Prefeasibility study on the State of Electronics Manufacturing and Assembly in Ghana

By

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DECLARATION

I hereby declare that this thesis is the result of my own original research work undertaken under the supervision of the undersigned, that all works consulted have been referenced and that no part of the thesis has been presented for another degree in this University or elsewhere.

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CERTIFICATION

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(Supervisor)	Signature	Date
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(Head of Department)	Signature	Date

DEDICATION

This work is dedicated to my lovely parents, Mr. and Mrs. Baffoe,

Mrs Mercy Sergeant

Ms Dorothy Akosua Baffoe

Ms Veronica Gyanbea Baffoe

And My friend

Kingsley Asiedu

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To my research fellows, friends and relatives who directly or indirectly helped me to accomplish this research work, God bless you all.

Last but not least, my appreciation goes to my mother, Mrs. Margaret Badu Baffoe. Thanks for the generous financial and moral support.

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ABSTRACT

The focus of this thesis is on the prefeasibility study on the state of electronics manufacturing and assembly in Ghana. The awareness of surface mount technology (SMT) and component miniaturization by selected electronics manufacturing and assembly companies in Ghana, selected departments in Kwame Nkrumah University of Science and Technology was investigated as well as the practice of SMT soldering techniques by the selected companies and the viability of setting up a laboratory for research in electronics manufacturing and assembly at KNUST. The views of Government Policy Makers about electronics manufacturing and assembly were also sought. Electronics manufacturing and assembly is electro-mechanical engineering process used for constructing electronic circuits either by Through-hole technology (where the components with wire leads are fitted into holes on the Printed Circuit Boards) or by SMT technology (where surface mounted components are mounted directly onto the surface of printed circuit boards).

The prefeasibility study was carried out by sending a set of questionnaires to rlg Communications in Ghana, KNUST students at College of Engineering and Departments of Physics and Computer Science (sample size of 275) as well as Government Policy Makers. The survey reveals that rlg imports SMT components such as Flat Chip Resistors (eg. MELF resistors), ceramic SMD capacitors, electrolytic SMD capacitors for SMT assembly and carries out soldering work using both hand and automation. Infra Red Reflow Soldering technique is used for the automated soldering whereas rework is done by hand soldering. For a sample size of one hundred and twenty-five (125) students from College of Sciences interviewed on the awareness of SMT, 67.2% were aware of SMT and component miniaturization whereas 32.8% were not aware. Out of a sample size of 150 students from College of Engineering interviewed on the awareness SMT, 68.7% were aware of SMT and component miniaturization whilst 31.3% were not aware. One hundred and twenty-two (122) stated the practical knowledge it will impart to students in different ways, one hundred and one (101) students mentioned economic benefit due to the fact that electronic products assembled on campus will sell cheaper than outside. Two hundred and seventy three (out of 275) students are in support of the idea of fusing electronics manufacturing and assembly module with some of their courses.

Responses from policy makers indicate that if electronic products are assembled in Ghana it should be made to suite the weather conditions in Ghana and should be affordable. This will require research work into the thermal challenge of the solder joint (solder joint integrity). Other responses from policy makers indicate the fact that local assembly of electronic product will help accelerate Ghana's economic development.

This study is part of a wider programme of work on the development of electronics manufacturing and assembly at KNUST for building capacity towards Ghana's economic development.

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ABRREVIATIONS AND SYMBOLS

Ag	Silver
ANSI	American National Standard Institute
BGA	Ball Grid Array
CFC	Chlorofluorocarbon
CMOS	Complementary Metal oxide Semiconductor
CSP	Chip Scale/ Size Package
CTE	Coefficient of Thermal Expansion
Cu	Copper
C4	Controlled Collapse Chip Connection
DEC	Delco Electronics
DIL	Dual-in-line
FIB	Focused Infrared Beam
GB	Gigabytes
IBM	International Business Machines
IEEE	Institute of Electrical and Electronics Engineers
IR	Infra Red
IPA	Isopropyl Alcohol

IPC	Inter-process Communication
JEDEC	Joint Electron Devices Engineering Council
J-STD	Joint Standard
LCCC	Leadless Ceramic Chip Carrier
LCD	Liquid Crystal Display
MCCSP	Metalized Conductor Chip Scale Package
MELF	Metal Electrode Leadless Face
MEMS	Microelectromechanical Systems
MMX	Matrix Math Extension
NGO	Non-governmental Organization
NYEP	National Youth Employment Programmes
OEIC	Optoelectronics Integrated Circuit
Pb	Lead
PCB	Printed Circuit Board
PGA	Pin Grid Array
PLCC	Plastic Leadless Chip Carrier
PWI	Process Window Index
QFP	Quad Flat Pack

RLG	Rogam Link-communication Group
Sb	Antimony
SG	Specific Gravity
SIR	Surface Insulation Resistance
SMC	Surface Mount Component
SMD	Surface Mount Device
SMT	Surface Mount Technology
Sn	Tin
SO	Small Outline
SOIC	Small Outline Integrated Circuit
SOJ	Small Outline J lead
SOT	Small Outline Transistor
TAL	Time Above Liquidus
TCE	Thermal Coefficient of Expansion
THC	Through-hole Components
THT	Through Hole Technology
VCSEL	Vertical-cavity surface-emitting laser
VOC	Volatile Organic Compounds

VPS	Vapour phase soldering
WLP	Wafer-Level Package
YAG-Nd	Yttrium-Aluminium-Garnet/ Neo-Dymium
ZIF	Zero Insertion force
^{o}C	Degree Celcius
°F	Degree Fahrenheit

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Modern electronics began with the pioneer days of radio communications. The development of radio, however, was preceded by earlier experiments in electricity and magnetism. The beginning of wireless transmission for radio communications arose from the works done by Heinrich Hertz, a German Physicist who in 1887 demonstrated the effects of electromagnetic radiation through space. Even though the distance of transmission was only a few feet, Hertz experiment proved that radio waves could travel from one place to another without the need for any connecting wires between the transmitting and receiving equipment. The experiment also proved that radio waves, although invisible, travel with the same velocity as light waves (High-resolution photos of components/PCBs", 2011).

Electronic components are classified as passive or active. Resistors, capacitors and inductors are examples of passive components. Active components are capable of rectifying, amplifying or changing energy from one form to another whereas passive components, on the other hand, can control energy but cannot amplify or modify it. The above components are described as through-hole in that they have wire leads at their ends where they are connected through holes in circuit boards to other components

Through-hole Technology (THT) components have been replaced by surface mount components through the Surface Mount Technology. Surface mount technology (SMT) is a technique for constructing electronic circuits in which the components (SMC or Surface Mounted Components) are mounted directly onto the surface of printed circuit boards (PCBs). Electronic devices so made are called *surface mount devices* or SMDs. In the industry it has largely replaced the through-hole technology construction method as said already, whereby components with wire leads are fitted into holes in the circuit board. A SMT component is usually smaller than its through-hole counterpart because it has either smaller leads or no leads at all. It may have short pins or leads of various styles, flat contacts, a matrix of solder balls (BGAs), or terminations on the body of the component. An intermediary technology, the mixed technology is also available which consists of SMT components on one side and THT components on the other side of the board.

Surface-mount technology emerged in the 1960s, gained momentum in the early 1980s and became widely used by the mid 1990s. Components were mechanically redesigned to have small metal tabs or end caps that could be soldered directly on to the PCB surface. Components became much smaller and component placement on both sides of the board became more common than with through-hole mounting, allowing much higher circuit densities. Surface mounting lends itself well to a high degree of automation, reducing labour costs and greatly increasing production and quality rates. Carrier Tapes provide a stable and protective environment for Surface mount devices (SMDs) which can be one-quarter to one-tenth of the size and weight, and passive components can be one-half to one-quarter of the cost of corresponding through-hole parts.

However, integrated circuits are often priced the same regardless of the package type, because the chip itself is the most expensive part. As of 2006, some wire-ended components, such as small-signal switch diodes, e.g. 1N4148, are actually significantly cheaper than corresponding SMD versions. Much of the pioneering work in this technology was by IBM. The design approach initially demonstrated by IBM in 1960 in a small-scale computer was later applied in the Launch Vehicle Digital Computer used in the Instrument Unit that guided all Saturn IB and Saturn V vehicles. Saturn Launch Vehicle Digital Computer is an article that describes this type of electronic packaging as of

1964 and also shows high-resolution photos of components/PCBs ("High-resolution photos of components/PCBs", 2011).

1.2 Problem Statement

A contributing factor to the low level of manufacturing in Ghana could be due to the fact that manufacturing engineering activities such as electronics components manufacturing and assembly have not been developed to any appreciable extent. A visit to the rlg communications revealed that all electronic components for the building of electronic products are imported. Not a single electronic component (through- hole, mixed technology or surface mount) is manufactured in Ghana irrespective of the significant number of manufacturing engineering colleges in almost all our tertiary institutions. This work is the beginning of a wider programme of work on the development of electronics manufacturing and assembly processes at the department of Mechanical Engineering, KNUST to help build capacity in this regard to accelerate Ghana"s economic development.

1.3Justification

The establishment of centers for production of electrical and electronic products; manufacture and assembly of computer equipment, electronic commerce, information network operation, medical transcription, legal databases, logistics management, insurance claim processing, back office operations and so on, demand the availability of the electronic components.

The electrical and electronic goods sector covers all items needed for the generation, transmission, distribution and utilization of electricity. Ghana"s electrical system peak load has been increasing at an average of 10% annually over the past ten years. While this rate is considered high, in absolute terms Ghana"s total load remains smaller than that of many small, industrialized countries. Demand for power is driven largely by Ghana"s economic growth, which is estimated at around 4% annually. In addition to increased commercial and industrial activity, demand is also driven by construction of new homes and purchases of electrical appliances and consumer goods. The above also places the need for improvised electronic products such as Surface Mount devices in the country (Invest in Ghana Information Technology, 1983).

Fluctuations in the US Dollar rates adversely affecting the cost of electronic components imported to Ghana also call for their manufacture and assembly in the country. Drastic currency devaluation after 1983 made it exceptionally expensive to purchase inputs and difficult to obtain bank credit, which hurt businessmen in the manufacturing sector. Furthermore, the Enterprise Resource Planning's tight monetary policies created liquidity crises for manufacturers, while liberalization of trade meant that some enterprises could not compete with cheaper imports. These policies hurt industries beset by long recession, hyperinflation, outmoded equipment, weak demand, and requirements that they pay 100 percent advances for their own inputs. Local press reports have estimated the closure of at least 120 factories since 1988, mainly because of competitive imports. The garment, leather, electrical, electronics, and pharmaceuticals sectors have been particularly hard hit. In 1990, even the New Match Company, the only safety match company in the country, closed (Manufacturing in Ghana-Wikipedia, 1990).

In 1986 the government established the Ghana Investment Promotion Center to assist in creating new enterprises. Between 1986 and 1990, the vast majority of projects approved 444 out of 621were in the manufacturing sector. Projected investment for the approved ventures was estimated at US$138 million in 1989 and at US$136 million in 1990. In the initial phase, timber was the leading sector, giving way in 1990 to chemicals. In 1991 the government established an office to deal with industrial distress in response to complaints that "unrestrained imports" of foreign products were undermining local enterprises. The 1992 budget included assistance for local industrialists; ¢2 billion was set aside as financial support for "deserving enterprises (Manufacturing in Ghana-Wikipedia, 1990).

To back up the justification for capacity building in SMT are some of the merits stated below:

- ☐ Much higher number of components and many more connections per component can be done on a PCB with increased functionality and quality.
- ☐ Fewer holes need to be drilled through abrasive boards.
- ☐ Simpler automated assembly is used here.
- ☐ Small errors in component placement are corrected automatically (the surface tension of the molten solder pulls the component into alignment with the solder pads).
- ☐ Components can be placed on both sides of the circuit board implying that SMT has high population density on the PCB than the Through-Hole Technology.
- ☐ Lower resistance and inductance at the connection (leading to better performance for high frequency parts).
- ☐ There is better mechanical performance under shake and vibration conditions.
- ☐ SMT parts generally cost less than through-hole parts.

Faster assembly is done in a short period of time. Some placement machines are capable of placing more than 136,000 components per hour (surface_mount_technology-wikipedia, 2011).

1.4 Goal

The overall objective of this thesis is to carry out a prefeasibility study on the state of electronics manufacturing and assembly in Ghana focusing on the awareness of SMT and component miniaturization by electronics manufacturing and assembly companies in Ghana, departments at KNUST, the practice of SMT soldering techniques by companies and checking the viability of SMT capacity building at KNUST as well as finding out the views of Government Policy Makers about SMT Technology in Ghana.

1.4.1 Specific Objectives

The specific objectives are:

- ☐ To find out the types of electronic components electronic manufacturing and assembly companies in Ghana import (whether surface mount components, through-hole or mixed technology components).
- ☐ To find out whether SMT electronic products could be assembled on KNUST campus.
- ☐ To determine the level of awareness of SMT and component miniaturization within the electronics manufacturing and assembly industry in Ghana,
- ☐ To determine how Ghanaians will patronize SMT electronic products assembled in Ghana from the electronics manufacturing and assembly companies in Ghana.

1.5 Scope of Research

The scope of the research work is to conduct a prefeasibility study on the state of SMT electronics manufacturing and assembly in Ghana. The research survey shall include the following specific areas whose sampling is clustered:

- ☐ The practical assembly conditions of SMT electronic products in Ghana. The type of SMT electronic products Ghanaian companies assemble, the difficulties encountered and how they solve them.

- How Ghanaians patronize SMT related products assembled in Ghana. .
- The awareness of SMT and component miniaturization by students in selected departments of KNUST.
- Students" interest in the introduction of Electronics Manufacturing and Assembly course into their programme.
- Government Policy Makers" views about SMT related electronic products manufactured and assembled in Ghana and how they think this technology can affect Ghana"s development.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Electronic Components

The assembly of electronic components has developed from glass encapsulation of triode valves in the 1930"s to the modern day printed circuit board assembly of very large scale integrated circuits. The following stages can be identified in this development:-

- ☐ Encapsulation of triode valves coupled by resistors and capacitors in one glass envelope (1930"s),
- ☐ Point- to- point wiring of valves on assembly chassis (late 1940"s),
- ☐ Through-hole or conventional assembly of components on PCBs (after 1948, the development of the transistor and integrated circuit)
- ☐ Thin and thick film hybrid technology (1960"s)
- ☐ Surface mount technology developed in the late 1970"s for aerospace applications, but is now the dominant assembly method

Electronic assembly originally used point-to-point wiring on the assembly chassis, and no printed circuit board at all. The through-hole assembly was developed to meet the mass production requirements of the electronics revolution in the 1950"s and 60"s. In this method of assembly, electronic components supplied as leaded discrete components (resistors, capacitors and transistors) or as integrated circuits are inserted through holes (punched or drilled) on the PCB, clinched and soldered. The conventional or through-hole components are typically large, and due to their leads and method of assembly, occupy too much space.

Surface Mount Devices (SMDs) which are miniature in size and often leadless were then developed to meet the demands for lighter, smaller and more densely populated circuits for use in the aerospace, military communications and consumer applications.

Surface Mount Technology (SMT) is used to mount SMDs on the surface of PCB. The Surface Mount and Through-Hole Assembly methods are illustrated in figure 2.1 below

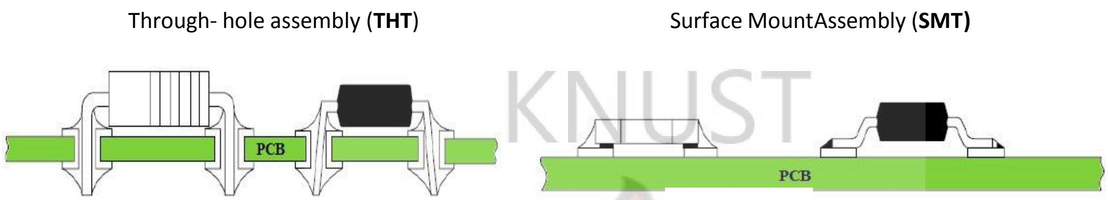


Figure 2.1: Surface Mount and Through-hole Assembly Techniques (Bernhard Wunderle, 2003).

The SMT approach differs from the conventional assembly methods because the devices are placed directly upon the pads on the board rather than by insertion of the component leads through h Surface mount assembly board. Unlike the conventional method in which component leads are inserted through plated holes to provide the electrical connection as well as mechanical strength, in SMT the SMDs rely on the solder joints for their electrical connection and mechanical integrity.

The use of SMT provides several benefits in the design and manufacture of electrical assemblies over the older through-hole technique. Among these are:-

- Reduced cost in production due to the use of smaller boards and smaller components.
- Much higher number of components and many more connections per component on PCB.
- Fewer holes need to be drilled through abrasive boards resulting in reduced material handling (size/weight reduction).
- Simpler automated assembly.

- ☐ Small errors in component placement are corrected automatically (the surface tension of the molten solder pulls the component into alignment with the solder pads).
- ☐ Components can be placed on both sides of the circuit board.
- ☐ Lower resistance and inductance at the connection (leading to better performance for high frequency parts).
- ☐ Better mechanical performance under shake and vibration conditions.
- ☐ SMT parts generally cost less than through-hole parts.
- ☐ Fewer unwanted RF signal effects in SMT parts when compared to leaded parts, yielding better predictability of component characteristics.
- ☐ Faster assembly. Some placement machines are capable of placing more than 136,000 components per hour.

2.2 Surface Mount Components

Surface Mount Components (active and passive), are functionally no different from their through-hole counterparts. What is different in surface mounting is the design and packaging of the components. Surface mount components provide greater packaging density because of their smaller size. Although most types of conventional through-hole components are now available in surface mount format, certain components are not yet available due to certain factors such as the requirement for large physical size. Some of the components which are available in surface mount formats for ICs and power devices are shown in figures 2.2a and 2.2b respectively and summarized below:

Passive Components: These include resistors, capacitors, inductors, transistors and diodes. They are generally rectangular and cylindrical in shape, and some can be very small (with outline dimensions measuring as small as 0.040 in X 0.050 in).

Active Components: Active Surface Mount Components have been developed to replace the conventional Dual-in-line (DIL) Integrated Circuit (IC) package. There are two main categories of chip carriers; Ceramic and Plastic. The Plastic Chip carriers are primarily used for commercial application while the Ceramic Chip Carriers are mostly for military applications. The carrier also comes as leaded or unleaded. There are two common lead forms: the gull wing- Lead and the J-Lead. Some of the widely used active component forms are:-

- Small outline (SO)- gull wing (8 to 28 leads)
- Small outline J (SOJ) - J-Lead (20 J-Leads on two sides)
- Plastic Leadless Chip Carrier (PLCC) – up to 84 J-Leads
- Quad Flat Pack (QFP) – gull wing (44 to 240 leads)
- Leadless Ceramic Chip Carrier (LCCC)

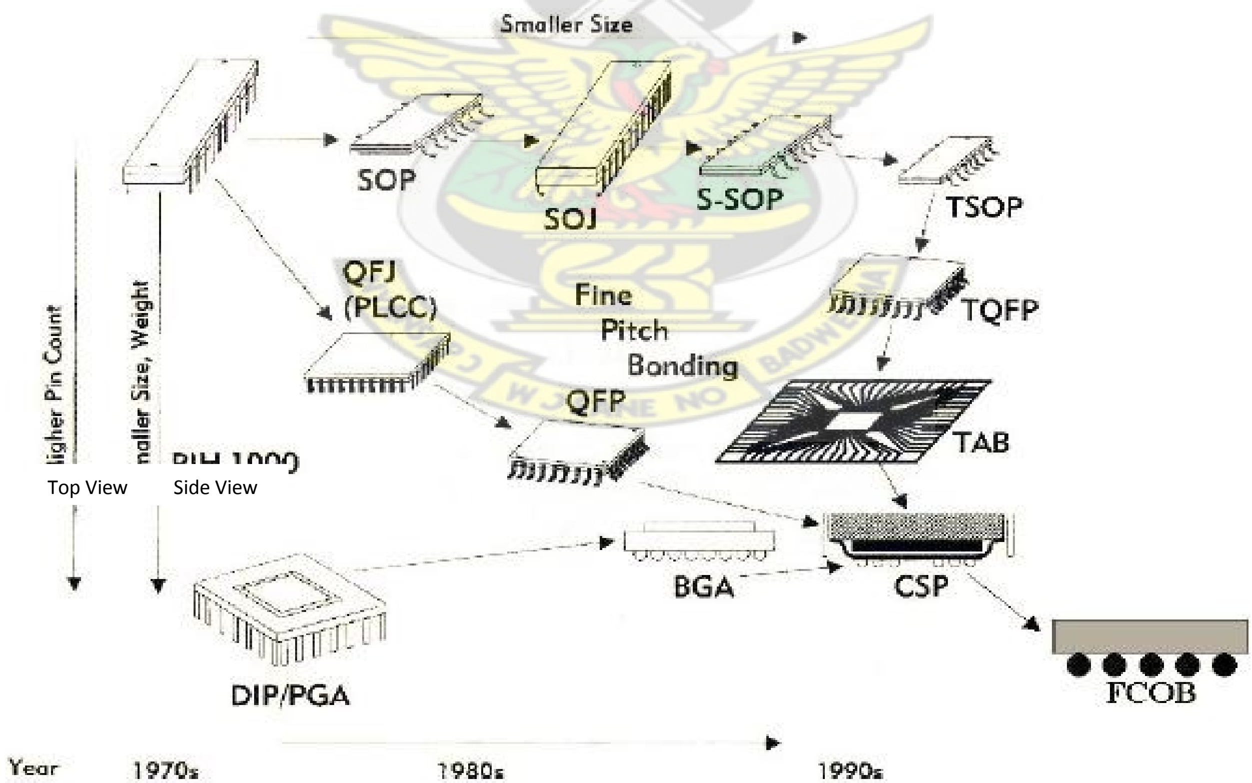


Figure 2.2a: Packaging Evolution for Integrated Circuits (Tummala et al, 1997).

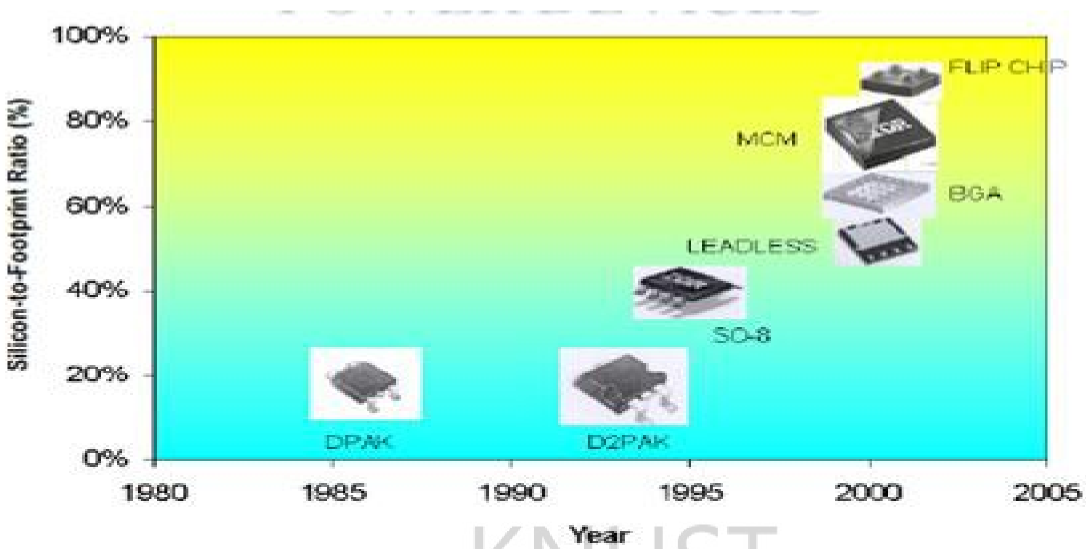


Figure 2.2b: Packaging Evolution for Power Devices (Xuejun et al, 2008).

2.3 Substrates for Surface Mounting

Substrates provide the packing and interconnecting structure of the assembly. They also play a crucial role in ensuring the electrical, thermal and mechanical reliability of electronic assemblies. There are three types of substrates which can be used for surface mounting:

- ***Ceramic:*** these are substrates made of alumina, beryllium or alumina nitride
- ***Organic:*** substrates made of copper clad materials based on organic resins reinforced by paper or glass fibre
- ***Inorganic:*** these are substrates based on a metallic core coated with inorganic insulator such as glass or glass ceramic.

The major difference between substrates used in surface mount assemblies and those used in conventional through-hole assemblies is the need for matching the thermal coefficient of expansions (TCE) of the substrates with those of the components. This helps to avoid possible failure of the joints during temperature cycling. This can be achieved by either using compliant leads or flexible substrates with in-built compliancy.

2.4 Solder Paste (Flux)

Solder paste sometimes refers to soldering flux that does not contain solder. Solder paste (or *solder cream*) is used to connect the leads of integrated chip packages to attachment points (*lands*) in the circuit patterns on a printed circuit board. The paste is typically applied to the lands using a stencil to "print" the paste, although other methods, like dispensing, are also used. Typically, solder paste accounts for 0.05% of a circuit board's final cost (Teardown of iPad 2, 2011).

Solder paste is used with surface mount devices. Majority of defects in circuit-board assembly are caused by issues in solder-paste printing process or due to defects in the solder paste. An electronics manufacturer needs experience with the printing process, specifically the paste characteristics, to avoid costly re-work on the assemblies. The paste's physical characteristics, like viscosity and flux levels, need to be monitored periodically by performing in-house tests.

A solder paste is essentially powdered metal solder suspended in a thick medium called *flux*. Flux is added to act as a temporary adhesive, holding the components until the soldering process melts the solder and makes a stronger physical connection. The paste is a gray, putty-like material. The composition of the solder paste varies, depending upon its intended use. For example, when soldering plastic component packages to a FR-4 glass epoxy circuit board, the solder compositions used are eutectic Sn-Pb (63 percent tin, 37 percent lead) or SAC alloys (tin/silver/copper, named for the elemental symbols Sn/Ag/Cu). If one needs high tensile and shear strength, tin-antimony (Sn/Sb) alloys might be used with such a board. Generally, solder pastes are made of a tin-lead alloy, with possibly a third metal alloyed, although environmental protection legislation is forcing a move to lead-free solder.

Solder paste is thixotropic (non-Newtonian, meaning that its viscosity changes over time with applied shear force, e.g. stirring). The *thixotropic index* is a measure of the viscosity of the solder paste at rest, compared to "worked" paste. Depending upon the formulation of the paste, it may be very important to stir the paste before it is used, to ensure that the viscosity is appropriate for proper application.

2.4.1 Classification

- **By Size:** The size and shape of the metal particles in the solder paste determines how well the paste will "print". A solder ball is spherical in shape; this helps in reducing surface oxidation and ensures good joint formation with the adjoining particles. Irregular particle sizes are not used, as they tend to clog the stencil, causing printing defects. To produce a quality solder joint, it's very important for the spheres of metal to be very regular in size and have a low level of oxidation. (Tarr, Martin,2010-10-03) Solder pastes are classified based on the particle size by JEDEC (JEDEC, 2012), (Solder Paste Task Group (January 1995). Table 2.1 shows the classification type of a paste compared with the mesh size and particle size

Table 2.1: Classification type of a paste compared with the mesh size and particle size

Type designation [JEDEC]	Mesh Size in Lines-per-inch	Max. size (no larger than)	Max. size (less than 1% but larger than)	Particle size in µm (80% min. between)	Avg. size in µm	Avg. size in µm (10% max less than)
Type 1			150	150-75		20
Type 2	-200/+325		75	75-45	60	20
Type 3	-325/+500		45	45-20	36	20

- **By Flux**

According to JEDEC standard J-STD-004 "Requirements for Soldering Fluxes", solder pastes are classified into three types based on the flux types:

1) **Rosin based** pastes are made of rosin, a natural extract from pine trees. These fluxes need to be cleaned after the soldering process using chlorofluorocarbons (CFCs). Due to the ban on CFCs, rosin fluxes are no longer predominant.
2) **Water soluble** fluxes are made up of organic materials and glycol bases. There is a wide variety of cleaning agents for these fluxes.
3) A **no-clean** flux is made with resins and various levels of solid residues. No-clean pastes save not only cleaning costs, but also capital expenditures and floor space. However, these pastes need a very clean assembly environment and may need an inert re-flow environment.

2.4.2 Properties of Solder Paste

In using solder paste for circuit assemblies, one needs to test and understand the various rheological properties of a solder paste.

- **Viscosity**

The degree to which the material resists the tendency to flow. In this case, varying viscosities of solder paste are desired at different levels of shearing force. Such a material is called *thixotropic*. When solder paste is moved by the squeegee on the stencil, the physical stress applied to the paste causes the viscosity to break down, thinning the paste and helping it to flow easily through the apertures on the stencil. When the stress on the paste is removed, it regains it shape, preventing it from flowing on the circuit board. The viscosity for a particular paste is available from the manufacturer's catalog; in-house testing is sometimes needed to judge the remaining usability of solder paste after a period of use.

- **Slump**

  The characteristics of a material's tendency to spread after application. Theoretically, the paste's sidewalls are perfectly straight after the paste is deposited on the circuit board, and it will remain like that until the part placement. If the paste has a high slump value, it might deviate from the expected behavior, as now the paste's sidewalls are not perfectly straight. A paste's slump should be minimized, as slump creates the risk of forming solder bridges between two adjacent lands, creating a short circuit.

2.4.3 Working Life

The amount of time solder paste can stay on a stencil without affecting its printing properties. The paste manufacturer provides this value.

2.4.4 Storage of Solder Paste

Solder paste should be stored in an airtight container at low, but above freezing, temperatures. It should be warmed to room temperature for use. Exposure of the solder particles, in their raw powder form, to air causes them to oxidize, so exposure should be minimized.

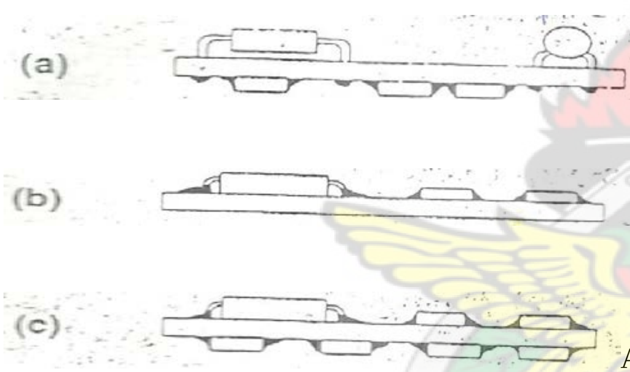
2.5 The Surface Mount Assembly Process

There are three commonly used types of surface mount assembly and to a large extent the type of SMT assembly is dictated by the application and the availability of components in surface mount format.

Currently Mixed Technology (one of the three assembly techniques) is the most widely used because of unavailability of components and the fact that most companies are still in the transition phase (changing all product designs from through-hole components to SMCs).

2.5.1 Types of Surface Mount Assemblies

The type of surface mount assembly or the method chosen for assembling surface mount components onto printed circuit boards determines the sequence of operations for its manufacture. The choice of soldering technique and equipment for forming the solder joints is also dictated by assembly type. Figure 2.3 illustrates the types of Surface Mount assembly and the stages involved in each:



Mixed technology

All SMC single sided

All SMC double sided

Figure 2.3: Types of Surface Mount assembly

Mixed Technology: in this technique, both SMCs and conventional through-hole components are used on the same board with the SMCs on the underside (figure 2.3a). Mixed Technology boards are assembled in the following sequence using wave soldering technique;-

- ☐ Insertion of leaded conventional components
- ☐ Inversion of PCB
- ☐ Application of adhesives for the SMCs
- ☐ Placement of SMCs
- ☐ Curing of adhesives

- ☐ Inversion of PCB again
- ☐ Wave soldering and
- ☐ Cleaning of assembly

(i) ***'All SMC' Single Sided Assemblies:***

a) If it is done by the Reflow Technique then the following sequence is used;

- ☐ Application of solder paste
- ☐ Placement of SMCs
- ☐ Reflow soldering and
- ☐ Cleaning of assembly

b) However, for wave soldering technique the assembly sequence is as follows;

- ☐ Application of adhesive for SMCs
- ☐ SMCs placement
- ☐ Curing of adhesive
- ☐ Inversion of PCB
- ☐ Wave soldering and
- ☐ Cleaning of assembly

(ii) ***'All SMC' Double Sided Assemblies:*** For assembly using the reflow soldering technique, the assembly sequence is the same as that used for „All SMC" Single Sided but here, side 1 is completed before the board is inverted and side 2 is then assembled.

Adhesive is sometimes used as well as solder paste on side 1 when large, and comparatively heavy SMCs are being assembled (to ensure they do not fall off during the reflow soldering operation (Advanced Manufacturing Technology: AMT 7 Applications).

Below is the schematic of SMT assembly line.

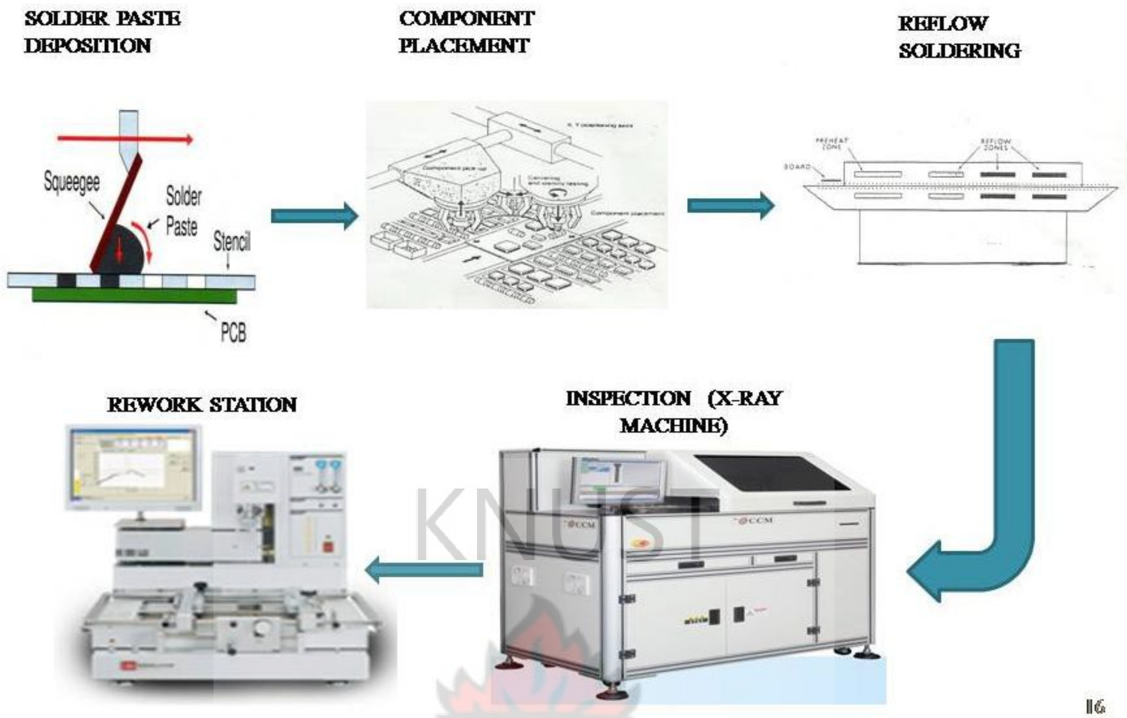


Figure 2.4: Schematic of SMT assembly line (AMT 7 Applications)

2.5.2 Solder Paste Deposition

There are three methods of depositing solder pastes, namely dispensing, screen/ stencil printing and pin transfer.

(i) *Dispensing:*

In this method, solder paste is deposited by being squeezed through the needle of a syringe. Most syringes utilize pneumatic systems which uses time and pressure controls to deposit the desired paste sizes/quantities. The dispensing technique is illustrated in Figure 2.5.

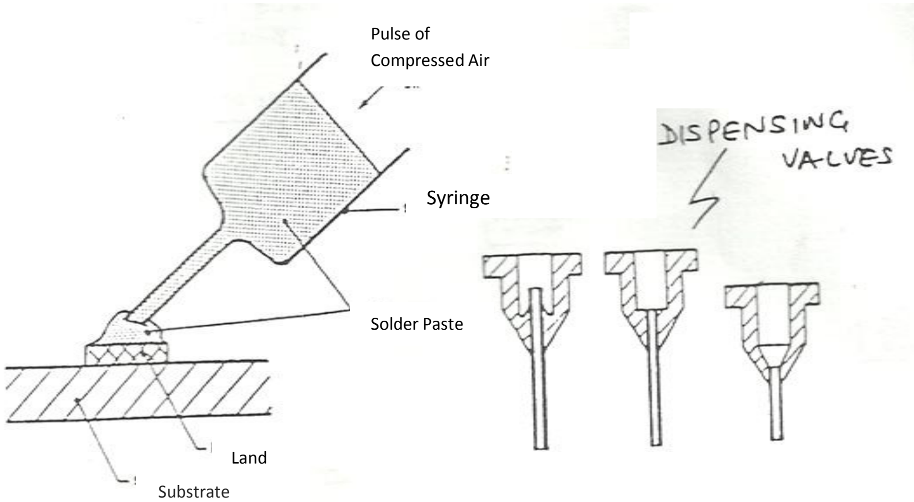


Figure 2.5: Solder Paste Dispensing method

The dispensing technique is relatively slow, as the paste is being dispensed on one land at a time. It is however very versatile implying that:

- It can be used to deposit paste on different shapes (dots, rectangles, squares or circles), and on inaccessible surfaces.
- Different materials (solder paste, adhesives, solder masks) can be dispensed with the same tool.
- It can be readily reprogrammed.

(ii) Screen and Stencil Printing:

Screen printing and stenciling are widely used in mass reflow soldering of surface mount assemblies. The schematic illustration of the screen, stencil and the printing process is shown in figures 2.6 and 2.7. They are similar processes involving pressing a squeegee against a screen or a stencil which has etched openings corresponding to the land patterns on the PCB. The solder paste is placed on the screen or stencil. During printing the paste is deposited on the PCB lands through the openings on the screen/ stencil when the squeegee traverses the length of the board.

Stencils and screens are functionally similar but they are used differently on the printing machine. While stencils are used in printing in both directions (print/ print), screens only allow for unidirectional printing (flood/ print mode). Screens are always used for off-contact printing to ensure good deposition while stencils can be used for both off- and on-contact printing.

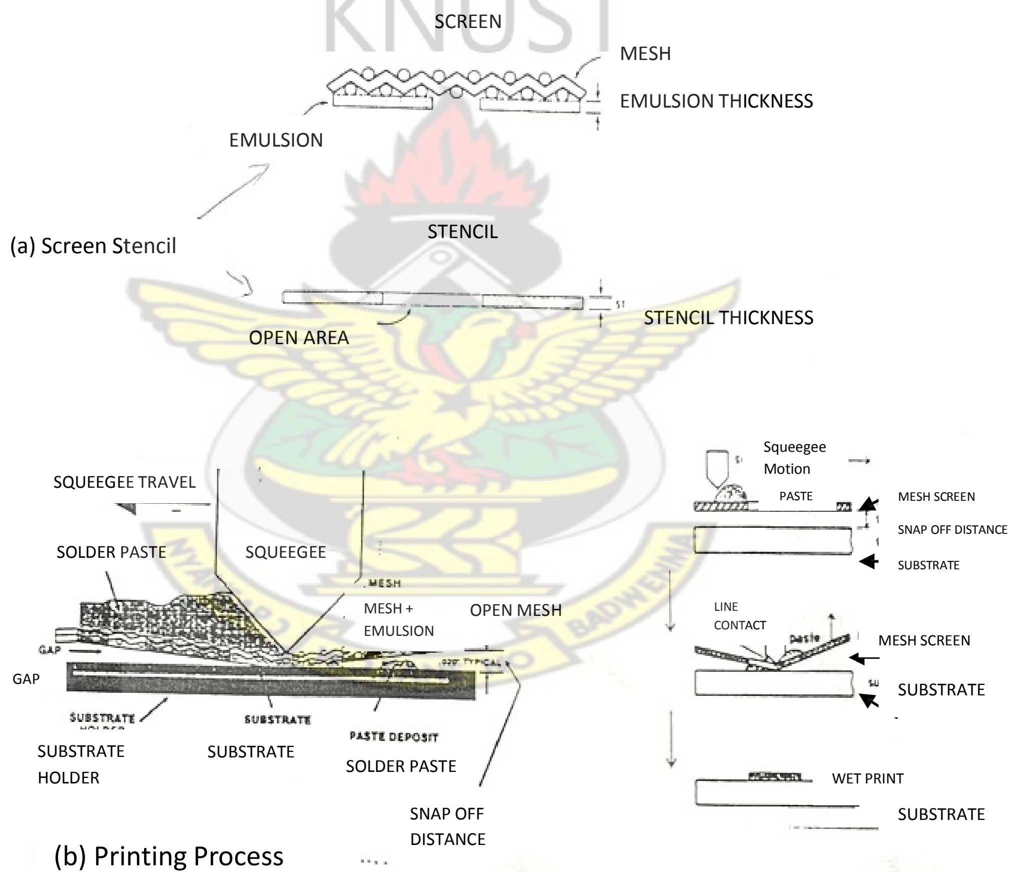


Figure 2.6: Illustration of Screen/ Stencil Printing

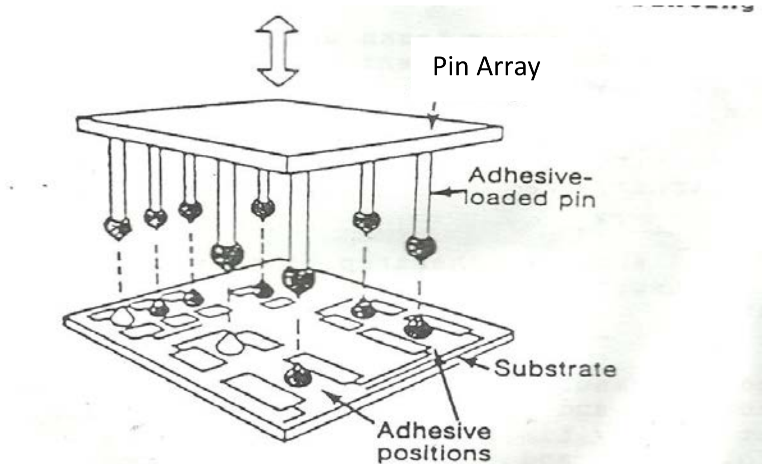


Figure 2.7: Illustration of Pin Transfer Method

(iii) Pin Transfer:

Pin transfer is another method available for depositing solder paste. The paste is picked up by dipping the pin into a paste bath and then transferred into the placement position. The process requires the design of a pin pattern which exactly corresponds to the PCB land pattern as shown in figure 2.7. The potential advantage of this method is the ability of depositing small quantities of paste on boards which are already populated, and the fact that a large number of dots can be placed simultaneously. The pin transfer is not widely used for paste deposition (Advanced Manufacturing Technology: AMT 7 Applications).

2.5.3 Component Placement

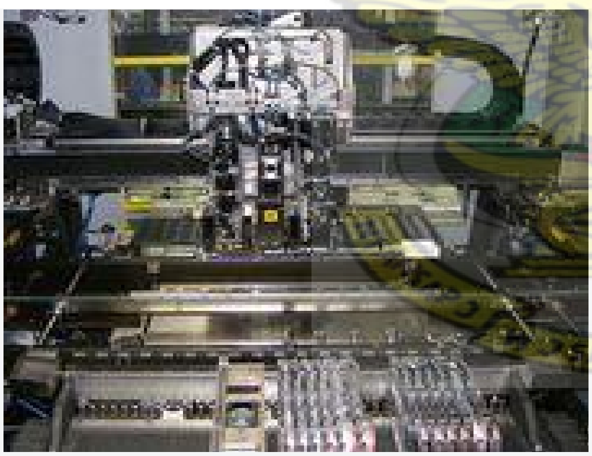
Component placement for surface mount assembly may be by manual, manually-assisted or completely automated. Regardless of the method of placement, there are six basic functions that must be performed in component placement, that are:

- ☐ ***Select:*** finding the required SMC for placement
- ☐ ***Present:*** orientation of SMC to ensure easy access for handling

- ☐ ***Pick:*** securing (that is grasping) and lifting the SMC
- ☐ ***Target:*** identifying the land pattern on PCB and the orientation
- ☐ ***Position:*** alignment of SMCs leads/ termination with PCB land pattern
- ☐ ***Place:*** setting down SMC and releasing it.

The nature of these tasks and the accuracy requirements means that automated component placement machines are always used. Some automated placement machines now incorporate mechanism for monitoring (for instance, checking identity of SMCs, their orientation and electrical properties). Automated placement machines also incorporate vision system which are used both for aligning SMCs during placement and for inspection.

Figure 2.8a and 2.8b show a photograph and a schematic part of an automated placement machine respectively, illustrating some of the functions in SMT component placement.



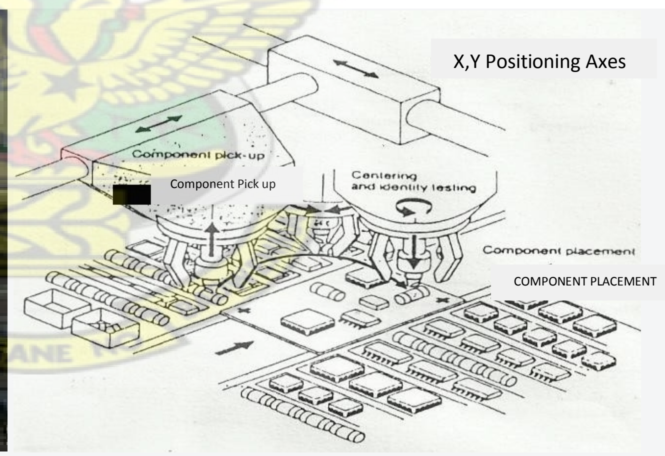


Figure 2.8a: Gantry style pick-and-place JUKI SMT machine

Figure 2.8b: Automated Component Placement Functions

Figure 2.8: Internal details of a two head, gantry style pick-and-place JUKI SMT machine.

In the foreground are tape and reel feeders, then the (currently empty) conveyor belt for printed circuit boards, and in the back are large parts in a tray. The gantry carries two pickup needles, flanking a camera (marked "do not touch" to avoid fingerprints on the lens).

Hand and manually-assisted placement is however used for prototyping and for small volume production. Hand or manual placement is very time consuming and requires a lot of concentration and organization, and is unreliable (as consistency and accuracy in placement cannot be guaranteed).

2.5.4 Soldering Techniques

There are many ways in which SMCs can be attached to the PCB. These include conductive adhesives, hand, bath and reflow soldering. Figure 2.9 shows some of the methods used for attaching SMCs to the PCB in surface mount assembly. Reflow and wave soldering are the dominant methods used in surface mount assembly. Although conductive adhesive is an option it is not widely used because of its high cost, lower conductivity and the associated assembly and rework problems. Hand soldering is also not applicable because of its difficulty in handling miniature SMCs and also controlling both heat supply and the right amount of solder.

Reliability should be the technical criterion for selecting soldering technique (and equipment) for SMT applications, since it is the final measure for the quality of the process and products. The soldering techniques used for SMT can be classified into two main groups:-

1. Bath or Machine Soldering (wave, dip and drag)
2. Reflow Soldering (radiation, conduction, condensation and convection)

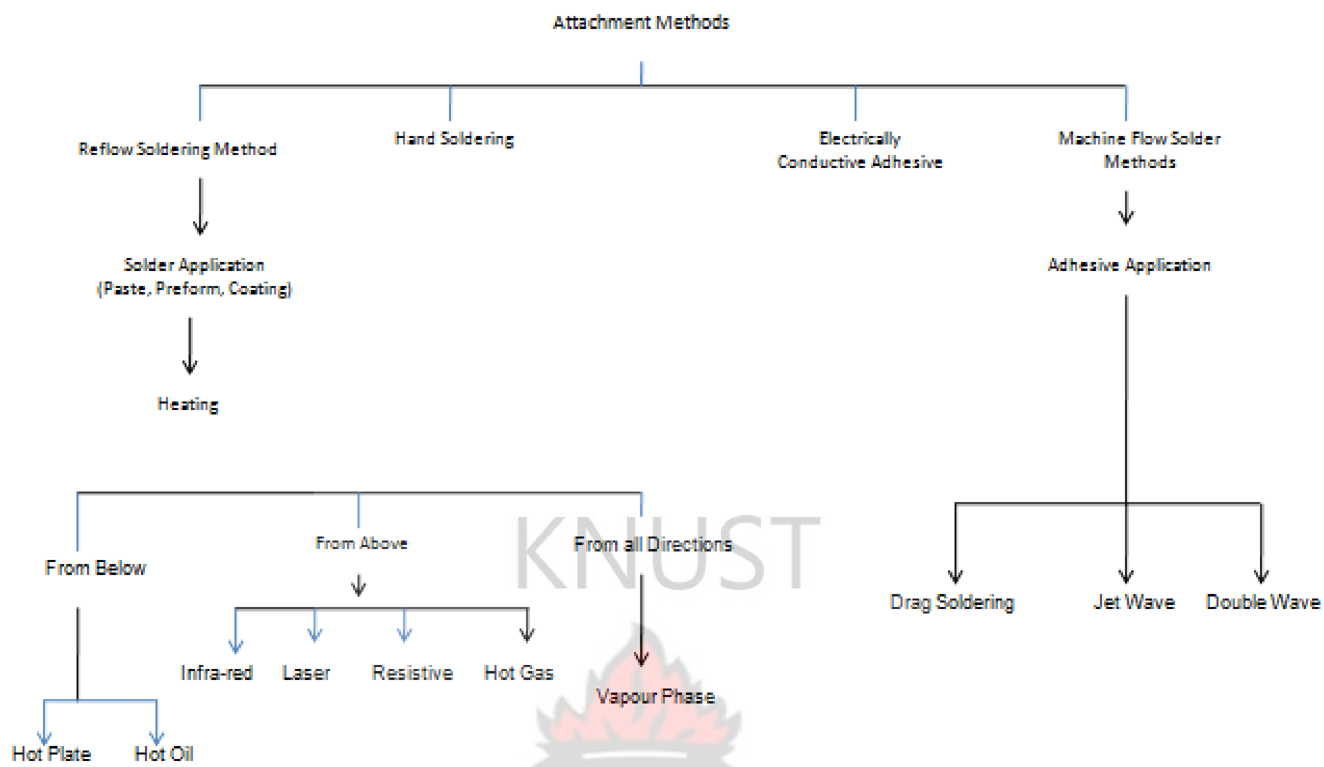


Figure 2.9: Methods for attaching SMCs to PCB

2.5.4.1 Bath or Machine Soldering

As the name suggests, bath soldering involves the meeting between molten solder and the surface of the board to be soldered. This meeting together can be achieved by: Dip Soldering:- where the board is lowered onto a static bath of solder and then removed.; Drag Soldering:- where the board is dragged horizontally across the surface of a static solder reservoir.; Wave Soldering:- in which the board is dragged almost horizontally across the crest of a wave of flowing solder.

Drag and Wave Soldering are the most popular methods and are used for mixed assemblies (in which leaded components and discrete SMDs on the solder side are soldered in one operation). They are however not suitable for soldering PCBs with high packing density multileaded SMDs. Dual wave soldering have been developed to help improve the quality of wave soldering.

(a) Dip Soldering

It is a small-scale soldering process by which electronic components are soldered to a PCB to form an electronic assembly. The solder wets to the exposed metallic areas of the board (those not protected with solder mask), creating a reliable mechanical and electrical connection. Dip soldering is used for both through-hole printed circuit assemblies, and surface mount. It is one of the cheapest methods to solder and is extensively used in the small scale industries of developing countries. Dip soldering is the manual equivalent of automated wave soldering. The apparatus required is just a small tank containing molten solder. PCB with mounted components is dipped manually into the tank when the molten solder sticks to the exposed metallic areas of the board.

Dip Solder Process

Dip soldering is accomplished by submerging parts to be joined into a molten solder bath. Figure 2.10 shows the schematic of Dip Soldering. Thus, all components surfaces are coated with filler metal. Solders have low surface tension and high wetting capability. There are many types of solders, each used for different applications such as Lead-Silver for strength at higher than room temperature. Tin-Lead is used for General Purpose; Tin-Zinc is used for Aluminum; Cadmium-Silver is used for strength at high temperatures; Zinc-Aluminum is used for Aluminum and corrosion resistance; Tin-Silver and Tin-Bismuth is used for Electronics. Because of the toxicity of lead, lead-free solders are being developed and more widely used. The molten bath can be any suitable filler metal, but the selection is usually confined to the lower melting point elements. The most common dip soldering operations use zinc-aluminum and tin-lead solders.

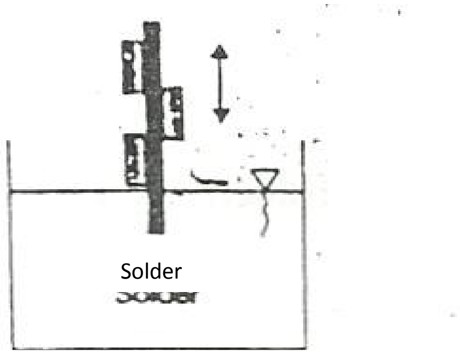


Figure 2.10: Schematic of Dip Soldering

Process Schematic

The work pieces to be joined are treated with cleaning flux. Then the work piece is mounted in the workholding device and immersed in the molten solder for 2 to 12 seconds. The work piece is often agitated to aid the flow of the solder. The work piece holder must allow an inclination of 3 to 5 degrees so that the solder may run off to insure a smooth finish.

Work piece Geometry

This process is generally limited to all metal work pieces, although other materials, such as circuit boards can also tolerate momentary contact with the hot molten solder without damage.

Set up and Equipment

1. There is not much equipment or setup for this process, all that is needed is the solder pot with its temperature control panel, the bath of molten solder, and the work holding device. Usually the work holding device is custom made for each respective work piece for either manual or automated dipping (Todd et al., 1994).

Solderability

Some materials are easier to solder than others. Copper, silver, and gold are easy to solder. Iron and Nickel are a little more difficult. Titanium, magnesium, cast irons, steels, ceramics, and graphites are hard to solder. However, if they are first plated they are more easily soldered. An example of this is tin-plating, in which a steel is sheet coated with tin so that it can be soldered more easily.

Applications

Dip Soldering is used extensively in the electronics industry. However, they have a limited service use at elevated temperatures because of the low melting point of the filler metals. Soldered materials do not have much strength and are therefore not used for load-bearing (Soldering of Non-Ferrous Alloys, 1999).

(b) Drag Soldering

This is where the board is dragged horizontally across the surface of a static solder reservoir. It is shown in figure 2.11.

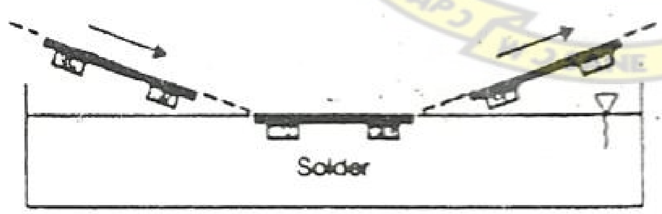


Figure 2.11: Schematic of Drag Soldering

(c) Wave Soldering

It is a large-scale soldering process by which electronic components are soldered to a printed circuit board to form an electronic assembly. The name is derived from the use of waves of molten solder to attach metal components to the PCB. The process uses a tank to hold a quantity of molten solder; the components are inserted into or placed on the PCB and the loaded PCB is passed across a pumped wave or waterfall of solder. The solder wets the exposed metallic areas of the board (those not protected with solder mask, a protective coating that prevents the solder from bridging between connections), creating a reliable mechanical and electrical connection. The process is much faster and can create a higher quality product than manual soldering of components (Advanced Manufacturing Technology: AMT 7 Applications).

Wave soldering is used for mixed technology assemblies (where the leads of through-hole components and the terminations of SMCs are soldered in a single pass). Although wave soldering can also be used on „All SMC" boards, it is not suitable for active SMCs. Dual wave systems which uses a primary turbulent (high pressure), and a secondary laminar wave, have been developed for soldering „All SMC" boards which are not densely populated. In the latter case, the components are glued by the placement equipment onto the printed circuit board surface before being run through the molten solder wave.

As through-hole components have been largely replaced by surface mount components, wave soldering has been supplanted by reflow soldering methods in many large-scale electronics applications. However, there is still significant wave soldering where SMT is not suitable (e.g. large power devices and high pin count connectors), or where simple through-hole technology prevails (certain major appliances).

Wave Soldering Process

The advent of the printed wiring board made it much easier, quicker and cheaper to assemble electronic equipment. The time saving benefit when making multiple solder joints was found first with hand soldering. However, bringing all the joints into a single plane, with the board as a barrier between solder and components, also created a structure in which soldering could be automated by solder dipping.

There are many types of wave solder machines, however the basic components and principles of these machines are the same. A standard wave solder machine consists of three zones: the preheating zone, the fluxing zone, and the soldering zone. An additional fourth zone, cleaning, is used depending on the type of flux applied. The basic equipment used during the process is a conveyor that moves the PCB through the different zones, a pan of solder used in the soldering process, a pump that produces the actual wave, the sprayer for the flux and the preheating pad. The solder is usually a mixture of metals. A typical solder has the chemical makeup of 50% tin, 49.5% lead, and 0.5% antimony. There are three types of waves: normal wave, a medium speed, long leads used for horizontal soldering; cascade wave, high speed, short leads, used for inclined soldering; and flat wave with extenders; medium to high speeds, long leads that is used for horizontal soldering (Tarr et al, 2010).

i) Process Characteristics

The following are characteristics of the wave soldering process:

- The solder connection is very reliable and also a clean connection. Unless the surfaces are unusually clean, flux always has to be applied in order to encourage wetting. When flux is heated, first its low-boiling constituents evaporate, and then it starts to decompose, generating smoke. It is easy to tin a component by dipping first in flux and then in solder, because the vapour and fumes can escape easily. However, just placing a flat fluxed board in contact with hot solder will trap solvent vapour between the two surfaces, preventing even contact between solder and joint, and resulting in solder skips.

- The process is automated so within a short time of exposure to air, the surface of molten solder grows a layer of oxide. Not only is this oxide unsolderable, inhibiting wetting, but the layer impedes free flow of the solder

- The process reuses the flux and solder that is left over. Unless the operation is very carefully carried out, it is difficult to avoid leaving surplus solder or solder spikes, even when the joint is fully molten when the source of solder is removed

- It does require inspection, some touch ups, and also testing

- The productivity and efficiency is increased. Some degree of movement of solder relative to the surfaces to be joined helps accelerate the wetting process, and is needed to make sure that solder reaches areas of the joint that are difficult to access.

Many of the first in-line machines used the „drag soldering" principle, where the board was moved across a static pot. The relative motion scrubbed the solder across the board and allowed flux volatiles to escape, and solder peel-back from the joint was enhanced by arranging for the board to exit smoothly at a slight angle to the pot surface. Automatic machines fluxed the board before solder immersion, and could incorporate pre-drying of the assembly to reduce the quantity of flux volatiles. A cover layer of oil was generally used to reduce oxidation, although this meant that cleaning was almost unavoidable (Tarr et al, 2010).

Wave soldering is an in-line process, during which the underside of the board is successively fluxed, preheated, immersed in liquid solder, and then cooled (Figure 2.14).

(a) Typical „Straight-through" style of wave soldering

(b) Inside of Wave Soldering Machine

Figure 2.12: Wave soldering machines

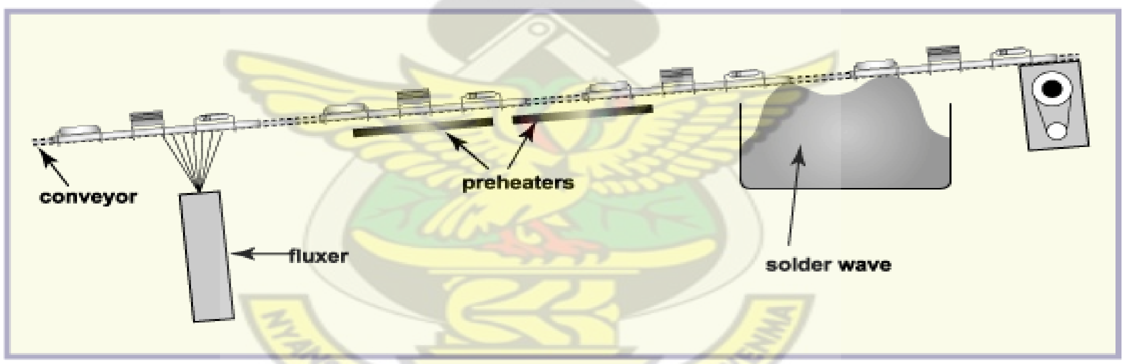


Figure 2.13: The Schematic Wave Solder sequence

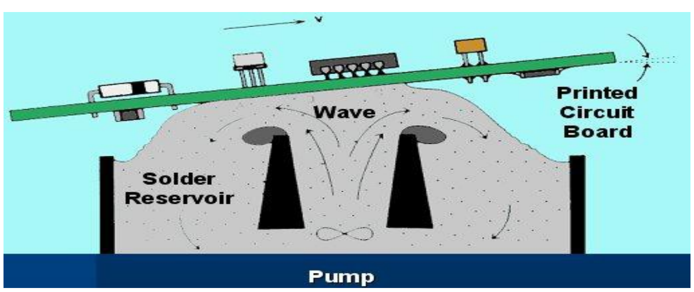


Figure 2.14: Wave soldering Stage

This process has to be carried out in a controlled and reproducible manner to ensure a high yield of good quality joints at the lowest possible cost. As a result, wave soldering machines have become increasingly sophisticated, in an attempt to control the many variables.

The temperature experience of the wave soldered joint, typically shows a steady temperature rise to over 100°C, then a rapid rise to a peak of 240−250°C at the time of solder immersion. On immersion, the area of the board in contact with the wave rapidly attains thermal equilibrium with the molten solder, so that all joints reach the same temperature. The fact that a large quantity of liquid metal is present to transfer heat is a key difference between wave soldering and reflow soldering, and one that explains the lack of a stabilisation plateau region.

Measuring the temperature profile has been particularly important in wave soldering to reduce the damage to surface mount devices: thermal damage is less of a problem with through-hole components, because the board acts as a heat shield (Tarr et al, 2010).

As with reflow, there is a critical contact time for soldering to take place − that is a minimum time a joint must be in contact with the solder to ensure a good joint. This depends on the type of joint, the solder pot temperature, and the board type − constructions differ in their thermal characteristics (Tarr et al, 2010).

There is a corresponding optimum contact time for an assembly, which is just long enough to ensure that all joints become fully wetted. This time will depend on what joint types are in the assembly and must be as long as the longest individual critical contact time. Generally contact times between 3- 4s are suitable for most applications, but 1−2s is used for boards with sensitive components. Working backwards, contact time determines the required conveyor speed and wave dimensions (Tarr et al, 2010).

Application of Wave Soldering

Wave soldering has numerous applications including component lead tinning, component manufacture, hybrid circuit assembly, and continuous wire tinning, but its main application is for soldering circuit board assemblies. The process for a through-hole component starts with selecting the part, cropping and forming it where necessary, inserting it into the board, and then applying molten solder to form the bond between the circuit board and component termination.

Through-hole components have to be held in position to prevent movement during handling and soldering, and especially to prevent them being pushed out of the hole during soldering. The upward force on the leads is a combination of their buoyancy (leads are less dense than solder) and the pressure of the solder wave. This „component lifting" problem is most commonly seen with parts such as connectors, with multiple terminations and often little interference between the leads and the holes in the board. Mechanical retention may also be needed where the leads are either to be left long or to be sheared very short before or after soldering (Tarr et al, 2010).

The many ways of keeping components in place include:

- 'Clinching" component leads after insertion, that is bending over the end of the lead that projects from the board, so that the component is pulled and held against the board
- Preforming the leads, using the residual spring in the lead to „interfere" with the hole
- With dual-in-line packages, the leads on opposite sides are set at an angle and have to be compressed to the vertical for insertion. Whilst they interfere with the holes, and are thus loosely retained, the leads on opposite corners are usually clinched for extra security
- Fitting retention clips to the handling jigs
- Applying temporary weights. These can be as simple as a bean bag, or as sophisticated as a shaped and weighted magnetic cover that is automatically loaded and removed

- „Shrink wrapping" with a plastic film heat-shrunk over the entire assembly. Problems arise when the components are not of a uniform height: tall parts can become twisted, whilst nearby components are left loose. Also the adhering plastic film may not allow flux fumes and expanding air to escape, causing blow-holes and insufficient solder rise
- „Spray webbing": applying a *top* surface spray that glues the components in place and comes off during cleaning. This can be applied as a hot melt system or as an evaporating spray
- Applying a molten low temperature material to the *bottom* of the board. Various wax-like materials are used that become detached and float to the top of the solder bath when passing through the wave.

The methods most frequently seen are the first four in the list above, but the choice will depend very much on the design requirement and equipment available. For example, although requirements for low joint profile are now more normally met by SM solutions, the heat shrunk plastic film method is still used for assemblies where the leads have to be cut short prior to soldering (Tarr et al, 2010).

Whatever the method, careful attention must be paid to static protection for sensitive assemblies. Also, the component leads must project below the board sufficiently both to ensure contact with the solder and to create joints where good wetting allows the underlying termination to be seen. This so-called „pin witness" forms part of the specification requirement for all through-hole joints: if solder is just „plastered" over the surface to cover the lead, as can happen if the solder temperature is too low, there is no guarantee that a proper joint has been formed underneath (Tarr et al, 2010).

Wave Soldering Surface Mount Components

SM components were originally conceived in the late 1960s for „hybrid microcircuits", using ceramic substrates. Parts were either hand-soldered or reflowed using a hotplate. This second process presented no problem, as circuits were usually of single-sided construction and the ceramic was stable, with good heat conductivity. However, soldering problems began when SM components started to be wave soldered to polymer circuit boards. Whilst chip components presented no problems, active component formats were not very „soldering-friendly", small outline integrated circuit packages (SOICs) and plastic leaded chip carriers (PLCCs) being especially difficult to wave solder. This is because the ends of the leads are too close to the relatively high body mouldings. The solder wave finds it difficult to access these corners, because of the high surface tension of the molten solder. Until wetting takes place, the solder surface in contact with a component is like a balloon pressing against the walls of a room – in a tight corner, at best it will only make contact at the periphery.

This „angle of aspect", formed between the upper edge of the component body and the end of the solderable lead, is about 60° for SOICs and can reach 90° for standard PLCCs.

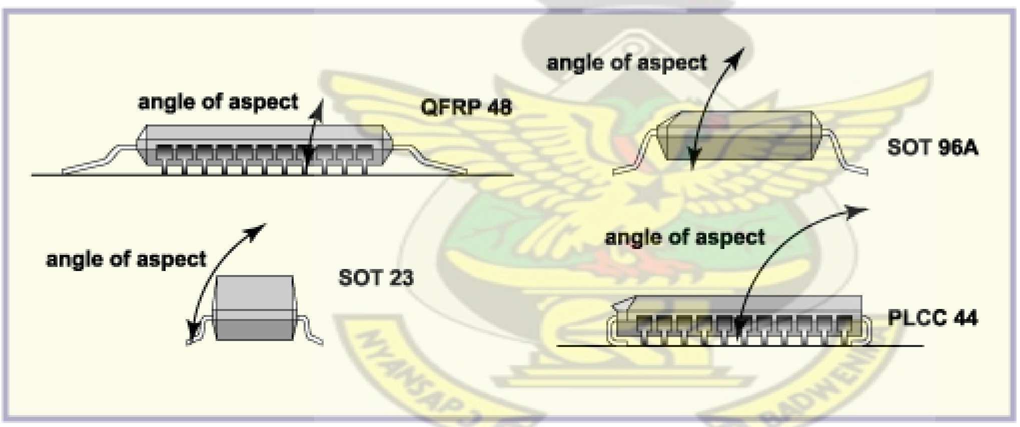


Figure2.15: The Contours of SOICs, PLCCs and QFPs

A similar sort of situation exists where SM parts are closely spaced, making it difficult for the solder to access the joint. There is no single solution: as you will be able to deduce from your later studies, this problem is both addressed during board design and tackled during manufacture by using waves with high turbulence and an appropriate angle of attack.

The trend towards thinner packages might be expected to make gull-wing formats easier to solder, because the angle of aspect is reduced. However, the reverse is the case: usually the lead pitch also becomes finer, and the reduced separation increases the incidence of bridging. Table 2.2 indicates the range of SM components for which wave soldering is suitable.

Table 2.2 Range of application of wave soldering

Lead Pitch	**Applicability of Wave Soldering**
1.27 mm (0.05 in.)	Straightforward
0.75 mm (0.03 in.)	More difficult requiring special layout provision
0.5 mm (0.02 in.)	Usually need to solder in an inert atmosphere
<0.5 mm (0.02 in.)	Wave soldering not recommended

'View and Touch up'

The solder joint faults introduced by the wave soldering process are normally „major" defects, that is they require rectification. Typical of these are bridges, spikes and solder skips, excess solder defects being the most common. When problems happen, they tend to affect wide areas of the board, and most test systems have difficulty in dealing with a number of short-circuits on a single assembly. It is therefore common practice to introduce a rework stage immediately after wave soldering. If a cleaning process has been specified, this rework is usually carried out after cleaning, but may sometimes be done beforehand, provided that the board is not excessively contaminated by flux and that care is taken to avoid the flux residues hardening and becoming more difficult to remove.

In what is graphically referred to as „view and touch-up", an operator both inspects and reworks the board. This is usually done under low magnification using a magnifier. A benefit is that there is direct feedback from inspector to rework operator on the location and type of defect! However, there are dangers in assigning dedicated operators to this task:

- It builds into the company ethos the belief that wave soldering is intrinsically a low yield process, and that some element of rework is essential, whereas good designs and well-controlled processes will give good results without adding cost
- Operators may attempt to produce a higher cosmetic standard of joint than is actually needed, in the process actually *reducing* the reliability of the joint by reworking it. This becomes more likely when the operator load is reduced by yield improvements.

Wave Soldering mixed technology assemblies

Mixed technology („Type 3") assemblies are often made by combining reflow and wave soldering. A typical process is to apply solder paste, place surface mount (SM) components on the top of the board, dry the paste, and then reflow the paste to create the joint. Next leaded components are inserted, the board is inverted, adhesive is applied, SM components are placed, and the adhesive is cured. After inverting the board once more, wave soldering completes the process.

Note that the SM parts are totally immersed in the solder wave. To avoid being washed away, they must be firmly secured to the board by applying glue before placement and curing the adhesive afterwards. Typical glues used are epoxies that are heat cured, the process taking place in a belt oven similar to that used for reflow.

Unfortunately, with wave soldering it is not easy to incorporate complex components on the underside, which limits the freedom of the layout designer. It also introduces a second type of soldering process, one that is (comparatively) low yield and difficult to control. The alternative of using solder paste and reflowing all the components is attractive, and cost reduction and process simplification are major driving forces behind what is called „intrusive reflow" or (more descriptively) „pin-in-paste". We will be exploring that theme in *Alternative techniques and off-board assembly*.

Materials for Wave Soldering

i) Flux

Fluxes used for wave soldering (also referred to as „preparation fluids") are usually low-viscosity liquids, and consist of a flux base combined with:

- activators
- solvents („thinners")
- surfactants and foaming agents (where needed).

There are four main categories of flux used in wave soldering:

- Conventional **rosin-based** fluxes, which use a base of isopropyl alcohol („isopropanol" or „propan-2-ol", but usually referred to as „IPA") and contain 5–20% of „solids" (rosin + activators). These fluxes will leave residues, which may or may not need to be removed, depending on their nature and properties
- Similar **low-solids** fluxes that have a solid content in the range 1–5%. They may be based on rosin or synthetic colophony substitutes. Low-solids fluxes are designed not to require post-solder cleaning
- **Water-soluble** fluxes, which contain active organic acid components in an alcohol base. The residue from these fluxes needs to be removed from the circuit assembly with a water wash
- **Water-based** fluxes in which active acidic components are blended with water. Depending on the concentration of active components in the mixture, these fluxes may be classified either as „no-clean" or „clean with water" types.

The trend to no-clean and water-soluble fluxes resulted from the CFC ban following the Montreal Protocol agreement of 1987. There have since been environmentally driven moves both to control the discharge of water used for washing and to reduce the emission of Volatile Organic Compounds (VOCs). The result has been a trend towards using water-based no-clean fluxes. Because water has a higher boiling point and is relatively slow to evaporate, these fluxes typically have a higher (10−20%) solids content, and generally require modification to the preheat part of the process. Flux changes in composition when in contact with the atmosphere. These changes take two forms:

- **Loss of solvents**, which increases both the solids content of the flux and its viscosity. These parameters are normally deduced from measurement of the specific gravity („SG") of the flux, and solvent loss can be compensated for by adding replacement solvent („thinners"). However, with rosin-based fluxes used in foam fluxers, the changes are very rapid, so constant monitoring and replenishment is required
- **Oxidation of the flux**, which reduces its fluxing effectiveness. Nothing can be done about this, other than replacing it by new flux. A typical recommendation is that flux exposed to the atmosphere should be replaced after 40−50 hours of use.

In order to get consistent fluxing results, either the condition of the flux has to be maintained scrupulously (with foam, wave or brush methods) or virgin flux has to be used once only (with spray fluxing). Low solids and no-clean fluxes tend to be most difficult to maintain in consistent condition, which in turn means that the industry is moving towards sealed spray fluxing systems.

ii) Solder

Although 60:40 tin: lead used to be favoured, the material of choice for all current wave-soldering applications is 63:37 tin: lead, that is, Pb37A (in the ANSI/J-STD-006 standard) or Sn63 (in QQ-S-571E), (The move to lead-free materials, 2000).

There are benefits of adding small amounts of silver to tin-lead eutectic solder, and the Pb36A alloy with 2% silver is very commonly used for solder paste. However, for wave soldering the benefits are normally outweighed by the greatly increased cost.

Fortunately, using the weaker alloy is not a major problem: a wave soldered joint tends to be stronger by design than a reflowed joint, being generally applied to through-hole components and surface mount parts on coarse lead pitch, with correspondingly large fillets. Restricting the use of Pb36A to solder pastes, where the demands on the joint are more stringent, and the metal cost is only a small percentage of the total, makes good economic and engineering sense.

Note that there will always be a substantial differential between the quoted trading prices of commodity metals and the cost of solders. Only a portion of this represents profit, as there are real costs associated with the additional refining and casting processes involved. Whilst specifications and manufacturing processes vary, electronic solders are very much purer than their counterparts in other industries, and have lower oxide content.

iii) Solder resist

Solder resist, or „solder mask", is an organic coating applied selectively to the surface of the board to restrict the contact area with the molten solder. As a result only non-masked areas will be wetted. Solder resist is usually a permanent coating and is left on the final product. It offers the benefits of increased electrical insulation, fillet control, and greater simplification of circuit design. Solder mask is essential for all surface mounting applications because of the fine tracks and small pad areas.

The material selected for a resist depends on the final substrate (rigid or flexible), the cost of the assembly, and the final product operating environment. Solder resists are generally made of epoxies and polyurethanes, but other materials such as acrylics and polyamides have been used.

It is extremely important that the chosen material forms a flat, smooth, hard surface of consistent thickness onto the board, otherwise solder webbing will occur. In addition, the materials must withstand soldering temperatures, as well as exposure to flux and any cleaning solvents.

The main advantages of solder resists are that they:

- ☐ reduce solder consumption
- ☐ slow the rate of contamination of the solder bath
- ☐ simplify printed wiring design by providing an insulating layer
- ☐ can be used to control the shape of the solder fillet
- ☐ permit closer spacing of traces covered by resist
- ☐ provide a partial conformal coating to the end product
- ☐ increase surface resistivity and reduce tracking in humid conditions.

This last item is particularly important from the reliability point of view – the increase in surface insulation resistance (SIR) is around two orders of magnitude.

The only downside for solder resist is that some resists may interact with solder to produce unexpected effects: an example of this is solder balling which is reported to take place during wave soldering under nitrogen.

Solder masks are mainly applied in one of three ways:

- ☐ pattern printing („screened")
- ☐ wet photosensitive film (generally curtain-coated)
- ☐ dry photosensitive film (hot laminated).

The latter two are necessary for fine-line applications because of their better pattern definition, and liquid solder mask is the most commonly used for high-density SM work, because of its thin coating and inherent consistency of thickness. More details are given in *Solder mask*.

Fluxing

Flux Application Methods

The correct quantity of flux has to be applied evenly to the entire surface to be soldered: unfluxed areas will not be soldered well, and over-thick deposits will lead to voids and solder balling. It is also desirable to flux the inside of any through holes, to aid wetting and solder pull-through. The presence of SMDs and the gaps between the bottom of the SMDs and the boards on the solder side of double sided boards means that larger amounts of flux and solvents are consumed on SMT assemblies when compared with conventional boards. To reliably drive off the solvents before the boards come into contact with molten solder, intensive curing and preheating is required. Most wave and drag soldering lines come with an integrated flux application system, and the most widely used methods are: foam fluxing and spray fluxing

i) Foam fluxers

Until the mid-1990s, the foam fluxer was the type most commonly fitted in automatic soldering lines. With this method (Figure 2.16) a flux „foam" is generated by passing low pressure air (<1bar) through aerator tubes immersed in a tank of liquid flux. Despite their common name, most of these „stones" are in fact made of polypropylene. Ceramic tubes are reported to be more reliable and easier to keep clean. The tubes, often fitted in pairs, are designed to break up the stream into tiny bubbles, and are covered by an open chimney that channels the foam upwards. The assembled board travels across the crest of this wave of foam, and a thin coating of flux is left on the board as the bubbles burst.

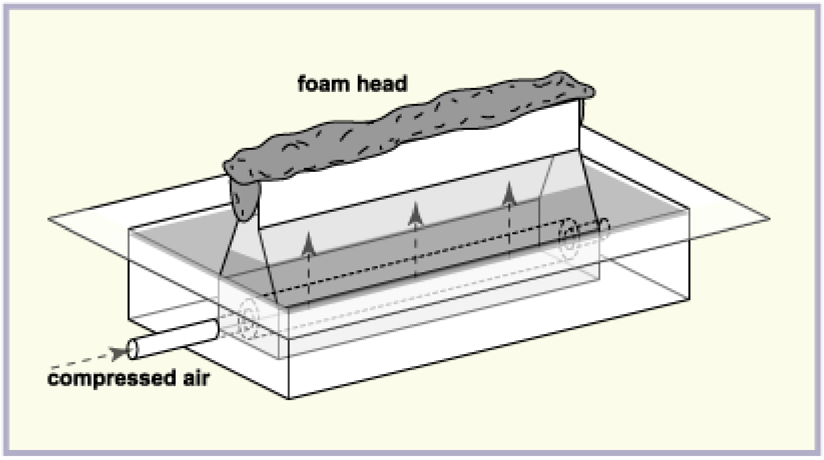


Figure 2.16: Schematic of foam fluxer

The flux used needs to be specifically formulated, with additives to aid the creation of stable foam with small bubbles. Typically, the flux is of low viscosity, achieved by having relatively low solids content. The thinner may be based on solvent or water, the latter becoming increasingly favoured because of environmental issues associated with VOCs. The normal foam fluxer without any special support is often labelled a *free foam head*, and can reach a height of around 15 mm. If greater heights are needed, for example, where long through-hole leads are used, a brush support can be introduced on both sides of the foam chimney and the total depth can be extended to above 25 mm. The maximum head of foam for a given type of flux depends on the nozzle type, the air pressure and the amount of flux above the aerator. The latter affects the stability of each flux bubble and therefore the foam head support and height. There are different types of nozzle used in a foam fluxing unit, and illustrates both how contact width can be increased for a given flux type and how the height of the foam head increases as the flux level is raised.

When setting up a fluxer, the flux level typically starts 10−15 mm above the aerator, and is increased gradually (up to about 35−40 mm) until no further increase in foam head height is observed. At the same time the bubbles become smaller, because the foam head is better supported.

The amount of flux deposited by a foam fluxer cannot be controlled directly by the operating parameters of the fluxer itself, but depends primarily on the speed of the board set by the conveyer and the viscosity of the flux. Note that the latter parameter depends on the solvent content of the flux and foam fluxers need constant addition of thinner to replace that which evaporates.

ii) Spray fluxers: Since the introduction of SM technology, spray fluxing has gained in popularity because the fine droplets can be propelled into the narrow gaps between closely-packed SM components, whereas foam bubbles may burst before they reach the joints at the base of the component body.

Most spray systems use a pressurised canister of flux feeding a spray head at which the required amount of material is atomised by air pressure or ultrasonic energy. A major benefit of a sealed system is that the flux is applied as received, so that there is no chance of contamination, and complicated flux controls are unnecessary. There are other advantages that outweigh the increased cost of the equipment compared to foam fluxers, and have made sealed spray systems popular, even as a retrofit option:

- ☐ the quantity of flux deposited per unit area of board can be adjusted and is relatively well controlled
- ☐ the area sprayed can be confined to the board, reducing flux usage and avoiding flux build-up on any carriers
- ☐ running costs are substantially reduced, because there is minimal evaporation of flux thinner
- ☐ by applying a thinner layer, better wetting is achieved and there is less flux residue
- ☐ long component wires (up to 18 mm) and high component density present no problem
- ☐ the technique works with a wide variety of fluxes.

Many of the spray fluxers in the market place have easily replaceable, air-powered nozzles, often fitted in pairs. Heads are fixed to a moving bar that provides a reciprocating action similar to that used in paint sprayers, in order to give complete even coverage of the board (Figure 2.17).

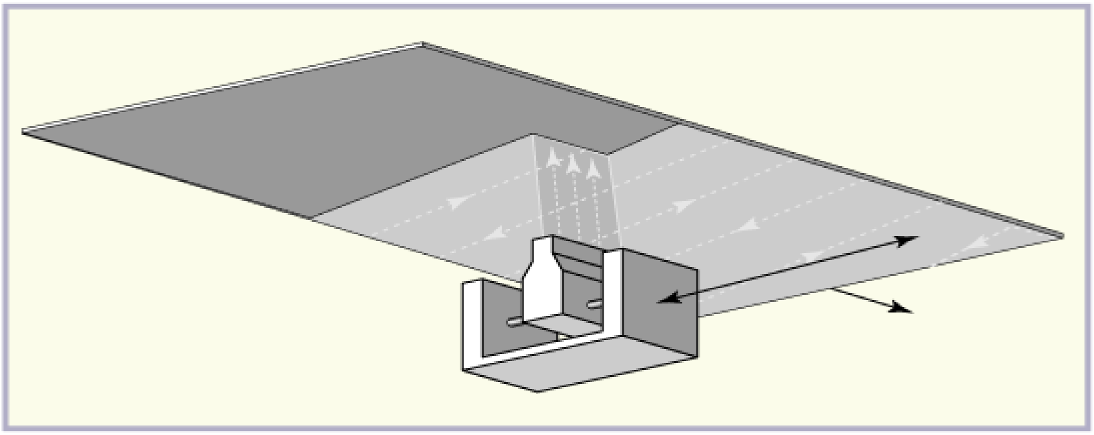


Figure 2.17: Reciprocating spray fluxer

Combined with a board sensor, the spray fluxer can be set to spray only the required area. Depending on whether the head movement is pneumatic or motorised, the limits of head travel may be set mechanically or electronically. The latter option makes it possible to control all fluxing functions by computer.

The main problems with reciprocating air-powered nozzles are that:

- ☐ the size of the flux droplets is large and the volume and spray velocity are difficult to control
- ☐ the fine-aperture nozzles tend to become clogged
- ☐ the head movement is unreliable and needs maintenance.

As a result, there are a number of competing spray systems that vary in the way that they address these problems and achieve wide, even coverage. Many of these have an ultrasonic spray mechanism, in which the energy in high frequency sound waves atomises the flux.

The amount of flux deposited varies directly with conveyor speed, but can also be controlled by adjusting the fluxer parameters. How this is done depends on the equipment being used. Generally, the more sophisticated the equipment, the more flexibility there is over the amount of flux deposited.

Common to all spray fluxers is the need for an efficient extraction system, which gathers any over-spray and the aerosol of small flux droplets that unavoidably forms wherever flux is atomised. This airborne flux must not be allowed to settle on the top surface of boards or on the soldering machine at large.

iii) Removing excess flux

Flux application is rarely totally even, and a fluxed board will usually drip surplus flux onto the preheater, reducing its efficiency and creating a fire hazard. There are two ways of removing excess flux, both of which are usually integrated into the fluxing unit:

- ☐ A fixed **brush** the width of the machine, similar to those used in foam fluxers for foam support
- ☐ An adjustable angled **air knife.**

On current machines, the air knife is the option normally fitted, as this avoids physical contact with the board. A brush head is only suitable for assemblies that are not sensitive to such contact. An additional benefit is that the air knife will drive flux up into plated holes to enhance top side wetting.

<u>Preheating</u>

Reasons for preheating

A freshly fluxed board cannot be wave soldered successfully unless its underside has been heated to a temperature of about 100°C, the exact temperature depending on the flux being used. The reasons for preheating a board are:

- ☐ to evaporate volatiles
- ☐ to start flux activation
- ☐ to reduce thermal shock on the assembly

- to meet the „thermal demand" of the assembly.

Removing the volatiles from the under surface of the board

Should excess flux solvent be left on a board through insufficient preheat application, a vapour blanket can form between the board and the solder wave. Needless to say this not only slows down the heat transfer between the molten solder and the board, but can also cause the solder to spit. This is a major cause of small globules adhering to the underside of a board. Where the flux thinners are solvents, they are easy to evaporate. However, water-based fluxes are more difficult to handle since they can retain enough moisture to spatter during the soldering process. Removing volatiles requires removing saturated air from below the board. With an inclined conveyor, there is usually sufficient movement caused by natural convection above the preheater. However, with horizontal or near horizontal conveyors, additional artificial air movement may need to be generated.

Even after preheating, a certain amount of „sizzling and spattering" can usually be anticipated when the board enters the wave. This is directly related to the amount of volatiles still left in the flux. However, over-drying is not recommended, as this makes the flux on the surface relatively immobile, interfering with solder wetting because it is not easily displaced by the wave.

Note that preheating alone is not enough to remove volatiles (such as moisture) that may have been absorbed into the PCB structure. These need to be removed by pre-baking.

On soldering, any volatiles in the printed wiring laminate will give off gaseous materials and cause blow-holes and entrapped gas pockets in the solder joint. This gas evolution may also create sufficient force to rupture the plated via barrel or cause delamination. These volatiles can be contaminants deposited during storage, handling, and assembly operations, trapped processing solutions, organic volatiles from the materials used in board fabrication, or natural moisture. However, pre-baking is a costly and time-consuming operation, and one which may impair solderability. Users should only need to bake a board before wave soldering either when packages have been left open for an extended period or when blow-holes are discovered.

Flux activation

Some fluxes like rosin, depend on heat (70−80°C) to become active at all. The level of activity of other types of flux also increases with increasing temperature.

Reduction of thermal shock

The thermal gradient between room ambient and soldering temperature is enough to cause serious damage to many materials, especially non-metals, and SM components should be specified to be compatible with wave soldering. This can be done simply by immersing the parts directly in a solder bath. Suitable tests are referenced in IPC standard 9501 *PCB* Assembly Process Simulation for Evaluation of Electronic Components.

For boards, the main concern is the distortion that occurs, often referred to as „warpage" or „warping". This is mainly caused by the difference in thermal expansion between the underside of the hot board, which is exposed to solder, and the cooler top. The result is that the centre depresses and pushes itself further into the wave, whilst the sides curl up and may not come into contact with the molten solder. The warpage is made worse by the random location of holes drilled in the board, internal copper layers, and by the uneven distribution of component weight.

Preheating the assembly reduces both the thermal gradient between the top and the bottom of the board, so reducing the potential for warping, and the thermal shock to which any SM components on the underside are subjected.

To meet the 'thermal demand' of the assembly

When making joints with liquid solder, you need to have sufficient thermal energy available to ensure that the interface remains liquid. If you dip a totally cold surface into solder, you will first freeze a film of solidified solder that masks the surface but is not in intimate contact with it. This has the result that heat transfer is impaired, so that the joint area takes longer to reach a temperature high enough for the solder to wet. In all soldering processes, the parts to be assembled must be hot enough *before* solder is applied to avoid this happening.

In wave soldering, the heat required to raise the surfaces to the wetting temperature comes from both preheating and contact with the solder wave. These work together to supply the heat necessary for the joining process. The higher the preheat temperature, the less heat is required from the wave. This can be translated into a shorter time in the solder wave, or higher production speeds.

Without an efficient preheating stage, high conveyor speeds would not be possible, nor (during the brief time available) could the molten solder be persuaded to rise through the plated holes in a multilayer board to form a meniscus on the top surface.

Preheater types

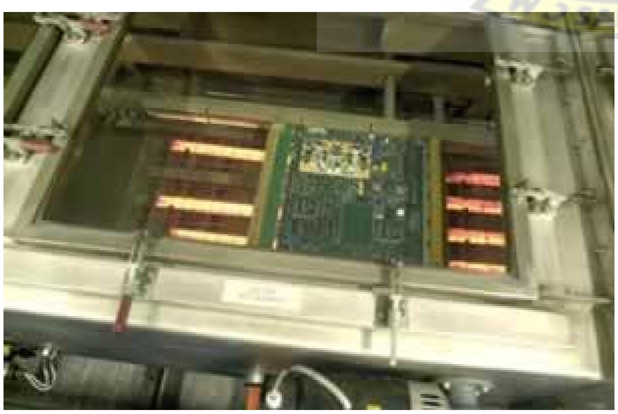


Figure 2.18: Infrared Preheater unit

Most systems provide the majority of their heat from underneath using infrared radiation. For the first drying stage of preheat, panels are common. These are hot plates or rods emitting long/medium wave infrared. For the more intense heating required later, quartz lamps emitting short wave infrared are frequently preferred for functional and maintenance reasons:

- They are easy to control and give high heat output
- They have an extremely fast response time, so can be switched on only when needed, reducing the running cost
- Fast response plus programmability makes them useful for systems that are frequently moved from one product to another. Some machines can be programmed to change parameters between individual boards
- It is possible to protect the heaters with a glass shield, simplifying cleaning
- Unprotected lamps run at high temperature, so are self-cleaning
- The reflectors behind quartz lamps are easily replaced when dirty.

Convection panels are becoming increasingly used, primarily to provide the air flow that is necessary to dry water-based fluxes.

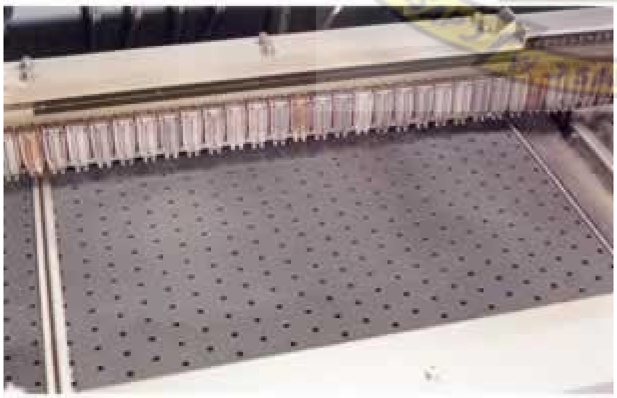


Figure 2.19: Convection panel in preheater

When preheating is applied only from below, the rate of temperature rise of the assembly can be insufficient for heavy or densely populated boards, because too much energy is conducted away from the underside. For that reason, many machines have additional pre-heaters mounted above the work, especially in the section immediately before the wave. The preheat requirements of products vary greatly, depending on the thermal demand of the assembly and the drying properties of the flux specified. For this reason, many wave soldering machines have modular preheat systems, which can be reconfigured on site for a specific application.

Whatever the set-up of preheaters in a machine it is most important that the whole board receives the same amount of thermal energy, because uneven preheating is a dangerous source of soldering faults. However most modern soldering lines give a warning if a heater in the preheating section should fail; some even prevent further boards from entering the machine in case of failure. Boards still in the machine must of course continue to travel forward, if they are not to be cooked or get stuck over the solder wave.

The solder wave

i) Construction

The solder wave provides direct contact between the solder and the component joints on the PCB. It can be divided into two distinct physical events:

ii) Final heat transfer – raising the surfaces of board and leads to wetting temperature. This is a function of:

- solder bath temperature
- wave contact length
- conveyor speed
- wave dynamics

iii) The supply of molten solder – providing solder for wetting and filling the gaps. This is a function of:

- ☐ the solderability of both surfaces
- ☐ design (pad to component ratio and fillet control)
- ☐ wave dynamic

As indicated, both parts of the process depend on wave dynamics or, more plainly, on the shape of the solder being pumped, its fluidity, flow rate and turbulence. There are a large number of wave designs but most are variations on the same technology (Figure 2.20).

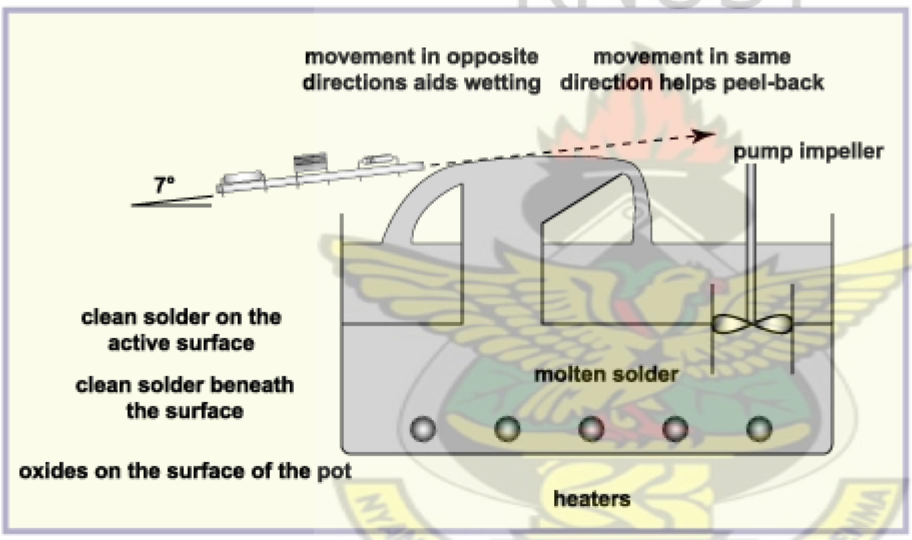


Figure 2.20: Working principle of wave-soldering machine

Defects of Wave soldering

Several soldering defects are associated with wave soldering, including:

- ☐ solder bridging
- ☐ non-wetted or insufficiently wetted solder joints

2.5.4.2 Reflow Soldering

It is a process in which a solder paste (a sticky mixture of powdered solder and flux) is used to temporarily attach one or several electrical components to their contact pads, after which the entire assembly is subjected to controlled heat, which melts the solder, permanently connecting the joint. The heating can be applied to the entire assembly from all directions or through the PCB, or locally to the solder paste or component leads and it can be accomplished by passing the assembly through a reflow oven or under a radiation of (1) an infrared lamp, laser, or by soldering individual joints with a hot air pencil; (2) conduction; (3) convection or; (4) condensation or vapour phase. The main characteristic of the reflow soldering is that the heat is applied separately after the application of the solder.

Reflow soldering is the most common method of attaching surface mount components to a circuit board. The goal of the reflow process is to melt the solder and heat the adjoining surfaces, without overheating and damaging the electrical components. In the conventional reflow soldering process, there are usually four stages, called "zones", each having a distinct thermal profile: *preheat*, *thermal soak* (often shortened to just *soak*), *reflow*, and *cooling* (Houston et al, 2008).

<u>Preheat Zone</u>

Maximum slope is a temperature/time relationship that measures how fast the temperature on the printed circuit board changes. The preheat zone is often the lengthiest of the zones and often establishes the ramp-rate. The ramp–up rate is usually somewhere between 1.0 °C and 3.0 °C per second. If the rate exceeds the maximum slope, potential damage to components from thermal shock or cracking can occur. Solder paste can also have a spattering effect. The preheat section is where the solvent in the paste begins to evaporate, and if the rise rate (or temperature level) is too low, evaporation of flux volatiles is incomplete (Houston et al, 2008).

Thermal Soak Zone

The second section, thermal soak, is typically a 60 to 120 second exposure for removal of solder paste volatiles and activation of the fluxes, where the flux components begin oxide reduction on component leads and pads. Too high or too low a temperature can lead to solder spattering or balling as well as oxidation of the paste, the attachment pads and the component terminations. Similarly, fluxes may not fully activate if the temperature is too low. At the end of the soak zone a thermal equilibrium of the entire assembly is desired just before the reflow zone. A soak profile is suggested to decrease any delta T between components of varying sizes or if the PCB assembly is very large. A soak profile is also recommended to diminish voiding in area array type packages (Briggs, 2010).

Reflow Zone

The third section, the reflow zone, is also referred to as the "time above reflow" or "time above liquidus" (TAL), and is the part of the process where the maximum temperature is reached. An important consideration is peak temperature, which is the maximum allowable temperature of the entire process. A common peak temperature is 20-40°C above liquidus (Briggs, 2010).

This limit is determined by the component on the assembly with the lowest tolerance for high temperatures (The component most susceptible to thermal damage). A standard guideline is to subtract 5 °C from the maximum temperature that the most vulnerable component can sustain to arrive at the maximum temperature for process. It is important to monitor the process temperature to keep it from exceeding this limit. Additionally, high temperatures (beyond 260 °C) may cause damage to the internal dies of SMT components as well as foster intermetallic growth. Conversely, a temperature that isn"t hot enough may prevent the paste from reflowing adequately.

Time above liquidus (TAL), or time above reflow, measures how long the solder is a liquid. The flux reduces surface tension at the juncture of the metals to accomplish metallurgical bonding, allowing the individual solder powder spheres to combine. If the profile time exceeds the manufacturer‟s specification, the result may be premature flux activation or consumption, effectively “drying” the paste before formation of the solder joint. An insufficient time/temperature relationship causes a decrease in the flux‟s cleaning action, resulting in poor wetting, inadequate removal of the solvent and flux, and possibly defective solder joints. Experts usually recommend the shortest TAL possible, however, most pastes specify a minimum TAL of 30 seconds, although there appears to be no clear reason for that specific time. One possibility is that there are places on the PCB that are not measured during profiling, and therefore, setting the minimum allowable time to 30 seconds reduces the chances of an unmeasured area not reflowing. A high minimum reflow time also provides a margin of safety against oven temperature changes. The wetting time ideally stays below 60 seconds above liquidus. Additional time above liquidus may cause excessive intermetallic growth, which can lead to joint brittleness. The board and components may also be damaged at extended times over liquidus, and most components have a well-defined time limit for how long they may be exposed to temperatures over a given maximum. Too little time above liquidus may trap solvents and flux and create the potential for cold or dull joints as well as solder voids.

Cooling zone

The last zone is a cooling zone to gradually cool the processed board and solidify the solder joints. Proper cooling inhibits excess intermetallic formation or thermal shock to the components. Typical temperatures in the cooling zone range from 30−100 °C (86−212 °F). A fast cooling rate is chosen to create a fine grain structure that is most mechanically sound. Unlike the maximum ramp-up rate, the ramp−down rate is often ignored. It may be that the ramp rate is less critical above certain temperatures, however, the maximum allowable slope for any component should apply whether the component is heating up or cooling down. A cooling rate of 4°C/s is commonly suggested. It is a parameter to consider when analyzing process results.

Etymolgy

The term "reflow" is used to refer to the temperature above which a solid mass of solder alloy is certain to melt (as opposed to merely soften). If cooled below this temperature, the solder will not flow. Warmed above it once more, the solder will flow again - hence "re-flow".

Modern circuit assembly techniques that use reflow soldering do not necessarily allow the solder to flow more than once. They guarantee that the granulated solder contained in the solder paste surpasses the reflow temperature of the solder involved.

Thermal Profiling

In the electronics manufacturing industry, a statistical measure, known as the Process Window Index (PWI) is used to quantify the robustness of a thermal process. PWI helps measure how well a process "fits" into a user-defined process limit known as the Specification Limit (Houston et al, 2008).

Each thermal profile is ranked on how it "fits" in a process window (the specification or tolerance limit). The center of the process window is defined as zero, and the extreme edge of the process window as 99 % (KIC Thermal, 2010).

A PWI greater than or equal to 100% indicates that the profile does not process the product within specification. A PWI of 99% indicates that the profile processes the product within specification, but runs at the edge of the process window (KIC Thermal, 2010).

A PWI of 60% indicates a profile uses 60% of the process specification. By using PWI values, manufacturers can determine how much of the process window a particular thermal profile uses. A lower PWI value indicates a more robust profile (Houston et al, 2008).

For maximum efficiency, separate PWI values are computed for peak, slope, reflow, and soak processes of a thermal profile. To avoid the possibility of thermal shock affecting the output, the steepest slope in the thermal profile must be determined and leveled. Manufacturers use custom-built software to accurately determine and decrease the steepness of the slope. In addition, the software also automatically recalibrates the PWI values for the peak, slope, reflow, and soak processes. By setting PWI values, engineers can ensure that the reflow soldering work does not overheat or cool too quickly (Houston et al, 2008).

Types of Reflow Soldering

Some specific methods are considered below:

(i) Infra-Red Reflow:

Infra-Red Reflow soldering is based on the energy of thermal radiation, which is transferred by electromagnetic waves originating from a substance at elevated temperatures.

If all the heat flux from an IR source is directed towards an object, then:

Heat Flux = Absorption + Transmission + Reflection;

and only the absorbed part of the radiation contributes to the heating.

If the IR source is at a temperature **T**, the heat flux density due to the thermal emission **q**, is a function of temperature and is given by the Stefan-Boltzmann law:

$$q = bT^4$$

where, b = Stefan-Boltzmann constant

T = the absolute temperature.

A typical IR soldering machine is shown in figure 2.21a. The IR source may be tungsten filament lamps, nichrome alloy quartz tubes or panels. Such equipment may have between 8 – 20 independently controlled panels with built-in thermocouples for temperature control. The IR panels heat the board travelling on the conveyor from the top and/ or bottom as necessary.

A gradual heating of the assembly is necessary to ensure that all volatile constituents of the solder paste are driven off. After an appropriate heating time, the assembly is then raised to the reflow temperature for soldering and then cooled. A typical IR reflow soldering profile is shown in figure 2.21b.

The IR reflow machines vary in size from small benchtop models to large floor standing version which incorporate computer control of the reflow profile and conveyor conveyer width setting. The reflow profile settings can be stored in memory, displayed on a VDU, and can be called up for future processing of a particular PCB assembly.

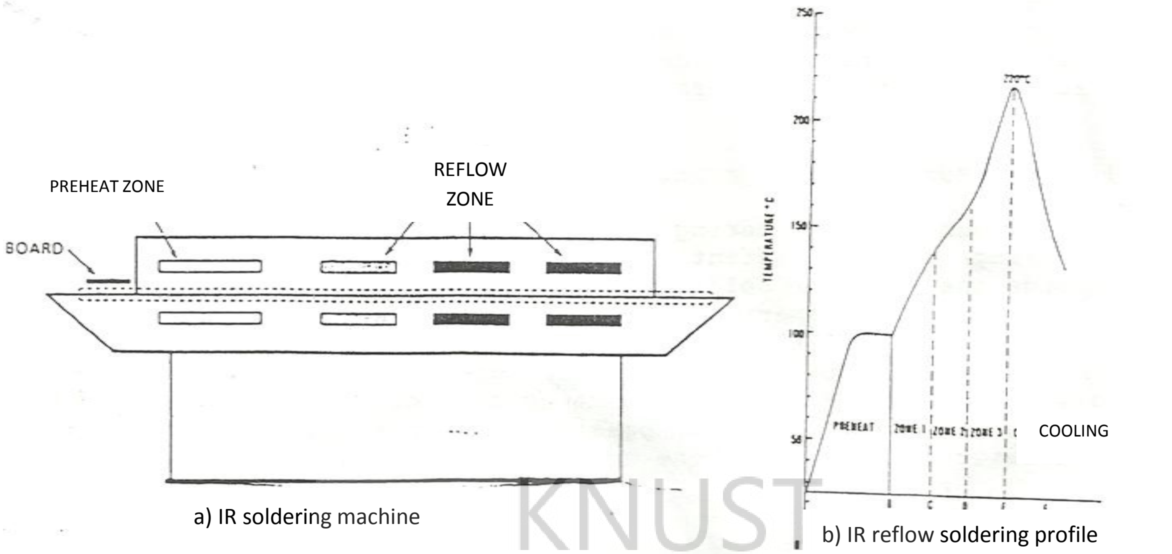


Figure 2.21: Infra-Red Reflow machine and Reflow profile.

(ii) Laser Reflow Soldering:

A LASER (Light Amplification by Stimulated Emission of Radiation) is a generator of an intense beam of monochromatic light, which can be used for reflow soldering. Laser heating may be considered as normal infra-red heating with two clear distinctions: the radiation is monochromatic and the energy can be applied locally.

Generally, there are two main types of lasers used for reflow soldering:

- Carbon dioxide gas lasers, and
- YAG-Nd (yttrium-aluminium-garnet/ neo-dymium) lasers.

Most laser soldering systems incorporate controls for providing different amounts of heat input to different joints on the same board.

The major advantage of laser reflow is that by heating only component leads/ pads, the components themselves are not subjected to very high temperatures. However, because they process under programmed control- only one joint at a time, they are considerably slower than other mass soldering systems. In addition, as a relatively new technique which is very expensive cost considerations has prevented its widespread use.

(iii) Vapour Phase Soldering:

Vapour phase soldering (VPS), also known as condensation soldering, uses the latent heat of vapourisation of a liquid to provide the heat for soldering. The latent heat is released as the vapour of the inert liquid condenses on the component leads and PCB lands. In VPS the liquid produces a dense saturated vapour, which displaces air and moisture. The temperature of the saturated vapour zone is the same as the boiling temperature of the inert liquid, making it possible to control the maximum temperature by selecting the appropriate liquid.

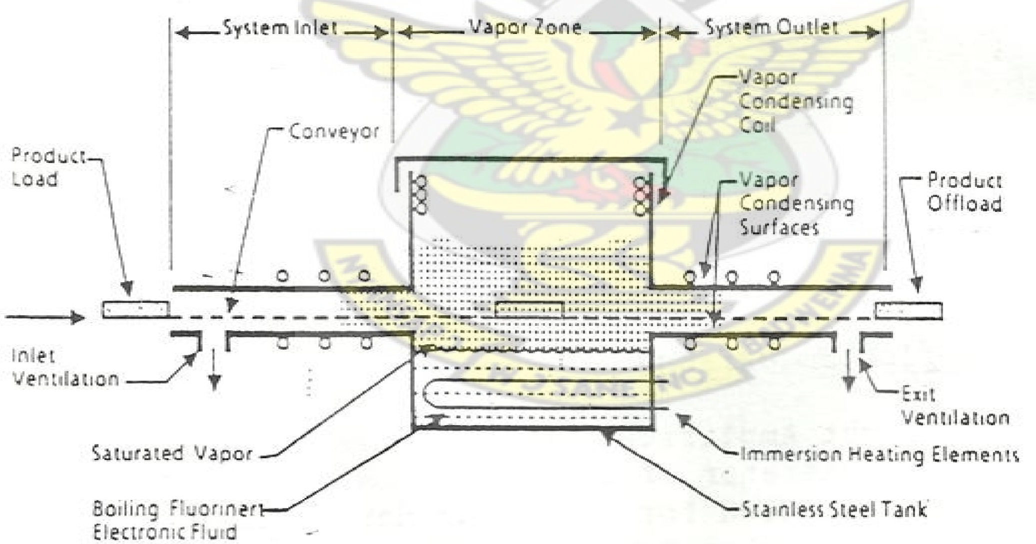


Figure 2.22: In-Line Vapour Phase Soldering System

Because heat transfer is produced by the hot vapour condensing on the cooler PCB assembly, heating is uniform and is not affected by the geometry of the assembly or thermal conductivity of the SMCs. There are two types of VPS machines:

- **the batch, and**
- **in-line VPS systems**

The In-line system is illustrated in figure 2.22.

2.6 Solder Joint Quality and Reliability

The reliability of a Surface Mount Assembly is a function of the intrinsic reliability of the SMCs used, PCB interconnecting conductor lines and the attachment processes. If the assembly does not function properly after soldering, remedial work is needed. This is generally termed repair or rework. Rework refers to the work which is carried out soon after the soldering operation to remove short circuits, to make joints which have failed to form during soldering and to improve those joints which do not have the desired shape. Repairs on the other hand, refer to the corrective work carried out after electrical testing, including those of replacing defective components, and correcting board defects.

The decisions on which solder joints are to be reworked or repaired is based on the assumption of knowing the ideal joint shape (the joint with the highest reliability under the conditions expected during its lifetime), and the soldering defects (both functional and cosmetic). The reliability of a solder joint is established through experimental testing, while solder defects are detected through inspection.

<u>Test for Reliability</u>

In surface mount assembly, the solder joint performs several functions and its integrity during service is an important performance measure. With the functions as electrical, thermal and mechanical linkage, solder joint integrity in a practical environment is very vital to the overall function of the assembly. The objective of the soldering process in Surface Mount Assembly is to achieve reliable joints, with negligible contact resistance and acceptable strength. For high reliability applications (such as military aerospace), solder joints which ensure failure-free working during the life of an equipment is required.

Most solder joint failures are known to be due to mechanical reasons (overstressing, vibrations, etc) rather than electrical reasons (such as overheating). There are, however many other possible causes of solder joint failure during service, these are summarized below:

- ☐ inferior or inadequate mechanical strength,
- ☐ creep (or time-dependent deformation under stress),
- ☐ mechanical fatigue,
- ☐ thermal fatigue,
- ☐ intrinsic thermal expansion anisotropy (2-phase alloy),
- ☐ corrosion-enhanced fatigue,
- ☐ intermetallic compound formation (binary alloy),
- ☐ voids (induces crack initiation),
- ☐ leaching (migration of silver and/ or gold).

In real life service, the failure mode is known to involve more than one of these phenomena and operates in combination. The complexities of these failure modes make the assessment of reliability very difficult. Some of the main experimental methods for assessing reliability are:

- ☐ powered functional cycling,
- ☐ temperature cycling,
- ☐ mechanical cycling and
- ☐ step stress testing.

Other tests such as humidity, powered life tests and micro sectional visual inspection of solder joints are also used. Experimental results have been reported in the literature and these show that the primary cause of solder joint failure in surface mounting is due to low cycle thermal fatigue. The cyclic strain arising from temperature cycling accounts for the observed failures.

Inspection of Soldered Joints

During the manufacture of the soldered Surface Mount Assembly, various types of inspection may be carried out either visually or using instrumentation. The typical inspection stages are:

- ☐ PCB inspection (Printed pattern),
- ☐ Paste deposit inspection (thickness, volume and registration),
- ☐ Pre-solder inspection (component placement),
- ☐ Solder joint inspection (joint shape and defects).

The purpose of using either visual or automated inspection is to ascertain the quality of the assembly in accordance with established requirements (or standards). When these requirements are not met, rework or repair is needed to ensure compliance. The automated method used for the above purposes include:

- ☐ 2-D vision,
- ☐ 3-D vision,
- ☐ Laser scanning,
- ☐ Real-time X-Ray methods.

The criteria for accepting or rejecting solder joint (or paste deposit, SMC misplacement with respect to PCB land) are usually set by individual manufacturers. This will depend upon the intended application, electrical requirements, the degree of control achieved over the manufacturing processes and the prevailing national and international standards.

2.7 SMT AND COMPONENT MINIATURIZATION

Due to the demand of high performance of electronic products with multi-functionality on the same space of the products, electronic manufacturers are consistently diminishing the net sizes of components. To meet the demands, many area-array packages are developed such as ball grid array (BGA), flip-chip and chip-scale packages (CSP).

2.7.1 Ball Grid Array (BGA)

A Ball Grid Array (BGA) is a type of surface-mount packaging used for integrated circuits.

Description

The BGA is descended from the pin grid array (PGA), which is a package with one face covered (or partly covered) with pins in a grid pattern. These pins conduct electrical signals from the integrated circuit to the printed circuit board (PCB) on which it is placed. In a BGA, the pins are replaced by balls of solder stuck to the bottom of the package. These solder spheres can be placed manually or with automated equipment. The solder spheres are held in place with a tacky flux until soldering occurs.(Soldering 101, 2011) The device is placed on a PCB with copper pads in a pattern that matches the solder balls. The assembly is then heated, in a reflow oven by an infrared heater, causing the solder balls to melt. Surface tension causes the molten solder to hold the package in alignment with the circuit board, at the correct separation distance, while the solder cools and solidifies. Figure 2.26a and 2.26b show a photograph of BGA.

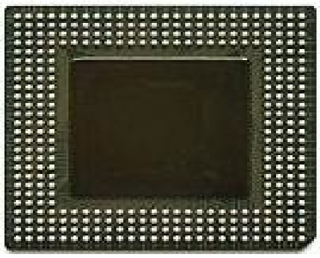


Figure 2.23a: Intel embedded Pentium MMX (Bottom view)

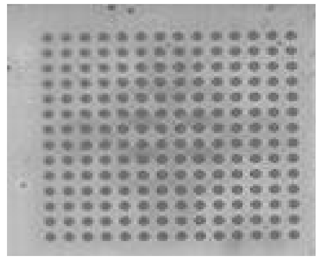


Figure 2.23b:X-Ray of BGA

2.7.1.1 Advantages of Ball Grid Array

<ins>**High density miniature package**</ins>

The BGA is a solution to the problem of producing a miniature package for an integrated circuit with many hundreds of pins. Pin grid arrays and dual-in-line surface mount (SOIC) packages were being produced with more and more pins, and with decreasing spacing between the pins, but this was causing difficulties for the soldering process. As package pins got closer together, the danger of accidentally bridging adjacent pins with solder grew. BGAs do not have this problem when the solder is factory-applied to the package.

<ins>**Better heat conduction**</ins>

A further advantage of BGA packages over packages with discrete leads (i.e. packages with legs) is the lower thermal resistance between the package and the PCB. This allows heat generated by the integrated circuit inside the package to flow more easily to the PCB, preventing the chip from overheating.

Low-inductance leads

The shorter an electrical conductor, the lower its inductance, a property which causes unwanted distortion of signals in high-speed electronic circuits. BGAs, with their very short distance between the package and the PCB, have low inductances and therefore have far superior electrical performance to leaded devices.

2.7.1.2 Disadvantages of Ball Grid Array

Noncompliant leads

A disadvantage of BGAs, however, is that the solder balls cannot flex in the way that longer leads can, they are not compliant. As with all surface mount devices, bending, due to a difference in coefficient of thermal expansion between PCB substrate and BGA (thermal stress), or flexing and vibration (mechanical stress) can cause the solder joints to fracture.

Thermal expansion issues can be overcome by matching the mechanical and thermal characteristics of the PCB to those of the package. Typically, plastic BGA devices more closely match the PCB thermal characteristics than ceramic devices. Mechanical stress issues can be overcome by bonding the devices to the board through a process called "under filling", which injects an epoxy mixture under the device after it is soldered to the PCB, effectively gluing the BGA device to the PCB. There are several types of under fill materials in use with differing properties relative to workability and thermal transfer. An additional advantage of under fill is that it limits tin whisker growth.

Another solution to non-compliant leads is to put a "compliant layer" in the package that allows the balls to physically move in relation to the package. This technique has become standard for packaging DRAMs in BGA packages.

Difficulty of inspection

Once the package is soldered down, it may be difficult to look for soldering faults. X-ray machines, Industrial CT Scanning machines (Jesse Garant & Associates, 2010), and special microscopes have been developed to overcome this problem. If a BGA is found to be badly soldered, it can be removed in a *rework station,* which is a jig fitted with infrared lamp (or hot air), a thermocouple and a vacuum device for lifting the package. The BGA can be replaced with a new one, or the BGA can be refurbished (or *reballed*) and re-installed on the circuit board. Packets of tiny ready-made solder balls are sold for reballing BGA's.

Due to cost of X-ray BGA inspection, electrical testing is very often used. Very common is boundary scan testing using IEEE 1149.1 JTAG port.

Difficulties with BGAs during circuit development

During development it is not practical to solder BGAs into place, and sockets are used instead, but tend to be unreliable. There are two common types of socket: the more reliable type has spring pins that push up under the balls, although it does not allow using BGAs with the balls removed as the spring pins may be too short.

The less reliable type is a ZIF socket, with spring pinchers that grab the balls. This does not work well, especially if the balls are a bit small.

Cost of equipment

Expensive equipment is required to reliably solder BGA packages; hand-soldering BGA packages are very difficult and unreliable, usable only for the smallest packages in the smallest quantities.

2.8 Flip Chip Technology

Flip chip, also known as Controlled Collapse Chip Connection or its acronym, C4, is a method for interconnecting semiconductor devices, such as IC chips and Microelectro-mechanical systems (MEMS), to external circuitry with solder bumps that have been deposited onto the chip pads. The solder bumps are deposited on the chip pads on the top side of the wafer during the final wafer processing step. In order to mount the chip to external circuitry (e.g., a circuit board or another chip or wafer), it is flipped over so that its top side faces down, and aligned so that its pads align with matching pads on the external circuit, and then the solder is flowed to complete the interconnect and this is shown in figure 2.27. This is in contrast to wire bonding, in which the chip is mounted upright and wires are used to interconnect the chip pads to external circuitry.

2.8.1 Process steps of Flip Chip Technology

1. Integrated circuits are created on the wafer
2. Pads are metalized on the surface of the chips
3. Solder dots are deposited on each of the pads
4. Chips are cut
5. Chips are flipped and positioned so that the solder balls are facing the connectors on the external circuitry
6. Solder balls are then remelted (typically using hot air reflow)
7. Mounted chip is "underfilled" using an electrically-insulating adhesive

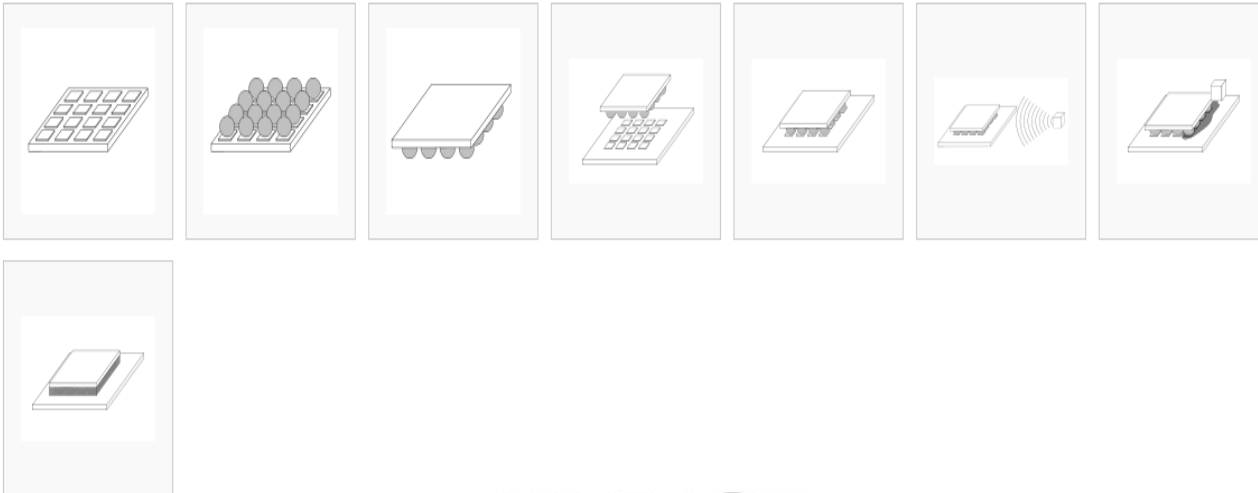


Figure 2.24: Schematic of flip chip Mounting Technologies

Wire bonding/Thermosonic bonding

The interconnections in a power package are made using thick aluminium wires (250 to 400 µm) wedge-bonded.

In typical semiconductor fabrication systems chips are built up in large numbers on a single large wafer of semiconductor material, typically silicon. The individual chips are patterned with small pads of metal near their edges that serve as the connections to an eventual mechanical carrier. The chips are then cut out of the wafer and attached to their carriers, typically via wire bonding such as Thermosonic Bonding. These wires eventually lead to pins on the outside of the carriers, which are attached to the rest of the circuitry making up the electronic system.

Flip chip

Processing a flip chip is similar to conventional IC fabrication, with a few additional steps (Solder Bump Flip Chip, 2007). Near the end of the manufacturing process, the attachment pads are metalized to make them more receptive to solder. This typically consists of several treatments. A small dot of solder is then deposited on each metalized pad. The chips are then cut out of the wafer as normal.

Recently, high-speed mounting methods evolved through cooperation between Reel Service Ltd. and Siemens AG in the development of a high speed mounting tape known as 'MicroTape‟ (Solder Bump Flip Chip, 2007). By adding a tape-and-reel process into the assembly methodology, placement at high speed, typically 20,000 placements per hour are achievable using standard PCB assembly equipment.

To attach the flip chip into a circuit, the chip is inverted to bring the solder dots down onto connectors on the underlying electronics or circuit board. The solder is then re-melted to produce an electrical connection, typically using an ultrasonic or alternatively reflow solder process. This also leaves a small space between the chip's circuitry and the underlying mounting. In most cases an electrically-insulating adhesive is then "underfilled" to provide a stronger mechanical connection, provide a heat bridge, and to ensure the solder joints are not stressed due to differential heating of the chip and the rest of the system.

2.8.2 Advantages of Flip Chip Technology

The resulting completed flip chip assembly is much smaller than a traditional carrier-based system; the chip sits directly on the circuit board, and is much smaller than the carrier both in area and height. The short wires greatly reduce inductance, allowing higher-speed signals, and also carry heat better.

2.8.3 Disadvantages of Flip Chip Technology

Flip chips have several disadvantages. The lack of a carrier means they are not suitable for easy replacement, or manual installation. They also require very flat surfaces to mount to, which is not always easy to arrange, or sometimes difficult to maintain as the boards heat and cool. Also, the short connections are very stiff, so the thermal expansion of the chip must be matched to the supporting board or the connections can crack (Demerjian et al, 2008). The underfill material acts as an intermediate between the difference in CTE of the chip and board.

History

1. The process was originally introduced commercially by IBM in the 1960s for individual transistors and diodes packaged for use in their mainframe systems.(Introduction to Flip Chip, 2011)

DEC followed IBM's lead, but was unable to achieve the quality they demanded, and eventually gave up on the concept. It was pursued once again in the mid-90s for the Alpha product line, but then abandoned due to the fragmentation of the company and subsequent sale to Compaq. In the 1970s it was taken up by Delco Electronics, and has since become very common in automotive applications.

Alternatives

Since the flip chip's introduction a number of alternatives to the solder bumps have been introduced, including gold balls or molded studs, electrically conductive polymer and the "plated bump" process that removes insulating plating by chemical means. Flip chips have recently gained popularity among manufacturers of cell phones, pagers and other small electronics where the size savings are valuable.

2.9 Chip Scale Package (CSP)

A chip scale package (CSP) (sometimes, chip-scale package with a hyphen) is a type of circuit chip. Originally, CSP was the acronym for chip-size packaging. Since only a few packages are chip size, the meaning of the acronym was adapted to chip-scale packaging. According to IPC"s standard J-STD-012, "Implementation of Flip Chip and Chip Scale Technology", in order to qualify as chip scale, the package must have an area no greater than 1.2 times that of the die and it must be a single-die, direct surface mountable package. Another criterion that is often applied to qualify these packages as CSPs is that their ball pitch should be no more than 1 mm.

The concept was first proposed by Junichi Kasai of Fujitsu and Gen Mukarami of Hitachi Cable. The first concept demonstration however came from Mitsubishi Electric. The die may be mounted on an interposer upon which pads or balls are formed, like with chip ball (BGA) packaging, or the pads may be etched or printed directly onto the silicon wafer, resulting in a package very close to the size of the silicon die: such a package is called a wafer-level chip-scale package (WL-CSP) or a wafer-level package (WLP).

Chip Scale Package, or **CSP,** based on IPC/JEDEC J-STD-012 definition, is a single-die, direct surface mountable package with an area of no more than 1.2 X the original die area. The acronym 'CSP' used to stand for 'Chip Size Package,' but very few packages are in fact the size of the chip, hence the wider definition released by IPC/JEDEC.

The IPC/JEDEC definition likewise does not define how a chip scale package is to be constructed, so any package that meets the surface mountability and dimensional requirements of the definition is a

CSP, regardless of structure. For this reason, CSP's come in many forms - flip-chip, non-flip-chip, wire-bonded, ball grid array, leaded, etc.

Because of this variety of chip scale packages developed in the industry, one cannot make any generalized assumptions on the manufacturability or reliability of the CSP as a homogeneous package group. It is often necessary to determine what the structure of the CSP is before any conclusion on its robustness or manufacturability can be made.

In an effort to systematically characterize the CSP as a package group, some quarters have come up with four (4) classifications or types for the CSP. These are: 1) the flex circuit interposer type; 2) the rigid substrate interposer type; 3) the custom lead frame type; and 4) the wafer-level assembly type.

The advantages offered by chip scale packages include smaller size (reduced footprint and thickness), lesser weight, relatively easier assembly process, lower over-all production costs, and improvement in electrical performance. CSP's are also tolerant of die size changes, since a reduced die size can still be accommodated by the interposer design without changing the CSP's footprint.

Chip scale packaging can combine the strengths of various packaging technologies, such as the size and performance advantage of bare die assembly and the reliability of encapsulated devices. The significant size and weight reduction offered by the CSP makes it ideal for use in mobile devices like cell phones, laptops, palmtops, and digital cameras (Chip Scale Package, 2010).

Types of Chip Scale Packaging

Chip scale packages can be classified into the following groups:

1. Customized lead frame-based CSP
2. Flexible substrate-based CSP
3. Flip-chip CSP (FCCSP)

4. Rigid substrate-based CSP
5. Wafer-Level redistribution CSP (WL-CSP)

2.9.1 Technology of Micro Chip scale Package

A typical chip scale packaging process starts with the mounting of the die on the interposer using epoxy, usually of non-conductive type (although conductive epoxy is also used when the die backside needs to be connected to the circuit). The die is then wire bonded to the interposer using gold or aluminum wires. Wire bond profiles must be as low and as close to the die as possible in order to minimize package size. Plastic encapsulation to protect the die and wires then follows, usually by transfer molding. After encapsulation, solder balls are attached to the bottom side of the interposer, after which the package is marked. Finally, the parts are singulated from the lead frame.

The chip scale package is relatively new, so industry standards for producing CSP's have not been completely developed. Nonetheless, the Institute for Interconnecting and Packaging Electronic Circuits (IPC) has already released J-STD-012, "Implementation of Flip Chip and Chip Scale Technology." This document discusses technology overview and design considerations, as well as material, processing, mounting, interconnection, reliability, and standardization aspects of CSP manufacturing. The industry is moving towards the development of more chip scale packaging standards. Some of the new standards being developed are, in fact, defined by J-STD-012. These standards are shown in Table 2.3

Table 2.3: Flip Chip and CSP Standards Currently Undergoing Development

Std No. 102	Mechanical outline Standard for Flip Chip or Chip Scale Configurations
Std No. 103	Performance Standard for Flip Chip/Chip Scale Bumps
Std No. 104	Test Methods for Flip Chip or Chip Scale Performance
Std No. 105	Flip Chip/Chip Scale Carrier Tray Standard
Std No. 106	Bare Dice as Flip Chip or Chip Scale Configuration Management Standard
Std No. 107	Design Standard for Flip Chip and Chip Scale Mounting Structures
Std No. 111	Design Standard for Flip Chip/Chip Scale Assembly Configuration
Std No. 112	Standard for Flip Chip/Chip Scale Assembly Performance Requirements
Std No. 113	Test Methods for Qualification and Evaluation of Flip Chip/Chip Scale Assemblies
Std No. 114	Standard for Flip Chip/Chip Scale Assembly Rework and Repair Techniques
Std No. 115	Flip Chip/Chip Scale Assembly Reliability Standard
Std No. 120	Qualification and Performance Standard for Flux used in Flip Chip Assembly

The primary technology of the company is a WLCSP process called Metallized Conductor Chip Scale Package (MCSP), which performs all IC packaging steps at the wafer level. The MCSP technology employs a glass sheet as substrate that is attached to a semiconductor wafer to form a redistribution layer directly on the wafer surface. The redistribution layer connects the fine-pitch bond pads on the semiconductor wafer to large-pitch interconnect pads on the glass sheet. The reduction of IC packaging steps from the traditional front and back-end processes to the wafer level significantly reduces production costs and improves yield.

Vias, drilled through the glass sheet to corresponding locations on the IC bond pads, create this second level redistribution layer. Thin film patterning on the glass prior to wafer attachment creates an array of traces, passive component level incorporation and 3D stacking capabilities. Independent of the semiconductor wafer this glass layer can be tested and component values trimmed according to specific requirements prior to attachment directly to the semiconductor wafer surface.

The patterned glass sheet is attached to a wafer with an optical adhesive, which can be selectively applied. These void areas can be used as optical windows or protective coverings in CMOS, Micro-electromechanical Systems (MEMS) and VCSEL device applications. Also the voids can be back filled with inert gases for specific applications. Once the glass and wafer are attached using very low temperature curing optical adhesives metal is deposited, which interconnects the IC bond pads and the metalized traces on the pre-tested glass sheet. The next level interconnect can be applied; either solder balls are attached or pads are created for further interconnect technologies. The completed wafer-glass structure is sawn and diced into individual packages. The resulting IC package using the MCSP process is equivalent to the original die size and is smaller and thinner than most conventional packages. The MCSP process is superior to other competing WLCSP processes because it uses industry-standard fabrication techniques, has lower manufacturing costs, an efficient development flow and short assembly cycle time. The company is in the process of expanding filings on several current MCSP patents.

Several troublesome industry applications are ideal for the MCSP technology. They are hermetically sealed chip-scale packages, filter networks in close proximity to IC processors, 3D stacking, Silicon-On-Insulator (SOI), and Optoelectronic IC (OEIC) data transmission. Along with standard integrated circuit packaging using WLCSP, the company has focused development activities on hermetic sealing at the wafer level, thin-film and thick-film passive component deposition, 3D stacking, SOI, and Optoelectronic WLCSP technologies.

2.9.2 Passive & Active Devices

Many electronics applications have serious space considerations that are pressuring manufacturers to reduce component size. Much of the motivation for this has come from military and aerospace needs, but today's miniaturization demands are more likely to come from other market segments including telecommunications (cellular phones), computers (laptops), instrumentation (handheld devices), and medical electronics (pacemakers). Such applications continue to drive size reduction in components for commercial uses as well as for applications with very high reliability requirements.

Miniaturization has been a key contributor to advances in electronic technology. Certainly, miniaturization has been made possible mostly through remarkable breakthroughs in reducing the size of active components. But as integrated circuits (ICs) get smaller and more complex, there is an increasing need to also reduce the space required for the supporting passive components.

Simply reducing the case size of a part is not always the most effective way to miniaturize or increase performance. Ever increasing processing speeds, lower operating voltages, more stringent compliance criteria and the continual drive to reduce the overall cost of ownership have been significant drivers in the adoption of integrated passive components by design engineers. Chip-scale packaging alone cannot completely satisfy these requirements. MCSP technologies passive component designs combine discrete components into volumetric-efficient multi-element packages. The MCSP integrated passive component designs combine multiple resistive and capacitive elements on a single chip, and these may be interconnected in a variety of network and array configurations. They can take the form of common circuit devices or application specific custom devices. These designs are the solution in combining both passive and active component networks directly on the IC surface, in a wafer level chip-scale package format, to meet the growing industry requirements.

The benefits of passive component integration are both technical and financial. Technically, they simplify the design process and enable much greater circuit densities. This allows equipment to be more compact, and with shorter in-circuit chip distances that reduce interconnection inductance, the circuit performance is improved. Component count is also reduced, leading to higher overall reliability.

Financial benefits include the significant reductions in cost that can be made by eliminating pick and place machine use. Tape and reel positions historically used for low value components are freed up for higher value parts, with faster assembly using fewer parts increasing manufacturing efficiency. Overhead costs associated with logistics and component inventories are also reduced. Processing and assembly cycle times are decreased. Combined with pre-testing and yield screening of the independently processed glass / component redistribution layer, final packaged financial benefits can be significantly increased (Micro Chip Scale Package, 2011).

2.10 Electronics Manufacturing and Assembly in Ghana

Through-hole and SMT technologies since their introduction in the mid 1990s have taken some time to reach African countries such as Ghana and Nigeria. At the moment, there are two known electronic manufacturing and assembly companies in Ghana namely; RLG and ZEPTO. Some of the works of rlg have been discussed in section 2.11:

2.10.1 RLG in Ghana

A subsidiary of the AGAMS Group of Companies, *rlg* Communications is a Ghanaian-owned limited liability company engaged in the production of communications equipment such as mobile handsets, electronic notebooks, tablets, laptops, LCD TV monitors and more. The *rlg* stands for Rogam Link-Communication Group. Besides the product range that it offers, *rlg* is also engaged in capacity building and training programmes in collaboration with Ghana"s Ministry of Youth and Sports as part of the

National Youth Employment Programmes (NYEP). Under these programmes *rlg* has established training schools to train tens of thousands of youth in ICT-related disciplines such as mobile phone repairs and assemblage, sales and service delivery skills, computer programming, hardware and software engineering among others (rlgghana.com, 2011).

The company has offices in China, Nigeria and Gambia with far advanced plans to expand into the West African sub-region, and subsequently into the rest of the African market.

rlg seeks to develop best quality technology in the electronic products assembled in Ghana and elsewhere, and to deliver quality and value to their customers, clients and other stakeholders. Over the years the company has evolved to become a key entity in the ICT industry and is on its way to becoming a global ICT player.

Mission of *rlg*

"To collaborate with stakeholders to empower the youth for the future"

Vision of *rlg*

"To become a global leader in the provision of quality Applied ICT education and skill development, and transfer this expertise to the production of innovative ICT products and services"

2.10.2 Rlg Products with SMT Technology

rlg produces mobile phones, laptops and tablets. Other products in the pipeline to be introduced soon onto the market include LCD TV screens etc.

1) Mobile Handsets

Mobile phone products of *rlg* come in a range of categories as presented below.

- **r-series**: mobile phones in this category are basic, less sophisticated, very moderately priced handsets produced and made affordable for all customers including low-income earners. They are on the market under brand types as r5, r6, r7, r30, r31, r40, r41, r45, r50, r62, r72, r101, r221 and r222.

g-series: This category covers types like the g49, g51 and g52 and they are a little more expensive than the r-series and yet are competitive in price and very affordable to the ordinary consumer. The g-series are relatively more sleek and sophisticated than the r-series.

- **I-series**: Like in many other ICT equipment manufacturing business rlg has developed products that are positioned as classy, touch-sensitive, android powered, more expensive, high-end, luxurious arm of its product line. There are two types, l8 and l9

2) Laptops

- **mgsOne**: *rlg's* current note-book named mgsOne is slim, light-weighted and performs best due to its relatively fast processor. With an exclusive aluminium coating, 4-hour long playing time, built-in wireless, webcam and Bluetooth features the 2GB, 12.1 inch LCD laptops produced by *rlg* are best suited for business, academic, home and everyday use.

- **mgsTwo**: This is upgraded version of the mgsOne with a CD Rom feature. It is light, easy to carry and quite stylish.

Figure 2.28 shows one of the laptops assembly halls of rlg.

Figure 2.25: Photograph of the Assembly Hall of rlg

3) Tablets

RLG FUSION tablet is a revolutionary dual SIM device operating on android, with a sensitive capacitive touch screen. This flagship product from *rlg* Communications is EVDO compatible and 3.5G compliant with cameras both in front and at the back, equipped with high speed wifi and in-built GPS and Bluetooth components. What is more, the fusion tablet offers the flexibility for adding up to 32GB of external memory. There is so much pride to derive from being associated with the FUSION.

2.10.3 Services and Support

1) Assembly of Devices

Rlg ultra-modern assembly plant has the capacity to assemble mobile phones, LCDs, laptops, internet routers and many other electronic devices.

2) Device Upgrade Service

First to be introduced in Ghana, this unique service offers our cherished customers the opportunity to trade-in their old devices at depreciated rate and top-up for any new range of devices on display.

3) Effective and Efficient After-Sales Service

rlg offers the best after-sales service in the country with the offer of twelve months warranty on all devices sold. Cherished customers enjoy the following facilities during the warranty period:

4) Outright Replacement

rlg offers full replacement of any device sold in case of genuine factory defects. Customers must come along with their warranty cards and submit it together with the handset to any rlg retail outlet. The certified engineers would assess the handset and authorise outright replacement in case of genuine factory defect.

5) Free Repair

Customers receive free servicing and repairs of all devices in case of any minor defects.

In case of accidental damage, customers only buy subsidised cost of the genuine part and then certified engineers of *rlg* fix the device at no additional cost to the customer.

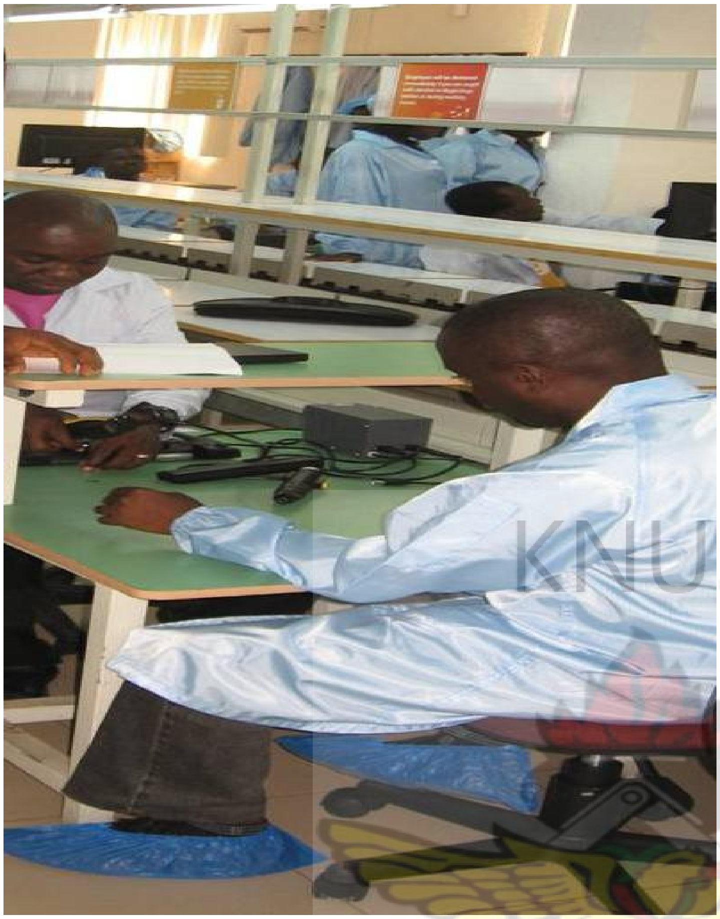


Figure 2.26: Photograph showing repairs of SMT component failure of rlg"s laptop

6) Flexible Corporate Package

rlg offers consignment sales to all telecom operators in the country. Offertory of flexible payment arrangement three months for staff of any corporate institution to lessen the burden of outright purchase is made.

2.10.4 RLG building Ghana's ICT; presents 60,000 laptops to Basic Schools

RLG communications which has kick-started Ghana"s ICT revolution by placing much attention to teaching and learning of ICT in basic schools. The company has presented 60,000 computers to hundred basic schools across the country. The move was in line with the basic Schools Computerization Project the company had established with the Ministry of Education.

The computers which are assembled in Ghana by RLG Communications will serve as tools for their development at the basic level of education.

RLG is the first indigenous firm to inaugurate an ultramodern mobile phone assembly plant in Ghana. The company amongst others aims at assembling, producing and distributing state of the art mobile phones and laptops. About 3,000 thousand laptops have already been distributed to various schools.

RLG SMT Assembly Line

RLG uses in-line SMT assembly configuration for the assembly of their products incorporating the following elements:

i. Solder paste deposition
ii. Component placement
iii. infra red reflow soldering machine
iv. Post soldering cleaning
v. Inspection
vi. Rework/repair

CHAPTER THREE

3.0 SURVEY METHODOLOGY, DATA PRESENTATION AND ANALYSIS

3.1 Design of the Case Study

First of all, a set of paper self-administered questionnaire was designed to capture very vital information about the awareness of SMT and through-hole technologies and the use of these technologies in electronic products by electronic manufacturing and assembly companies in the country and other institutions (university and policy makers).

3.2 Design of Questionnaires:

In designing the questionnaire certain factors were considered to check the design of electronic components mounting in the country:

1) *Technical feasibility*: that is, the existence of electronic manufacturing and assembly companies in Ghana that use the surface mount technology.

2) *Benefit to customer and producer*: here, attention was paid to how much the assembly companies in Ghana will spend on buying surface mount devices made in the country instead of importing them from other countries which also takes lengthy periods of time to reach them. Attention is paid to the fact that customers will also buy electronic products made in the country at less price compared to products imported from other countries and highly taxed.

3.3 Production Questions:

1) Availability of materials: This refers to the continuous existence of raw materials in the country to be used for the manufacture and assembly of the electronic products.

2) Availability of human resources: This is about the availability of skilled labour.

3) Logistics: That is the capital to be expended on workers and materials.

3.4 Marketing Questions:

1) Cost / Price: This answers the question, „Can customers afford the cost of electronic products assembled in Ghana?"

2) Profitability: This is to check whether or not producers of the products will make gains from the products they sell to customers.

3) Competitive pressure: This is where the electronic company struggles to get customers to purchase their products as similar companies spring up wanting to get the attention of the same customers within the country.

4) Size and growth of targeted market: That is how far the electronic manufacturing company wants to grow. What percentage of the country"s population the company wants to target. .

3.5 Case Study and Collection of Data

1) *Preparation of survey (questionnaire).* The Questionnaire was designed for different groups of people and this included one electronic assembly company, electrical Engineering Students-KNUST and Policy makers:

Documentation / archival of records: Answers to the questionnaire have been kept for future analysis.

3.6 Data Presentation and Analysis

This section focuses on the data collected from the research and the analyses of the data. The data gathered in this study were analyzed using Microsoft Office Excel 2007 tool. The results have been presented in sections according to data sources. The instrument of data collection was divided into sections and subsections containing related research items. Data was collected from three different areas (*rlg* communications, KNUST students from Colleges of Science and Engineering and Government Policy Makers).

Section 3.6.1 shows the data collected from rlg and its analysis, 3.6.2 shows that of KNUST students and 3.6.3 the information from Government Policy Makers.

3.6.1 Data from RLG Communications and Analysis

3.6.1.1 Phase 1 of *RLG* Communications

Phase 1 of the questionnaire deals with the patronization of Ghanaians with regards to goods manufactured and assembled in Ghana using Surface Mount Technology. It also shows SMT components failure of the products and how they are solved.

Table 3.1: Number of People Using RLG Products Assembled in Ghana within Their First Three Months of Operation, 2011

Region	Number of People Using Rlg Products With Smt Technology Within First Month of Operation	Number of People Using Rlg Products With Smt Technology Within Second Month of Operation	Number of People Using Rlg Products With Smt Technology Within Third Month of Operation	Sub-Total of People Using Rlg Products With Smt Technology Within Three Months of Operation
Greater Accra	1521	4573	8128	**14222**
Eastern	989	2973	4981	**8493**
Western	597	689	1048	**2334**
Volta	396	861	1174	**2431**
Ashanti	906	3594	6648	**11148**
BrongAhafo	793	1902	4914	**7609**
Northern	557	1087	2210	**3854**
Upper East	207	663	963	**1833**
Upper West	174	342	809	**1325**
Total Number of People Using RLG Products with SMT Technology Within Three Months				**53699**

Table 3.2: Number of Customers Complaining about SMT Component Failure of Products Bought within RLG First Three Months of Operation, 2011

Region	**Number of Smt Component Failure Within First Month of Operation Complained By Customers**	**Number of Smt Component Failure Within Second Month of Operation Complained By Customers**	**Number of Smt Component Failure Within Third Month of Operation Complained By Customers**
Greater Accra	59	21	9
Eastern	33	18	6
Western	41	13	8
Volta	29	16	3
Ashanti	25	9	5
BrongAhafo	19	10	0
Northern	13	4	3
Upper East	14	2	1
Upper West	6	3	0
Total Smt Component Failure in Nine Regions	**239**	**96**	**35**

Table 3.3: Number of SMT Component Failure In Products Solved Within The First Three Months of Operation, 2011

Region	**Number of Smt Component Failure In Products Solved Within First Month of Operation**	**Number of Smt Component Failure In Products Solved Within Second Month of Operation**	**Number of Smt Component Failure In Products Solved Within Third Month of Operation**
Greater Accra	55	19	9
Eastern	33	18	6
Western	39	13	8
Volta	27	13	3
Ashanti	25	9	5
Brong Ahafo	19	9	0
Northern	13	4	3
Upper East	14	2	1
Upper West	6	3	0
Total Number Of Smt Component Failure in Nine Regions Products Solved	**231**	**90**	**35**

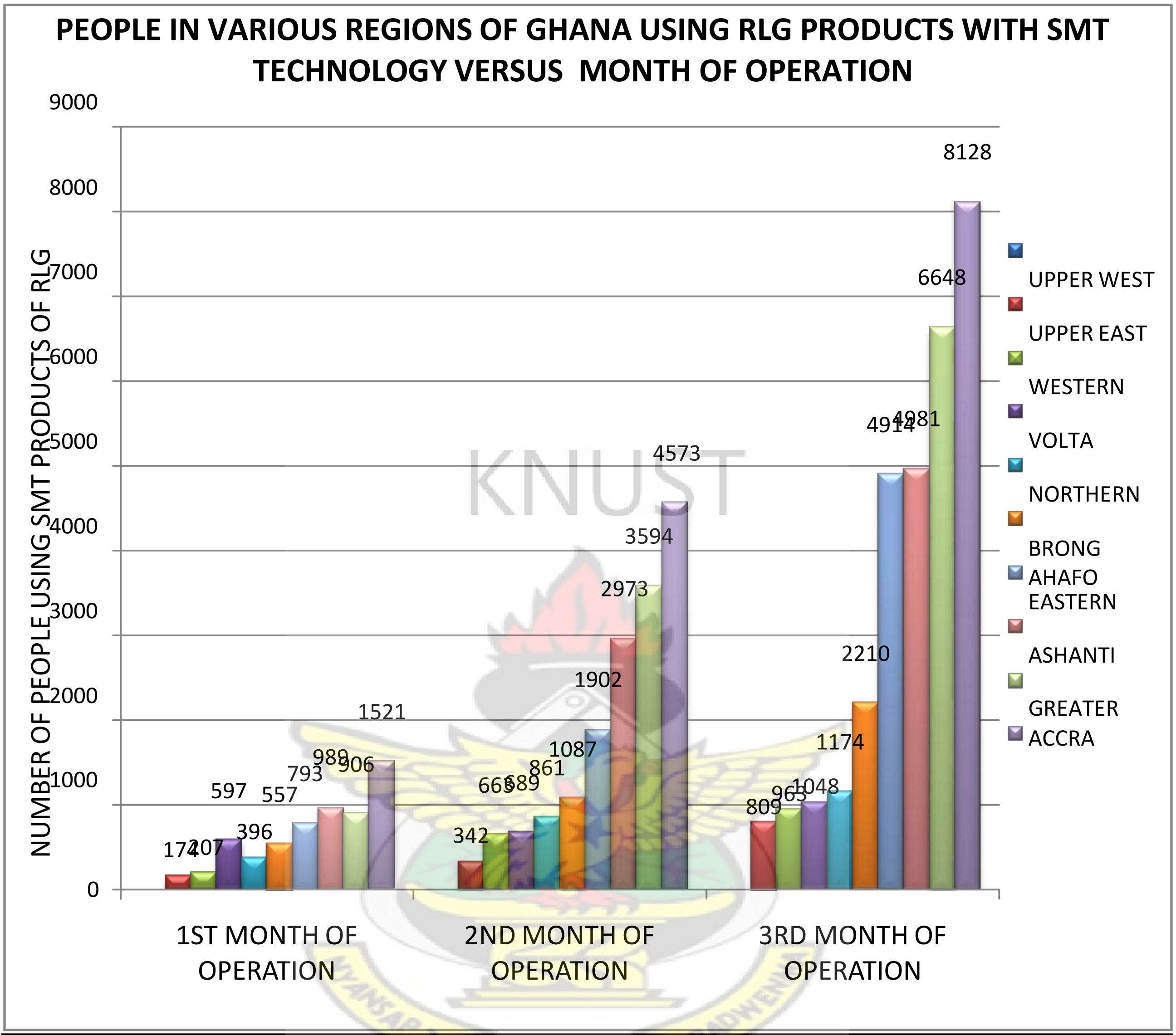


Figure 3.1: Number of people using rlg products with SMT Technology

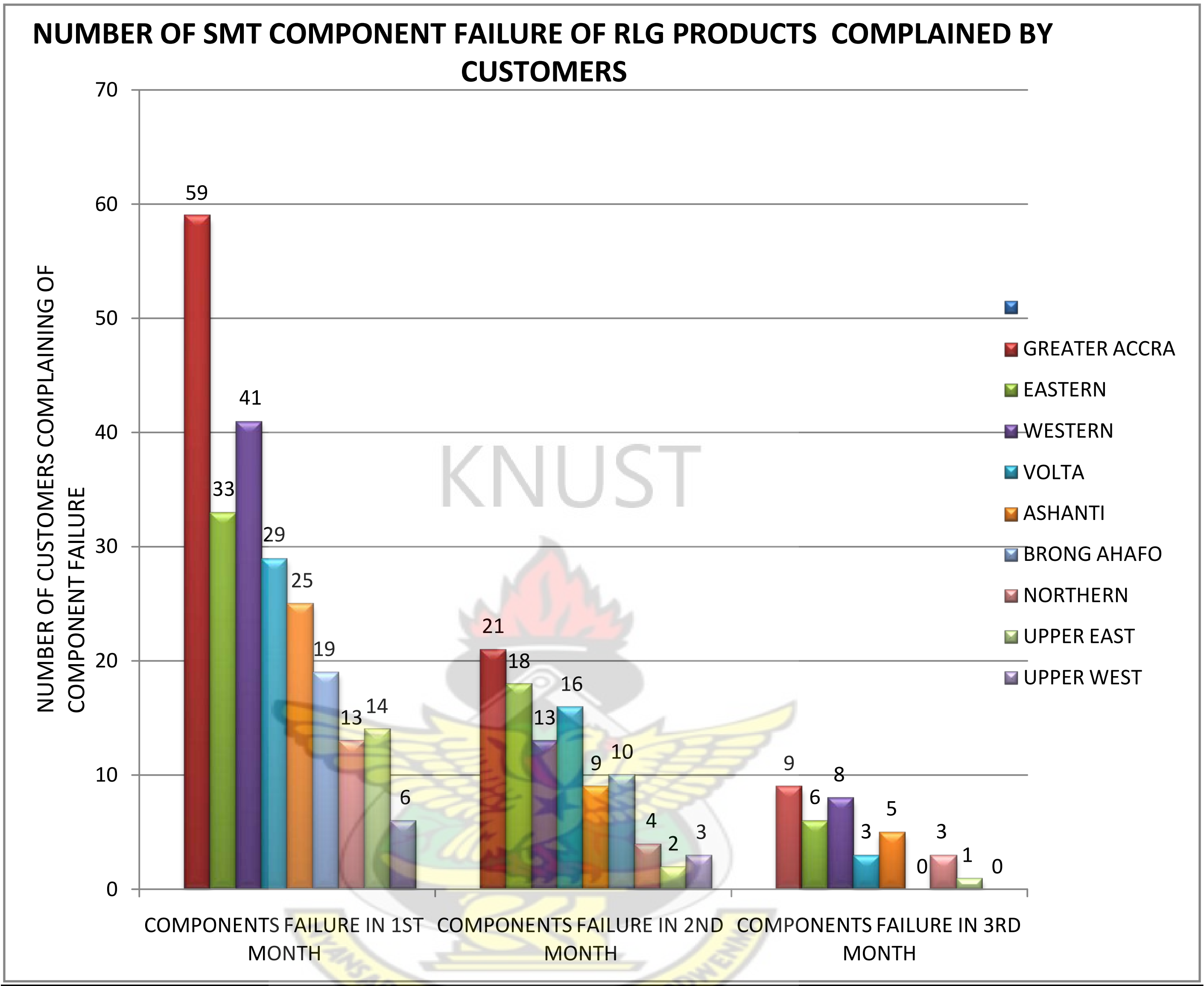


Figure 3.2: Peoples" complain of component failure of rlg products

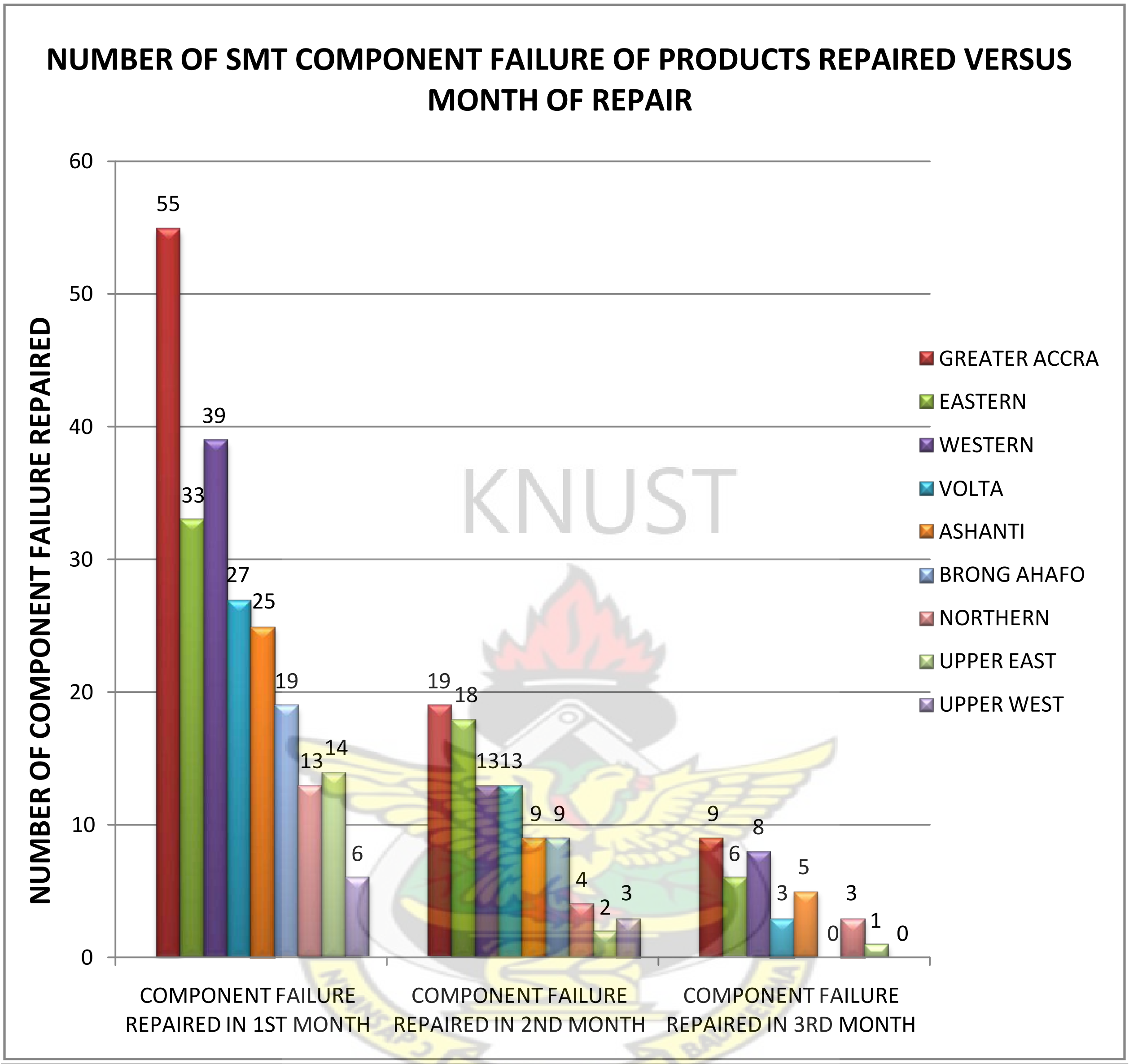


Figure 3.3: component failure repaired by rlg communications

Analysis of Phase 1

In this analysis, Central Region is left out since rlg has no office there so no data could be collected about their electronic products usage. Due to this, Central Region has been excluded in all analysis.

Table 3.1 shows people"s usage of rlg products with SMT technology within the first three months of operation in the year 2011. There is increment in usage as time goes on since people were not aware initially. Greater Accra records the maximum usage (14,222 people) whereas Upper West Region records the minimum usage (1,325) at the end of three months.

Table 3.2 shows component failure of rlg‟s products using SMT technology within the first three months of operation. It was the SMD Capacitors of the batteries for mobile phones, tablets and iPads that failed. Some of the MELF resistors on the ICs also failed due to the fact that there is frequent electricity power fluctuation and when it rises beyond the resistors‟ tolerance, they get burnt. Fifty-nine (59) complains came from Greater Accra Region in the 1st month, twenty-one complains in the 2nd month and 9 complains in the 3rd month. This shows an improvement in rlg SMT processes as time goes on.

Table 3.3 shows the number of SMT component failure solved within the first three months of operation. Rlg was able to solve 55 out of 59 complains in Greater Accra Region within the first month. Most of the components were replaced using rework soldering but for components beyond repair, customers were given new products. Rlg was also able to solve 19 out of 21 complains within the 2nd month of operation in Greater Accra Region. In the 3rd month, rlg solved all 9 complains of products in Greater Accra Region. This is the same for the other eight regions in the country.

Figures 3.1 to 3.3 show the graphical representations of the above results.

3.6.1.2 Phase 2 of *Rlg* Communication

This part of the questionnaire checks for the practical feasibility of SMT components assembly in Ghana by selected electronic manufacturing and assembly companies. This part was answered by one of the hardware engineers with HND, BSC and CFC certificate and has had five years of electronics working experience in other companies. Table 3.4 shows the thermal profile parameters of rlg‟s reflow technique.

Table 3.4: Thermal Conditions of RLG Reflow Technique

ZONE	THERMAL CONDITIONS	
	Temperature (^{o}C)	Time (Sec)
Preheat	80	0
Thermal Soak	120	12
Reflow	120	60
Cooling	220	75

Rlg Communication operators are aware of SMT technology. The company frequently uses rosin based flux and No-clean Flux on their PCBs and the type of solder paste and brand number normally used is AMTECH RMA223which is lead free solder paste (Sn/Ag/Cu).

Boards are transported to the stations of work by racks and conveyor and carry out component placement by hand. Rlg carries out soldering work both by hand and automation and uses the infra red reflow soldering technique. Thermal profile conditions are as follows: preheat temperature rises to 80^{o}C with initial time of 0 seconds and then reads up to 12 seconds; The thermal soak is carried out within 18 seconds at a temperature of 120°C; Reflow temperature rises from 120°C to 220°C where they sometimes go 20 to 30°C above liquidus; Cooling is done at a rate of 3°C/s. The cooling is done in short time to create a fine grain structure (most mechanically sound) but is limited by the differences in CTE (coefficient of thermal expansion) of the joining surfaces.

After soldering work, cleaning is not done but sometimes done by hand using Kontact Spray after which inspection is carried out by the quality control team on sample basis using the Flexia BGA/SMT Video Microscope.

After the soldering process if boards fail during inspection, rework/ repair is done. During rework a temperature of 150°C (22°C – 35°C for infra red) is used.

Figure 3.4 shows a typical reflow thermal profile of rlg reflow machine in Ghana.

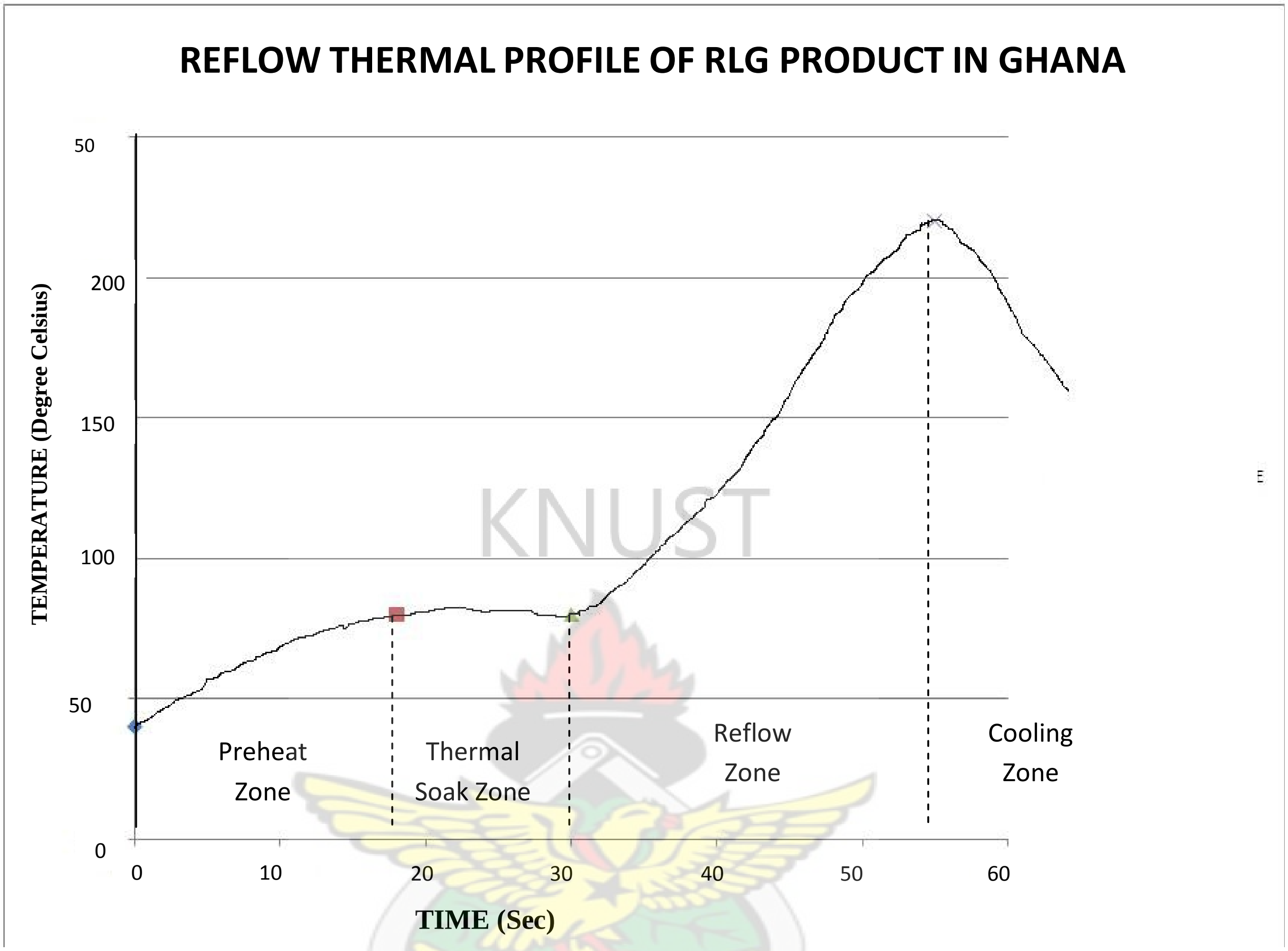


Figure 3.4: Reflow Thermal Profile of Rlg product in Ghana

3.6.2 Data from KNUST Students

Out of the whole student body, it was practically possible to question a sample size of 275 (125 from College of Sciences and 150 from College of Engineering). These two colleges were chosen for the study because some of the departments deal with electronics components for instance Department of Electrical and Electronic Engineering, Telecommunication Engineering, Mechanical Engineering, Physics and Computer Departments.

3.6.2.1 KNUST Students' Response to Questionnaire

Table 3.5: Awareness of KNUST College of Science Students of SMT and Component Miniaturization

Year of Student	**Number of Students Aware of SMT and Component Miniaturization**	**Number of Students not Aware of SMT and Component Miniaturization**
1st Year	3	14
2nd Year	21	5
3rd Year	28	9
4th Year	32	13
SUB-TOTAL	**84**	**41**
TOTAL	**125**	

	Percentage of Students Aware of SMT and Component Miniaturization	$\frac{84}{125} \times 100\% \approx 67.2\%$	Percentage of Students not Aware of SMT and Component Miniaturization	$\frac{41}{125} \times 100\% \approx 32.8\%$

Table 3.6: Awareness of KNUST College of Engineering Students of SMT and Component Miniaturization

<table>
<tr><th>Year of Student</th><th colspan="2">Number of Students Aware of SMT and Component Miniaturization</th><th colspan="2">Number of Students not Aware of SMT and Component Miniaturization</th></tr>
<tr><td>1st Year</td><td colspan="2">9</td><td colspan="2">23</td></tr>
<tr><td>2nd Year</td><td colspan="2">19</td><td colspan="2">13</td></tr>
<tr><td>3rd Year</td><td colspan="2">33</td><td colspan="2">8</td></tr>
<tr><td>4th Year</td><td colspan="2">42</td><td colspan="2">3</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>SUB-TOTAL</td><td colspan="2">103</td><td colspan="2">47</td></tr>
<tr><td>TOTAL</td><td colspan="4">150</td></tr>
<tr><td></td><td>Percentage of Students Aware of SMT And Component Miniaturization</td><td>$\frac{103}{150} \times 100\% \approx 68.67\%$</td><td>Percentage Of Students not Aware of SMT and Component Miniaturization</td><td>$\frac{47}{150} \times 100\% \approx 31.33\%$</td></tr>
</table>

Table 3.7: Students" view on the setup of electronics manufacturing and assembly laboratory at KNUST

STUDENTS' VIEW	**NUMBER OF STUDENTS WITH THE SAME VIEW**
Practical Knowledge impartation to students	122
Economic Benefit	101
Other views	52
TOTAL NUMBER OF STUDENTS	**275**

Table 3.8: Students" interest in the fusion of electronics manufacturing and assembly module with their courses

INTEREST IN ELECTRONICS MANUFACTURE AND ASSEMBLY MODULE AS PART OF TAUGHT COURSES	**NUMBER OF STUDENTS**
Yes	273
No	2
TOTAL NUMBER OF STUDENTS	**275**

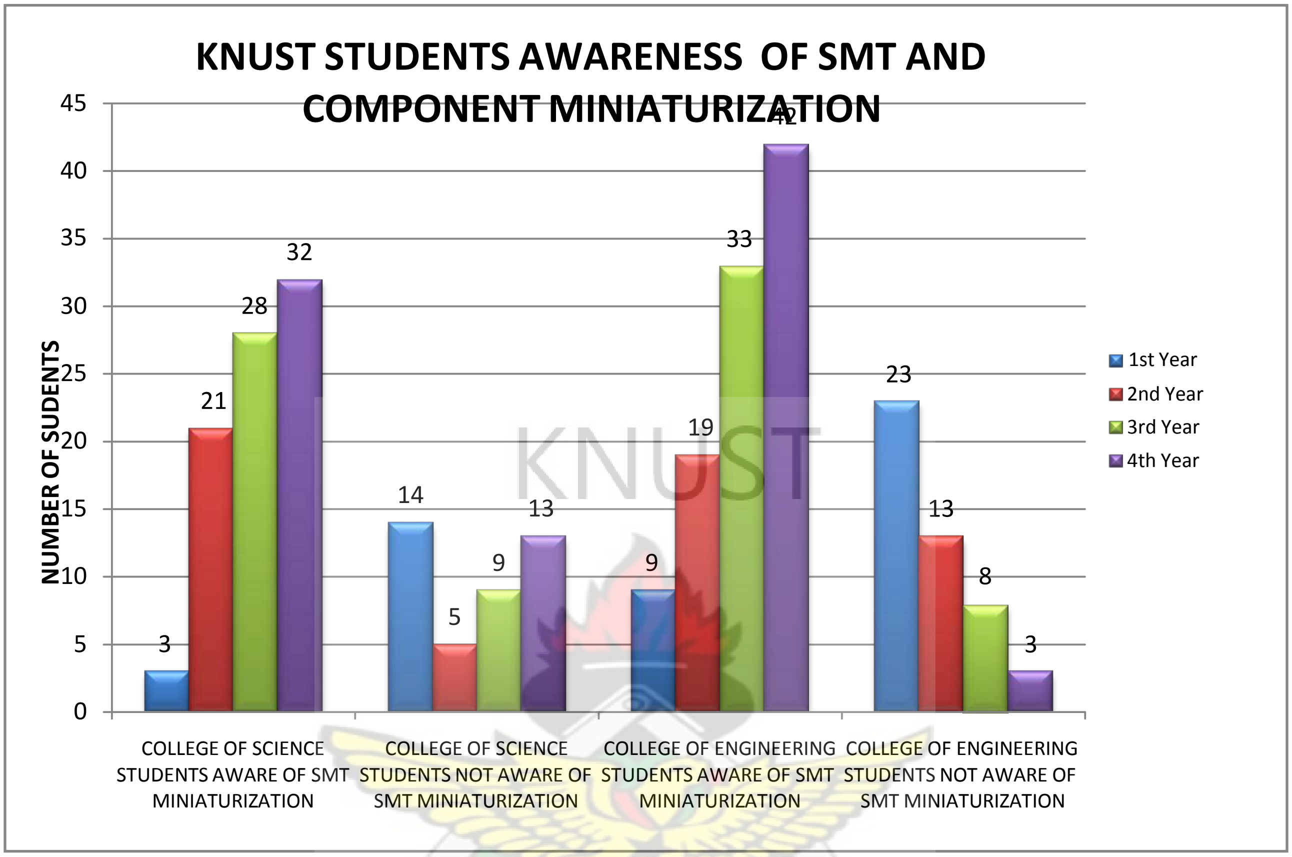


Figure 3.5: Students awareness of SMT and Component Miniaturization at KNUST

3.6.2.2 Analysis of Data from KNUST Students

Table 3.5 shows that out of one hundred and twenty-five (125) students from College of Sciences interviewed, only three (3) of the 1st year students are aware of SMT and component miniaturization whilst fourteen (14) are not aware.

Twenty-one (21) of the 2nd year students are aware of SMT whilst five (5) are not because something on SMT is taught in Computer Science Department in a course called „Circuit Theory".

Obviously, the number of awareness of SMT and Component miniaturization in 3rd and 4th year has increased since most of the students read wide at the library and from the internet. For a sample size of one hundred and twenty-five (125) students from College of Sciences interviewed on SMT, 67.2% is aware of SMT Component and Miniaturization whereas 32.8% is not aware and this is made up of the 1st year students.

At the College of Engineering, most of the 1st year students (23 from the sample size) were not aware of SMT and Component Miniaturization because some said it was not taught in their courses.

However, the 2nd (19), 3rd (33) and 4th (42) year students are very much aware of SMT and Component Miniaturization because something on SMT is taught in some of their courses.

For a sample size of 150 students from College of Engineering interviewed on SMT, 68.7% is aware of SMT and component Miniaturization whilst 31.3% is not aware of it and it is the 1st year students that form this percentage.

Again, when a question was asked on students" personal views about SMT component and electronic products being assembled at KNUST laboratories;

- ☐ 122 stated the practical knowledge it will impart to students in different ways,
- ☐ 101 students mentioned the economic benefit due to the fact that electronic products assembled on campus will sell cheaper than outside,
- ☐ 52 gave other views which were less relevant to what this thesis is seeking.

Now, 273 (out of 275) students support the idea of fusing electronics manufacturing and assembly module with some of their courses.

3.6.3 Responses from Government Policy Makers:

3.6.3.1 Policy makers views about electronic products manufactured and assembled in Ghana:

- From the Research Department of Parliament House- Accra, the Deputy Director of Research, on the 21st of November 2011 said if electronic products are made and assembled in Ghana they should be made to suit the weather conditions in the country and also meet peoples" pocket.
- The Municipal Chief Executive (MCE) of Sunyani Municipal Assembly said RLG products with SMT technology are good and need commendation especially *rlg* phones.
- District Chief Executive of Asante Akim South District Assembly mentioned the fact that the manufacture and assembly of electronic products in the country will reduce taxes and duties paid for imported electronic goods.
- The District Chief Executive of Tain District Assembly stated two of his views quoted below;

1) Ghana cannot be called a developed nation when we cannot use our hands and minds to do things for ourselves. Through this we can become a developed nation.
2) Such move will also encourage the learning of science for the promotion of greater things in the future. I see it as good!

- Finally, District Chief Executive of Jaman South-East District Assembly said they can be manufactured based on our local conditions- both climatic and affordability.

3.6.3.2 How the government policy makers think electronic manufacturing and assembly technology can affect Ghana's Development:

- The Deputy Director for Research said this will create jobs for people. It will allow the transfer of technology to Ghanaians where also taxes would be paid by the workers.
- M.C.E of Sunyani Municipal Assembly said this would affect Ghana"s development very positively since no country develops just by agriculture but by Information Technology.
- The D.C.E of Asante Akim South District Assembly also said the manufacture and assembly of electronic products will create employment for some students whilst in school and even outside school so that they do not become social misfit.

- D.C.E of Tain District Assembly mentioned the fact the SMT Technology can affect the development of Ghana scientifically and promote the economy as people get interested in made in Ghana goods. Many people would then go into manufacturing since we have other experts.
- The D.C.E of Jaman South-East District Assembly said this technology would improve our living conditions by way of job creation. That would help the assemblers and government to generate taxes for development.

CHAPTER FOUR

4.0 DISCUSSION OF RESPONSES

4.1 Introduction

This chapter presents the discussion of responses of the administered questionnaires. The results of the research are discussed under five main headings:

- ☐ Type of SMT electronic products the selected company (rlg) assembles, the difficulties encountered and how they are solved.
- ☐ Ghanaians" patronization of products with SMT technology assembled by Ghanaian electronics manufacturing companies.
- ☐ The awareness of SMT and component miniaturization by students in certain departments of KNUST.
- ☐ The students" interest in the introduction of electronics manufacturing and assembly module into their syllabus.
- ☐ Government Policy Makers" views about building capacity in the manufacture and assembly of electronic products with SMT technology and how they think this technology can affect Ghana"s economic development.

4.2 Type of SMT electronic products the companies assemble, the difficulties encountered and how they are solved:

The research has revealed that rlg in Ghana assembles laptops, notebooks, tablets, mobile phones, flat screen TV and storage devices of different kinds. This part is under phase 1 of the questionnaire.

Some products failed to function properly after some time of usage because surface mount devices such as SMD Capacitors of the batteries for mobile phones, tablets and iPads failed. Some of the MELF resistors on the ICs also failed after some time due to the frequent electricity power fluctuations in Ghana and when it rises beyond the resistors" tolerance, they get burnt. Fifty-nine (59) complains sprung from Greater Accra Region in the 1st month, twenty-one complains in the 2nd month and 9 complains in the 3rd month of operation. This improvement is probably due to improvement in the SMT assembly Process.

4.3 Ghanaians' patronization of products with SMT technology assembled by Ghanaian electronics manufacturing companies.

Table 3.1 shows how Ghanaians patronize products with SMT technology assembled by rlg within their first three months of operation in the year 2011. There is increment in the usage as time goes on since people were not aware initially. Accra records the maximum usage (14222 people) whereas Upper West Region records the minimum usage (1325) at the end of three months. This equally implies that if SMT manufacturing and assembly begins in KNUST, everything about it would be widespread as time goes on.

Table 3.2 shows component failure of products with SMT technology within the first three months of rlg operation. It was the SMD Capacitors of the batteries for mobile phones, tablets and iPads that failed. Some of the MELF resistors on the ICs also failed after some time due to the fact that there is frequent electricity power fluctuation in Ghana and when it rises beyond the resistors" tolerance, they get burnt. Fifty-nine (59) complains were recorded in Greater Accra Region in the 1st month, twenty-one (21) complains in the 2nd month and nine (9) complains in the 3rd month. This is probably due to improvement in the assembly technology.

Table 3.3 shows the number of SMT component failure solved within the first three months of operation. Rlg was able to resolve fifty-five (55) out of fifty-nine (59) component failure of their electronic products in Greater Accra Region within the first month. Most of the components were replaced but those failures beyond repairs, they compensated the customers with new SMT products of the damaged ones. They were also able to solve nineteen (19) out of twenty-one (21) complains within the 2nd month of operation in Greater Accra Region. In the 3rd month, they solved all nine (9) complains about their product in Greater Accra Region. This is the same for the other nine regions in the country.

4.4 The awareness of SMT and component miniaturization by students in selected departments of KNUST

It has been realized that Physics Department under College of Sciences studies electronics in their 2nd academic year. Table 3.5 shows that out of one hundred and twenty-five (125) students from College of Sciences interviewed only, three (3) of the 1st year students are aware of SMT and component miniaturization whilst 14 are not informed. Twenty-one (21) of the 2nd year students are aware of SMT whilst five (5) are not because something on SMT is taught in Computer Science Department in a course called „Circuit Theory".

Obviously, the number of awareness of SMT and component miniaturization in 3rd and 4th year has increased since most of the students read wide at the library and from the internet. For a sample size of one hundred and twenty-five 125 students from College of Sciences interviewed on SMT, 67.2% is aware of SMT and component miniaturization whereas 32.8% is not aware and this is made up of the 1st year students.

At the College of Engineering, most of the 1st year students (23 from the sample size) were not aware of SMT Miniaturization because some of them said it was not taught in their courses.

However, the 2nd (19), 3rd (33) and 4th (42) year students are very much aware of SMT Miniaturization because something on SMT is taught in some of their courses.

For a sample size of one hundred and fifty (150) students from College of Engineering interviewed on SMT, 68.7% is aware of SMT and component miniaturization whilst 31.3% is not aware of and this is mainly the 1st year students.

Again, when a question was asked on students" personal view about electronic products to be assembled at KNUST;

- ☐ 122 stated the practical knowledge it will impart to students in different ways,
- ☐ 101 students mentioned economic benefit due to the fact that electronic products assembled on campus will sell cheaper than outside,
- ☐ 52 gave other views which were less relevant to what this thesis is seeking.

4.5 How Can Electrical Engineering Department Contribute To The Development Of SMT at KNUST?

Some students from Electrical Engineering Department gave the following suggestions:

- ☐ Design of detectors to detect unwanted foreign materials which students enter exam hall with
- ☐ Redesign circuits to control some of the lift cases on campus that do not function properly anymore
- ☐ Can design circuit for mechanical engineering department to use to build mechanized brooms for campus zoom lion team instead of using palm fronds for sweeping.

- ☐ Can also make circuit tracks to be used for security cameras to protect students at KNUST campus since students" lives are exposed to armed robbers, murderers and so on.

4.6 KNUST students' interest in electronics manufacturing module introduction into the syllabus.

273 (out of 275) students support the idea of fusing electronics manufacturing and assembly module with some of their courses.

From the analysis above, since there is a trace of awareness of SMT and component miniaturization, it can be put into practice. If electronic manufacturing and assembly were done at KNUST apart from imparting practical understanding to Science and Engineering Students the students could also sell the electronic assembled products outside the institution.

4.7 Government Policy Makers' views about SMT electronic products manufactured and assembled in Ghana and how they think this technology can affect Ghana's development.

The two views stated by the District Chief Executive of Tain District Assembly:

1) Ghana cannot be called a developed nation when we cannot use our hands and minds to do things for ourselves. Through this we can become a developed nation

2) Such move will also encourage the learning of science for the promotion of greater things in the future. I see it as good!

From Statements (1) and (2), it is known that most Ghanaian students pursue particular programmes at the tertiary institutions and at the end find themselves in some jobs where they cannot practice what they learned in school. For instance a student studied Mechanical Engineering and after completion became a teller in a bank counting money.

Again, the Municipal Chief Executive of Sunyani Municipal Assembly said electronics manufacturing and assembly would affect Ghana"s development very positively since no country develops just by agriculture but by information technology. It is known that 60% of Ghana"s population is engaged in agriculture yet we import some food stuffs like rice from America and peach apples from Israel. Only 3% of Israel"s population is engaged in agriculture and yet they export some of their food stuffs to other countries like America and Ghana.

Agriculture in itself does not bring development to a country but value addition to the agricultural production does. If proper electro-mechanization could be applied to our agricultural farming, Ghana could develop much and that would create different forms of employment for students whilst in school and even outside school so that they do not become social misfit as stated by the D.C.E of Asante Akim South District Assembly.

All the mentioned policy makers said the government is willing to fund the capacity building of SMT Technology in the country and to help create employment in this area.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this research work was to carry out a prefeasibility study on the state of electronics manufacturing and assembly in Ghana focusing on the awareness of SMT and component miniaturization by selected electronics manufacturing and assembly company in Ghana, selected departments at KNUST, the practice of SMT soldering techniques by the selected company and checking the viability of setting up electronics manufacturing and assembly laboratory at KNUST.

The Major conclusions can be summarized as follows:

Conclusions on the types of electronic components the selected company imports

1. Rlg communications link imports SMT components like flat chip resistors for surface mount applications (eg. MELF resistors), ceramic SMD capacitors, electrolytic SMD Capacitors and others.

Conclusions on practical assembly conditions of SMT electronic products assembled in Ghana

Rlg carries out soldering work on these components using hand soldering for rework and automated soldering using Infra Red Reflow Soldering technique and AMTECH RMA223 lead free solder paste.

Conclusions on SMT electronic products the selected company assembles, the difficulties they encounter and how they solve them

2. Rlg in Ghana assembles laptops, notebooks, tablets, mobile phones, flat screen TV, MP3 and MP4 players and storage devices of different kinds.

3. Some products failed to function properly after some time of usage because surface mount devices such as SMD Capacitors of the batteries for mobile phones, tablets and iPads failed. Some of the MELF resistors on the ICs also failed after some time due to the frequent electricity power fluctuations in Ghana and when it rises beyond the resistors" tolerance, they get burnt. Fifty-nine (59) complains sprung from Greater Accra Region in the 1st month, twenty-one complains in the 2nd month and 9 complains in the 3rd month. This improvement is probably due to improvement in the SMT assembly Process.

4. Within three months of operation, rlg was able to solve fifty-five (55) out of fifty-nine (59) components failure of products purchased in Greater Accra Region within the first month. Most of the components were replaced but in the case of failures that were beyond repair, customers were given new products to replace the damaged ones. Rlg was also able to solve nineteen (19) out of twenty-one (21) complains within the 2nd month of operation in Greater Accra Region. In the 3rdmonth, all 9 complains were solved in Greater Accra Region. This is the same for the other nine regions in the country.

Conclusions on the awareness of SMT and component miniaturization by students in selected departments of KNUST

5. For a sample size of one hundred and twenty-five (125) students from College of Sciences interviewed on SMT, 67.2% shows awareness of SMT and component miniaturization whereas 32.8% were not aware and this is made up of the 1st year students. 2nd year students from Computer Science and Physics Departments are aware of SMT and component miniaturization since something on SMT is taught in Computer Science Department in a course called „Circuit Theory".

6. Out of a sample size of 150 students from College of Engineering interviewed on SMT, 68.7% is aware of SMT and component miniaturization whilst 31.3% is not aware and it is the 1st year students that form the latter percentage.

Conclusions on students' interest in electronics manufacturing and assembly module introduction into their syllabus

7. Two hundred and seventy-three (273) out of two hundred and seventy-five (275) students are in support of the idea of fusing electronics manufacturing and technology (SMT and component miniaturization) module with some of their courses.

Conclusions on the students' view on if electronic manufacturing and assembly is carried out at KNUST

8. One hundred and twenty-two (122) stated the practical knowledge it will impart to students in different ways
9. One hundred and one (101) students mentioned the economic benefits due to the fact that electronic products assembled on campus will sell cheaper than outside
10. Fifty two (52) gave other views which were not relevant .

Conclusions on Government Policy Makers' views about SMT electronic products manufacturing and assembly in Ghana

11. From the Research Department of Parliament House- Accra, The Deputy Director Research, on the 21st of November 2011 said if electronic products are made in Ghana they should be made to suit the weather conditions in the country and also meet peoples" pocket.
12. District Chief Executive of Asante Akim South District Assembly mentioned the fact that the manufacture and assembly of electronic products in the country will cease taxes and duties paid for imported electronic goods.
13. The District Chief Executive of Tain District Assembly stated two views quoted below;
    b) Ghana cannot be called a developed nation when we cannot use our hands and minds to do things for ourselves. Through this we can become a developed nation

c) Such move will also encourage the learning of science for the promotion of greater things in the future. I see it as good!

14. District Chief Executive of Jaman South-East District Assembly said they can be manufactured based on our local conditions- both climatic and affordability.

Conclusions on how the Government Policy makers think electronic manufacturing and assembly technology can affect Ghana’s Development

15. The Deputy Director for Research said this will create jobs for people. It will allow the transfer of technology to Ghanaians where also taxes would be paid by the workers.
16. M.C.E of Sunyani Municipal Assembly said this would affect Ghana"s development very positively since no country develops just by agriculture but by Information Technology.
17. The D.C.E of Asante Akim South District Assembly also said the manufacture and assembly of electronic products will create employment for students whilst in school and even outside school so that they do not become social misfit.
18. D.C.E of Tain District Assembly mentioned the fact the SMT Technology can affect the development of Ghana scientifically and promote the economy as people get interested in made in Ghana goods.
19. The D.C.E of Jaman South-East District Assembly said this technology would improve our living conditions by way of job creation. That would help the assemblers and government to generate taxes for development.

5.2 Recommendations

On the basis of this research work the following recommendations are made:

1. It was observed that some products malfunctioned after some time of usage because SMT components like SMD capacitors of the batteries for mobile phones, tablets and iPads failed. Some of the MELF resistors on the ICs also failed after some time due to frequent electricity

power fluctuations in Ghana and when it rises beyond the resistors" tolerance, they get burnt. It is recommended that Ghanaian Polytechnics and Universities embark on research work in electronic manufacturing and assembly in order to help local companies solve problems such as these.

2. Rlg can collaborate with KNUST to apply proper scientific technique to the soldering processes (ie, the soldering profile parameters have to be optimized using design of experiment).

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APPENDIX:

QUESTIONNAIRE

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY DEPARTMENT OF MECHANICAL ENGINEERING

TOPIC: PREFEASIBILITY STUDY FOR THE STATE OF ELECTRONICS MANUFACTURING AND ASSEMBLY IN GHANA

Dear respondent,

I am a postgraduate student of the Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi. This questionnaire is to obtain information to find out which types of electronic components the electronic assembly companies in Ghana import whether surface mount components or through-hole components:

To find out whether or not SMT electronic products could be manufactured and assembled on KNUST campus with reference to the information to be collected from the electronics manufacturing and assembly companies whether or not they are already practicing SMT techniques in their manufacturing processes:

To determine how fairly Ghanaians patronize SMT electronic products made in Ghana.

3.5.1 To The Electronic Assembly Companies in Ghana (*rlg*Communications)

PHASE 1

Name of Electronic Assembly Company: ………………………………………..

Position of respondent to questionnaire in the company……………………………………………….

When did the electronic assembly company start in Ghana? …./…../……..

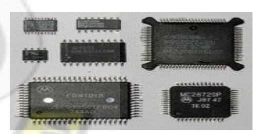
Did you ever work on Through-hole components? 

YES ☐ NO ☐ N/A ☐

If yes, were there any problems you encountered working on them? Name few:

……

……



Are you using SMC (Surface Mount Components) now?

YES ☐ NO ☐

What types of components do you import for the assembly operation? Resistors, capacitors and others:

……

………………………………………………..

Do you get the exact SMCs that you request for?

YES ☐ NO ☐

If no, then list the equivalent SMCs that you are given?..
....

Which countries (country) are your SMCs imported from? …………………………………………….

How is the mode of your SMCs importation? By airplane ☐ y ship ☐ rsonally o☐ ☐

How long does it take for the SMCs delivery? Weeks ☐ months ☐ ecific ☐

Would you ever like to use SMCs made in Ghana? YES ☐ NO ☐

What are some of the SMT products you assemble?

……

……..

Does your company start the assembly from scratch or your producers assemble some of the components for you?

In brief, state some of the difficulties you encounter during the SMC assembly process:

……

……

……

Do Ghana weather conditions affect your SMC assembly process in any way?

YES ☐ NO ☐

If yes, how (in brief)?

……

……

…………………………………………………………………………………………………

Do your SMCs producers impose on you what exactly you should build up with the components or you are at liberty to use your own innovative for the assembly process?

……

…………………………………………………

What are the frequent accidents that happen at your place? Please list some of them:

……

……

…………………………………………………………………………………………………

What steps have you taken to minimize the accidents?

……

……

…………………………………………………………………………………………………

How do you dispose of waste components? To Zoomlion bins ☐o scrap industries ☐her ☐

Please list some of the products of your assembly company?
………

How popular are your products to Ghanaians? Fairly ☐ Much ☐ Very much ☐

What percentage of the population does your company want to have access to your product?.......

How do you intend to do the above?
………
………
………
………
……………………………………….

How are you funded? NGOs ☐ Loans ☐ Self-fund ☐ other ☐

Please fill in the tables below:

Table 3.9: First Month After Company Started Operation

REGION	NUMBER OF PEOPLE USING RLG"S PRODUCTS WITH SMT TECHNOLOGY	NUMBER OF CUSTOMERS COMPLAINING ABOUT SMT COMPONENT FAILURE OF THEIR PRODUCTS BOUGHT	NUMBER OF SMT COMPONENT FAILURE IN PRODUCTS SOLVED
Greater Accra			
Eastern			
Western			
Volta			
Ashanti			
Brong Ahafo			
Northern			
Upper East			
Upper West			
TOTAL			

Table 3.10: Second Month After Company Started Operation

REGION	NUMBER OF PEOPLE USING RLG"S PRODUCTS WITH SMT TECHNOLOGY	NUMBER OF CUSTOMERS COMPLAINING ABOUT SMT COMPONENT FAILURE	NUMBER OF SMT COMPONENT FAILURE SOLVED
Greater Accra			
Eastern			
Western			
Volta			
Ashanti			
Brong Ahafo			
Northern			
Upper East			
Upper West			
TOTAL			

Table 3.11: Third Month After Company Started Operation

REGION	NUMBER OF PEOPLE USING RLG"S PRODUCTS WITH SMT TECHNOLOGY	NUMBER OF CUSTOMERS COMPLAINING ABOUT SMT COMPONENT FAILURE	NUMBER OF SMT COMPONENT FAILURE SOLVED
Greater Accra			
Eastern			
Western			
Volta			
Ashanti			
Brong Ahafo			
Northern			
Upper East			
Upper West			
TOTAL			

PHASE 2

Definition of Terms: SMT_ Surface Mount Technology**; PCB_**Printed Circuit Board; **ICB_**Integrated Circuit Board; **SMC_**Surface Mount Component; **THC_**Through-hole Components

Definition of Symbols: Pb–Lead Sn–Tin Ag–Silver Cu–Copper

Definition of Pictures: a) THC; b) SMC; c) Component placement on PCB; d) Hand Soldering; e) ICB

a b c d e

Name of Electronic Assembly Company: …………………………………………………………………………..

Position of respondent to questionnaire in the company…………………………………………………….

Level of qualification of respondent ………………………………………………………………………….

Period of experience of respondent in the electronic assembly company ……………………

Are you aware of the SMT trends (miniaturization)? Yes ☐ No ☐

If yes, please answer the following:

Before Solder Paste Application

What type of flux do you apply on boards?

Rosin based flux ☐ Water soluble flux ☐ No-clean flux ☐

Solder Paste Application and SMT Component Placement

What type of solder paste do you use? (Brand & Number)……………………………………………

Which of the following group does your solder paste belong to?

Pb/Sn ☐ Sn/Cu ☐ Ag/Cu ☐ Sn/Ag/Cu ☐

What is the shelf life of the solder paste? ....

Is any kind of inspection performed after the paste is applied? Yes ☐ No ☐

What is the time elapse between paste application and components placement? ....

What type of material is your stencil made from? Brass ☐ Stainless Steel ☐ N/A ☐

How are boards transported to the next station of work? Racks ☐ Conveyor ☐ By Hand ☐

How is SMT component placement done? By Hand ☐ Automated Machine ☐

If component placement is done by Automated Machine, what is the brand and model number of the machine? ……………………………………………………………….

Soldering Work

How is the flux applied? By Spray ☐ By Foam ☐

How is your soldering carried out? By: Hand soldering ☐ Automated Soldering ☐

Which soldering technique do you use? Reflow Soldering ☐ Bath Soldering ☐

*If you carry out **reflow soldering**, please answer the following:*

How is your solder reflow (work) carried out? By: Infra Red ☐ Convection ☐ Vapor Phase ☐

What is the thermal profile of your reflow soldering? 1-*Preheat temperature (.....^{o}C.), Duration (......seconds)+: 2-*Thermal soak temperature (.....^{o}C), Duration (......seconds)+: 3-*Reflow temperature range (.....^{o}C.), Duration (...seconds)+: 4-*Cooling temperature (.....^{o}C.), Duration (......seconds)

*If you carry out **bath soldering**, please answer the following:*

How is your soldering carried out? By: Wave soldering ☐ Dip soldering ☐ Drag soldering ☐

Cleaning

Is cleaning done after soldering? Yes ☐ No ☐

How is the cleaning done? Manually ☐ Automated Machine ☐

What chemical is used for cleaning?..

Inspection

Is there any inspection done after components are placed? Yes ☐ No ☐

If yes, how is it done? Microscope ☐ Magnifying Glass ☐

Is inspection done on a sample basis or 100% inspection is done? ....

Which team in the company does the inspection? ....

What is done if boards fail during inspection? Reject ☐ Re-inspect ☐ Rework/Repair ☐

Rework

Before rework, what type of desoldering equipment is used? ....

Can the temperature during rework be controlled? Yes ☐ No ☐

What is the typical temperature during rework? ……………………………….

How are boards retested after they have been reworked? …………………………………………………………………

Skill Impartation

Do you admit students periodically to be taught the assembly process? Yes ☐ No ☐

What are the entry requirements for a student to gain admission into your institution? BECE minimum aggregate…………, WASECE minimum aggregate ………………. Other requirement ………………

How long does it take a student to complete his/ her course in your institution? ……………………………..

What types of certificates are given to students who complete the institution successfully?

Diploma ☐ Degree ☐ Other (please specify) ☐

If qualification is not degree, are you willing to embark on BSC and MSC programmes?

Yes ☐ No ☐

3.5.2 To KNUST Students in Electrical Engineering Department

Gender of respondent: Male ☐ Female ☐

Department of respondent: ………………………………………………………….

Year of respondent (student) in school:

1st Year ☐ 2nd Year ☐ 3rd Year ☐ 4th Year ☐

Are you aware of the SMT trends (miniaturization)? Yes ☐ No ☐

Is anything on SMT taught in any one of your courses? Yes ☐ No ☐

If no would you be interested if a course in electronics manufacturing and assembly is introduced into your syllabus? Yes ☐ No ☐

What are your views if electronic products were assembled at KNUST (Ghana)? ……

……

Do you think the electrical engineering department can contribute to the development of SMT?

Yes ☐ No ☐

If yes please explain how (e.g. in the development of controls; circuit tracks design, etc): ……

……

3.5.3 To Government Policy Makers (Parliament House; MP; MCE; DCE)

Name of respondent ………………………………………………………………………………

Status of respondent ………………………………………………………………………………

What are your views about electronic products manufactured and assembled in Ghana? ……

……

To what extent do you think electronic manufacturing and assembly technology can affect Ghana's development?………

……

Is the government willing to fund the capacity building of such technology in the country?

Yes ☐ No ☐

Is the government also willing to help create employment in this area? Yes ☐ No ☐