

Printed circuit board assembly

- the complete works

P.J.W. Noble

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Chapter 10

Manual, light-guided, semi-automatic and robotic assembly

In many applications where ACI is chosen as the assembly method to be used for the majority of components on a board, there is a need to assemble after the ACI stage a number of components which are either uneconomic to handle by machine, or impossible. There are four main alternative ways of dealing with this situation. The first is simply to use a manual assembly operation, relatively easy if there is just a connector or transformer, or simply one or two bulky items to be added to the board; if it is obvious where they go there is no need for any form of guidance system. The second of these can be best described as the light-guided system, where a projected image on to the board shows the operator where the component should go and a binning system brings that component to the operator's hand. This method has the advantage of increasing the speed of assembly over manual methods, and at the same time maintaining the assembly accuracy close to that of the ACI machine. There is also a type of machine available (Figure 10.1) called 'Microgrid' which narrows the operator search area down and is a stage just short of full light-guided.

The third way is by using the so-called semi-automatic machines. These machines could include machines for inserting pins or for inserting DILs, for example. These are machines which insert the component automatically but the board location is controlled by an operator; they are in fact the half-way house between pure manual assembly and fully automatic assembly. A fourth method uses robotic techniques for assembling these components. Here the field for assembly suddenly expands enormously simply because of the many alternative ways of using robotic assembly techniques and robot arms. One of the problems of robotic arms however, is their lack of precise positional control. It is necessary when inserting leads of components into printed circuit boards to hold the accuracy to perhaps between 0.001 or 0.002 in. as a tolerance. At the time of writing virtually all robotic arms fail to meet this standard, as the application for which they were originally designed does not demand this level of accuracy. However, there is an



Figure 10.1 The microgrid. A simple component identification/location system

increasing use of robotic arms with vision systems, which would enable errors to be largely eliminated, thus bringing the accuracy into the same order as the ACI machine.

This chapter discusses and explains the four different types of system which will, in most users' factories, be complementary to full ACI. In some factories however, the use of one or more of the above techniques is already well known and well understood; what the company needs to do is add ACI, while using its existing systems as a complement to ACI. For that reason this discussion on the alternative techniques is essential for the full appreciation of the needs of the printed circuit board assembly area. Only in rare cases can boards be assembled without further work after the ACI process, e.g. the addition of transformers, connectors etc. There are also the mechanical items such as heat sinks, nuts and bolts, rivets, washers, insulators and others, to be added to the board, and in the vast majority of operations these can economically be done only by a human operator. This may well change over the next decade or two but for the lifetime of this book it is deemed that it is necessary to outline the alternative assembly techniques.

10.1 Manual assembly

It may appear at first sight that it is unnecessary to describe manual assembly when related to printed circuit boards. However, even with manual assembly there are a number of approaches taken by different companies and assembly systems, which are applicable to full manual techniques but probably not applicable when the manual assembly technique is supplementary to automatic assembly methods. Even with manual techniques it is necessary to have a well-organized kitting system which will almost certainly have to be supplemented by some form of component pre-forming, of the type which produces the goal-post configuration for axial components, and which in the case of bandolier components cuts them from the bandolier to provide them in loose form with the correct pitch pre-formed for insertion. With i.c.s however there is also a need to provide some form of insertion tool, in order to close the i.c. leads up to the correct pitch prior to insertion. Most i.c.s are manufactured with the leads splayed so that they are readily held in automatic assembly machines, and for this reason it is necessary to close the lead pitch down to insert them in the holes of a normal printed circuit board or socket. There are small tools available for this purpose such as i.c.s' illustrated in Figure 10.2.

Another key point to bear in mind when setting up manual assembly operations is incipient damage to components caused by static. Thus in most applications of printed circuit board assembly it is wise to take anti-static precautions when assembling components to boards. The reason is to prevent the build-up of charge on terminals to devices which create a potential which can cause either catastrophic breakdown, or

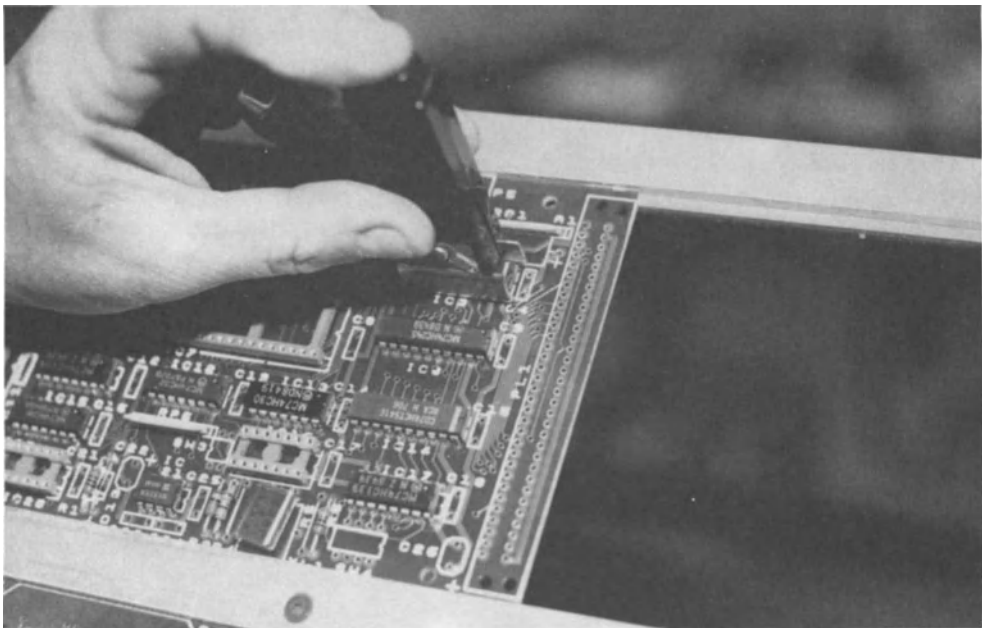


Figure 10.2 Hand placement of DIL

incipient breakdown in the structure of the device. This was commonly thought to be applicable to metal-oxide-semiconductor (MOS) devices only, whose input gate is effectively a capacitor made up of the metal on one side (being the input) the insulation (gate) and substrate (silicon). The typical gate thickness or capacitor thickness for such devices is in the region of 0.1 to 0.2 micrometres, and whose breakdown voltage is in the region of 50 to 75 volts. This breakdown, unlike the breakdown in semiconductor devices under test, is irreversible, and thus catastrophic.

One of the problems of such static damage is that it may not show itself during assembly or test of the printed circuit board but may well have caused sufficient damage so that the life of the component (and hence printed circuit board) is reduced to perhaps days or weeks. It has been recognized, however, that static damage can effect other devices besides MOS, and therefore a broad approach to anti-static protection makes sense in most printed circuit board assembly operations. In order to achieve anti-static protection the operator should be requested to wear clothing which does not generate static, i.e. not use artificial materials but try to use materials that are naturally available, such as cotton, or to use materials which are specifically anti-static, or have some form of conduction capability. In addition, a loose-fitting strap tying the operator to ground is advisable on the hand which may be handling the component. The work bench then should also have an element of anti-static protection in the component packaging and holding devices, in the printed circuit board holding devices, and for any tools and equipment that may come in contact with the particular component or printed circuit board under assembly.

It should be borne in mind that not only should one protect the i.c.s from the chance of static build-up and thus damage, but from all components to be added to the board, because a component with a high static charge added to the board subsequently, even if it doesn't damage the component in question, may well create high potential across the input to a vulnerable device. Therefore anti-static protection for all forms of component should be mandatory, where there is any doubt about static damage. The photograph illustrates a typical manual assembly bench, with full anti-static protection, and highlights those items which are available from a number of manufacturers (Figure 10.3).

There are many ways of structuring a manual assembly operation. The two most obvious are the single-location assembly of the entire board – where the operator has access to the complete kit for assembling the printed circuit board at a single station. This has the advantage that it increases operator interest, but the clear disadvantage is that the operator then has to search for the positions of the components when assembling a new board, before learning the full board and component geography. One of the dangers of the learning cycle is that the operator will become blasé about his or her ability to remember all the locations, errors will creep in and, because there is no correction process, those errors will become cumulative. Therefore there is a very high probability that manual assembly using this technique will have poor reliability coupled to a slow learning curve.

In order to circumvent this problem other companies have laid out the assembly in a flow line, where each operator may assemble only a small number of components on each board as it passes. This clearly has the advantage that the learning curve is very much shorter, but has a number of disadvantages. Foremost among the disadvantages is that the operator interest level drops very rapidly giving rise to sporadic errors. In addition, one operator missing from the line or leaving the line at any one time can create a situation



Figure 10.3 A typical manual assembly bench with anti-static precautions

where the entire assembly line has to stop and wait until an operator returns. Clearly this is an unacceptable problem and therefore a further operator irritation is to have to ask permission to leave the line and either be replaced or wait until the whole line can leave at the same time. This is a somewhat retrograde use of human labour and is hardly to be encouraged in the latter part of the twentieth century. However, it does have advantages provided the manager and the operator interest can be maintained at a good level.

10.2 Light guidance

In order to circumvent the learning curve problem and the problems associated with the blasé approach to memorizing component positions and polarity, there was introduced some two decades ago, the concept of a light-guided approach to assembly. With this method one still effectively has the manual operation of the assembly process, but the component to be assembled is presented to the operator either by a unique binning system, or by a light indicating in which bin the component to be placed is held. A projected image on the printed circuit board showing where that particular component is to be inserted, links to the bin.

Over the years there have been a number of attempts to make this process simple and straightforward to operate, and the machinery has now reached a high degree of

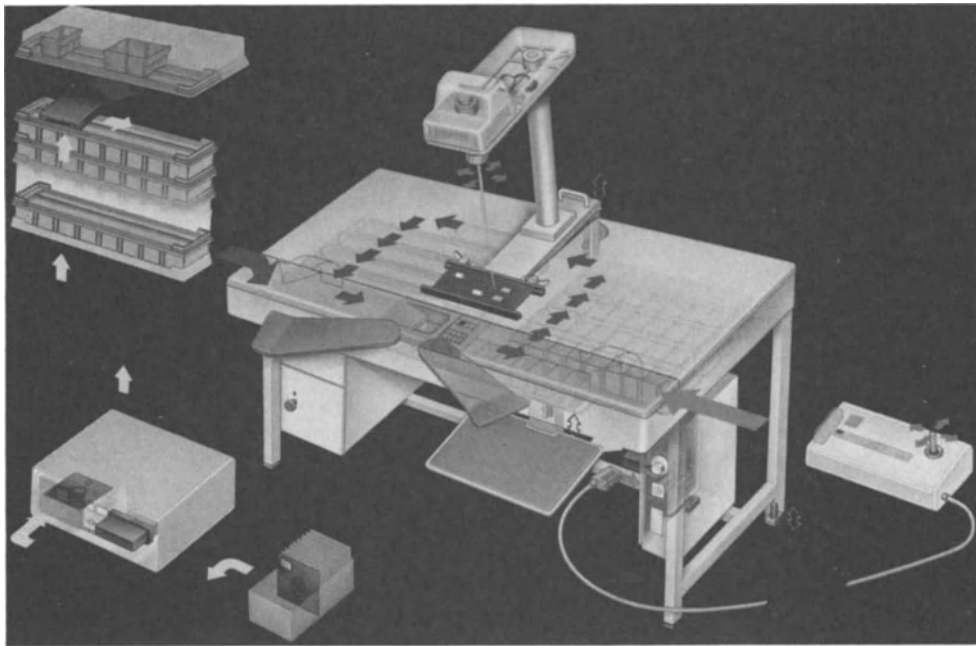


Figure 10.4 A light guided assembly bench



Figure 10.5 A light guided component location – by projected light beam



Figure 10.6 A light guided station (Contax) including an out and clinch mechanism sophistication. In the early days use was made of 35 mm film, slides, or various plates in order to produce the image. This was subsequently replaced by a single projected beam of light which was manipulated so as to produce a single or multiple image on the pcb under computer control, the light beam being deflected by galvanometer mirrors and therefore apparently static to the operator. A sophisticated improvement on this has been to replace the illuminator with a laser, thus increasing the apparent brightness of the image on the pcb and simplifying the optics necessary to increase that brightness. Figures 10.4, 10.5 and 10.6 show such workbenches.

Programming techniques for such equipment have varied over the last few years and have now reached a level where they are comparable to programming ACI machines in their simplicity. The use of such light-guided systems reduces the learning curve practically to zero, and also enables any change of components to be introduced without the operator necessarily having to be trained or told in any formal way that there has been a change to the design to the board. The advantages are thus clear cut, and the maximum benefit from such systems can be gained from the reduction in learning curve; therefore these machines are ideally suited to the small- and medium-run batches so typical of most industry. When a company is producing high-volume board throughput of the same type continuously, however, there are other advantages for using such systems. With guidance systems the operator is always under the control of the programme and should thus always produce a reliable assembly.

Management however, must play a role in the use of these machines in that it is not unknown for operators to ignore the machine and to work ahead of the programme. Because they think they remember the assembly sequence they work ahead of the programme in an attempt to reduce the assembly time. The dangers of allowing this to

happen are quite clear when one considers the likely effect of design changes, component shortages, etc. on a kit for assembly.

When using such machines as a supplement to ACI, the number of components these machines are to handle is reduced dramatically over the norm for assembly, and therefore it becomes arguable as to whether they are necessary or not. In the case of a well-managed company using the preferred component list approach, it is quite probable that the number of components that cannot be inserted by ACI, or by automatic means, is going to be quite small – and restricted to those components where there may only be one or two of a type on a board. Because of their odd nature it becomes obvious where those components are to be inserted, and certainly very easily remembered by the operator. Therefore it may well be that the supplement to ACI is not necessarily a light-guided system. However, for those companies that already have light-guided systems in their assembly, and are stepping forward into automatic assembly, then the light-guided systems can be used with great benefit to help with those components not assembled by ACI. An additional reason is that a company already in production will not necessarily operate a preferred list of components.

One has in mind radial components, sockets, transistors, etc. which can all be handled by ACI provided the components are chosen correctly, or one is prepared to invest the capital necessary for the various machines to handle them. However, in many applications the additional investment to handle some of these components is out of the question, and then the light-guide system with the manual operator comes into its own, as a supplement to ACI.

10.3 Semi-automatic assembly

The third approach to assembling components is often mistaken, or confused with the light-guided system, and that is the range of machines known as semi-automatic. In this case there is no guidance for the operator, but the operator is necessary in order to place the pcb in the correct position for the component to be inserted. Generally speaking there is a simplified program which will select the component (or range of components) in a suitable order to be added to the pcb, the operator then moves the board from component to component. When in the correct location the operation actuates a switch which will place the component into the board and bend the leads, to carry out the other functions of component assembly.

In essence this is a half-way house between manual assembly and fully-automatic component assembly, which in most instances can carry on without any form of operator intervention or involvement – other than to be available should the machine stop for any reason and to recover faults. It is applicable to those companies which perhaps have a restricted range – for example DIL components to insert, who can use ACI for their axial components and use semi-automatics for their DILs and manual for the odd component that follows this process. One has in mind in this application for example, power-supply manufacturers who may well have a number of axial components to assemble, maybe only one or two DIL components and a number of odd components including heatsinks, transformers, etc. in order to build their product.

It is not usual for semi-automatic machinery to be used in high-volume production which is capable of being handled by full automatic machinery, but it definitely has a place

in the company with low volumes (proportionately) of one particular type of component. Semi-automatic machines are also applicable to some of the passive components such as pins, etc.

10.4 Robotic assembly

The fourth, and perhaps the most difficult to define, is the use of a robotic arm system. Robotic arm systems are in use in a very restricted number of companies throughout the world and generally have been developed for specific pcb lines rather than for general use. It is not the purpose of this book to discuss the various or specialized uses of equipment – more the generalities of pcb assembly and therefore the use of robotic arms at this stage will not be detailed. It is anticipated by the author that within the next five to ten years true robotic assembly systems and single-cell assembly systems will come into their own, and therefore will form an increasing part of the contents of this book in future years.

When we refer to robotic assembly we are referring essentially to the adaptation of robotic arms and systems to the assembly of components into or on to printed circuit boards. By their nature, robotic arms are based on $R\theta$ movements rather than x,y co-ordinate movements and therefore the adaptation of robotic arms has tended to create a situation where the robotic arm simulates the movement of a human being's arms, i.e. the robot arm goes to pick up the component from a feeding mechanism, takes the component over the printed circuit board and places it on to the board with the leads going through or not as the case may be.

Clearly this is a very simplistic view of robotic arm operation and if it were that simple everybody would be doing it. The snags occur with robotic systems in that the components still have to be fed to a suitable pick-up point and in so doing they have to be formed (or pre-formed) and occasionally cut prior to robotic handling. Thus any system of robotic assembly has to have similar feeding mechanisms to those used on 'conventional' automatic machinery. The robot arm also has to have appropriate heads or gripping mechanism to pick up the component. The component is then placed over the board in similar manner to that of automatic machinery, and placed on to or through in the correct position. When placed through the board, leaded devices have to be bent and/or cut underneath the board, and therefore an extra mechanism is required to achieve this.

In addition, an $R\theta$ movement by its nature tends to have reasonable repeatability but poor accuracy (when considered in the light of printed circuit board assembly). The requirement to assemble a printed circuit board usually defines that the accuracy of assembly on a mechanical system should be within ± 0.002 in. (0.05 mm). Virtually all robotic arms are considerably worse than this in accuracy; however, by using vision systems to back up the assembly operation it is possible to increase this accuracy dramatically and achieve suitable assembly accuracies. The vision systems used can also be programmed to correct for the placement of components and their orientation on vacuum nozzles for surface mount assembly, and therefore by using a robotic arm a suitable degree of accuracy may be achieved. In addition one still needs the feeder mechanisms and the cutting and bending mechanisms for the appropriate components and therefore the cost of such a system is comparable to or higher than the cost of a dedicated assembly system.

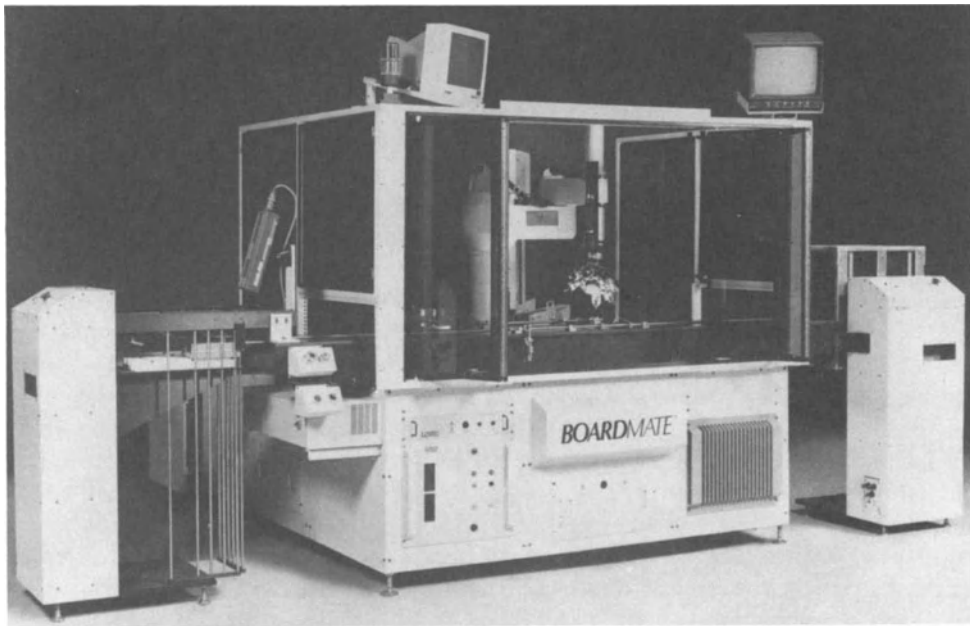


Figure 10.7 A robotic assembly system

An example of the new flexible assembly system coming on to the market is a system called Boardmate manufactured in the USA by Alliance Automated Systems. The Boardmate is a robotic assembly system capable of handling and assembling a wide variety of components on to and into a pcb. The machine is capable of handling axials, radials and DIPs as well as odd forms and surface-mounted components. It is a recent development and the author is aware of some eight installations worldwide at the time of writing the book. The basic robotic arm is based on the Adept Arm which carries a turret of handling devices and has available a number of feed systems on to that turret. The end result of such an assembly system should be the complete assembly of a pcb.

It is a very new equipment on the market and as such could be regarded as untried; however, judging from the specifications available to the author (which should be confirmed by going direct to the agents or the company itself), it is capable of assembling boards at the rate of roughly one component every two seconds, and has a number of feeders available capable of handling a wide range of components. The handling of the board itself is via a pass-thru magazine/conveyor so that with suitable magazine input and output the device is capable of assembling boards continuously or for long periods of time without operator intervention. It incorporates the vision system and other refinements in order to provide fully flexible assembly. It is inevitably relatively expensive and the entry price is well above the entry price of more dedicated systems, but it does indicate the direction in which the technology is beginning to move. The product is illustrated in detail in Figure 10.7.

Other books in this series give great detail of robotic systems and their application and should be consulted for full detail.