

	2-42	Kc sulphur dioxide
	2-43	Kd hydrogen sulphide
	2-44	guidance on test T
	2-45	XA immersion in cleaning solvents
	2-46	guidance to test Kd
	2-47	mounting of parts for tests Ea, Eb, Fc, Fd, Ga
	2-48	guidance on tests to simulate effects of storage
	2-49	guidance to test Kc
	2-50	Z/AFc combined cold/vibration
	2-51	Z/BFc combined dry heat/vibration
	2-52	Kb salt mist cyclic
	2-53	guidance to tests Z/AFc and Z/BFc
	2-54	Ta solderability
	2-55	Ee bounce
	3	Background information (multi-part)
97		Grid system for printed circuits
160		Standard atmospheric conditions for test purposes
191		Mechanical standardization of semiconductor devices
	1	Preparation of drawings of semiconductor devices
	2	Dimensions
	3	General rules for the preparation of outline drawings of integrated circuits
	4	Coding system and classification into forms of package outlines for semiconductor devices
	5	Tape automated bonding (TAB) of integrated circuits
194		Terms and definitions for printed circuits
240		Characteristics of electric infra-red emitters for heating purposes
249		Base materials for printed circuits
	1	Test methods
	2-1	Phenolic cellulose paper copper-clad laminated sheet, high electrical quality
	2-2	Phenolic cellulose paper copper-clad laminated sheet, economic quality
	2-3	Epoxide cellulose paper copper-clad laminated sheet, defined flammability
	2-4	Epoxide woven glass fabric copper-clad laminated sheet, general purpose grade
	2-5	Epoxide woven glass fabric copper-clad laminated sheet, defined flammability
	2-6	Phenolic cellulose paper copper-clad laminated sheet, defined flammability
	2-7	Phenolic cellulose paper copper-clad laminated sheet, defined flammability
	2-8	Flexible copper-clad polyester (PETP) film
	2-9	Epoxide cellulose paper core, epoxide glass cloth surfaces copper-clad laminated sheet, defined flammability
	2-10	Epoxide non-woven/woven glass reinforced copper-clad laminated sheet, defined flammability
	2-11	Thin epoxide woven glass fabric copper-clad laminated sheet, for multi-layer printed boards
	2-12	Thin epoxide woven glass fabric copper-clad laminated sheet, defined flammability, for multi-layer printed boards
	2-13	Flexible copper-clad polyimide film
	2-15	Flexible copper-clad polyimide film, defined flammability
	3	Special materials
	3-1	Prepreg
	3A	Copper foil
286		Packaging of components for automatic handling
	1	Tape packaging of axial components
	2	Tape packaging of components with unidirectional leads
	3	Tape packaging of leadless components
326		Printed boards

	1	General information for the specification writer
	2	Test methods
	3	Design and use of printed boards
	4	Specification for single- and double-sided printed boards with plain holes
	5	Specification for single- and double-sided printed boards with plated through-holes
	6	Specification for multi-layer printed boards
	7	Specification for single- and double-sided flexible printed boards without through connections
	8	Specification for single- and double-sided flexible printed boards with through connections
352		Solderless connections
	1	Solderless wrapped connections

Table 12.6 IEC QC standards

Reference	*Content*
001001	Basic rules of the IEC quality assessment system for electronic components (IECQ)
001002	Rules of procedure of the IECQ
001003	Guidance documents
001004	Specifications list
001005	Qualified products list
300000	Generic specification: fixed capacitors
300200	Sectional specification: tantalum capacitors
300300	Sectional specification: aluminium electrolytic capacitors
300400	Sectional specification: metallized polyethylene terephthalate film dielectric capacitors
300500	Sectional specification: metallized polycarbonate film dielectric capacitors
301200	Sectional specification: metallized polypropylene film dielectric capacitors
301300	Sectional specification: metallized polypropylene film dielectric AC and pulse capacitors
400000	Generic specification: fixed resistors
400100	Sectional specification: low power non-wirewound resistors
400200	Sectional specification: power resistors
400300	Sectional specification: precision resistors
400400	Sectional specification: resistor networks with individually measurable resistors
400500	Sectional specification: resistor networks in which not all resistors are individually measurable
700000	Generic specification: semiconductor devices
750100	Sectional specification: discrete semiconductor devices (previously numbered QC750000)

Table 12.7 ANSI standards and publications

American National Standards Institute (prefixed ANSI)

Reference	*Part*	*Content*
MC96		Temperature measurement thermocouples

American Society for Quality Control (prefixed ASQC)

Reference	*Part*	*Content*
Q1		Generic guidelines for auditing of quality systems
A2		Definitions for acceptance sampling involving the per cent or proportion of variant parts and components
E2		Guide to inspection planning
A3		Quality systems terminology
Q90		Quality management and quality assurance standards — information guidelines for selection and use
Q91		Quality systems — model for quality assurance in design/development, production and installation
Q92		Quality systems — model for quality assurance in production and installation
Q93		Quality systems — models for quality assurance in final inspection and test
Q94		Quality management and quality system elements — guidelines

Electronic Industries Association (prefixed EIA)

Reference	*Part*	*Content*
162		Test standard for ceramic based printed circuits
186		Passive electronic component parts — test methods 1 to 13
	14	Passive electronic component parts — test methods 14
208		Printed wiring, definition and register
213		Test point locations for printed wiring assemblies
216		Method of test for adhesion of printed wiring
251		Test to determine the temperature rise as a function of current in printed conductors
296		Lead taping of components in axial lead configuration for automatic insertion
319		Solderability of printed wiring boards
402		Liquid rosin fluxes
467		Lead taping of components in hybrid radial lead configuration for automatic insertion
468		Lead taping of components in radial configuration for automatic insertion
481		Taping of surface mount components for automatic placement

Institute of Electrical and Electronics Engineers (prefixed IEEE)

Reference	*Part*	*Content*
200		Reference designations for electrical and electronic parts and equipments

Institute for Interconnecting and Packaging Printed Circuits (prefixed IPC)

Reference	*Part*	*Content*
T50		Terms and definitions for interconnecting and packaging electronic circuits
SC60		Post solder solvent cleaning handbook
AC62		Post solder aqueous cleaning handbook
L108		Specification for thin laminates, metal clad, primarily for high-temperature multi-layer boards
L109		Specification for glass cloth, resin-preimpregnated (B stage) for high-temperature multi-layer printed boards
L112		Specification for foil clad, polymeric composite, laminate
L115		Plastic sheet, laminated, metal-clad, for high-temperature performance printed boards
L125		Plastic substances, clad or unclad, for high speed/high frequency interconnections
CF150		Specification for copper foil for printed wiring applications
FC231		Specification for flexible bare dielectrics for use in flexible printed circuit wiring
FC232		Specification for adhesive coated dielectric films for use as cover sheets for flexible printed wiring
FC233		Flexible adhesive bonding films for printed circuits
FC240		Single-sided flexible printed wiring
D300		Printed board dimensions and tolerances
D310		Guidelines for phototool generation and measurement techniques for printed circuits
SD320		Specification for rigid, single- and double-sided printed boards
D322		Guidelines for selecting printed wiring board sizes using standard panel sizes
D325		Documentation requirements for printed boards
NC349		Computer numerical control formatting for driller and routers
D350		Printed board description in digital form
D351		Printed board drawings in digital form
D352		Electronic design data description for printed board in digital form
AM361		Specification for printed boards made on rigid substrates with additive process
AM372		Electroless copper film for additive printed boards
DW425		Design and end product requirements for discrete wiring boards
A600		Guidelines for acceptability of printed boards
A610		Acceptability of printed board assemblies
CM770		Guidelines for printed board component mounting
SM782		Printed circuits — surface mount land patterns (configurations and design rules)
S804		Solderability test methods for printed wiring boards
S805		Solderability test for printed circuit component leads and terminations
SM840		Qualification and performance of permanent polymer coating (solder mask) for printed boards
ML910		Specification for design and end production of rigid multi-layer printed boards
D949		Design standard for rigid multi-layer printed boards
ML950		Performance specification for rigid multi-layer printed boards

Underwriters Laboratories (prefixed UL)

Reference	*Part*	*Content*
746	E	Polymeric materials — industrial laminates, filament wound tubing, vulcanized fibre, and materials used in printed wiring boards
796		Printed wiring boards

Table 12.8 USA defense standards and publications

Reference	*Part*	*Content*
DODISS		Department of Defense Index of Specifications and Standards
Std202		Test methods for electronic and electrical component parts
Hdbk217		Reliability prediction of electronic equipment
Std242		Electronic component parts
Std275		Printed wiring for electronic equipment
Hdbk338		Electronic reliability design handbook
Std414		Sampling procedures and table for inspection by variables for per cent defective
Std429		Printed circuit terms and definitions
Std454		Standard general requirements for electronic equipment
Std461		Electromagnetic interference requirements
Std462		Electromagnetic interference procedures
Std810		Environmental test methods
Std883		Test methods and procedures for microelectronics
Std1495		Multilayer printed wiring boards
Std2000	1	Soldering technology, high quality and reliability
	2	Part and component mounting for high quality and reliability
	3	Criteria for high quality and reliability soldered technology
	4	General-purpose soldering
T10727		Tin plating, electrodeposited or hot dipped
P13949		Copper clad, laminated plastic sheet for printed wiring
F14256		Fluxes
P28809		Printed wiring assemblies
G45204		Gold electroplating
I46058		Insulating compounds, electrical, for conformal coatings of printed circuit assemblies
P50884		General specification for flexible printed wiring boards
P55110		Printed wiring boards
P55640		Multilayer printed wiring

Table 12.9 DIN standard groups and relevant selected standards

Group	*Standard*	*Part*	*Content*
1280			Testing of electrical apparatus and components in general
1290			Environmental testing for electrical engineering
	40046		Environmental tests (multi-part)
1420			Testing of electric components
1430			Printed circuits, printed boards
	40801		Printed circuits (multi-part)
	40802		Base materials
	40803		Drawings
	40804		Terms and definitions
	41494		Mechanical structures: 482.6 mm (19 inch) racks
	LN9407		Base materials (multi-part)
	VDE3710		Printed circuit board manufacture (multi-part)
2240			Electroplating, applied electrochemistry
	50960		Electroplated and chemical coatings (multi-part)
2315			Electromagnetic compatibility
3235			Soldering, brazing
	1707		Soft solders, composition, use
	1912		Concepts and terms for soldered and brazed joints
	8501		Soldering irons
	8505		Soldering and brazing processes (multi-part)
	8511		Fluxes (multi-part)
	8514		Solderability, terms
	8515		Defects
	8516		Soft solders with flux cores
	8526		Testing of soldered joints
	32506		Solderability tests (multi-part)

Table 12.10 Miscellaneous standards and publications

Reference	*Part*	*Content*
JEP95		JEDEC registered and standard outlines for semiconductor devices
JESD1		Leadless chip carrier pinouts standardized for linears
JESD2		Digital bipolar logic pinouts for chip carriers
JESD11		Chip carrier pinouts standardized for CMOS 4000, HC and HCT series of logic circuits
JESD99		Glossary of microelectronic terms, definitions and symbols
JESD100		Terms, definitions and letter symbols for microcomputers and memory integrated circuits
QQS571E		Solder, tin alloy, tin-lead alloy — US Federal specification
ULCC796		Printed wiring boards (Underwriters Laboratories of Canada)

Glossary

Absorptivity Percentage of infra-red energy amount absorbed by a substrate, as compared with total amount of incident infra-red energy.
Activated Condition of a compound of mixture having higher chemical activity than normally found.
Activated flux Rosin-based flux, with one or more activators added.
Activator Additive in a flux which aids the flux's cleaning ability.
Additive Action of adding the track to a PCB base material.
Aerosol Fluid particles small enough to be airborne.
Air levelling *Syn:* hot air levelling.
Alloy A combination of two or more metals. Alloys generally have significantly different properties than constituent elements. An example is solder, which is a mixture of tin and lead.
Ambient temperature Dry bulb temperature of a surrounding atmosphere.
Amorphous A condition where atoms and molecules of a material are not arranged in definite pattern or form (that is, the material is not crystalline). A characteristic of amorphous materials is lack of certain well-defined physical properties such as distinct melting-point or boiling point. Generally, amorphous materials are poor conductors of heat and electricity. Glass, carbon and rosin are examples of amorphous materials.
Anion Negatively charged atom or radical.
Anode Positive pole of a plating cell, from which negatively charged ions leave the plating solution by conversion back to their parent atoms or groups of atoms. They are discharged as gas, redissolve into solution, or precipitate as sludge.
Aspect ratio Ratio of thickness of a printed circuit board to a hole's pre-printed diameter. If the aspect ratio is too high, say 3 or more, holes are susceptible to cracking.
Atom Smallest particle of an element which can enter into a chemical combination. Molecules are composed of atoms.
Auto-ignition point Temperature where vapour from a material in air will burst spontaneously into flame. Not to be confused with flash point.
Automated optical inspection (AOI) Text fixture method in which printed circuit boards are checked at bare-board, pre- or post-soldered stages of assembly by optical means.
Automatic component insertion (ACI) Insertion of components into a through-hole board by automatic means.
Azeotropic system A system of two or more liquid compounds, having a boiling-point at any particular composition which is lower than any constituent's boiling-point.

Backplanes Interconnection panels used to connect rack-mounted printed circuit boards.

Bare-board testing Testing procedure in which printed circuit boards are tested prior to assembly of components.

Base (1) Insulating layer of a printed circuit board; (2) a substance dissolved in water which produces hydroxyl ions comprising an atom of oxygen and an atom of hydrogen.

Bed-of-nails fixture Arrangement of pin-type probes on a plate, which is pressed up against a printed circuit board, allowing electrical connections to be made for test purposes.

Blind via A via on a multi-layer PCB which does not go completely through the board. *Syn:* buried via.

Blistering Where copper track lifts from a printed board surface after soldering.

Blow holes Defects in plated through-hole solder joints, where gases burst through solder as it solidifies, usually at the bottom of a fillet. Cavities are often deep and not washable. Compare with pin holes.

Bond strength Strength of adhesion between two joined materials. *Syn:* peel strength.

Bonding wire Fine gold or aluminium wire between bonding pads on a semiconductor and base lands.

Bridging Where solder joins two or more conductive parts which are not meant to be connected.

Bumps Inner terminations of a tape automated bond integrated circuit.

Buried via *See* blind via.

Butt joint A joint formed by a surface mount component lead which directly abuts the printed circuit board track. Butt joints are formed by J-lead and cropped-lead components.

Capability approval Component approval stage in BS9000/CECC/IECQ systems, for components designed and manufactured by the manufacturer.

Capability manual Documented manufacturing system required in the process of capability approval to BS9000/CECC/IECQ systems.

Capillary action Interaction between a liquid and a small diameter opening in a solid; whereby liquid is drawn into the opening by surface tension.

Carriers Holders for electronic parts which enable handling during production.

Chip (1) substrate on which semiconductor components are produced; (2) discrete surface mounted capacitors and resistors.

Chip carrier Holder for surface mounted integrated circuit devices.

Chip-on-board Technology using semiconductor die which are mounted directly onto printed circuit board terminations.

Circuit density Amount of circuits on a given area of printed circuit board.

CFC Chlorinated fluorocarbon.

CLCC Ceramic leaded chip carrier.

Clinching Act of banding component leads underneath the board, on insertion, to hold the component in position.

Coefficient of thermal expansion (CTE) Ratio of dimensional change to a degree change in temperature.

Cold short Brittle condition in metal at temperatures below recrystallization temperature.

Cold short joint Solder joint exhibiting cold short properties. Do not confuse with solder joints which solidify under vibrations (properly called *disturbed joints*) or joints made with insufficient heat (properly called *insufficient heat joints*).

Colophony *See* rosin.

Combinational test Test procedure using both in-circuit test and functional test methods.

Condensation soldering *Syn:* hot vapour, or vapour phase soldering.

Conformal coating Encapsulation process, comprising a thin coating over an assembly.

Contact angle *See* wetting angle.

Contaminant An impurity or additive which affects characteristics of a material or surface.

Controlled collapse chip connection (C4) *See* flip-chip.

Copper mirror test Test for corrosivity of flux to a thin copper film vacuum-deposited on glass plate.

Corrosion Slow destruction of materials by chemical agents and electrochemical reactions. Most common form of corrosion is rust, where oxygen in air reacts with iron to form iron oxide.

Crazing *See* measling.

Creep strength Resistance of a material to stretching and deformation.

CS soldering process Soldering process in which components are positioned on a printed circuit board, before application of solder and heat.

CTE Coefficient of thermal expansion.

Cure Change physical properties of a material by chemical reaction.

Definition Accuracy of deposition of solder creams, solder masks, circuit track lines and so on.

Delamination Separation of laminates within a laminated printed circuit board, either between copper foil and board, or between internal layers of board.

Dendritic growth Metallic filament growth between conductors. Caused by electrolytic action. *Syn:* whiskers.

Device under test (DUT) Term used to describe a component, printed circuit board or assembly subjected to a test. *Syn:* unit under test (UUT), and loaded board.

Dewetting Occurrence during soldering, where an initial bond is formed, followed by a withdrawal of solder from the joint, leaving irregularly shaped mounds of solder separated by areas covered with a thin solder film. Base metal is not exposed.

DIL Dual-in-line. Refers to component shape with two parallel rows of connection leads. *Syn:* DIP.

DIP Dual in-line package. *See* DIL.

Dip soldering Mass CS soldering process in which assembled boards are dipped into a bath of molten solder.

Disturbed solder joint Joint created when a solder fillet solidifies while joint is vibrating. Result is a weak, non-uniform metallic structure, with many micro-cracks. Do not confuse with *cold short joint.*

Dragout Where a printed circuit board passing through a soldering or cleaning process takes with it some material, say, solder or solvent, used in the process.

Drag soldering Mass CS soldering process in which assembled boards are dragged across the surface of a bath of molten solder.

Drawbridging Form of surface mount component mis-alignment occurring in some SC soldering processes, where chip components lift off their pads at one end to resemble a drawbridge. *See* mis-alignment, tombstoning.

Dross Solder oxides and impurities such as flux residues which float in or on a molten solder bath.

Dry-film photoresist Photoresist with thin surface layer of polyester, aiding handling.

Dual-in-line, dual in-line package Component type where leads are in two parallel rows. *See* DIL, DIP.

Dual-wave soldering Wave soldering process using two solder waves.

Dummy track Track underneath a surface mounted component, unused for electrical purposes, to aid component adhesion.

Electroless copper deposition Process in which base laminate is coated with a layer of copper due to chemical deposition.

Electrolytic copper deposition Process in which base laminate is coated with a layer of copper due to electrolytic deposition.

Electromagnetic compatibility (EMC) Principle in which any electronic or electrical appliance should be able to operate without causing electromagnetic interference, and without being affected by electromagnetic interference.

Embedding Encapsulation process, of thick protective material.

Encapsulation Generic term for protection of assemblies, reducing the effects of environmental conditions.

Environmental stress screening (ESS) Manufacturing stage in which all assemblies are subjected to abnormal stresses, with the aim of forcing all early failures to occur. *Syn:* reliability screening.

Etchant Solution used to remove copper from non-circuit areas on printed circuit boards.

Etchback Process in PCB manufacture, in which holes are cleared of prepreg seepage, prior to metallization.

Etch resist Chemical applied to PCB track surface to prevent subsequent etch.

Eutectic point of solder Melting-point of solder with 62% tin and 38% lead alloy proportions. It has the lowest melting-point of any solder alloy proportions.

Failure Termination of a device or system's ability to perform its function.

Fiducials Optically recognizable location marks on a circuit board.

Fillet Solder between two metals in a joint.

Fine lines General term to suggest accurate PCB production with very narrow track widths.

Fine pitch Surface mount component shapes with lead pitches smaller than about 0.65 mm (0.025 inch).

Finish Protection of surface of cabinet.

Flash point Temperature at which a volatile liquid mixes with air in proportions which produce a flammable gaseous mixture.

Flatpack Integrated circuit type with semiconductor chip enclosed in a shallow rectangular or square package, having component terminations on two or four sides. Generally intended for surface mounted assemblies.

Flexible PCB A printed circuit board with a flexible base laminate.

Flexi-rigid PCB A rigid PCB with a flexible tail.

Flip-chip Semiconductor die, inverted and mounted directly to printed circuit board pads. Solder is subsequently deposited on pads. This technology is called a chip-on-board technique, or controlled collapse chip connection (C4).

Flooding

Fluorocarbon Compound of fluorine and carbon.

Flux Additive in the soldering process, which aids cleaning and wetting of the metal surfaces to be soldered.

Flux activity A measure of the cleaning ability of a flux in the soldering process.

Functional test Test procedure in which an assembly's overall operational characteristics are tested by simulating normal function. *Syn:* go/no-go test.

Fusing Heating an electroplated tin/lead layer to ensure an interfacing alloy bond occurs.

Gap Spaces between adjacent PCB tracks.

Glob-top Protective encapsulation over semiconductor die mounted directly on circuit board.

Golden board Term to describe the ideal properties of a printed circuit board.

Go/no-go test *See* functional test.

Gull-wing lead Surface mount component lead configuration where end views of leads resemble a wing of a gull in flight. Gull-wing leads form simple lap joints when soldered.

Halide Compound containing a halogen (that is, fluorine, chlorine, bromine, iodine, or astatine). Used as activators in flux. Residues of halide activated fluxes are considered dangerous and must be removed.

Halide-free flux Flux which contains no halides.

Halo effect Minor delamination of board material, resist or laminate around holes.

Halogen Fluorine, chlorine, bromine, iodine and astatine are all halogen elements.

Halogenated hydrocarbon Organic compound in which hydrogen atoms linked to carbon atoms are replaced by halogen atoms. Generally used as a solvent.

Heated collet Method of soldering surface mounted components, where an electrically-heated collet is positioned over the component terminals so that solder under the terminals melts.

Heat management PCB design philosophy, ensuring adequate heat dissipation. *Syn:* thermal design.

Hot air levelling Process used to coat printed circuit boards with a thin and uniform solderable layer of solder. It involves immersion of the printed circuit board into molten solder then, on withdrawal, application of hot air from a hot air knife. This clears holes of solder, and removes excess solder from land, pads and track. *Syn:* air levelling.

Hot-cracking Cracking of a solder joint as a result of uneven cooling. For example, if a joint is formed between a massive part and a small part, the massive part acts as a heatsink — drawing heat from the joint. Stresses caused by this unequal cooling can crack or fracture the joint.

Hot-short Brittleness in a solder joint due to elevated temperature.

Hot tinning Application of a solderable coating by a molten solder wetting process.

Hot vapour soldering SC soldering process using the latent heat of evaporation of a liquid, where the heat from the liquid's vapour heats the printed circuit board. *Syn:* vapour phase soldering.

Hybrid assembly Electronics assembly in which thin- or thick-film passive components, and leadless components, are mounted on a substrate.

Hydrocarbons Organic chemical compounds containing only hydrogen and carbon atoms.

Hygroscopic Ability of a material to absorb water, usually from air. Rosin is an example of a non-hygroscopic material — consequently, after soldering, rosin residues do not absorb water from the atmosphere.

Icicling Formation of spikes of solder after soldering, if excess liquid solder is not removed from a joint quickly enough.

Image *See* track.

Impregnation Encapsulation process, of protective material injected into all spaces or voids between components.

In-circuit test (ICT) Test procedure in which circuit nodes of an assembly are accessed by pin-type probes, to test individual components within the circuit. *Syn:* manufacturing defects analysis and pre-screening.

Infra-red fusing Use of infra-red radiation to melt solder in paste, cream, or electroplated form.

Infra-red radiation Band of electromagnetic wavelengths lying between the extreme of visible light and the shortest microwaves. Strong absorption of infra-red radiation by many substances makes it a useful means of applying heat energy.

Infra-red signature analysis Test procedure in which soldered joints are heated by laser then optically monitored during cooling.

Infra-red soldering SC soldering process using infra-red radiating elements to create heat.

Inner lead bonding Process of bonding termination leads to a tape automated bond integrated circuit's bumps.

Insufficient heat joint A solder joint formed under too low a heat or for too short a contact time. Evident by poor wetting, poor solder rise, or a chalky appearance.

Intermetallic compound Compound of elements, having a fixed ratio of the elements in the compound.

J-lead Surface mount component lead configuration where leads bend underneath the component to resemble the letter *J*.

Joint Metallic bonds between two or more component metal terminals, using solder as the bonding material.

Kiss pressure Initial pressure applied to layers to be bonded into multi-layer PCB, whereby the prepreg layers soften and flow to fill voids within the layers.

Laminar wave Solder wave which has little or no turbulence.

Land Part of PCB track, allocated to the connection of a component lead. *Syn:* pad.

Lap joint Solder joint between two metal surfaces, where surfaces overlap.

Layout Overall shape of conductive track on a PCB. *Syn:* pattern, image.

LCCC Leadless ceramic chip carrier.

Leaching Removal of thin layers of component end terminations by solution into solder. *Syn:* scavenging.

Leaded component A component with wire terminations.

Leadless ceramic chip carrier (LCCC) Sealed, ceramic integrated circuit package.

Leadless component A component without wired terminations.

Lead pitch Distance between centres of adjacent leads of a component.

Levelling Process of removal of much of a thick tin/lead layer, to leave behind a thin, level, layer.

Liquidus Temperature at which an alloy is completely molten.

Loaded board *See* device under test.

Loading Supplying an automatic component insertion head with components.

Manufacturer's approval First stage required in component approval through BS9000/CECC/IECQ systems.

Manufacturing defects analysis *See* in-circuit test.

Mask Metallic stencil-type structure, used to apply solder paste or cream.

Mass soldering Process which solders many components to a printed circuit board simultaneously.

Mealing Condition where conformal coating separates from a printed circuit board or components, forming visible spots or patches.

Mean time between failure (MTBF) A measure of how often failure can be expected.

Mean time to failure (MTTF) Average time between failures.

Mean time to repair (MTTR) A measure of how long it takes a service engineer to get to the failed system, locate and repair the fault.

Measling Separating of fibres in glass cloth of a printed circuit board laminate, showing as discrete white spots or crosses underneath the surface. *Syn:* crazing.

MELF Metal electrode leadless face.

Meniscograph Instrument for measuring surface solderability, using the wetting balance method. It measures and plots time and forces required for the test specimen to change from buoyancy in solder to a downward pull as wetting takes place.

Mesh size Number of holes per linear measure in a screen printing material.

Metal-cored PCB A printed circuit board, with an internal thermal plane.

Metal electrode leadless face (MELF) Cylindrical surface mount component package, metallized at each end.

Metallization Processes involved in forming a conductive layer on a PCB base material, generally by electroless copper deposition, followed by subsequent copper and tin/lead plating.

Mis-alignment Where two-terminal surface mounted components move during the soldering process, due to the different times that lands at opposite ends of the component reach soldering temperature. *See* drawbridging, tombstoning.

Mixed assembly Electronics assembly in which leaded and leadless components are inserted and mounted. *Syn:* mixprint.

Moulded circuit board (MCB) *See* moulded PCB.

Moulded PCB A printed circuit board, comprising an injection-moulded base and plated track. *Syn:* three-dimensional moulded circuit board, moulded circuit board.

Moving probe Test fixture method, in which two or more probes are robotically controlled to move around points on a printed circuit board.

Multi-layer PCB A printed circuit board, comprising three or more layers of track, insulated and laminated together into one board.

Multi-wired PCB A printed circuit board, comprising a conventional single- or double-sided board, with insulated wire tracks laid on to build up connections.

Node Electrical junction between two or more components.

Non-activated flux Rosin-based flux without activator.

Non-polar compound A compound with electrical charges distributed symmetrically over each molecule's surface. Because of this no electrical effects in or out of solution are exhibited.

Non-wetting Condition where part or all of a surface does not wet during soldering. Non-wetting is evident because base metal is visible. It is usually due to presence of an interference layer such as organic contaminant, tarnish, dirt and so on, on the surface.

Onsertion Slang term for the placement of components on a PCB or surface mounting substrate.

Open joint An unsoldered connection or missed joint.

Organic Historically, this refers to compounds found in organisms and containing carbon. Generally refers now to most carbon-containing compounds.

Organic halides Organic compounds containing halogens.

Oxidation Occurs specifically when oxygen combines with a metal. Generally refers to any process where a metal loses electrons in conversion to a metallic ion with a positive charge.

Outer lead bonding Process of bonding the terminations of a tape automated bond integrated circuit to a circuit board.

Outgassing Emission of gas or air from a printed circuit board or joint, as the board is soldered.

Pad *See* land.

Panel plating Processes in metallization of PCB track, in which tin/lead is selectively plated.

Passivation Surface oxidation which acts as a barrier to further oxidation or corrosion.

Paste *See* solder paste.

Pattern *See* track.

Pattern plating Processes in metallization of PCB track, in which copper and tin/lead layers are plated selectively.

PCB Printed circuit board.

Peel strength *See* bond strength.

pH Measure of acidity or alkalinity of a solution. A pH of 7 is neutral — neither acid nor alkaline. Solutions with pH above 7 are alkaline, those below 7 are acid.

Phase diagram Graphical representation of temperature phases in an alloy. A tin/lead phase diagram (that is, solder) shows solidus and liquidus temperatures for a range of tin/lead proportions.

Photo-printing Process of photographically applying a resist to the surface of a PCB.

Photoresist Layer, laminated onto the surface of a PCB, as part of a photo-printing process.

Pick and place Sequential placement of surface mounted components onto a circuit board.

Pickling Process in metallization, where the base laminate is prepared for subsequent electroless copper deposition.

Pin holes Shallow surface imperfections occurring in solidifying solder. They can be cleaned out, and they do not weaken the structure. Compare with blow holes.

Placement centre Area of an automatic component placement machine where the component is centred to an absolute position in the placement head.

Plastic leaded chip carrier (PLCC) Surface mount component rectangular package with J-leads on all four sides.

Plated-through hole (PTH) Method of connecting between track layers on a PCB, where drilled or punched holes or vias are metallized.

PLCC Plastic leaded chip carrier.

Polar compound A compound in which electrical charges are distributed asymmetrically over its molecular surface. Ionizable compounds such as flux activators are usually polar compounds.

Potting Encapsulation process, of embedding the assembly inside a container.

Pre-screening *See* in-circuit test.

Preforming Act of shaping component leads prior to insertion into a PCB. *Syn:* prepping.

Preheat Application of heat, applied at a determined rate, from ambient temperature to a desired elevated temperature.

Preparation fluid *See* flux.

Prepping *See* preforming.

Prepreg Bonding layer of fibre glass impregnated with epoxy resin, used in multilayer and similar PCB manufacture.

Print and etch *See* subtractive.

Printed circuit board (PCB) Assembly method using a base laminate of non-insulating material with selective tracks of conducting material to hold components and electrically connect between them. PCBs may be of through-hole or surface mount form. *Syn:* printed wiring board.

Protective coating Coating applied to a manufactured printed circuit board, prior to assembly with components.

PTH Plated-through hole.

Purchaser assessment Buying procedure in which parts must be assessed by the purchaser, prior to use.

PWB Printed wiring board.

Quadpack Surface mount component package with leads on all four sides, usually with gull-wing leads.

Qualification approval Component approval stage in BS9000/CECC/IECQ systems, for components simply manufactured (that is, not designed) by the manufacturer.

Qualified products list (QPL) List of components, whose manufacturers have been assessed as to their capability to manufacture.

Quality Achievement of a system to conform to its specified performance.

Quality assessment schedule (QAS) Supplementary document to BS5750/EN29000/ISO9000 systems, defining in precise terms the quality requirements of an industry seeking capability assessment and registration under the standard.

Quality manual Documented quality system required for capability assessment and registration to BS5750/EN29000/ISO9000 systems.

Quench Rapid cooling of molten solder to below its melting point.

Reduction Specifically, removal of oxygen from a compound. Generally, reduction signifies a decrease in an element's or an ion's positive charge.

Reflow *See* SC soldering process.

Registration Location of a circuit by means of fixed points.

Reliability A system's ability to perform its required function.

Reliability screening *See* environmental stress screening.

Resin smear Prepreg between layers of a drilled multi-layer PCB which has softened and flowed to cover copper tracks within the structure.

Resist Chemical used to prevent part of a PCB from undergoing some action.

Resolution Measure of the thinness of a line a photoresist can successfully reproduce in a circuit.

Rosin Naturally occurring resin which is a mixture of several organic acids, of which abietic acid is the main component. Constituent of many organically soluble fluxes, distilled from pine tree sap. *Syn:* colophony.

Saponification Reaction converting rosin into rosin soap — process in post-soldering cleaning processes allowing water to be used as a cleaner, rather than solvent.

Scavenging *See* leaching.

SC soldering process Soldering process in which solder is first applied to a printed circuit board, followed by components and heat.

Screen Grounded or earthed conductive enclosure, to prevent radiated electromagnetic interference.

Screen printing Process to coat boards with resist, using a stretched material suspended above the board. A squeegee is used to force the resist through holes in the material and to push the material down to touch the board. *Syn:* silk-screen printing.

Seeding Process in electroless copper deposition, where the sensitised board is dipped into an acidic solution of palladium chloride.

Self-alignment Tendency of slightly mis-aligned components to become aligned during SC soldering processes. Caused by solder surface tension.

Semi-additive PCB manufacturing technique which uses both subtractive and additive processes.

Sensitize Process in electroless copper deposition, where the board is dipped into acidic stannous solution.

Sequential placement Placement of surface mounted components onto a circuit board one after the other.

Shadow effect Effect of different joint temperatures, in SC soldering processes, where component bodies prevent radiant heat from infra-red elements reaching joints. *See* shadowing.

Shadowing (1) Where radiant infra-red heat in SC soldering processes is prevented from reaching joints by local component bodies (2) where solder fails to wet joints of a wave soldered assembly because local component bodies block solder flow.

Shelf life Length of time, under specified conditions, a stored material is useable.

Silk-screen printing *See* screen printing.

Silver chromate paper test Qualitative test to determine presence of ionic halides. Typically used to check mildly activated fluxes contain no halides.

Silver nitrate test Similar to the silver chromate paper test, this is a qualitative test to check for presence of ionic halides.

Simultaneous placement Placement of more than one surface mounted component onto a circuit board at a time.

Single-wave soldering Wave soldering process using just one solder wave.

Small-outline integrated circuit (SOIC) Surface mount integrated circuit with two parallel rows of gull-wing leads.

Small-outline J-lead (SOJ) Surface mount integrated circuit with two parallel rows of J-leads.

Small-outline transistor (SOT) Surface mount component with two gull-wing leads on one side and one on the other.

SMC Surface mount component.

SMD Surface mount device.

SMOBC Solder mask over bare copper.

SMT Surface mount technology.

SOIC Small-outline integrated circuit.

SOJ Small-outline J-lead component.

Solder Alloy of tin and lead, used to form mechanical joints between electronic components and printed circuit board copper lands.

Solderability Ability of a metal to be wet by solder.

Solder balls Undesired small balls of solder remaining on printed circuit board after soldering processes.

Solder bridge Undesired connection between joints or tracks of a printed circuit board, in the form of excess solder.

Solder cream *See* solder paste.

Solder fillet *See* fillet.

Solder mask *See* solder resist.

Solder mask over bare copper (SMOBC) Assembly technique which uses a solder resist to protect part of a printed circuit board's copper track from oxidation while coating the remaining unprotected track with solder.

Solder paste Combination of solder, flux, solvent and suspension agent, used in SC soldering processes. *Syn:* solder cream.

Solder preform Solder moulded into predetermined shapes, for application around a joint area prior to application of heat.

Solder resist Selective coating on a printed circuit board, to prevent wetting of solder over covered areas. *Syn:* solder mask.

Solder skip Joint not properly soldered due to shadowing by one or more component bodies, as an assembly is wave soldered.

Solder thief Additional solder land, positioned to follow the last component mounting land of a surface mount assembly board through a mass CS process soldering machine, to prevent solder accumulation and bridging.

Solder voids *See* outgassing.

Solder wicking Where solder on the terminal of a surface mounted component soldered in an SC soldering process rises up from the printed circuit board land, leaving insufficient solder on the land to give a good joint.

Solidus Temperature at which a metal alloy begins to melt, although most of the alloy is solid.

SOT Small-outline transistor.

Spidering *See* webbing.

Standard conditions Contractual conditions stated by Government purchasers.

Stripping Process of removal of resist.

Substrate Base of a thick-film hybrid, or surface mounted, assembly.

Subtractive Action of defining track on a PCB and removing excess conductor. *Syn:* print and etch.

Surface conditioners Liquid cleaners used to restore solderability of metals prior to soldering.

Surface insulation resistance Electrical resistance of insulating material, determined under specified environmental and electrical conditions, between a pair of contacts, conductors or grounding devices in various combinations. One of the most important parameters in determination of solder flux residues.

Surface mounted assembly (SMA) Electronics assembly in which leadless components are mounted directly on the board surface.

Surface tension Property of liquids created by molecular forces existing in the surface film. It tends to contract the volume into a form with the least surface area. Breakdown of surface tension can be accomplished by addition of certain chemical agents, resulting in the liquid flowing out and wetting surrounding material surfaces. One of the functions of flux in the soldering process is to breakdown surface tension of solder, thereby causing solder to wet metal surfaces to be jointed. Surface tension is higher in nitrogen than in air.

Surfactant Chemical added to water to lower its surface tension. Contraction of *surface active agent.*

Synthetic activated flux (SA) A highly active flux, whose residues are soluble in commonly used halogenated solvents.

TAB Taped automated bonded.

Tail A flexible circuit attached to a rigid PCB.

Taped automated bonded (TAB) Semiconductor die assembly method, where the die is supplied in a tape-reel form, complete with terminating lead frame. Each die is mounted directly to a printed circuit board, so is a chip-on-board process. TAB devices are sometimes called *mikropacks.*

TCE Thermal coefficient of expansion.

Temperature profile Graphical portrayal of temperature experienced by an assembly as it passes through a soldering process.

Tensile strength Characteristic of a material which describes its resistance to fracture when stretched.

Tenting Process in which selected holes in a printed circuit board are covered with solder resist.

Termination Leads or metallized surfaces of components.

Thermal bridge Metal cover over components mounted on a PCB with a thermal plane. Specifically to aid heat dissipation.

Thermal coefficient of expansion (TCE) Incremental change in dimension due to a 1°C temperature rise.

Thermal conductivity Property of a material which describes its ability to conduct heat.

Thermal design *See* heat management.

Thermal mis-match Loose term describing problems of different thermal coefficients of expansion of surface mounted components and circuit board base materials.

Thermal path analysis Thermal management design process.

Thermal plane A heatsink, bonded to the surface of a PCB before component insertion, or laminated within a PCB, to aid heat dissipation, specifically in closely packed PCBs.

Thermal via A via used specifically to aid heat dissipation from a component, thermally connecting the area around or underneath the component on a PCB to a thermally dissipative area.

Thermode Electrically heated element, used in an SC soldering process.

Through-hole assembly Electronics assembly in which leaded component leads are inserted through holes in the board.

Tinning Coating of a metal surface with tin or solder alloy to improve or maintain solderability, or to aid a later soldering process.

Tombstoning Severe form of mis-alignment, where the two-terminal component lifts into a vertical position.

Undercut Narrowing of a printed circuit board track during etching, by horizontal attack by etching solution.

Unit under test (UUT) *See* device under test.

Vapour phase soldering (VPS) *See* hot vapour soldering.

Vendor assessment Buying procedure in which the manufacturer of parts assesses the product, alleviating necessity for the purchaser to do so, prior to use.

Via Plated-through hole connecting two or more conductor layers of a printed circuit board.

Vision Inclusion of some form of camera on an automatic component insertion or placement machine, to enable high accuracy of component positioning.

Void Absence of solder at specific point.

Warpage Twisting of a printed circuit board out of flat surface, caused by uneven heating or poor support while soldering.

Wave soldering Mass CS soldering process in which assembled boards are dragged across the surface of a wave (or waves) of molten solder.

Webbing Softening of printed circuit board laminate as it passes over a solder wave, such that fine particles of solder are picked up by the tacky board surface. *Syn:* spidering.

Wetting Action of initial flow of solder over a metal, under heat.

Wetting agent Chemical material added to a liquid to reduce surface tension.

Wetting balance Method of assessing solderability of metals.

Whiskers *See* dendritic growth.

Wicking Movement of solder by capillary action along fibres or strands of metal.

X-ray imaging Optical test procedure, using the ability of x-rays to pass through certain substances more easily than others.

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AMT — Advanced Manufacturing Technology
CPG House
Glenageary Office Park
Dun Laoghaire
Co Dublin
Ireland

Advanced Packaging
17730 West Peterson Road
Libertyville
IL 60048
USA

Assembly Engineering
Hitchcock Publishing Company
Hitchcock Building
Wheaton
IL 60188
USA

Circuitree
340 Martin Avenue
Santa Clara
CA 95050
USA

Circuit World
MCB University Press
60/62 Toller Lane
Bradford
West Yorkshire
BD8 9BY
England

Circuits Assembly
Miller Freeman Publications Inc
2000 Powers Ferry Center, Suite 450
Marietta
GA 30067
USA

Circuits Manufacturing
Miller Freeman Publications Inc
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CA 94105
USA

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Lake Publishing Corp
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Electronic Packaging & Production
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Highlands Ranch
CO 80126
USA

Electronic Production
Inside Communications
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Blair House
184–186 High Street
Tonbridge
Kent
TN9 1BQ
England

Electronics Manufacturing International
Rue Verte 216
1030 Brussels
Belgium

Electronics Manufacturing Products
MIT Marketing Services
Featherstone House
375 High Street
Rochester
Kent
ME1 1DQ
England

Electronics Times
30 Calderwood Street
Woolwich
London
SE18 6QH
England

Electronics Weekly
Quadrant House
The Quadrant
Sutton
Surrey
S12 5AS
England

Elektronik
Magna Media Verlag AG
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D-85540 Haar

EPP
Konrad in Verlag Robert Kohilhammer Gmbh
Ernst-Mey-Str 8
70771 Leinfelden-Echterdingen
Germany

European Semiconductor
361 City Road
London
EC1V 1LR
England

Hybrid Circuit Technology
Lake Publishing Corp
17730 West Peterson Road
Box 159
Libertyville
IL 60048
USA

Industry Ireland
Tower Hill Publications Ltd
38 Grafton Street
Dublin 2
Ireland

PCB Magazine
La Prima Rivista Italiana sui Circuiti Stampati
AD Communication snc
Palazzo Blanc
Pizza del Popolo
3-00187 Roma
Italy

Printed Circuit Assembly
1790 Hembree Road
Alpharetta
GA 30201
USA

Printed Circuit Fabrication
Miller Freeman Inc
600 Harrison Street
San Francisco
CA 94107

Productronic
Huthig Gmbh
Paul-Gerhardt-Allee 46
D-81245 Munchen
Germany

SEMI (Semiconductor Equipment and Materials International)
Avenue de Cortenberg 79
B-1000 Brussels
Belgium

Soldering and Surface Mount Technology
MCB University Press
60/62 Toller Lane
Bradford
West Yorkshire
England

SMT Surface Mount Technology
IHS Publishing Group
17730 West Peterson Road
Box 159
Libertyville
IL 60048-0159
USA

TIN International
Kingston Lane
Uxbridge
Middlesex
UB8 3PJ
England

What's New in Electronics
30 Calderwood Street
Woolwich
London
SE18 6QH
England

Worldwide addresses

UK Governmental Departments

Department of Trade and Industry

For copies of Printed Circuit Board Assembly:
Department of Trade and Industry
Information Engineering Directorate
Kingsgate House
66–74 Victoria Street
London SW1E 6SW

Ministry of Defence

For general advice and guidance on selling to MoD:
Ministry of Defence
New Suppliers Service
Lacon House
Theobalds Road
London
WC1X 8RY

For small firms:
Ministry of Defence
New Suppliers Service
(Small Firms Group)
Lacon House
Theobalds Road
London
WC1X 8RY

For advice on selling information technology to MoD:
Ministry of Defence
Director General Information Technology Systems (DGITS)
IT (Industry Liaison Officer)
Room 557
Northumberland House
Northumberland Avenue
London
WC2N 5BP

For advice on marketing and selling defence products overseas:
Ministry of Defence
Director of Marketing Services
Defence Export Services Organization
Room 707
Stuart House
23–25 Soho Square
London
W1V 5FJ

For advice on defence quality assurance:
Ministry of Defence
Directorate of Quality Assurance/Policy
Room 125
Building 22
Royal Arsenal West
Woolwich
London
SE18 6ST

Institutions and associations

The SMART Group (for the advancement of surface mount and related technologies)

84 Easton Street
High Wycombe
Bucks
HP11 1LT

The NPL Soldering Science and Technology Club

National Physical Laboratory
Teddington
Middlesex
TW11 0LW

British Association of Brazing and Soldering (BABS)

The Welding Institute
Abington Hall
Abington
Cambridge
CB1 6AL

The Circuit Equipment and Materials Association (CEMA)

c/o CEMA
Victoria Road
Northants
NN10 0AS

International Society for Hybrid Microelectronics (ISHM)

13 Firlands
Bracknell
Berkshire
RG12 3SB

Printed Circuit Interconnection Federation (PCIF)

45 Beaufort Court
Admirals Way
South Quay
London
E14 9XL

Institute of Metal Finishing (Printed Circuit Group)

Exeter House
48 Holloway Head
Birmingham
B1 1NQ

ITRI (formerly International Tin Research Institute)

Kingston Lane
Uxbridge
Middlesex
UB8 3PJ

The Computing Services Association

Hanover House
73/74 High Holborn
London
WC1V 6LE

The Electronic Engineering Association

Leicester House
8 Leicester Street
London
WC2H 7BN

Institute for Interconnection and Packaging (IPC)

2215 Sanders Road
Northbrook
IL 60062

Electronic Industries Associations (EIA)

2001 Eye Street NW
Washington DC 20006

Surface Mount Technology Association (SMTA)

5200 Willson Road
Suite 215
Edina
MN 55424

International Electronic Packaging Society

PO Box 687
Chicago
IL 60690

Electronics Manufacturing Productivity Facility (EMPF)

714 North Senate Avenue
Indianapolis, IN
46202-3112

ITRI International

778 George F. Highway
Johnson City
NY 13790

International Microelectronics and Packaging Society (IMAPS)

1850 Centennial Park Drive
Suite 105
Reston
VA 20191

Standards organizations and bodies

American National Standards Institute (ANSI) and cooperating bodies

American National Standards Institute

1430 Broadway
New York
New York 10018

Electronic Industries Association (EIA)

2001 Eye Street Northwest
Washington DC 20006

Institute for Interconnecting and Packaging Electronic Circuits (IPC)

3451 Church Street
Evanston
Illinois 60203

Institute of Electrical and Electronics Engineers (IEEE)

345 East 47th Street
New York
New York 10017

Instrument Society of America (ISA)

PO Box 12277
Research Triangle Park
North Carolina 27709

British Standards Institution

British Standards Institution (BSI)
Linford Wood
Milton Keynes
Buckinghamshire
MK14 6LE

Deutsches Institute für Normung (DIN)

Burggrafenstrasse 4-10
D-1000 Berlin
30 T:26011

International Electrotechnical Commission and National Committees

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CH-1211
Geneve 20
Switzerland

Australia:

Australian Electrotechnical Committee
Standards Association of Australia
80 Arthur Street
North Sydney
NSW 2060

Belgium:

Comité Electrotechnique Belge
3 Galerie Ravenstein
B-1000 Bruxelles

Canada:

Standards Council of Canada
Communication Branch (Sales)
350 Sparks Street
Nbr 1200
Ottawa
Ontario
K1R 758

Denmark:

Dansk Elektroteknisk Komite
Strandgade 36 st
DK-1401
Kobenhavn K

France:

Comité Electrotechnique Français
12 place des Etats-Unis
F75783
Paris
CEDEX 16

Germany:

VDE-Verlag GmbH
Auslieferungsstelle
Merianstrasses 29
D-605
Offenbach aM

India:

Indian Standards Institution
Sales Service
Manak Bhavan
9 Bahadur Shah Zafar Marg
New Delhi 110002

Italy:

Comitato Ellettrotecnico Italiano
Viale Monza 259
1-20126 Milano

Japan:

Japanese Standards Association
1–24 Akasaka 4
Minato-Ku
Tokyo 107

Netherlands:

Nederlands Normalisatie-Instituut
Afd Verkoop en Informatie
Kalfjeslaan 2
2600 GB Delft

Norway:

Norsk Elektroteknisk Komite
Postboks 280 Skoyen
N - 0212
Oslo 2

Spain:

Comission Permanente Española de Electricidad
Francisco Gervas No 3
Madrid 20

Sweden:

Standardiseringskommissionen i Sverige
Box 3295
S-10366 Stockholm 3

Switzerland:

Comité Electrotechnique Suisse
Association Suisse des Electriciens
Seefeldstrasse 301
8034 Zurich

United Kingdom:

British Standards Institution
BSI Sales Department
Linford Wood
Milton Keynes
Buckinghamshire
MK14 6LE

United States of America:

American National Standards Institute
1430 Broadway
New York
New York 10018

Defence

UK Ministry of Defence

Directorate of Standardization/Stan 1
Room 5138
Kentigern House
65 Brown Street
Glasgow
G2 8EX

United States Federal Standards and Specifications

Washington DC: GPO
United States Military Standards and Specifications
Washington DC: DOD

Appendix 1 Why not blame the machine?

Let's be humorous…

A guide for the misguided

Contrary to popular notion, it's not always easy to blame the machine. With this in mind, we've compiled this helpful little guide in the hope it will point aspiring 'machine blamers' in the right direction. We have concentrated on the art of blaming wave soldering machines, but the principles are universal and can be applied in most other fields — reflow soldering, fluxing, football, marriage… err, yeah! You get the idea.

First of all it is important to remember you are not alone. There are many thousands of blamers out there, right now. Doing it! As your experience grows you will start to recognize fellow exponents among your colleagues. Some of you who have been blamers for years without realizing it will experience the pleasure of self-awareness when you read this guide.

You are in good company. Machine blaming has a proud history going back to Roman times, when well-trained 'machina inculpatores' would go around kicking chariots, ballista (and occasionally legionaries) after they had lost a battle. Their working life was rather short because the well-known Roman sandal offered very little toe protection, and redundant inculpatores would hobble off into obscurity. Today we have learned from their mistakes and anyone seriously considering a career in machine blaming should invest in a robust pair of hard shoes. A good kicking style is an essential element of the profession. One of the all-time greats in the game, a certain Frederick Newkes of Ealing Broadway in England, kicked a machine to pieces before it had even been completely installed. Nice one, Fred!!!

Operating instructions

One of the first things an experienced machine blamer does is make sure he personally receives all manufacturer's instructions and operating manuals. Not so he can read them, of course, but to make sure nobody else does. It's no good having someone in a position to dispute your arguments. Best thing to do, we feel, is to throw them away. Almost as effective is to file them under *13* or use them as a wedge to prop up that wobbly table.

Installation

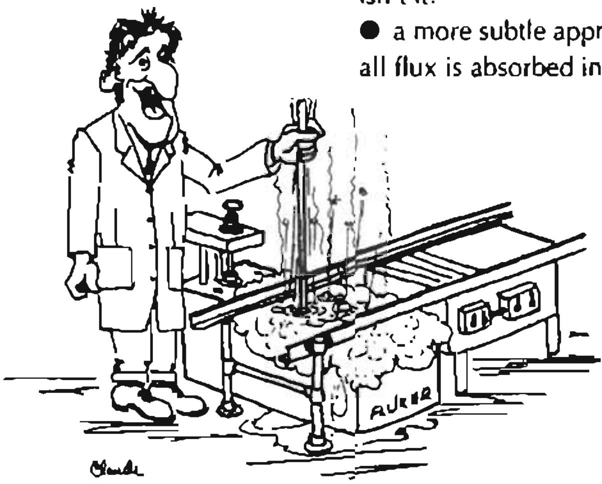
Next major obstacle to overcome is the visit by the manufacturer's representative during installation. He will, if given free rein, check to see the machine is properly installed then instruct and advise in processing methods. This is often a sticky problem and requires a great deal of ingenuity to ensure no-one learns anything useful during the visit. Different practitioners of the art have perfected their favourite techniques, but probably the most effective is to ensure anyone who will be involved with the machine is absent during the visit — annual vacations may have to be shuffled a bit. This leaves you as sole recipient of any information, which of course you can forget immediately using the well-tried 'in-one-ear-and-out-the-other' technique.

So now you are on your own. The machine is in your hands and your authority unassailable. An enviable situation for any enthusiast. You are absolutely and unequivocally indispensable. Name of the game now is to see how long you can keep going with a 90% or more rejection rate, calling the manufacturer at least once every week to point out the product's shortcomings. Following specific pointers for various stages of the process may be useful.

Fluxing

It is not difficult to find the correct flux for your purposes and to obtain good fluxing, but with a little planning and foresight you can make it impossible. You will probably find flux manufacturers as irritatingly helpful as machine makers — you will have to plan your strategy accordingly. These suggestions should be enough to ensure absolutely rotten fluxing for a long time:

- thin out flux to about half its recommended concentration. You can always point out that this cuts down on flux cost and reduces post-soldering cleaning requirements
- if this starts to bore you, try the other extreme. Never check the specific gravity of the flux, keep covers off when the machine is not operating and allow the flux to become a thick, contaminated sludge. Bad results are guaranteed and the machine will, of course, take the blame
- another good idea is to mix different types of flux. After all, a flux is a flux, isn't it?
- a more subtle approach is to over-etch the printed circuit board so that all flux is absorbed into the board material
- with foaming-type fluxers it is always useful to have an oily, wet compressed air supply so that the aerator becomes blocked and functions badly, and water from the compressed air line builds up in the flux
- the flux removal air knife can be really useful. By feeding excessive air through it, you can really blow the flux — and the board for that matter — onto the ceiling. Alternatively you can be less adventurous, simply blocking the air-knife holes with dripping flux, or setting the air-knife angle wrong to kill the foam crest.



Preheating

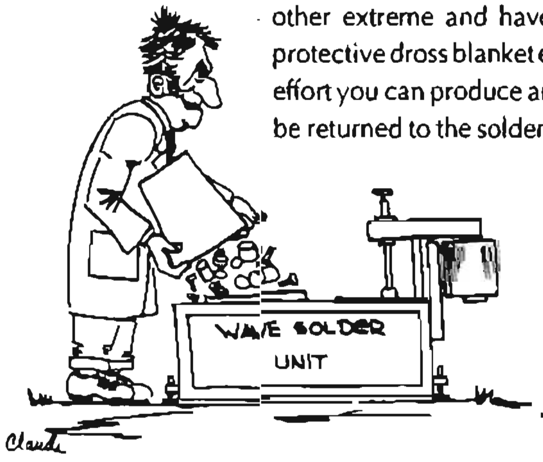
Preheating is another area which, if handled properly, can cause disastrous results. Remember, nothing can spoil a machine blamer's day more than a machine which works perfectly. Some useful hints:

- slow down conveyor speed and increase preheat temperature to maximum. This should completely dry out a rosin flux, making soldering impossible
- alternatively, reduce preheat temperature and increase conveyor speed to maximum. This will produce nearly as high a rejection rate and has the added attraction of promoting solvent explosion in through-holes, causing bad joint formation *and* spreading small solder balls over the component side of the board
- you might also try running the preheat at very low temperatures, with the solder temperature very high. This produces maximum thermal shock and, even if soldering is acceptable, there's a good chance components will be damaged.

Soldering

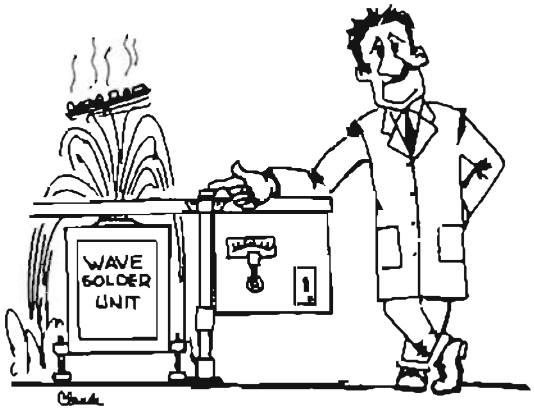
The soldering unit itself offers a multitude of ways to ruin results and get in a few good kicks at the machine:

- first move is to buy the cheapest solder you can get your hands on. After all, it looks the same in the pot. Don't be put off by talk of *eutectic, 60/40, the importance of not exceeding contamination levels* and other such nonsense
- once you have the mucky solder in, allow it to accumulate as much dross as possible. Regular cleaning and dross removal are to be avoided if you want to maintain a suitable low standard. For a change, you could got to the other extreme and have the dross skimmed every hour. Removing the protective dross blanket encourages formation of more dross and with a little effort you can produce around 40 kilos a week. Dross should not, of course, be returned to the solder supplier for salvage at approximately half the cost



- the solder unit has all sorts of controls which can be incorrectly set to give poor results. Don't bother with levelling the unit, then try running the wave at maximum setting to produce as much turbulence as possible. Even more dramatic failures can be obtained by allowing solder level in the pot to drop way below normal to encourage circulation of dross particles in the wave

- another good technique is to set the solder unit and wave at wrong heights to effortlessly produce a good flow of solder over the top of the board. No-one will be able to doubt that *this* will solder the components in position — and watching the printed circuit boards go through the solder wave is quite amusing, too!



- as we have pointed out, there are many more ways of getting terrible results and you can have hours of fun finding them out for yourself. Play around with conveyor angle, solder temperature, wave height, entry and exit conditions and so on, to see which combination gives the highest rejection rate. It is always a good idea to keep a secret log of these settings so that you can reproduce them with minimum effort and save your energy for blaming the machine.

Printed circuit boards

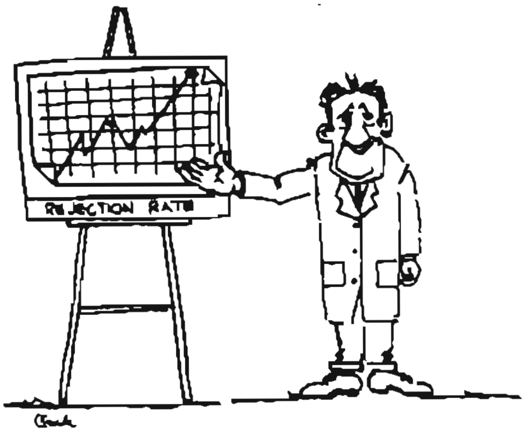
It is often overlooked what great potential for getting bad soldering results lie in the printed circuit board itself. No-one will be any the wiser and you can still take it out on your machine.

First area for you to work on is in actual production of the board. Although this may be a little out of your control you will be surprised how effective you can be with just a little effort. Familiarize yourself with good board design and manufacturing practices. Having the ability to recognize a well-designed and well-made board gives you the opportunity to opt for an inferior and cheaper product.

In the second area, that of storage and preparation of boards prior to soldering, there is much more scope for your talents:

- make sure boards are stored for as long as possible, to increase chances of bad solderability. This effect can be optimized if you select a nice humid, corrosive environment for storage, say, near a plating shop

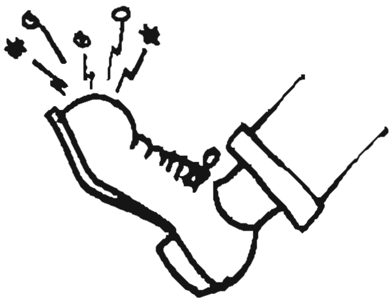
- make sure boards have not been hot-air levelled with a solder coating. This drastically preserves solderability and will cause problems in getting really poor results later on
- if you are obliged to use a cleaning technique prior to soldering, avoid chemical processes which effectively remove the oxide layer from copper tracks. An abrasive cleaning method, if handled right, will allow you to get grit embedded in the copper surfaces which will result in beautiful dewetting during soldering. It may also remove any epoxy coating on the board which allows solder balls to adhere to the board material. What more could you ask for?



Over to you

We realize we have only scratched the surface in this guide, but we have great faith in the imagination and ingenuity of dedicated machine blamers and know you will develop your own techniques in your personal style. Remember, above all, to continually call the manufacturer and complain about the machine. Let them know the movement is alive and well. They may send someone to straighten things out but don't worry — it won't take you more than a day or two to get that rejection rate back up there again.

Good luck and — ahem— good kicking!



Original text by Alan Roberts
Original artwork by Claude Legault and Alan Roberts
Original document Why not blame the machine?, *courtesy of Electrovert*

Appendix 2 Problems & solutions

Soldering is a logical process. There are, however, many variables which must be maintained to keep the process in control. For example, provided that:

- solderable printed circuit boards
- solderable parts
- good flux
- good solder
- the correct amount of heat for the minimum amount of time
- process control
- process measurement

are used, the process stands a good chance of functioning properly. On the other hand, if any of these variables are *not* correctly maintained problems will arise.

Given all these variables, it is not always easy to isolate the cause of any particular problem when things go wrong. Hopefully, Appendix 1 gives some insight — in a light manner — into how easy it is to slip into a situation where problems occur.

This appendix attempts to address this — listing, in the table over, some of the problems which can occur in any electronics assembly manufacture, whether by CS or SC soldering process. Possible causes of these problems are also listed, so it is quite a simple job to find solutions which can help get a process back into control.

Note that many problems are not necessarily caused by things out of control within the soldering process. Many problems are, indeed, the fault of assembly, fabrication, or design processes which are badly or improperly maintained.

	Soldering processes																																
	Solder temperature too high	Solder temperature too low	Solder wave height too high	Solder wave height too low	Solder wave uneven	Solder contaminated	Excessive solder dross	Preheat temperature too high	Preheat temperature too low	Flux contaminated	Flux specific gravity too low	Flux specific gravity too high	Flux no longer active	Flux not making contact	Flux foamhead too low	Fluxer uneven	Flux blow-off excessive	No flux blow-off	Pallet too hot	Conveyor speed too high	Conveyor speed too low	Conveyor vibration	Conveyor angle too high	Conveyor angle too low	Board removed too early	Board not seated right	Board re-run	Incorrect weight placement	Excessive weights used	Defective fixture	Heating rate too high	Temperature too high	Process too long
Blistering	●							●													●						●						
Blow-holes					●																												
Bridging		●	●	●	●	●		●	●	●	●		●	●	●	●	●		●	●	●			●			●			●			
Cold short joint	●	●				●		●												●	●	●			●								
Components lifted			●		●												●					●	●		●	●		●		●			
Dendritic growth										●																							
Dewetting		●		●		●			●	●	●	●	●	●	●	●	●	●	●	●	●					●	●						
Discoloured solder joint	●					●		●	●	●										●	●												
Disturbed joint	●		●	●	●	●														●		●			●	●			●				
Drawbridging																												●			●		
Entrapped flux vapours		●		●					●	●										●													●
Excessive dross	●		●			●			●			●						●															
Excessive flux used										●		●				●		●															
Excessive solder (both sides)	●		●		●	●										●		●			●			●		●	●						
Excessive solder (component side)	●	●	●		●																●					●	●	●	●	●			
Excessive solder dragout		●	●			●								●	●	●	●		●	●										●			
Flooding	●	●	●		●			●	●																	●	●	●	●	●			
Flux trapped									●	●		●						●		●										●			
Halo effect																																	
Grainy solder		●				●	●		●											●		●			●								
Icicles		●		●	●	●		●	●	●	●		●	●	●	●	●		●	●		●		●	●	●	●			●			
Incomplete fillet																															●		
Insufficient heat joint		●			●																												
Insufficient solder flow-through	●	●		●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●			●			●	●	●		●			
Insufficient solder (solder side)	●			●	●	●		●	●	●	●	●	●	●	●	●	●		●	●			●			●				●			
Laminate discoloration																																●	●
Leaching																																●	●
Masking failure	●							●													●						●						
Measling	●							●													●						●						
Misalignment																				●		●			●	●		●	●	●			
Non-wetting		●		●		●			●	●	●	●	●	●	●	●	●	●	●	●	●					●	●						
Omitted solder				●	●			●		●		●	●	●	●	●	●		●	●						●	●	●		●			
Open joint																																	
Outgassing	●	●		●	●				●	●	●	●	●	●	●	●		●	●	●	●		●			●	●			●			
Rough solder	●		●	●	●	●														●		●			●	●			●				
Scavenging																																●	●
Shadowing (wave soldering)											●				●				●							●				●			
Shadowing (infra-red soldering)									●											●													
Skipped solder				●	●			●		●		●	●	●	●	●	●		●	●						●	●	●		●			
Solder balls	●		●		●				●	●	●							●		●										●			●
Solder wicking									●													●									●		
Tombstoning																															●		
Warpage	●							●	●												●					●	●	●	●	●			
Webbing		●				●	●	●		●	●		●	●	●	●	●		●	●	●						●			●			

Assembly processes													Fabrication processes														Design processes																
Board contamination	Component contamination	Component leads too long	Component leads too short	Excessive mask	Insufficient mask	Improper board handling	Excess solder deposition	Mis-aligned component	Solder paste viscosity too low	Oxidized solder paste	Insufficient solder paste	Screen or stencil clogged	Board oxidized	Board contamination	Masking in holes	Ink in holes	Misregistration of mask	Cracks in circuit track	Epoxy glass exposure	Defective mask material	Moisture in laminate	Hole/pad misregistration	Board warped	Rough plated-through hole	Masking breakdown	Component contamination	Pallet design	Large plane on component side	Large plane on solder side	Internal plane	Hole-to-lead ratio too small	Hole-to-lead ratio too large	Component orientation	Circuit track orientation	Size of board	Weight distribution	Circuit track width	Large unfilled holes	Paste alloy	Low metal content in paste	Pad size mismatch	Solder mask problem	Particle size too small
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Appendix 3 Soldering safety

Safety in soldering processes is a vital topic. So vital it must be covered in depth in any book of this nature. Equipment and machines in soldering processes are, by their very construction and use, hazardous. Used properly, of course, they present no danger. But, used improperly, they are lethal weapons — waiting to kill or maim. The authors implore users of such equipment to be careful and to use accepted and safe procedures. In particular we recommend that users:

- read, understand and follow equipment suppliers' manuals
- read, understand and follow latest national regulations on uses and storage of materials
- invest in proper safety training
- establish safety regulations and procedures within your work areas, which follow these recommendations
- enforce these established recommendations and procedures among your workforce.

Contents of this appendix

We have organized this appendix in as clear a way as possible. There are seven tables detailing safety hazards found in systems and general safety concerns. These tables are:

- Table A3.1 — safety hazards, health effects, first aid, methods of avoidance and safety reminders in use of wave soldering systems
- Table A3.2 — safety hazards, health effects, first aid, methods of avoidance and safety reminders in use of infra-red soldering systems
- Table A3.3 — safety hazards, health effects, first aid, methods of avoidance and safety reminders in use of solvent cleaning systems
- Table A3.4 — safety hazards, health effects, first aid, methods of avoidance and safety reminders in use of aqueous cleaning systems
- Table A3.5 — general safety aspects in the work area
- Table A3.6 — safety aspects when removing and handling dross
- Table A3.7 — safety aspects of fume evacuation and housekeeping.

Finally, we thank Electrovert for its permission allowing us to rely almost totally on use of the Electrovert booklet *Product Safety Handbook* in compilation of this appendix.

Note: should local, state, federal, national or other laws, regulations or recommendations concerning safety exist, they shall take priority over the suggested procedures in this book.

Table A3.1 Wave soldering systems

Safety hazard	Description	Health effects	First aid
Inhalation of lead dust	When performing maintenance work on or near solder, you risk inhaling lead dust. Lead dust, which is a form of dross, looks like a black powder and floats on the surface of the solder. If you disturb the dust (say, by blowing, cleaning or skimming off dross) it can become airborne and consequently inhalable. Breathing lead dust, which is nearly invisible when airborne, can cause lead poisoning.	Excessive inhalation can result in acute or chronic illness. Some of the symptoms are anaemia, insomnia, weakness, constipation, nausea and abdominal pain. Prolonged inhalation may result in kidney and nervous system disorders.	If you accidentally inhale lead dust, call a doctor or poison control centre immediately.
Ingestion of lead particles	As solder and dross contain large amounts of lead, there is a potential health hazard from absorbing the material through skin or eye contact, or eating or handling it.	Overexposure to lead may produce symptoms of anaemia, insomnia, weakness, constipation, nausea and abdominal pain. Prolonged overexposure can result in acute or chronic illness. In extreme cases, the illness is fatal.	If you have become exposed, remove all contaminated clothing and wash all exposed skin surfaces. Consult your plant health and safety officer.
Solder explosions	Solder explosions can be caused in two main ways: • air pockets — when solder melts from solid to liquid states, pockets of air may become trapped under the solder surface. These may suddenly be released, rising quickly to the surface causing an explosion of solder which spews in all directions. This spewing hot solder is very dangerous • liquid spills — water or other liquids spilled onto molten solder cause explosions, sending tiny solder and water droplets flying into the air.	Burns to the skin, or harm to other body parts — especially eyes.	It's very difficult to judge the severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible.

Avoidance	Safety reminders
• wear a mask or respirator that fully eliminates inhalation of dust and, before performing any work on or near the solder station skim off all dross from the solder surface. Your mask protects you and removing dross makes the work area safer for everyone • avoid standing over the solder unit.	• because airborne lead dust is nearly invisible, those who are unaware of the hazard will be unable to recognize it. Make sure everyone knows how to recognize and avoid lead dust hazard • besides breathing, lead dust can enter your body in other ways (say, through your mouth, eyes or skin). Refer to *Ingestion of lead particles* • most countries specify control limits for airborne lead. Check applicable safety regulations • make sure your respirator is certified to eliminate lead particle inhalation.
• avoid standing over the solder unit • never eat, drink or smoke while handling solder or working at a solder machine • always wash hands after handling solder or dross • wear heavy gloves over disposable rubber gloves when handling solder or dross. Minimize direct handling of solder and dross • wear eye protection and protective clothing when working with molten solder and dross • keep all protective clothes, even shoes, at the workplace. Do not mix protective clothing with street clothing. Best method is to remove protective clothes in one room, shower, and put on street clothes in another room. Employers must clean the protective clothing according to local regulations • wear a certified respirator or mask when working over solder or dedrossing • always store dross in a sealed container • pregnant women should avoid all exposure to lead.	• wear high temperature gloves, safety glasses, and denim or leather apron. As these will eventually become contaminated with lead residue, do not wear them anywhere except in the vicinity of the solder machine. This prevents dragging of lead residue throughout the manufacturing facility • alternative safety attire might include disposable respirator, rubber gloves, disposable gown, disposable cap and disposable shoe covers. These items should be disposed in a covered container to reduce possibility of lead contamination.
• air pockets — always cover the solder pot when melting solder from solid to liquid. If you must remove the cover, always wear protective and heat-resistant clothing, such as a protective mask, goggles, temperature-resistant gloves and apron • liquid spills — keep all liquids away from the solder pot. Never use a dripping wet cloth when cleaning your solder system — use only a damp cloth.	• keep the solder pot covered as much as possible, especially when melting the solder from solid to liquid state.

Table A3.1 Wave soldering systems — continued

Safety hazard	Description	Health effects	First aid
Molten solder	Hot molten solder is a constant hazard. It can severely burn, and can burn through non-protective clothing. In wave soldering systems, temperature of molten solder typically ranges from 200° to 350° C.	Molten solder causes severe burns.	It's very difficult to judge severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible.
Flux and thinner fire hazards	Fluxes and thinners are flammable and are therefore a constant fire hazard. As flux tanks are near hot preheaters you must always be alert to possibility of fire. If flux from assemblies, say, is allowed to drip continuously on to preheaters, these flux drippings can ignite and flashback to the fluxer. If fluxer ignites, a major fire could result.	Health hazards of a flux/thinner fire include burns, smoke inhalation and inhalation of potentially toxic chemicals.	It's very difficult to judge severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible. Consult doctor immediately in case of smoke inhalation.
Flux and thinner health hazards	Ingestion, absorption or inhalation of flux and thinner chemicals can represent serious hazards.	Health effects of fluxes and thinners depend on types used. Contact your flux and thinner suppliers to determine health effects.	If you have ingested or inhaled large amounts of these chemicals, contact a doctor immediately. Follow first aid procedures recommended by suppliers.
Noxious vapours and gases	During wave soldering it is normal for gases and vapours to be created from interaction of flux, thinner and solder with the printed circuit board. If inhaled, these fumes can cause illness.	Prolonged or repeated inhalation of these fumes can lead to health problems.	• if you inhale small amounts of these fumes, seek fresh air • if you inhale large amounts of these fumes, see a doctor as soon as possible.

Avoidance	Safety reminders
• when working around molten solder always use heat-resistant protective clothing and handling material. Such clothing includes heat resistant gloves, apron, safety shoes and safety glasses or face protection.	• whenever possible, let solder cool before working in the area.
• avoid overfluxing assemblies. Use minimum flux needed • ensure the fluxer air knife is adjusted according to instruction in its operating manual • never smoke or ignite an open flame around the machine • when filling flux tank and flux thinner reservoirs, always pour from a container with a spill-proof spout • enforce a good housekeeping program on a frequent and continuous basis. If possible use non-flammable flux and thinner • keep the exhaust system working to prevent buildup of hazardous atmospheres • install an automatic fire suppression system.	• fire fighting safety — if there is a fire in your machine, do not point extinguisher directly at the flux or thinner, as this may cause hot flux and thinner to splatter • motors — all motors tend to create sparks as they operate — a small amount is normal. Should a serious problem develop in a motor, a dangerous amount of sparking might occur. These sparks could ignite flammable flux or thinner vapours and cause an explosion or fire. Perform regular maintenance to ensure all motors are in good working order • preheaters — clean preheaters frequently and on a regular schedule. Do not allow thick residues of flux to build up on or around heating plates or fixtures. Keep the area around flux and thinner tanks and reservoirs as clean as possible.
• fumes from fluxes must be vented or filtered during machine operation, to avoid accumulation. Always ensure ventilation system is on before soldering • when handling flux and thinner wear appropriate gloves, mask and protective clothing • wash hands after handling flux and thinner • use a spill-proof container to prevent spillage • contact your flux and thinner suppliers and request applicable material safety data sheets.	• all fluxes decompose on heating. Polyurethane fluxes, say, can break down to toluene drisocyanate (TDI) which causes respiratory problems. Some rosin fluxes decompose into acidic compounds which might damage skin and respiratory system. Others might break down into aldehydes which irritate respiratory system • aldehydes should be maintained at a level below 0.1 mg m^3 (measured as formaldehyde, and TDI should be maintained at a level of 0.005 ppm.
• ensure your wave soldering system is connected to an exhaust system of sufficient capacity to effectively evacuate all fumes. Always ensure the evacuation system is on and properly operating. Before operating the wave soldering system, shut all windows and doors enclosing it • minimize risk by staying a safe distance away from the fumes that rise out of the process modules, especially the solder wave.	• most fumes produced by the wave soldering system are created when the printed circuit board passes over the solder wave. Key job of the evacuation system is to remove these fumes as well as the residual fumes resulting from evaporation of flux and thinner • always consult suppliers' material safety data sheets pertaining to flux, thinner and solder you use. These data sheets provide information which is important to your health and safety.

Table A3.1 Wave soldering systems — continued

Safety hazard	Description	Health effects	First aid
Hot surfaces	There is always a risk of being burned when you work around a wave solder system. Preheaters, solder pots, rail guards, conveyor parts and exposed metal surfaces are burn hazards. Outside surfaces of the system such as the solder pot hood and viewing windows can also become very hot, at times reaching temperatures in excess of 70°C.	Hot surfaces can cause severe skin burns.	It is very difficult to judge severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible.
Mechanical hazards	All moving parts of a wave soldering system including pulleys, sprockets, chains and the conveyor represent a potential hazard. Take care not to get your hands or fingers caught in any moving mechanisms. Be mindful of long hair, neckties, bracelets, necklaces and other parts of your attire that can get caught in a moving mechanism and cause an injury.	Long hair, loose clothing and fingers may get caught in moving parts, resulting in severe injury.	Type of first aid depends on severity of injury. If a deep wound with severe bleeding occurs, apply pressure directly to the wound to minimize blood loss. Contact emergency services at once.
Electrical hazards	Power panels and terminal blocks of wave soldering machines present an electrical hazard. High voltages are present on various parts of systems.	An electrical shock can result in burns and severe bodily harm, depending on the power in the shock. An extreme shock can stop the heart and result in death.	• consult a doctor as soon as possible • if victim is unconscious, ensure his or her airway is unobstructed. Cardio-pulmonary rescuscitation might be necessary.
Remote operation hazard	Computer-controlled wave soldering machines can be started via the computer link. This capability is a potential hazard. If someone is servicing the machine while someone else decides to operate it from a remote location, the service person could be injured.	Remote control could be used to turn on solder heaters, preheaters or moving system parts, resulting in burns or physical harm to personnel working on or around the machine.	Treatment depends on injury type. In case of skin burns, run the burned skin under water for at least five minutes. In case of serious burns or physical injury, contact a doctor immediately.

Avoidance	Safety reminders
• always wear heat-resistant gloves and protective clothing when working on or around a soldering system • never handle finished boards without wearing protective gloves • do not touch viewing windows unless you are wearing protective gloves • before servicing a wave solder system, allow time for it to cool down. Never perform service on a hot preheater or solder module unless absolutely necessary. If the system must be serviced while hot, wear heat-resistant protective garments.	• if you doubt whether something is hot or not, assume it *is* hot and do not touch it • never place any foreign material, flammable or not, on the machine.
• always stop all moving parts when adjusting or performing maintenance procedures on the machine. When a machine is running keep well clear of moving parts • most pump and conveyor drives are equipped with a guard to provide protection, or clutches to provide built-in slippage in event of jamming. Be very careful when working in the immediate vicinity of such moving parts • wear safety head gear (nets, caps and so on) to prevent long hair from getting caught in system parts. Never operate or service the system while wearing neckties, necklaces, loose garments and so on.	• establish and follow safety regulations and procedures prohibiting operation of the system with untied long hair, loose clothing or neckties.
• to avoid exposure to high voltages, ensure protective power panels remain in place during operation. Before working on any electrical circuit, turn main power off and verify voltages with a voltage meter at the main power disconnect switch • electrical work should only be carried out by qualified electricians and maintenance personnel • always shut off main power before performing any repairs on electrical circuits • prior to applying power for the first time, ensure a system is properly grounded.	• only qualified electricians should work on electrical circuits • prior to applying power for the first time, ensure the system is properly grounded.
• press the emergency stop button before servicing the system • on systems equipped with an auto/manual mode keyswitch, turn the keyswitch to manual mode in addition to using the emergency stop button. If you must operate the system in manual mode for servicing or testing, you can always disconnect the remote control cable.	• computer-controlled machines can be started remotely. Always press the emergency stop button which prevents the machine from being remotely started.

Table A3.2 Infra-red soldering systems

Safety hazard	Description	Health effects	First aid
Hot surfaces	There is always a risk of being burned when you work around an infra-red soldering system. Conveyor, conveyor rails, and boards moving through a system are all burn hazards. Outside surfaces of a system can also be hot, at times reaching temperatures of 66°C (150°F).	Hot surfaces can cause severe skin burns.	It is difficult to judge severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible.
Fire hazards	As infra-red soldering systems operate at high temperatures, they are potential fire hazards. There are two main fire hazards in an infra-red soldering system: motors and infra-red heaters. • motors — all motors tend to create sparks as they operate. A small amount of sparking is normal. Should a serious problem ever develop in a motor, a dangerous amount of sparking might occur, igniting flammable materials • heaters — if boards are left stationary inside a system, high temperatures created by infra-red heaters may cause them to ignite.	Health hazards of a fire in an infra-red soldering system include burns and smoke inhalation.	It's very difficult to judge severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible. Consult doctor immediately in case of smoke inhalation.
Noxious vapours and gases	During an infra-red soldering process gases and vapours are created from heating of flux and solder in the solder paste. Most of these fumes are contained in the soldering chamber. Inhalation can cause illness. Another source of harmful fumes could arise if a board is trapped and burnt in the system. Fumes produced may be hazardous.	Prolonged or repeated inhalation of these fumes can lead to health problems.	• if you inhale small amounts of these fumes, seek fresh air • if you inhale large amounts of these fumes, see a doctor as soon as possible.
Remote operation hazard	Computer-controlled infra-red soldering machines can be started via the computer link. This capability is a potential hazard. If someone is servicing the machine while someone else decides to operate it from a remote location, the service person could be injured.	Remote control could be used to turn on heaters or moving system parts, resulting in burns or physical harm to personnel working on or around the machine.	Treatment depends on injury type. In case of skin burns, run the burned skin under water for at least five minutes. In case of serious burns or physical injury, contact a doctor immediately.

Avoidance	Safety reminders
• always wear heat-resistant gloves and protective clothing when working on or around a soldering system • never handle finished boards without wearing protective gloves • do not touch the cover of the system unless you are wearing protective gloves • before servicing a system, allow time for it to cool down. Never perform service on a hot heater unless absolutely necessary. If the system must be serviced while hot, wear heat-resistant protective garments.	• if you doubt whether something is hot or not. Assume it is hot and do not touch it • never place any foreign material, flammable or not, on the machine.
• practice good housekeeping techniques around the machine, follow operating instructions and closely follow maintenance schedules • keep flammable solvents and other flammable materials away from the soldering system. Never place such materials on or around the machine when operating • never stop the machine with a board left inside. Perform regular maintenance to ensure all motors are in good working order.	• always follow good housekeeping, operating and maintenance procedures. Never place any foreign material, flammable or not, on the system.
• always connect the fume evacuation system, and ensure its proper operation before staring to solder • minimize risk by staying a safe distance away from fumes rising out of the process.	• remember that fumes produced in an infra-red soldering system are the result of evaporation of chemicals from solder paste. Key job of an evacuation system is to remove these potentially harmful fumes.
• press the emergency stop button before servicing the system • on systems equipped with an auto/manual mode keyswitch, turn the keyswitch to manual mode in addition to using the emergency stop button. If you must operate the system in manual mode for servicing or testing, you can always disconnect the remote control cable.	• computer-controlled machines can be started remotely. Always press the emergency stop button which prevents the machine from being remotely started.

Table A3.2 Infra-red soldering systems — continued

Safety hazard	Description	Health effects	First aid
Electrical hazards	Power panels and terminal blocks of infra-red soldering machines present an electrical hazard. High voltages are present on various parts of systems.	An electrical shock can result in burns and severe bodily harm, depending on the power in the shock. An extreme shock can stop the heart and result in death.	• consult a doctor as soon as possible • if victim is unconscious, ensure his or her airway is unobstructed. Cardio-pulmonary rescuscitation might be necessary
Mechanical hazards	All moving parts of an infra-red soldering system including pulleys, sprockets, chains and the conveyor represent a potential hazard. Take care not to get your hands or fingers caught in any moving mechanisms. Be mindful of long hair, neckties, bracelets, necklaces and other parts of your attire that can get caught in a moving mechanism and cause an injury.	Long hair, loose clothing and fingers may get caught in moving parts, resulting in severe injury.	Type of first aid depends on severity of injury. If a deep wound with severe bleeding occurs, apply pressure directly to the wound to minimize blood loss. Contact emergency services at once.

Avoidance	Safety reminders
• to avoid exposure to high voltages, ensure interlocks and protective panels remain in place during operation. Before working on any electrical circuit, turn main power off and verify voltages with a voltage meter at the main power disconnect switch • electrical work should only be carried out by qualified electricians and maintenance personnel • always shut of main power before performing any repairs on electrical circuits • prior to applying power for the first time, ensure a system is properly grounded • on some infra-red machines, access covers are equipped with interlocks so main power is automatically cut off if a panel is opened. These panels and interlocks must not be disabled.	• only qualified electricians should work on electrical circuits • prior to applying power for the first time, ensure the system is properly grounded.
• always stop all moving parts when adjusting or performing maintenance procedures on the machine. When a machine is running keep well clear of moving parts • most conveyor drives are equipped with a guard to provide protection, or clutches to provide built-in slippage in event of jamming. Be very careful when working in the immediate vicinity of such moving parts • wear safety head gear (nets, caps and so on) to prevent long hair from getting caught in system parts. Never operate or service the system while wearing neckties, necklaces, loose garments and so on.	• establish and follow safety regulations and procedures prohibiting operation of the system with untied long hair, loose clothing or neckties.

Table A3.3 Solvent cleaning systems

Safety hazard	Description	Health effects	First aid
Solvent explosion or fire	If you operate a solvent cleaning system with an unapproved solvent, your machine may become an explosive fire hazard. Certain solvents, though seemingly harmless, can break down and with time decompose into potentially flammable materials.	Solvent fires or explosions cause serious skin burns. Exposure to solvent and inhalation of toxic fumes created can cause illness.	In event of solvent explosion or fire, immediately evacuate injured personnel from the hazardous area, then call for medical and fire-fighting assistance.
Solvent hazards	Ingestion, absorption, or inhalation of solvent can represent serious hazards. Precise nature of hazards depends on solvent type.	To determine hazards, contact your solvent supplier and request a *materials data sheet*	• if you have ingested or inhaled large amounts of solvent, contact a doctor immediately • on inhalation of small amounts of these solvents, seek fresh air • on skin contact, wash thoroughly with soap and water.
Hot surfaces	There is always a risk of being burned when you service a solvent cleaning system. Some components such as immersion heaters and heat pump, and exposed metal surfaces can become very hot and so are hazards.	Hot surfaces can cause severe skin burns.	It is very difficult to judge severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible.
Mechanical hazards	All moving parts of the solvent cleaning system including pulleys, sprockets, chains and the conveyor represent a potential hazard. Take care not to get your hands or fingers caught in any moving mechanisms. Be mindful of long hair, neckties, bracelets, necklaces and other parts of your attire that can get caught in a moving mechanism and cause an injury.	Long hair, loose clothing and fingers may get caught in moving parts, resulting in severe injury.	Type of first aid depends on severity of injury. If a deep wound with severe bleeding occurs, apply pressure directly to the wound to minimize blood loss. Contact emergency services at once.
Electrical hazards	Power panels and terminal blocks of solvent cleaning machines present an electrical hazard. High voltages are present on various parts of systems.	An electrical shock can result in burns and severe bodily harm, depending on the power in the shock. An extreme shock can stop the heart and result in death.	• consult a doctor as soon as possible • if victim is unconscious, ensure his or her airway is unobstructed. Cardio-pulmonary rescuscitation might be necessary.

Avoidance	**Safety reminders**
• operate a solvent cleaning machine only with recommended solvents.	• always keep a solvent data sheet handy. This provides medics and fire-fighters with information for emergency care and fire-fighting tactics. Data sheets are available from your solvent supplier.
• when handling solvent, wear appropriate gloves, mask and protective clothing to prevent contact through inhalation, ingestion or absorption • use a spill-proof container to prevent spillage and its consequent hazard or dissipation into the atmosphere you breathe • if you have to lift a viewing window, allow the vapour line to collapse first. Opening a window before vapour has had time to collapse causes excess escapement of solvent and possible harm.	• follow good housekeeping rules to keep work area free of toxic solvent substances. Reserves of solvents should be locked away • always turn the plant ventilation system on before operating the machine.
• always wear heat-resistant gloves and protective clothing when servicing a solvent cleaning system • before servicing a system, allow time for it to cool down. Never perform service while components are hot, unless absolutely necessary. If the system must be serviced while hot, wear heat-resistant protective garments.	• if you doubt whether something is hot or not, assume it *is* hot and do not touch it • never place any foreign material, flammable or not, on the machine.
• always stop all moving parts when adjusting or performing maintenance procedures on the machine. When a machine is running keep well clear of moving parts • most pump and conveyor drives are equipped with a guard to provide protection, or clutches to provide built-in slippage in event of jamming. Be very careful when working in the immediate vicinity of such moving parts • wear safety head gear (nets, caps and so on) to prevent long hair from getting caught in system parts. Never operate or service the system while wearing neckties, necklaces, loose garments etc.	• establish and follow safety regulations and procedures prohibiting operation of the system with untied long hair, loose clothing or neckties.
• to avoid exposure to high voltages, ensure interlocks and protective power panels remain in place during operation. Before working on any electrical circuit, turn main power off and verify voltages with a voltage meter at the main power disconnect switch • electrical work should only be carried out by qualified electricians and maintenance personnel • always shut off main power before performing any repairs on electrical circuits • prior to applying power for the first time, ensure a system is properly grounded.	• only qualified electricians should work on electrical circuits • prior to applying power for the first time, ensure the system is properly grounded.

Table A3.4 Aqueous cleaning systems

Safety hazard	Description	Health effects	First aid
Hot surfaces	There is always a risk of being burned when you work around heaters and motors of an aqueous cleaning system. Some components such as immersion heaters and heat pump, and exposed metal surfaces can become very hot and so are hazards. Printed circuit boards exiting the dryer module can be very hot.	Hot surfaces can cause severe skin burns.	It is very difficult to judge severity of a burn yourself. Run burns under cold water immediately, for at least five minutes. Consult a doctor as soon as possible.
Mechanical hazards	All moving parts of the aqueous cleaning system including pulleys, sprockets, chains and the conveyor represent a potential hazard. Take care not to get your hands or fingers caught in any moving mechanisms. Be mindful of long hair, neckties, bracelets, necklaces and other parts of your attire that can get caught in a moving mechanism and cause an injury.	Long hair, loose clothing and fingers may get caught in moving parts, resulting in severe injury.	Type of first aid depends on severity of injury. If a deep wound with severe bleeding occurs, apply pressure directly to the wound to minimize blood loss. Contact emergency services at once.
Electrical hazards	Power panels and terminal blocks of aqueous cleaning machines present an electrical hazard. High voltages are present on various parts of systems.	An electrical shock can result in burns and severe bodily harm, depending on the power in the shock. An extreme shock can stop the heart and result in death.	• consult a doctor as soon as possible • if victim is unconscious, ensure his or her airway is unobstructed. Cardio-pulmonary rescuscitation might be necessary
Remote operation hazard	Computer-controlled aqueous cleaning machines can be started via the computer link. This capability is a potential hazard. If someone is servicing the machine while someone else decides to operate it from a remote location, the service person could be injured.	Remote control could be used to turn on heaters or moving system parts, resulting in burns or physical harm to personnel working on or around the machine.	Treatment depends on injury type. In case of skin burns, run the burned skin under water for at least five minutes. In case of serious burns or physical injury, contact a doctor immediately.

Avoidance	Safety reminders
• always wear heat-resistant gloves and protective clothing when servicing an aqueous cleaning system • never handle finished boards without wearing protective gloves • do not touch the outside of the dryer module • before servicing a system, allow time for it to cool down. Never perform service while components are hot, unless absolutely necessary. If the system must be serviced while hot, wear heat-resistant protective garments.	• if you doubt whether something is hot or not, assume it *is* hot and do not touch it • never place any foreign material, flammable or not, on the machine.
• always stop all moving parts when adjusting or performing maintenance procedures on the machine. When a machine is running keep well clear of moving parts • most pump and conveyor drives are equipped with a guard to provide protection, or clutches to provide built-in slippage in event of jamming. Be very careful when working in the immediate vicinity of such moving parts • wear safety head gear (nets, caps and so on) to prevent long hair from getting caught in system parts. Never operate or service the system while wearing neckties, necklaces, loose garments and so on.	• establish and follow safety regulations and procedures prohibiting operation of the system with untied long hair, loose clothing or neckties.
• to avoid exposure to high voltages, ensure interlocks and protective power panels remain in place during operation. Before working on any electrical circuit, turn main power off and verify voltages with a voltage meter at the main power disconnect switch • electrical work should only be carried out by qualified electricians and maintenance personnel • always shut off main power before performing any repairs on electrical circuits • always mop up spilled water from the work area. Water is a conductor of electricity and greatly increases risk of electrical shock • prior to applying power for the first time, ensure a system is properly grounded.	• only qualified electricians should work on electrical circuits • prior to applying power for the first time, ensure the system is properly grounded.
• press the emergency stop button before servicing the system	• computer-controlled machines can be started remotely. Always press the emergency stop button which prevents the machine from being remotely started.

Table A3.5 Safety in the work area

General safety concerns	Description
No-smoking signs	Post large, clearly visible no-smoking signs in the work area. Establish a means of monitoring and enforcing this regulation.
Fire extinguishers	If a machine is equipped with an automatic fire extinguisher system, ensure the fire extinguisher reservoir is kept full and primed before operating the machine. If a machine does not have an automatic fire extinguisher system, keep an approved fire extinguisher near the machine at all times. Familiarize yourself with operation and use of your fire extinguisher. While fighting a flux fire, do not point the extinguisher directly at the flux or solder. Turn off the system's input power before fighting any fire.
Solvent spills	Due to an ever-present possibility of solvent spills, ensure necessary equipment is always available for efficient clean-up operations. Keep a mobile ventilation unit to hand — fitted with a filter for extracting solvent particles from the atmosphere.
Breathing masks	Ensure dross removal operations are carried out without exposing operators to excessive lead-in-air pollutants. All operators should be provided with a suitable safety-rated oral-nasal respirator, which will provide effective protection from lead dust and fumes up to ten times any permitted exposure limit.
Safety garments	Always keep protective clothing to hand. Protective clothing is required when servicing any hot machine, or handling hot printed circuit boards. Full safety clothing includes wearing protective mask, goggles, high temperature gloves, apron and protective footwear. Operators must remove all protective clothing and wash thoroughly before eating, drinking or smoking. Under no circumstances should eating, drinking or smoking be permitted around the machine, or where lead is present.
Safety data on fluxes, solvents and so on	Never store flammable materials around a soldering machine. Heat from any source may ignite flammables. Never place items, flammable or not, on any machine. This presents a fire hazard. Keep to hand a material safety data sheet on chemicals used in machines.
Housekeeping	Keep your soldering system as clean as possible. Enforce a frequent and consistent housekeeping programme. Cleaning of conveyor chains and sprockets, and tunnel entrances must receive special attention, and be done in such a way to avoid inhalation, or ingestion via fingers, of lead deposits. Cleaning staff should use vacuum or wet cleaning methods and be suitably attired. No lead compounds should be disposed of via an incinerator.

Description

Table A3.6 Safe removal and handling of dross

Use the right container	The dross container should have a lid and should be closed to prevent dust scatter during handling and transport. Dust scatter can be minimized by dampening dross with water once cool.
Make advance preparations	Make advance arrangements ensuring all necessary tools, respirators, and safety equipment are available to allow dross to be removed without exposing operators to excessive lead-in-air concentrations. Operators should be provided with overalls and gloves to prevent contamination of personal clothing and hands.
Make sure the area is adequately ventilated	The solder bath and dross container should both be enclosed, and both under exhaust ventilation. Means should be provided for dross removal within the enclosure. Where this is not possible, local exhaust ventilation should be used.
Use a respirator	Operators should be provided with a suitable oral-nasal respirator, sufficient to provide protection from lead dust and fumes up to ten times any permitted exposure limit.
Send dross to a reclamation centre	Dross should be returned to a secondary smelter to reclaim metal contents, either directly or through an approved scrap metal dealer.
Stow protective clothing and wash frequently	Operators should remove overalls and other protective clothing and store it in a place where it will not spread contamination. Wash thoroughly before eating, drinking or smoking. Under no circumstances should eating, drinking or smoking be permitted while operators are working around lead.
Know and abide by safety regulations	Most countries specify a control limit for lead-in-air, blood-lead level and other biological parameters. Refer to local legislation and comply with medical surveillance and biological monitoring requirements.

Table A3.7 Fume evacuation and housekeeping

Importance of fume evacuation systems	Because fumes from soldering equipment may contain lead or airborne solvents, it is essential to install an adequate fume evacuation system. A good system performs two basic tasks: • filtering • monitoring.
Use a fume filtering system	Establish a fume filtering or extraction system. Use a fume filtering system which is based on activated carbon as a filter medium. A system should be placed so that most fumes from the soldering process are captured. Ensure units do not interfere with soldering operations.
Check air quality on a regular basis	Monitor lead content of workplace air at regular intervals during operation. Check air quality on a regular basis. Operating environments change throughout the course of a working day due to opening and closing windows, air movement and so on. This makes it necessary to update readings frequently.
Clean your fume evacuation system regularly	Periodically dismantle and clean exhaust ventilation ductwork using appropriate safety measures for handling lead. Regular cleaning keeps contaminants down to a minimum, reduces chance of fire, and improves efficiency of exhaust systems.
Housekeeping	Good housekeeping and cleaning of equipment on a continuously monitored maintenance schedule is very important to safety and reliability of the equipment's operation.

Appendix 4 Comparing soldering processes & machines

Even though there's a surprisingly few soldering processes, there is often confusion when it comes to making a choice and deciding upon the process which best suits an assembly manufacturer's requirement. In many situations, assembly manufacturers have already made up their minds which process (and, indeed, even the machine) they want. In other situations, an almost bewildering array of soldering machine manufacturer's information and literature seems to make the choice impossible.

This appendix aims to help clarify the whole situation, simply comparing all soldering processes in a straightforward tabular form. Table A4.1 (adapted from Siemens) lists various components encountered in electronics assembly soldering and, comparing the many soldering processes available, summarizes process suitabilities for component types and possible production rates.

Finally, a selection chart is included which allows prospective buyers of soldering machines to rate machines from various machine manufacturers. This will help give an unbiased evaluation of machines, in a direct comparison.

Table A4.1 Comparing soldering processes and component types (after Siemens)

Soldering process	*Component type*							
	Through-hole components	*Two-terminal and SOT*	*SO, VSO*	*PLCC*	*FP*	*TAB*	*Packing density*	*Production rate*
CS processes								
Wave	+	+	0	–	0	–	low	high
Dual-wave	+	–	–	–	0	–	medium	high
Dual-wave with hot-air knife	+	+	+	0	0	–	medium	high
SC processes								
Infra-red	–	+	+	+	+	+	high	high
Vapour phase	–	+[1]	+	+[2]	+	+	high	high
Laser	–	+	+	+	+	+	high	medium
Heated collet	–	–	+	+	+	+	high	low
Hot air	–	+	+	+	+	0	high	medium

Notes:

[1] risk of tombstoning

[2] risk of solder wicking

\+ suitable

0 hardly suitable

– not suitable.

Wave soldering machine evaluation

Use this scoresheet to compare soldering machines. Mark in a suitable score for each machine evaluated. When the scoresheet is completed, simply add up each machine's score to determine the machine which best suits your application.

	Score for each machine			
	1	2	3	4
Details about machine manufacturer:				
● name				
● size of company				
● years of business in machine soldering				
● machines in the field				
● customer list				
● technical support				
● maintenance support				
● spare parts holding				
Maximum board width solderable:				
Fluxer:				
● foam				
● wave				
● brush				
● spray				
● air knife				
● roll-out facility				
● different flux unit retro-fittable				
● flux density controller				
● other options				
Preheater:				
● calrod				
● metal plate				
● lamp type				
● infra-red				
● number of preheater units				
● top preheaters retro-fittable				
● board temperature monitoring				
● closed loop system				
● other options				

	Score for each machine			
	1	2	3	4
Solder wave:				
● single wave				
● double wave				
● extended wave				
● jet wave				
● oil cover coat				
● air knife				
● type of heaters				
● size of pot				
● roll out solder pot				
● wave height monitoring				
● board support				
Conveyor system:				
● finger				
● chain drive				
● conveyor angle adjustment				
● finger cleaner				
● direct speed indicator/compensation				
● different pallet designs				
● different finger designs				
● conveyor robustness/repeatability				
Board production throughput (theoretical):				
Machine controls:				
● manual				
● computer				
● computer/manual backup				
● time clock				
● digital readouts				
General machine:				
● build standard				
● access for maintenance				
● aesthetics of machine				
● process viewing				

	Score for each machine			
	1	2	3	4
Training:				
● theoretical				
● operator hands-on				
● machine maintenance				
● course outlines				
● course instructor				
Machine options:				
● fire protection system				
● nitrogen system/retro-fittable				
● solder feed				
Materials supplied with system:				
Manuals supplied:				
Other documentation:				
Recommendation spare parts list:				
Delivery:				
Safety:				
Total per column				
Machine evaluation score factor:				

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