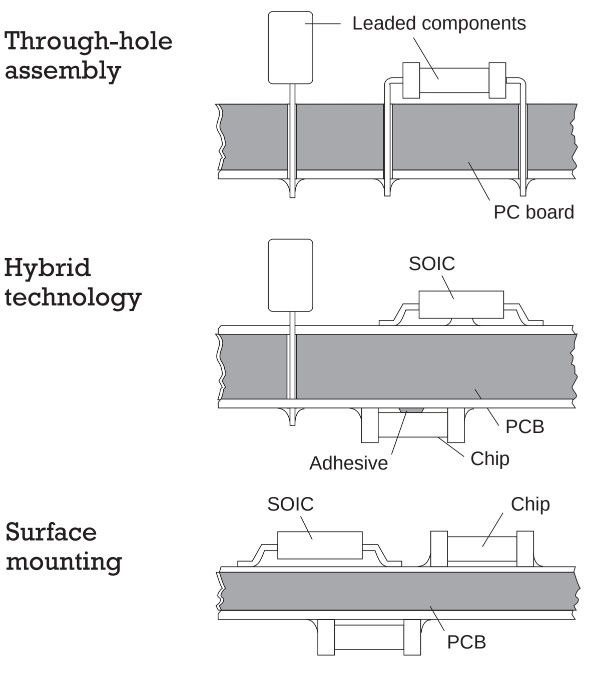
An introduction to surface mounting

What is surface mounting?

In conventional board assembly technology the component leads are inserted into holes through the PCB and connected to the solder pads by wave soldering on the reverse side (through-hole assembly). In hybrid circuits ‘‘chips’’, ie. leadless components or SOICs, (Small Outline Integrated Circuits) are reflow soldered onto the ceramic or glass substrate in addition to the components already integrated on the substrate. Surface mounting evolved from these two techniques (Figure 1).

In through-hole technology the components are placed on one PCB side (component side) and soldered on the other (solder side) (Figure 1,top), whereas in surface mount technology the components can be assembled on both sides of the board (Figure 1, bottom). The components are attached to the PCB by solder paste or adhesive and then soldered.

Figure 1 **PCB technologies**



What are SMDs?

The abbreviation SMD* for Surface Mounted Device is the most common designation for this new component. SMDs are designed with soldering pads or short leads and are much smaller than comparable leaded components. In contrast to conventional components, the leads of which must be inserted into holes, SMDs are directly attached to the surface of the PCB and then soldered. Figure 2 shows some basic SMD types. Surface mountable components include ‘‘chips’’** with cubic dimensions, cylindrical SMDs, plastic packages with solder pins (SOT, SO, VSO package), chip carrier packages, miniature IC packages (Quad Flat Pack, Flat Pack) and special SMDs such as inductors, trimmers, quartz crystals, switches, connectors, relays etc.

* The terms SMC (Surface Mounted Component), SMT (Surface Mount Technology), SMA (Surface Mount Assembly) are also used.

** The designation ‘‘chip’’ should only be used when confusion with semiconductor chip as used in semiconductor technology can be avoided.

SMD types:

Cubic components (‘‘chips’’)

eg. 0402, 0603, 0805, 1206, 1210, 1812, 2220, .. formats.

Cylindrical components

MELF[1], MINIMELF
SOD[2] 123, 323,
SOT[3] 23, 143, 89, 323, 363
SO[4] 4...28 pins (SOIC)
VSO[5] 40 pins

Chip carrier

Plastic case (PLCC[6]) and ceramic case (LCCC[7])

ICs with gull-wing leads

Flat pack and quad flat pack

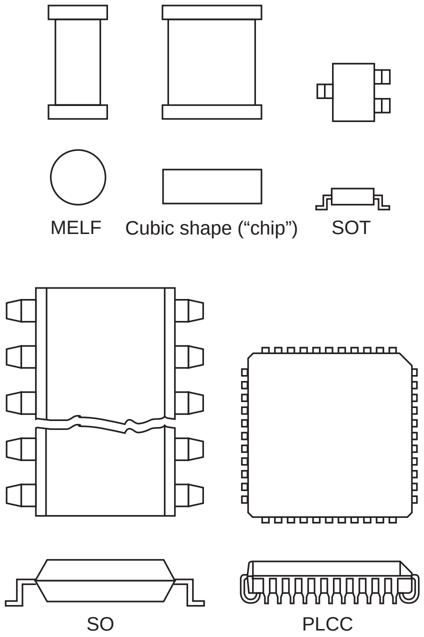
Special packages for:

Inductors, trimmers, quartz crystals, switches, connectors, relays etc.

[1] Metal Electrode Face Bonding
[2] Small Outline Diode
[3] Small Outline Transistor
[4] Small Outline (Integrated Circuit)
[5] Very Small Outline
[6] Plastic Leaded Chip Carrier
[7] Leadless Ceramic Chip Carrier

Note: Some diodes are available in the SOT packages (in these cases the package is still referred to as a SOT package).

Figure 2 **SMD types**



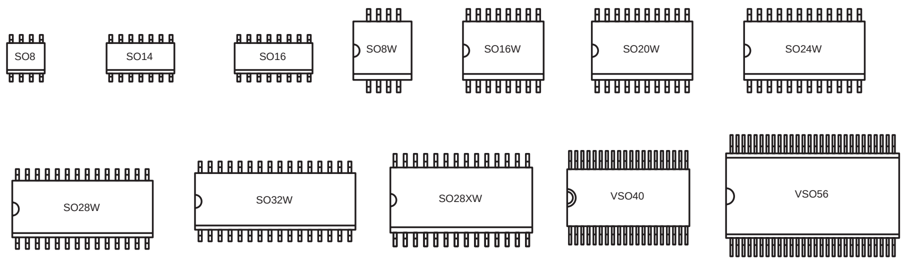
Discrete semiconductor SMD dimensions:

Package	Dimensions (mm) (typ. excl. pins) (L, W, H)
0402	1.0 × 0.5 × 0.35
0603	1.6 × 0.8 × 0.8
0805	2.0 × 1.25 × 0.95
1206	3.2 × 1.6 × 1.05
1210	3.2 × 2.5 × 1.2
1812	4.5 × 3.2 × 2.0
2220	5.7 × 5.0 × 1.8
MELF	5.9 × 2.2 Ø (cylindrical)
MINIMELF	3.6 × 1.4 Ø (cylindrical)
SOD 123	2.7 × 1.55 × 1.35
SOD 323	1.7 × 1.25 × 0.9
SOT 223	6.5 × 3.5 × 1.8
SOT 23	2.9 × 1.3 × 1.1
SOT 143	2.9 × 1.3 × 1.1
SOT 89	4.5 × 2.6 × 1.5
SOT 323	2.0 × 1.25 × 0.9
SOT 343	2.0 × 1.25 × 0.9

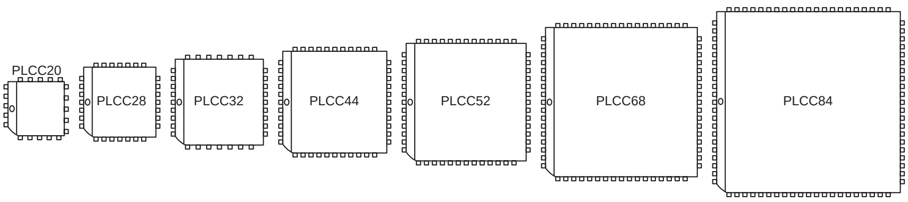
Note: 0402 ... 2220 packages have a wide tolerance on height eg. 0805 height can be ±50%.

Figure 3 **IC semiconductor SMD dimensions**

Small Outline (SO) and Very Small Outline (VSO) packages



Plastic Leaded Chip Carrier (PLCC) packages



Key to package types (for table 1 see overleaf)

JEDEC = Joint Electron Device Engineering Council, a subordinate organisation of Electronic Industries Association (EIA) in U.S.A.

EIAJ = Electronic Industries Association of Japan

SO/SOP = Small Outline Package

SSOP = Shrink Small Outline Package

VSOP = Very Small Outline Package

TSOP = Thin Small Outline Package

TSSOP = Thin Shrink Small Outline Package

PLCC = Plastic Leaded Chip Carrier

PQFP = Plastic Quad Flat Package

Note: Width and length refer to body, and thickness dimension includes leads.

Table 1 **Information for Figure 3**

Package type	Package size W × L × T (mils) see note	Pitch (mils)
SO (JEDEC standard)		
SO8	154 × 193 × 60	50
SO14	154 × 339 × 60	50
SO14W	294 × 354 × 99	50
SO16	154 × 390 × 60	50
SO16W	294 × 404 × 99	50
SO20	294 × 504 × 99	50
SO24W	294 × 604 × 99	50
SO28W	296 × 706 × 100	50
SO (EIAJ standard)		
SO14 (EIAJ)	209 × 402 × 76	50
SO16 (EIAJ)	209 × 402 × 76	50
SO20 (EIAJ)	209 × 496 × 76	50
SSOP (JEDEC standard)		
SSOP 20	154 × 341 × 63	25
SSOP 24	154 × 341 × 63	25
SSOP 48	295 × 625 × 102	25
SSOP 56	295 × 725 × 102	25
SSOP (EIAJ standard)		
SSOP 20 (EIAJ)	209 × 283 × 76	25.6
SSOP 24 (EIAJ)	209 × 323 × 76	25.6
SSOP 40 (EIAJ)	295 × 535 × 90	25.6
VSOP 40	294 × 614 × 103	25.6/30
VSOP 56	434 × 860 × 113	29
TSOP (EIAJ standard)		
TSOP 32	724 × 315 × 39	29.7
TSSOP (EIAJ standard)		
TSSOP 20	112 × 256 × 47	25.6
PLCC (JEDEC standard)		
PLCC 20	350× 350 × 173	50
PLCC 28	450× 450 × 173	50
PLCC 32	450× 550 × 132	50
PLCC 44	650× 650 × 173	50
PLCC 52	750× 750 × 183	50
PLCC 68	950× 950 × 183	50
PLCC 84	1150× 1150× 183	50
	(mm)	**(mm)**
PQFP 44 (EIAJ)	10× 10 × 2.1	0.8
PQFP 48 (JEDEC)	7× 7 × 1.7	0.65
PQFP 80 (JEDEC pending)	12 × 12 × 1.5	0.5
PQFP 80 (JEDEC)	14 × 14 × 2.35	0.65
PQFP 80	14 × 20 × 2.9	0.8
PQFP 100 (JEDEC)	14 × 14 × 2.9	0.65
PQFP 100 (EIAJ)	14 × 14 × 2.9	0.65
PQFP 100 (JEDEC pending)	14 × 14 × 1.5	0.5
PQFP 132 (JEDEC)	950 × 950 × 168 (mils)	25 (mils)
PQFP 144	20 × 20 × 1.5	0.5
PQFP 160 (JEDEC pending)	28 × 28 × 3.65	0.65
PQFP 160	28 × 28 × 3.5	0.65
PQFP 196 (JEDEC)	1350 × 1350 × 168 (mils)	25 (mils)
PQFP 208 (JEDEC pending)	28 × 28 × 3.65	0.5

Advantages of surface mounting

The three major benefits of surface mounting are:

- Rationalisation
- Miniaturisation
- Reliability.

A consistent concept in relation to board layout, assembly, processing and testing is essential for an efficient application of surface mount technology; in other words, the aim should be an optimised overall concept. The component price, for example, should not be seen isolated, but with regard to the total cost including placement, soldering and testing which may already be considerably lower than with conventional board assembly technology.

The advantages of surface mounting compared with through-hole assembly are detailed under the headings of; components, PCB, assembly, reliability and rework.

Components

- SMDs are much smaller than leaded components, thus enabling a smaller board size, higher packing density, reduced storage space and finally smaller equipment can be manufactured
- Light weight makes them ideal for mobile appliances
- No leads means high resistance to shock and vibration
- Cutting and bending of leads are eliminated
- Parasitic inductance and capacitance due to leads are substantially reduced making SMDs particularly suitable for RF applications
- Automatic assembly machines ensure accurate placement
- PLCCs, PQFPs and Ball Grid Arrays permit a considerably higher number of pins
- Closer capacitance tolerances can easily be obtained for capacitors with low capacitance values
- The growing demand for SMDs results in lower production costs, so that further cost reductions can be anticipated. In some cases, the surface mount version of a component is already cheaper than the leaded version.

Printed circuit board (PCB)

- Surface mount technology makes PCB's smaller. When using SMDs on both sides of the board, size can be reduced by more than 50%. On the other hand, maintaining the PCB size implies reduced packing density and thus higher yields and higher reliability
- In many cases the printed circuits can be shortened and reduced in number. Owing to the compact "leadless" construction the electrical characteristics can easily be reproduced, thus cutting the cost for adjusting RF circuits
- Surface mount technology does not require a special PCB material; standard materials such as phenolic resin laminated paper and glass-fibre laminated epoxy material are quite suitable, but of course, special materials, eg. for RF circuits, can be used too
- The elimination of through-holes entails a further cost reduction. This is quite an important factor, as the cost for the drilling of holes can amount up to 10% of the total PCB cost
- Mixed assembly with leaded components is possible on the same PCB. In addition, the H.I.T (Hierarchical Interconnection Technology) Connector system allows designers to integrate SMD boards with through-hole boards.

Assembly

The average cost per component for both manual and automatic assembly can be considerably cut by surface mounting, because the smaller number of assembly machines[1] entails less capital investment, maintenance, servicing and factory space.

- A major advantage of surface mounting is the high component placement rates attained by automatic placers. Fast machines can place several hundred thousand components on the PCBs per hour
- A wide range of manual and semi-automatic machines are now available at low cost. This means the entry cost for SMD assembly can be lower than for leaded components
- Automatic placement systems for SMDs feature high placement reliability. Failure rates of less than or equal to 20ppm (parts per million) can be obtained by machines capable of identity checking and defective recognition. This means that out of a million placed components only max. 20 are not at all or incorrectly assembled
- In mixed assembly, any ratio of SMDs and leaded components is possible, thus facilitating transition to the new technology.

[1] At present three assembly machines are usually required for leaded components:
insertion machine for radial-leaded components,
insertion machine for axial-leaded components,
insertion machine for DIPs.

(See table 2 'SMD Placement Systems')

Reliability

The demands on quality and reliability of PCB assemblies increase steadily. It is a matter of fact, that in this respect SMDs have at least to meet the standard set by conventional through-hole technology.

As surface mount technology is a relatively new development, sufficient proven information on quality and reliability is not yet available. However, the following general statements can be made:

- The failure rate of SMDs does not exceed that of leaded components. Omission of leads means one point of contact less. Owing to their small size and light weight SMD assemblies feature a higher resistance to mechanical stress (vibration, shock) than the corresponding assemblies with leaded components
- A quality approval for SMDs used in hybrid circuits can usually be applied to surface mounting as well
- In many cases the soldering methods are the same as with other mounting methods. The known advantages and disadvantages apply to surface mount technology as well. One should bear in mind, however, that the criteria for judging solder joints are different for wave soldering and reflow soldering. For example, the filling of through-holes

Table 2 **SMD placement systems**

Criterion	Classification of placement system				
	Entry-level system	**Standard system**	**High-speed pick & place system**	**High-speed chip shooter**	**High-speed simultaneous system**
Placement speed (components/ hour)	<2000	2000-4000	4000-10,000	10,000-40,000	40,000-300,000
Placement process	Sequential, pick & place	Sequential, pick & place	Sequential, pick & place	Sequential, revolver head	Sequential/simultaneous or simultaneous, product-specific placement head
PCB changeover	Manual	Manual or automatic	Automatic	Automatic	Automatic
Number of component types	<60	60-120	120-300	80-300	Product-specific
Flexibility	High	Very high	Very high	High	Small number
Extension possibilities	Restricted	Varied	Varied	Varied	Small number
Target group/range of application	Small series, prototype production, training	Wage placers, middle-class companies	Wage placers, middle-class and large companies	Middle-class and large companies, speed-oriented production	Companies in the consumer goods industry, production of maximum quantities

with solder is only possible with the wave soldering method, with reflow soldering the amount of solder is too small.

Rework

Elimination of component preparation, high placement reliability provided by automated systems, and careful planning of each step of the design and production process, considerably reduce expensive rework of PCB assemblies with SMDs.

A wide range of rework equipment for soldering and de-soldering SMDs is now available at low cost.

Restrictions and special features of surface mounting

Maximum packing density - one of the primary goals in surface mount technology - requires the use of miniature components, ie. certain IC packages (eg, VSO). This involves problems, not necessarily resulting from surface mount technology as such, but from miniaturisation in general.

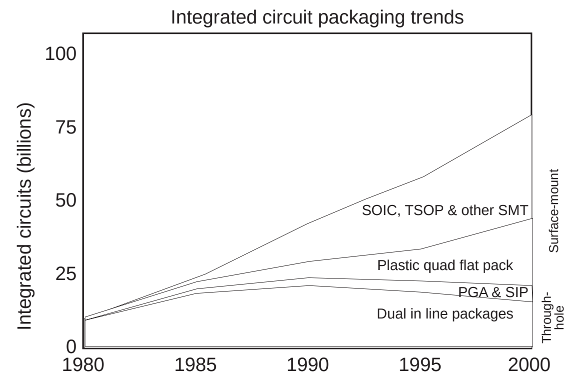
- The use of high-pin-count ICs may require new PCB design (fine etching and super-fine etching) and an increased number of layers (multi-layer) because the space between the IC pins is too narrow for printed circuits
- Due regard must be paid to heat dissipation. The high packing density may cause thermal problems. Special PCBs with good thermal conductivity can aid heat removal, if necessary
- The use of ceramic components is restricted. Due to the different thermal expansion coefficient of ceramic and PCB material, ceramic SMDs with edges longer than 6mm should not be used on phenolic resin laminated paper and epoxy glass fibre boards
- Not all SMDs are suitable for dip or wave soldering. This has to be considered when designing the PCB
- Some components are not yet available in SMD versions. Not all SMDs available are standardised
- High voltages naturally require certain minimum spacings
- Visual inspection of solder joints becomes difficult if the leads are partially beneath the component body. Therefore, soldering methods should be optimised so that visual inspection will become unnecessary
- Test methods have to be adjusted to SMD assemblies. Development of new adaptors may be required
- Repair of SMD assemblies may be more costly than conventional PCB assemblies.

Market forecast for SMD applications

Figure 4 shows the increasing share of surface mount technology in the market. In Europe, the replacement of leaded components on PCB assemblies by SMDs reached 50% in 1993.

Many manufacturers are reporting higher sales of SMD components compared to leaded components. Some have committed much larger production capacities for SMD because of the recent market growth, and increasingly new ICs are being launched into the market with no leaded equivalents.

Figure 4 **Integrated circuit packaging trends**



Fixing SMDs by adhesive

New in surface mounting is the gluing procedure required for fixing the components, essential when the PCB is to be turned upside down for soldering. A range of suitable adhesives are available in the **RS** Catalogue. The adhesive has to meet numerous requirements. It must provide reliable fixing of the components (also of heavy ones) on all kinds of PCBs. Furthermore, it should feature uniform viscosity to ensure easy handling; a pot life of at least several days is advisable. The adhesive should feature short curing time at low temperature. On one hand the adhesive is required to withstand high thermal stress, and on the other hand it must permit removal of SMDs from the assembled board in case of repair. For repairs the component body is heated, so that the adhesive becomes soft and allows the component to be removed without damaging the printed circuit below it. The adhesive has to be non-toxic, as odourless as possible, and free of solvents. It should also feature good heat conductivity.

The component outline should be such that the adhesive can be easily applied, ie. the distance between component body and board must be toleranced closely (Figure 5).

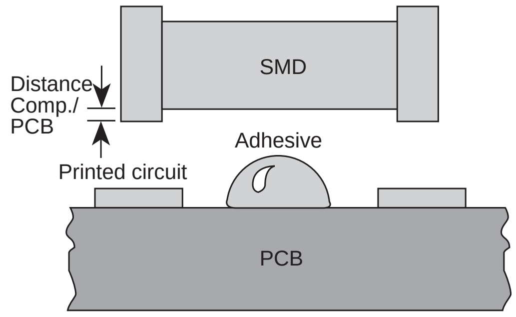
There are three methods of dispensing the adhesive;

- by applicator
- by pin transfer
- by screen printing.

Not all adhesives are equally suitable for all methods.

Refer to Table 3 for suggested adhesive dot volumes applicable to various SMD packages.

Figure 5 **Form of the adhesive dot and component outline**



Component and adhesive dot have to be shaped such that the component is reliably wetted while the contact area remains free of adhesive.

Soldering techniques

An appropriate soldering method is particularly important for obtaining good electrical contact and inhibiting short circuits. The choice of the soldering procedure depends on the PCB design (single or double-clad, multi-layer etc.), the components supplied, and the production facilities. While many SMDs are suitable for all soldering methods, the soldering technique for ICs, for example, has to be chosen very carefully. In addition to manual soldering, there are several automated soldering methods such as bath soldering (wave and dip soldering) and reflow soldering.

With bath soldering, the solder is applied during the soldering process itself, whereas with reflow soldering the solder is applied before. For this reason, the preconditions for bath soldering, eg. component orientation and configuration are quire different from those for reflow soldering. The reflow method is particularly advisable for soldering certain ICs, eg. large SO packages, PLCCs and VSOs.

Wave soldering

Wave soldering is the most popular automated soldering process in the production of PCB assemblies. The solder bath temperature lies between 240 and 260°C and the dwell time is 1 to 3 seconds. Before soldering the flux is applied.

High packing density on the PCB side to be wave soldered involves the problem of solder bridges and shadows (not completely wetted leads and pads). Therefore, PCB layout, ie. component configuration, should match the soldering method used.

Dual-wave soldering best meets requirements of surface mounting. The first turbulent wave sends up a jet of solder to ensure good wetting of all metalisation areas, while the second more laminar wave removes the excess solder (solder accumulations and bridges).

Reflow soldering

In reflow soldering a specific amount of solder, eg. in the form of solder paste, is applied to the PCB. After attaching the SMDs the reflow process is performed by one of the following methods:

- Contact heat soldering
- Infrared soldering.

Table 3 **'Volume of adhesive dots'**

SMD size	SMD-clearance (mm)	Distance between PCB surface and SMD (mm)	Diameter of adhesive dot after placement (mm)	Volume of adhesive dot (mm^3)
0805	0.03	0.06	0.9	0.04
1206	0.03	0.06	1.4	0.09
1212	0.03	0.06	1.7	0.14
1812	0.03	0.06	2.0	0.19
2220	0.03	0.06	2.5	0.29
SOT 23	0.05	0.08	0.9	0.05
SOT 143	0.05	0.08	0.9	0.05
SOT 89	0.01	0.04	1.2	0.05
SO 8	0.15	0.18	1.5 - 2.5[1)]	0.3 - 0.9[1)]
SO 14	0.15	0.18	1.5 - 2.5[1)]	0.3 - 0.9[1)]
SO 20L	0.20	0.23	2.0 - 3.0[1)]	0.7 - 2.2[1)]
MINI-MELF (0204)	0.05	0.08	1.0	0.10
MELF (0207)	0.10	0.13	1.0 - 1.0[1)]	0.3 - 0.6[1)]

[1)] Minimum value for adhesives with high wet strength; Maximum value for adhesives with low wet strength

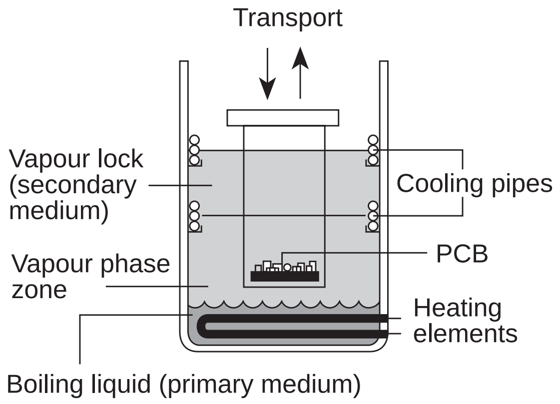
- Forced Convection soldering
- Vapour phase soldering.

Refer to Table 4 for a comparison of soldering processes.

Infra-red reflow ovens are ideal for low and medium volume PCB assembly lines.

Forced air convection allows for greater control and reliability when removing and placing a wide range of surface-mount components. It can eliminate mechanical stresses caused by contact heating devices and allows greater tolerance of operator error.

Figure 6 **Principle of vapour phase soldering**



The latest reflow technique is vapour phase soldering, where the entire PCB is uniformly heated until a defined temperature is reached; there is no possibility of overheating. The defined temperature (eg. 215°C) in a saturated vapour zone is obtained by heating an inert (neutral) fluid to the boiling point. A vapour lock above this primary vapour zone prevents the expensive primary medium from escaping (Figure 6).

When the assembled PCB is immersed in the vapour zone the vapour condenses at the cold parts and transfers its heat to the workpiece. Adequate heating control ensures continuous vapour supply. Summing up, it can be said that vapour phase soldering though expensive, is a very gentle method that excludes overheating. It is particularly suited to applications where components with different thermal capacity are densely positioned or if adequate heating cannot be provided otherwise.

Assembly variations

Figure 7 shows the PCB assembly variations possible with SMDs: Assemblies exclusively with SMDs in the top row (Figure 7a and 7b), mixed assemblies, ie. SMDs combined with leaded components in the middle (Figure 7c and 7d), and mixed assembly consisting of dip solderable components (on solder side) and non-dip-solderable components (on component side) and in the last row (Figure 7e). The versions illustrated in Figures 7b, c,d and e require double-clad PCBs.

Table 4 **Comparison of Reflow Soldering Processes**

Comparison of Reflow Soldering Processes				
Process	**Heat transfer**	**Complexity of PCB**	**Costs**	**Application**
Soldering Iron	Contact	low	low	prototyping/servicing
IR	IR-radiation+ natural convection	low to medium	low	widespread
FC	forced convection	high	medium	gain in importance
VP	vapour phase	very high	high	in a few cases

In mixed assemblies with SMDs and leaded components (Figures 7 and 8) the leaded components are usually placed first, then the board is turned over and the adhesive applied. Subsequently the SMDs are placed, the adhesive is cured and after a renewed turn over the board is wave soldered.

Figure 7 **Variations of PCB assemblies**

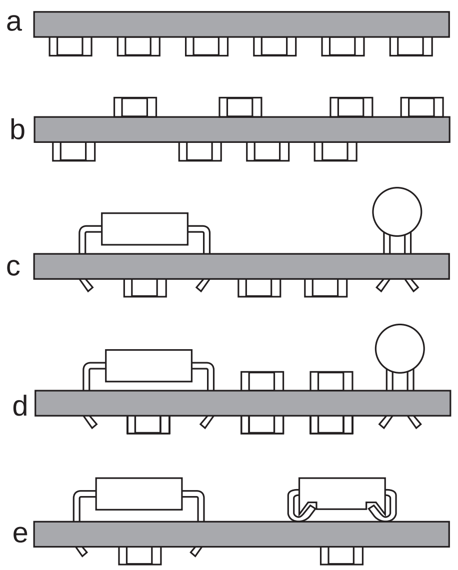
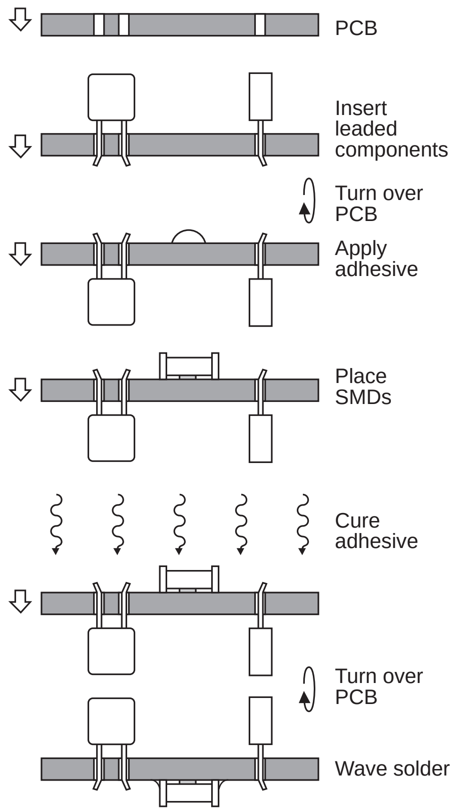


Figure 8 **Mixed assembly of SMDs and leaded components (Variant 1)**



The second variant shown in Figure 9 differs from the first in so far as the adhesive is applied by screen printing at first; the following production steps are executed as illustrated in Figure 9. This procedure has the advantage that the adhesive can be applied by screen printing, however, it has to be taken into account that because of the already mounted SMDs vacant board space is required for the mounting tools of the insertion machines, which are needed for cutting and bending the leads of conventional components.

The procedure for double sided SMD mounting is as follows:

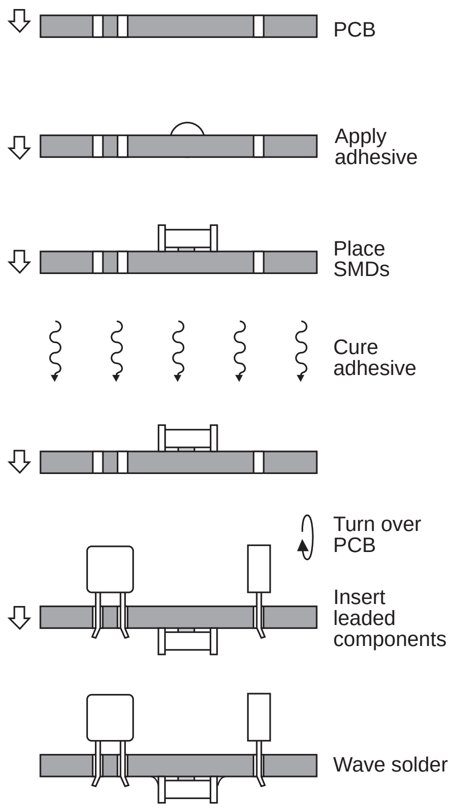
- Screen printing of solder paste
- SMD placement
- Reflow soldering
- Insertion of leaded components
- PCB turn over
- Application of adhesive
- Placement of SMDs on the reverse side
- Curing of the adhesive
- PCB turn over
- Mounting of components requiring special handling
- Fluxing, wave soldering.

Here both reflow and wave soldering are used. Assemblies including leaded components always require wave soldering.

The aim is a uniform mounting procedure with the exclusive use of SMDs. Figure 10 shows examples for totally surface mounted assemblies with reflow soldering (top) and wave soldering (bottom).

Figure 11 is a flow chart for the various assembly and soldering variants.

Figure 9 **Mixed assembly of SMDs and leaded components (Variant 2)**



PCB layout

The following factors have to be considered when laying out a PCB for surface mount components.

- Component

  The component used determines the soldering method and thus the PCB layout; mixed assemblies, for example, require wave soldering, certain SMDs require reflow soldering.
- PCB and component tolerances and the accuracy of placement influence the size of the solder pad.
- Placement machines

  The placement equipment used can substantially influence the PCB layout. Some machines impose restrictions on the component configuration, eg. defined spacings, vacant space for placement tools, space for rotating the components.
- Soldering methods

  The soldering method influences the PCB layout in so far as sufficient spacing must be provided between adjacent printed circuits and components, since with wave soldering the solder is applied during the soldering procedure itself (shadow effect of components). Certain minimum distances between adjacent printed circuits and components must also be kept to avoid solder bridges. For the same reason very closely spaced components must not be wave soldered.
- RF applications

  RF circuits require a special layout anyway, because here spacing and printed circuits are subject to particular conditions
- Quality requirements

  Different quality levels entail different solder pad dimensions
- Design method

  The layout also depends on the design method, ie. on whether it has been designed manually or by means of CAD systems and by which CAD system. Computer aided design requires certain spacings to be kept and sometimes certain solder pad dimensions.

RS Components gratefully acknowledge the help and advice of **Siemens plc Semiconductors** in the production of this data sheet.

Further information can be found in ‘‘The World of Surface Mount Technology’’ manual (**RS** stock no. 436-588). This covers a wide spectrum of topics facing designers and production engineers of surface mount boards. Please refer to current **RS** Catalogue.

Figure 10 **PCB exclusively with SMDs, reflow soldered or wave soldered**

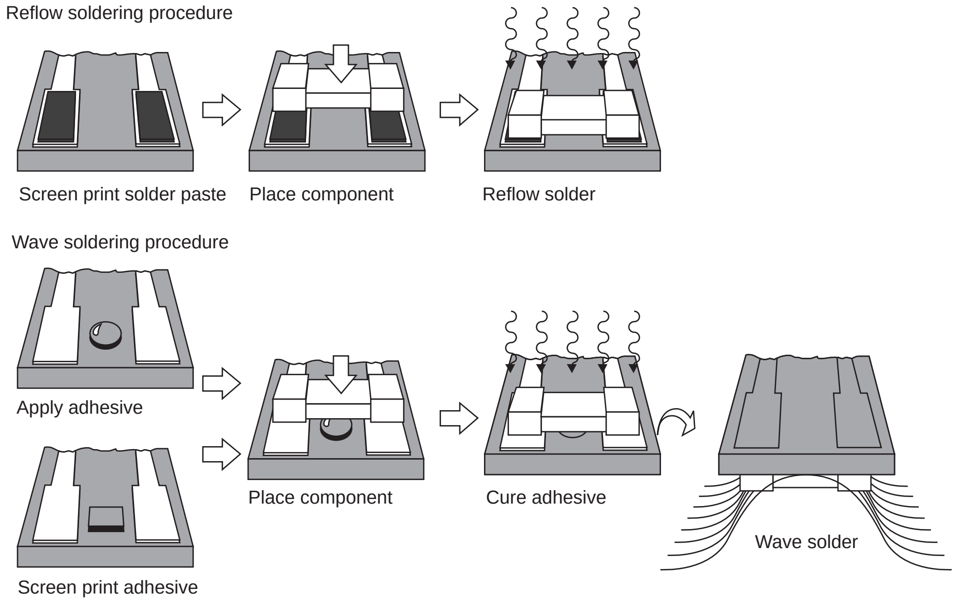


Figure 11 **Possible assembly procedures for SMDs and leaded components**