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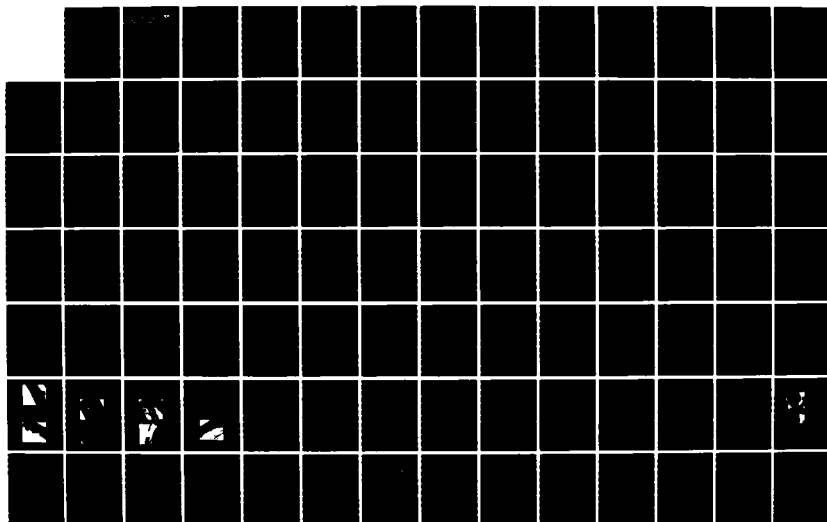
SOLDERING TECHNOLOGY (6TH) PROCEEDINGS OF ANNUAL
SEMINAR 17-18 FEBRUARY 1982(U) NAVAL WEAPONS CENTER
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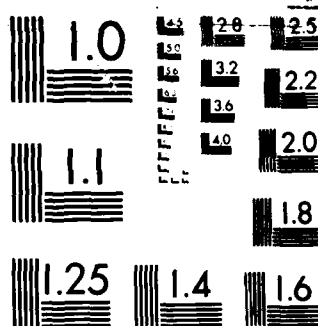
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Soldering Technology



PROCEEDINGS
OF
6TH ANNUAL SEMINAR

17 - 18 February 1982

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IN REPLY REFER TO

Thank you for your interest in soldering technology, and your attendance at this seminar.

It is vital that we maintain a continued interest and attempt to resolve our many production problems prior to adverse effects on fleet hardware. It is necessary that we design for ease of manufacturing and it is necessary that we eliminate the unjustified amounts of touch-up that is going on throughout industry today. The only way that this can be done is to understand our many problems and admit that they are there, then do something to eliminate them - corrective measures.

These proceedings are published for your information and do not necessarily reflect the views of the Naval Weapons Center or the Government.

Thank you for your attendance.

JIM D. RABY
Head, Soldering Technology Branch
Code 3681

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TECHNICAL DEVICES COMPANY

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THE NEW SOLDER MACHINE

By

Douglas N. Winther, President

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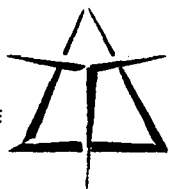
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ABSTRACT - A New Soldering Machine

- I Brief history of Technical Devices Company for those not familiar with our capabilities and experience in the field of equipment for the electronics industry.
- II Consumer Research Study of industry needs, wants and future requirement for automatic soldering of PCB's.
- III Machine design program Inaugurated.
Project Goals:
 - 1. Improved variable width solder wave to automatically conform to the printed circuit board width.
 - 2. Automatic control of solder wave height as related to PCB.
 - 3. Elimination of manual adjustments through servo systems and motorized drives as practical.
 - 4. Servo control of rails and holding fingers for uniform clamping pressure.
 - 5. Automatic variable width of preheater elements to conform with width of PCB.
 - 6. Automatic control of foam flux wave width.
 - 7. Develop high rel logic processor for coordinated control of all systems.
 - 8. Incorporate energy-efficient methods for all sub systems.
 - 9. Provide ease of maintenance, and accessibility to all functions for service and cleaning.
- IV Resulting achievements of design goals and other system improvements as provided by the new Mark IV Wave Soldering system.

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TECHNICAL DEVICES COMPANY

INTRODUCTION

For those not familiar with Technical Devices Company we give a brief history of the company. We are a manufacturer of production equipment for the electronics industry and a subsidiary of Banner Industries, Inc., a diversified New York Stock Exchange corporation headquartered in Cleveland, Ohio. Technical Devices Company has been involved in the design and development of such equipment since its inception in 1952, thirty years ago. The company started as an engineering R and D operation, and, as a result of certain engineering studies, the need for improved production equipment for the industry became evident. This resulted in the development of our current product lines such as:

1. The MARK V Component Lead Former - a result of a reliability study for Autonetics. The MARK V eliminated Autonetics' problem of damaged components during the cutting and forming process and was the only machine authorized for the Minute Man program.
2. The MARK I - Models B and C Wave Soldering Machines.
3. The MARK II Semi-Automatic Wire Cutter & Stripper Machine.
4. The MARK III Circuit Card Fixture and other products.

Technical Devices Company also engineered and developed the original PERT System of automatic component insertion machines. This was the first variable span equipment and the first of the sequencing machines. The PERT System was later sold to United Shoe Machinery Corporation, now the DYNA/PERT machine group of Emhart.



This paper will introduce our new MARK IV Wave Soldering System with its unique and innovative features. Prior to design and development of this new system a consumer research study was made to determine the needs, wants and future requirements for the automatic soldering of printed circuit cards. The study consisted of polling users of all makes of soldering machines, the sales representatives and visitors at NEPCON and other trade shows and seminars. As a result of this study, we established the following project design criteria and specifications:

1. Improved variable width solder wave to automatically conform to the printed circuit board width.
2. Automatic control of solder wave height as related to the printed circuit board.
3. Elimination of manual adjustments through servo systems and motorized drives.
4. Servo control of rails and holding fingers for uniform clamping pressure.
5. Automatic variable width of active preheater elements to conform with the width of the printed circuit card for energy savings.
6. Automatic control of the foam flux wave width.
7. Development of a high reliability logic processor for coordinated control of all systems.
8. Incorporation of energy-efficient methods for all systems.
9. Provision for ease of maintenance and accessibility to all functions for service and cleaning.

Three years of design and development have resulted in our new MARK IV, a sixteen inch (16"), palletless wave soldering system, which we would now like to describe:



SOLDER WAVE GENERATOR SYSTEM

To develop an automatic soldering system consistent with our design criteria, it was necessary to first design and develop a new and improved solder wave generator and control system. Our new system, designated in our patent application as "Adjustably Dimensioned Uniformly Distributed Solder Wave Apparatus", features an automatically controlled variable wave width, i.e., transverse to the direction of the circuit card transport, that automatically conforms to the width of the board being processed. The pumped height of the wave is electronically controlled to insure the optimum interface between the bottom of the circuit board and the solder wave.

Prior to this invention, the problem of redirecting a horizontal flowing stream of solder to a controlled and uniform vertical flow direction had necessitated the usual screens, baffles, tortuous flow paths and other flow impedances. Our requirements for a variable wave width further complicated the then common solutions. As a result, we developed a new and innovative solution, which we believe to be a significant advance in the state of the art.

In this new design (Fig.1) a horizontal flow of solder from a centrifugal pump moves up an inclined distribution ramp where the vanes form the vertical chambers.

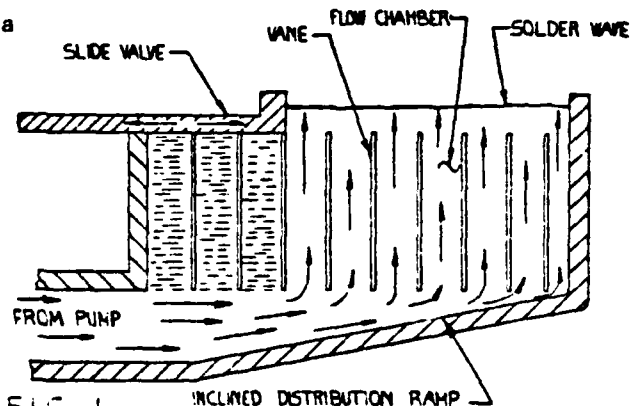
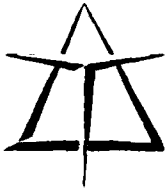


FIG. 1
3



SOLDER WAVE GENERATOR SYSTEM (continued)

Each vane picks up equal amounts of solder of equal kinetic energy and redirects it to vertical flow. This flow arrangement insures equality of the emerging solder from each flow chamber and the uniformity along the entire width of the total wave being pumped. Needless to say, the height and width of these flow chambers are critical to the design of a uniform and laminar (non-turbulent) solder wave. To assure equal flow and kinetic energy in each of the vertical flow chambers, a greater velocity of solder flowing in the inclined distribution ramp is required than would be needed or desired in the open solder wave. (Fig. 2) To reduce this velocity and to shape the wave (in the direction of the card travel) the vertical flow chambers are upwardly expanded. Approximately 75% of the solder flows towards the upcoming circuit card with approximately 25% flowing from the opposite side of the solder duct which produces an excellent peel back effect to minimize bridging and icicling. The wave form produced by this design is best suited to a fixed-angle conveyor. To vary the width of the wave (Fig.1) to accommodate different circuit board sizes, a sliding valve moves across the tops of the vertical flow chamber to seal off those chambers covered by the valve plate.

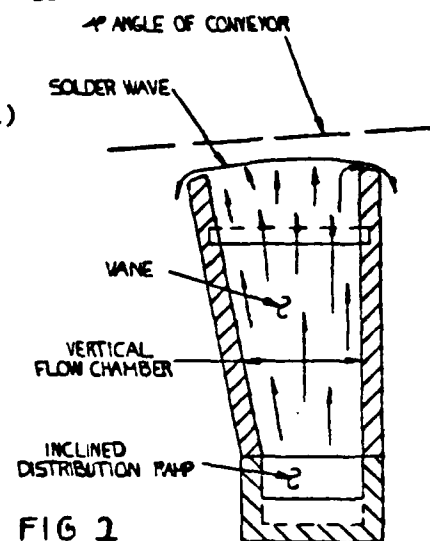
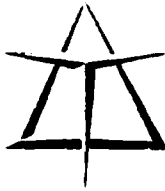


FIG 2



SOLDER WAVE GENERATOR SYSTEM (continued)

All, or substantially all, of the flow is blocked in those covered chambers, thereby diverting the flow in the inclined distribution ramp to those chambers whose outlets are open. The solder is pumped by a centrifugal impeller which is powered and directly connected to a high torque, low speed DC servo motor fabricated to our specifications. Since the height of the solder wave is a product of the motor speed, an electronic wave height (Fig. 3)

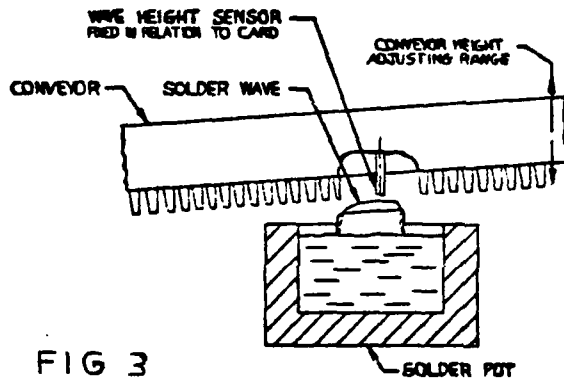


FIG 3

sensor and amplifier controls the motor speed to maintain the wave height in relation to the sensor position. The sensor is fixed to the conveyor rail in a direct relation to the

circuit board. Should longer lead lengths or other protrusions below the card require the rails to be raised, the solder wave height would also increase, and the relation or interface of the circuit board and solder wave would remain the same. The directly coupled motor also eliminates belts, pulleys, counter shafts and bearings and their maintenance.

The wave generator system is mounted on a well insulated solder pot heated by six 1100 watt heating elements. For optimum thermal transfer, the heating elements are inserted in straight tubular sheaths extending inside and through the solder area.



SOLDER WAVE GENERATOR SYSTEM (continued)

The elements may be withdrawn when solder is either solid or liquid. Solder temperatures up to 600°F are accurately maintained by a zero crossing, proportional, 3-phase controller with heavy duty triacs. The desired temperature is set by a control knob on the instrument panel and the actual temperature is displayed by a digital panel instrument. A solder level panel light indicates the need to add solder. A drain valve is integral with the pot for removing solder. A seven-day skip timer automatically, at selected times, turns the solder pot heat off during non-use periods, and on prior to expected use, to assure maximum up time. The solder pot holds approximately 560 pounds of solder, and it is mounted on rails with a motor drive to smoothly move the entire solder wave generator assembly to the rear of the machine for easy cleaning and service.

THE CONVEYOR SUB-SYSTEM

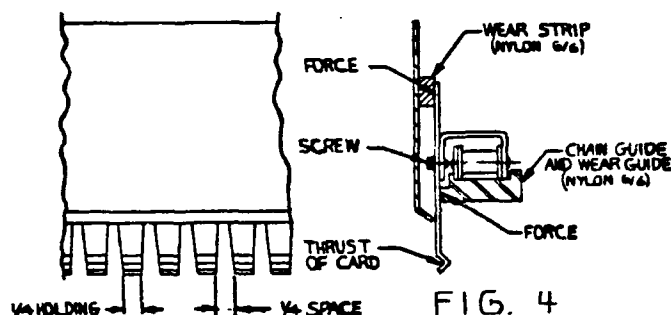
The conveyor transports the printed circuit card assemblies over the foam fluxer, the hot air knife, the preheater and the solder wave at a fixed incline of 4° to achieve the optimum relationship with the solder wave shape. Our design criteria dictated that major improvements be made over conventional conveyor design resulting in a unique system that features:



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THE CONVEYOR SUB-SYSTEM (continued)

1. Conveyor rails constructed of stainless steel, designed to provide high torsional and bending stiffness. Servo control of conveyor width and predetermined card gripping tension to provide fast and accurate setup, reduction of board warpage and damage due to excess finger pressure, elimination of hand cranking and guessing as to gripping tension.
2. Closely spaced (Fig.4) quick change titanium transport



fingers contact the card edges along 50% of the length on both sides (1/4" grip length, 1/4" air repetitiously). Two screws secure each pair of titanium fingers for quick change (no rivets).

3. The conveyor transport has an infinitely variable speed range from 0-15 feet per minute and is driven by an SCR controlled permanent magnet motor. Speed is displayed on the control panel by a digital panel indicator. Drive is through two synchronized universal joint shafts to eliminate the problem of linear sliding motion through keyed or splined drive bushings with their tendency to gum up and stick.
4. Conveyor height over the solder wave is adjustable to accommodate different lengths of lead protrusions below the circuit board. This function is controlled electrically from the instrument panel. A panel indicator shows the clearance for protrusions under the circuit board. This feature eliminates the necessity of pumping an excessively high wave when not required, thereby reducing the amount of dross generated, and extra heating energy used.



THE CONVEYOR SUB-SYSTEM (continued)

5. The finger cleaning system consists of a centrifugal pump which moves solvent from a stainless steel tank through a distribution manifold and Viton hoses to the finger cleaner stations on the return side of each conveyor rail, where pumped solvent and brushes clean the fingers as they pass through the station. Excess solvent is returned to the tank through Viton hoses. All parts of the system including the hoses are highly resistant to the solvents commonly used.
6. To reduce friction and to prevent galling, the conveyor chains ride in heat resistant nylon guides. (Fig.4). The finger thrust is countered by the wear strips as indicated in the illustration. Provisions have been made for the differential thermal expansion of the nylon vs. the stainless steel conveyor rails.
7. The circuit card entrance guides are designed for easy interface with an automatic production line or manual loading.
8. The logic system inhibits any change in conveyor rail width while the conveyor is transporting circuit boards even though the operator commands such a movement.

THE FLUXING SUB-SYSTEM

One of the most commonly used methods of applying flux to the bottom side of the printed circuit card is by foaming the flux. Although other methods of flux application such as liquid wave and spray were considered, and may be offered as future optional equipment, we chose the foam fluxing system for this machine. The fluxing sub-system consists of:

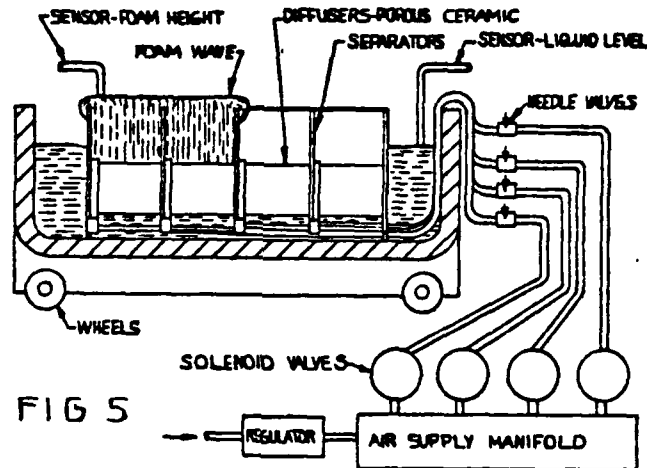
1. A flux tank and riser ducts that are constructed of linear polypropylene to resist attack from the most active fluxes and their constituents.
2. The width of the foam flux wave is automatically controlled by the width of circuit cards being run. Unnecessary foam is not generated, resulting in significant savings in flux and changes in specific gravity.



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THE FLUXING SUB-SYSTEM (continued)

3. The flux duct (Fig.5) is a series of four independent wave generating chambers with ceramic diffusers for aeration. Each section is automatically activated

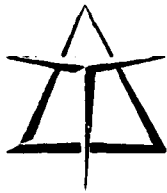


(or de-activated) in 4-inch increments to conform more closely to the width of the circuit board. Each chamber has its independent needle valve adjustment to compensate for any changes in density of the ceramic diffusers. This insures uniformity of the foam height across the full 16-inch foam flux wave.

4. The control panel for the flux sub-system has an ON/OFF switch, air pressure gauge and a regulator. A yellow light is provided to indicate low flux level. Another yellow light indicates a low wave height. Two green lights are provided, one to show an adequate level of flux in the tank, and another indicates sufficient foam height.
5. The flux tank and duct assembly is mounted on wheels and is easily rolled out for cleaning and maintenance.
6. A flux density meter with digital readout is available as optional equipment.

AIR KNIFE AND PREHEATER SUB-SYSTEM

The hot air knife is incorporated in the preheater system. (Fig.6) Utilizing otherwise wasted heated air from the preheater, the hot air knife removes excess flux from the bottom side of the



AIR KNIFE AND PREHEATER SUB-SYSTEM (continued)

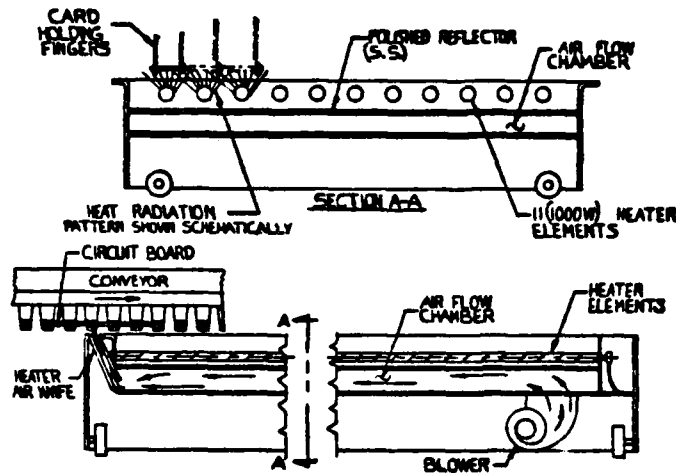


FIG. 6

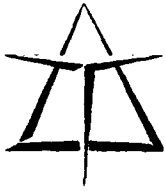
circuit card (eliminating the need for a flux wipe-off brush), gently pushes the flux up into the plated-through holes, removes most volatiles from the flux and promotes better fluxing by distributing

the flux evenly and starting the heat activation cycle just prior to infrared preheating.

The preheater uses eleven 1000 watt 30" long tubular heating elements running parallel to the direction of the card travel. The elements are positioned to evenly heat the circuit board across its width without areas of temperature variation. These heaters are automatically energized to conform with the width of the circuit card being processed. Heating elements not required for the circuit card size are not energized thereby saving significant amounts of electrical energy.

The heating element assembly is mounted over a mirror finished reflector which directs a portion of the infrared energy back to the circuit card. The whole system is mounted on rollers and is easily movable for maintenance and servicing.

The control panel for this sub-system has an ON/OFF switch for the hot air knife, an ON/OFF switch for the preheater,



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AIR KNIFE AND PREHEATER SUB-SYSTEM (continued)

a variable setting temperature control dial and a digital temperature readout used as a reference.

HOOD ENCLOSURE

The hood encloses the work area for operator safety, provides for exhausting flux fumes and removal of rising heat. It has sliding safety glass for easy and quick access to the machine. For maintenance and servicing of the machine the hood may be elevated to give complete access to all areas of the soldering system. The control panel has an UP/DOWN switch for raising or lowering the hood, and ON/OFF switch for the ventilation system and an ON/OFF switch for internal hood lighting. The hood and all sub-systems are supported by a welded square tube frame of great rigidity and strength.

ELECTRONIC SUB-SYSTEM

Three in-line instrument panels located across the front of the machine, each adjacent to the function it manages, provide the indicators and controls needed for normal automatic operation. As a part of the electronic controls, a dedicated CMOS logic system inhibits certain functions if all operational requirements are not met or are contraindicated such as:

1. The conveyor width servo is inhibited while the conveyor is transporting boards so as to prevent damage to the circuit boards or to the machine.
2. The hood must be down while soldering circuit boards to provide operator safety.



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ELECTRONIC SUB-SYSTEM (continued)

3. Conveyor will not transport boards if solder wave, preheater and/or fluxer are off.
4. The solder pump and other operating requirements will not run until the solder has reached the preset temperature.
5. The ventilation system must be operating before circuit boards may be soldered.

Although a great many conditions must be met to operate the equipment in its automatic mode, a KEY switch is provided to override the logic system when maintenance and service are required.

CONCLUSION

We believe we have met our design goals. When the MARK IV Wave Soldering System is used in conjunction with an automatic assembly line and an in-line cleaning system, the automatic cycle of assembly, soldering and cleaning completes the major phases of the printed circuit board assembly process.

"Wave Fluid Entrapment in Solder Joints"

Sam Mitchell, The Boeing Company, Seattle, Washington

Operator observations during solder joint touch up indicated the presence of voids with an entrapped liquid foreign material. Subsequent investigations confirmed it to be solder wave fluid used with the intermixed system. Metallographic analysis techniques indicated a potential reliability problem. An extensive test program was performed with solder plugs and joints containing large amounts of entrapped wave fluid. This hardware was then tested to verify the reliability. No test failures occurred nor have any field failures occurred.

"Flow Solder Tinning of Be-Cu Leads"

Cy Noritake, ; The Boeing Company, Seattle, Washington
Sam Mitchell

Flow solder defect inspection on Be-Cu Connector leads showed a common poor wetting behavior. Process analysis revealed that the connectors had been pretinned using the flow solder machine to remove gold plating. Metallographic analysis established two contributing factors for the poor solder joints, contaminated leads and dissolution of the copper plate. Process corrections have resulted in elimination of both contributing factors.

ENVIRONMENTAL EFFECTS OF FUMES CREATED DURING SOLDERING

by

Dr. Wallace Rubin,
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Hertfordshire, England.

INTRODUCTION

Since the introduction of the Health & Safety at Work Act in the UK¹ and similar legislation worldwide, our attention has been more forcibly directed towards the dangers of low levels of atmospheric pollution. In the electrical and electronics industries, where we had taken a great deal for granted, we now find that extraction as was installed might be inadequate to remove fumes created during soldering; and solvents which had previously been considered 'safe' now come into the category of hazards.

My involvement in different aspects of Health & Safety has covered a wide range. My company has organised meetings with medical officers of health of all major electrical companies to discuss the effects of flux fumes; as a member of a development laboratory with a works production background, I have had need to deal with Government officials employed in the medical and chemical services of the UK Factory Inspectorate; and I am a representative on an International Committee (part of Group 1A of the International Institute of Welding), which includes a responsibility to keep up to date on all matters appertaining to Health & Safety.

METAL FUMES

Solder and flux manufacturers have always been conscious of the potential hazards which might arise during soldering, particularly in relation to metal vapours. Fortunately, provided

soldering takes place with rosin or other non-corrosive type fluxes at temperatures below 500°C, there is literally no problem with the effects of tin and lead. Cadmium will become a hazard at around this temperature, but generally with non-corrosive fluxes, volatile metal fumes are not evident. With active acid fluxes, metal halide fumes do arise at relatively lower temperatures, but we will not discuss this aspect of health and safety during this presentation. We are hoping that the work conducted by Van Der Molen in the USA will clarify this issue.²

FLUX FUMES

Fumes arising during the decomposition of rosin during hand soldering of non-corrosive fluxes have been proven to have created a sensitised condition in soldering operatives, and most of the published work in this regard relates to tests originally carried out by the Brompton Hospital in London.^{3,4} We had long been aware of the fact that rosin is a skin sensitiser under certain extreme conditions, but at the Brompton it was the first occasion where it had been proven that rosin decomposition fumes were a hazard.

This raises many aspects of work practice.

The position may have been complicated by the method of assessing the concentration of the fumes by expressing results in terms of formaldehyde, which is a known hazard.⁵ In fact, the aldehydes in the flux fumes are related to the abietic acid, rosin-like fractions of the breakdown products which, because of their unknown compositions, are conveniently expressed in terms of formaldehyde. As a result of a misunderstanding, many occupational hygienists have regarded flux fumes as containing formaldehyde, and

therefore as being toxic from a chemical standpoint. Fortunately, this misconception is being clarified, and I was pleased to note that the EPA in the USA has recently decided to take a much more lenient view of the effects of formaldehyde anyway.⁶

Efficient fume extraction has now become an important requirement in production areas, and the present TLV limit of 0.1 mg/m³ of aldehyde expressed as formaldehyde in the atmosphere near the breathing zones of operators is the determining regulation. It is possible that an alternative resinous component present in greater proportion in the fumes will become a new TLV standard.⁷

The presence of fumes represents a hazard whatever their nature and much work has been carried out in order to provide alternative resinous fluxes which will fume less and whose fumes will not have sensitising properties. A great deal of experimental work has already shed light on the rosin syndrome. Using pentaerythritol tetrabenzoate, for instance, as the basis for an alternative flux, fuming has been reduced by over 60%, as revealed by the graphs of relative weight losses against rosin fluxes. The heat stability of the alternative resins also means that the fumes are chemically identifiable as undecomposed ester, and this information, together with other evidence resulting from work carried out at the Huntingdon Research Centre,⁸ has given our Health & Safety Executive and Industry the measure of confidence needed to use the alternative in production. The major tests needed to be carried out are those required by the documentation of the Health & Safety Executive⁹ and include:-

Investigation of acute toxic effects,

skin and eye irritation and sensitisation,

sub-acute toxic effects

47 and Screening tests for mutagenic and potential carcinogenic activity.

The particle analysis of the fumes has also been carried out and may also be important because of the large variation in dimensions.⁸

Table 1 - Particle size distribution in fumes from rosin and non-rosin (Xersin) flux fumes.

Fumes evolved from Sn60 16 swg 4% w/w flux-cored solder wire fed 1 cm/second on to solder bit at 300°C.

Anderson Seive		Weight of residues in mg	
Ref. No.	Mesh Size (microns)	Non-rosin	Rosin
0	11	N.D.	0.07
1	7	Trace	0.10
2	4.7	Trace	0.12
3	3.3	Trace	0.25
4	2.1	Trace	0.17
5	1.1	0.118	1.10
6	0.65	0.063	0.34
7	0.43	0.040	0.15
Total weight collected (mg)		0.221	1.40

NOTE: At 300°C rosin flux blocked equipment in two minutes
 At 330°C rosin flux blocked equipment in three seconds
 At 330°C non-rosin flux did not block equipment even after 30 minutes

Recent work carried out in Rumania has provided a complete chemical analysis of flux fumes.¹⁰ Also, at Siemens, Berlin, a similar study carried out under carefully controlled conditions has confirmed the presence of traces of lead and tin as well as innumerable breakdown products of rosin in flux fumes,¹¹ and this

work is continuing in the hope that it will confirm the levels of safety to be applied in industrial working conditions.

ADDITIVES AND DILUENTS

Although the major component of non-corrosive fluxes is rosin, there are additives known as activators which might also conceivably add to environmental problems. It is known that hydrazine, which has been used in flux formulations, is a powerful bronchial irritant, and certain fluorine chemicals are also known to be a hazard. However, the major additives in most commercially available fluxes include amine hydrochlorides and carboxylic acids, and from work which has been carried out it is understood that the relatively small proportions present in the flux fumes do not create a health hazard.³

More important than the additive activators are the large volumes of solvents now used in producing liquid fluxes in a form convenient for use in automatic equipment such as that needed for wave soldering. Common solvents include isopropanol, acetone, butanol, methylethyl ketone, and derivatives of glycol ethers. With these, the problems are mainly associated with the potential fire risk, because of the solutions after application to components needing to be passed over pre-heating zones to remove the solvent before soldering. Perhaps more thought should be given to the installation of adequate flame-proof electrical equipment for fume extraction at such locations.

Additionally, these solvents have threshold limits which are relatively low and good extraction is mandatory. Fortunately, in these circumstances where automatic soldering takes place, extraction represents a more simple problem than removal of fumes from individual hand-soldering locations.

In many instances it is necessary for flux residues to be removed and a secondary problem of the safe removal of the results of the washing process has to be faced, but this is not strictly within the scope of this presentation.

CONSEQUENCES AND INTERPRETATION OF LEGISLATION

The importance of adequate atmospheric control cannot be over-emphasised, but we must be careful that we are sufficiently liberal in our interpretation so as to prevent production and development being too tightly bound by legislation. Personally, I have survived an overdose of phosgene; have used benzene as a solvent without taking undue precautions other than to prevent skin contact; and have worked for years in an environment in which asbestos and silica dusts were not controlled. It is not proposed that this is acceptable, but the evidence suggests that the after-effects are not necessarily fatal, and that, as with the new approach to the effects of formaldehyde in the atmosphere, we might similarly be reasonable for rosin and other fumes.

Additionally, we must bear in mind the considerable costs and overheads relating to specialists and the large amount of available research and development time that might be needed purely for environmental control. I know of one university chemistry department which is planning to spend two million pounds on improved fume cupboards where the present installations are considerably better than any of those which were used in the laboratories in which I was a student, and with which I have worked most of my chemical life. There must be many factories and laboratories which are working without apparent problems and who, by strict interpretation of legislation, would be forced to expend all their technical resources on health and safety developments.

VAPOUR PHASE SOLDERING

A further aspect of toxic breakdown products caused during soldering relates to the new technique of vapour phase condensation reflow where high boiling perfluorinated liquids provide vapours of temperature above the melting point of solder. The system was invented at Western Electric some eight years ago¹² and has led to a number of commercially available reflow apparatus¹³ where liquid is heated at the base to provide a vapour which condenses on cooling coils, and above which there is a secondary blanket of a lower boiling halogenated liquid. The main perfluorinated liquids are at present either amines¹⁴ or derivatives of ethers¹⁵ and the work of Zado and Turbini¹⁶ has highlighted the possibility of chemical breakdown to evolve perfluorinated isobutylene, (PFIB), which is known to be a most dangerous chemical with a low threshold limit value. The likelihood of chemical breakdown increases in the presence of organic flux residues which will inevitably be present and occurs because of the chemical weakness of the perfluorinated carbon to fluorine bonds adjacent to the nitrogen or oxygen atoms in the structure of the main chemical. Much work is now needed both to redesign vapour phase reflow equipment to remove harmful vapours, and, more fundamentally, with the chemicals, to see whether they can be modified to provide a chemical structure which is more heat stable.

CONCLUDING REMARKS

Problems associated with environmental effects created during soldering need not present undue problems if handled in a commonsense way by production management.

It demands a good understanding between management, factory controllers, environmental hygienists, and the work force and their union representatives. Between them they must exercise intelligent understanding of the potential health problems and reasonable means of their prevention.

Suppliers of flux chemicals and of equipment must likewise work closely with all concerned to assist in maintaining a healthy working environment.

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ANALYSIS OF COMMON SOLDER PROBLEMS

Prepared by:

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ABSTRACT

Many solder problems may appear similar and are grouped together in broad categories. Further subdivision is often possible by analysis using metallographically prepared, epoxy mounted cross-sections. A basic metallurgical knowledge of the solder structure, of plated coatings, and of solderability criteria permits this analysis.

This paper consists of the following sections following the introduction.

1. Solder Structure
2. Impurities in Solder
3. Electronic Lead Solderability
4. Printed Circuit Board Solderability

The examples described were all problems encountered during the manufacture of electronic assemblies.

PRODUCTIVITY IMPROVEMENT IN SOLDERING TECHNOLOGY

Prepared by:

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"PRODUCTIVITY IMPROVEMENT IN SOLDERING TECHNOLOGY"

PRODUCTIVITY/PRODUCT QUALITY

OVER THE PAST SEVERAL YEARS, THERE HAS BEEN A REAL AND GROWING CONCERN ON THE DECLINE IN PRODUCTIVITY IN THIS COUNTRY. POOR QUALITY HAS RESULTED IN THE RECALL OF VARIOUS PRODUCTS PRODUCED IN THIS COUNTRY. NBC HAD AN HOUR LONG "WHITE PAPER" ON TELEVISION ANALYZING THE DECLINE IN PRODUCTIVITY AND PRODUCT QUALITY IN THIS COUNTRY. NUMEROUS ARTICLES HAVE APPEARED IN MAGAZINES AND NEWSPAPERS ON THIS MATTER. THE JANUARY ISSUE OF QUALITY MAGAZINE REPORTED A SURVEY THAT US WILL LOSE ITS POSITION AS THE WORLD PRODUCTIVITY LEADER BY THE END OF THE DECADE. EVEN CONGRESS IS CONCERNED. IN 1980, THE GENERAL ACCOUNTING OFFICE HAD A ROUNDTABLE DISCUSSION ON THE PROBLEM OF PRODUCT QUALITY.

WITH THESE OPENING REMARKS, I'M SURE YOU ARE WONDERING WHAT PRODUCTIVITY/PRODUCT QUALITY HAS TO DO WITH SOLDERING TECHNOLOGY AND THIS SEMINAR. IN THE NEXT FEW MINUTES I WILL TRY TO RELATE PRODUCTIVITY WITH SOLDERING TECHNOLOGY.

THE JANUARY ISSUE OF QUALITY MAGAZINE POINTED OUT THAT:

- O MANAGEMENT ATTITUDES AND ABILITIES MUST BE CHANGED TO IMPROVE PRODUCTIVITY.
- O WORKERS HAVE LESS PRIDE IN WORKMANSHIP THAN THEY DID TEN YEARS AGO.
- O WORKERS TODAY ARE LESS LOYAL AND LESS MOTIVATED TO WORK.

TWO SURVEYS CONDUCTED BY ASQC IN 1981 SUPPORT THESE FINDINGS. THERE MUST BE SOME TRUTH TO THESE POINTS SINCE WE ARE BUYING MORE CARS, TV, MICROCHIPS, ETC. FROM JAPAN.

LET ME PROVIDE YOU WITH MY THOUGHTS ON WHY WE ARE IN THIS CONDITION.

FIRST OF ALL, WE HAVE A CONCEPT OF ASSURANCE (QUALITY ASSURANCE). THIS CONCEPT STEMS FROM THE INDUSTRIALIZATION MOVEMENT IN THIS COUNTRY.

FREDERICK TAYLOR IN THE EARLY 1900'S ESTABLISHED THE FUNCTIONALIZATION CONCEPT WHICH WAS IMPLEMENTED BY THE HENRY FORD PRODUCTION LINES. FUNCTIONAL SPECIALIST GROUPS WERE FORMED TO IMPROVE EFFICIENCY. AS SUCH, THE PRACTICE OF "INSPECTION" AND

LATER ON "QUALITY CONTROL" WAS ESTABLISHED AS A SEPARATE INDEPENDENT GROUP. THE "CONTROL OF QUALITY" OR THE "ASSURANCE OF QUALITY" IS BY INSPECTION FOR ACCEPTANCE OR REJECTION BY AN INDEPENDENT GROUP. TODAY, WE KNOW THAT "QUALITY ASSURANCE" INCLUDES OTHER ASSURANCE ACTIVITIES SUCH AS DESIGN REVIEW, STATISTICAL ANALYSIS, ETC. BUT, THIS INDEPENDENT QUALITY ORGANIZATION DOES NOT REALLY "CONTROL" THE QUALITY OF THE PRODUCT. IT ONLY ESTABLISHES THE METHODS TO PREVENT DEFECTIVE PRODUCTS FROM LEAVING THE BACK DOOR. CONTROL OF QUALITY IS REALLY IN THE HANDS OF THE OPERATOR AND/OR THE PROCESS. IN OTHER WORDS, YOU CAN NOT INSPECT QUALITY INTO THE PRODUCT.

SOLDERING TECHNOLOGY IS A CLASSIC EXAMPLE FOR OPERATOR AND PROCESS CONTROLS WHERE INSPECTION CANNOT ESTABLISH THE QUALITY OF THE PRODUCT. CONTROLS CAN BE DIVIDED INTO MANAGEMENT CONTROLLABLE AND OPERATOR CONTROLLABLE.

MANAGEMENT MUST PROVIDE THE NECESSARY TRAINING AND TOOLS TO THE OPERATOR TO DO THE JOB RIGHT THE FIRST TIME. MANAGEMENT MUST ESTABLISH THE WORKMANSHIP STANDARDS FOR THE WORKER TO FOLLOW. MANAGEMENT MUST CREATE AN ENVIRONMENT FOR THE OPERATOR TO BE MOTIVATED AND HAVE PRIDE IN HIS WORKMANSHIP.

THE OPERATOR MUST HAVE THE KNOWLEDGE AND SKILLS TO DO THE JOB RIGHT--TO BE A CRAFTSMAN IN HIS TRADE. THE WORKER MUST COMPLY WITH THE ESTABLISHED STANDARDS.

IN THE EARLY DAYS OF THE APOLLO PROGRAM, SOLDERING WAS A MAJOR PROBLEM THROUGHOUT THE AEROSPACE INDUSTRY. THERE WAS NO STANDARD IN SOLDERING WITHIN NASA OR AMONG OUR CONTRACTORS. THERE WERE CONFLICTS BETWEEN NASA AND OUR CONTRACTORS ON WHAT IS RIGHT AND WRONG. IN FACT, THERE WERE CONFLICTS AMONG THE NASA CENTERS. ONE OF THE MAJOR ACHIEVEMENTS WE MADE IN THE SPACE PROGRAM WAS THE ESTABLISHMENT OF OUR SOLDERING STANDARDS. AND BY MANAGEMENT DIRECTION, WE ESTABLISHED SOLDERING SCHOOLS TO TRAIN OPERATORS TO SOLDER CORRECTLY USING THE PROPER TOOLS. WE CANCELLED OUR SOLDERING SCHOOLS SEVERAL YEARS AGO, DUE TO FUND LIMITATION, BUT I STILL GET CALLED ON A REGULAR BASIS FROM PEOPLE WHO WANT TO BE NASA CERTIFIED. OUR SOLDERING HANDBOOK IS STILL THE BEST SELLING DOCUMENT THAT WE HAVE.

THE JAPANESE TOOK THE SAME APPROACH THAT WE DID IN SOLDERING AND NATIONALIZED QUALITY CONTROL BY GIVING THE CONTROL OF QUALITY TO THE OPERATORS. MANAGEMENT AND WORKERS WERE TRAINING IN THE FUNCTION OF QUALITY CONTROL, NOT QUALITY ASSURANCE.

IN LIGHT OF THE PRODUCTIVITY POSTURE THIS COUNTRY IS IN AND THE CONCERN ON THE PART OF THE DEPARTMENT OF DEFENSE ON THE DEFENSE INDUSTRIAL BASE, IT IS TIME THAT WE TAKE SOME POSITIVE STEPS TO IMPROVE OUR PRODUCTIVITY AND THE QUALITY OF OUR PRODUCTS. THIS SOLDERING TECHNOLOGY SEMINAR IS ONE METHOD FOR IMPROVEMENT. HOWEVER, THE ACCEPTANCE BY GOVERNMENT AND INDUSTRY OF WORKMANSHIP STANDARDS IN ELECTRICAL/ELECTRONIC ASSEMBLY FABRICATION WILL FURTHER ENHANCE THE DEFENSE AND AEROSPACE INDUSTRIAL BASE.

BASED ON OUR EXPERIENCE IN OUR SOLDERING STANDARD, WE HAVE INITIATED A PROGRAM TO DEVELOP ADDITIONAL WORKMANSHIP STANDARDS IN:

- 1. CABLEING AND WIRING
- 2. PRINTING WIRING BOARDS
- 3. SOLDERLESS CONNECTIONS
- 4. CONFORMAL COATING

DEVELOPMENT OF OTHER STANDARDS WILL BE INITIATED AS REQUIRED. WE HAVE INVITED YOU AND INDUSTRY TO BE FULL PARTNERS IN THE DEVELOPMENT OF NEW STANDARDS. IT IS OUR GOAL THAT WE HAVE STANDARDIZATION OF WORKMANSHIP PRACTICES THROUGHOUT OUR INDUSTRIAL COMPLEX. TO ACHIEVE THIS GOAL WE MUST HAVE THE FULL COOPERATION BY ALL OF YOU. I LOOK FORWARD TO YOUR SUPPORT IN THIS EFFORT.

HOWEVER, THE FUTURE IS NOT HANDS-ON SOLDERING. THE FUTURE IS IN AUTOMATION AND ROBOTICS WITH NEW AUTOMATIC CONTROLS OF THE PROCESSES IF WE ARE TO HAVE ANY PRODUCTIVITY GROWTH IN THIS DECADE. WE MUST INITIATE A POSITIVE PROGRAM NOW TO MAINTAIN OUR LEADERSHIP IN THE WORLD. THE AIR FORCE HAS INITIATED AN EFFORT TO DEVELOP A "FACTORY OF THE FUTURE" TO OFFSET RISING COSTS AND DECLINING PRODUCTIVITY. SEVERAL AEROSPACE COMPANIES LIKE BOEING, GE, GD/FW, HAO, NORTHROP, ETC., ARE INVOLVED WITH THIS EFFORT.

WE WITHIN NASA HAVE INITIATED AN AGENCY-WIDE PRODUCTIVITY IMPROVEMENT PROGRAM TO SEEK WAYS TO MAKE QUANTUM JUMPS IN PRODUCTIVITY. HOWEVER, NASA NOR THE AIR FORCE CAN DO IT ALONE. INDUSTRY MUST BE A FULL PARTNER IN THIS EFFORT.

IN CLOSING, I CHALLENGE ALL OF YOU, BOTH GOVERNMENT AND INDUSTRY ATTENDEES TO WORK TOGETHER TO IMPROVE PRODUCTIVITY IN THE SOLDERING TECHNOLOGY. YOU HAVE THE VEHICLE TO DO THIS WITH THE NWC SOLDERING TECHNOLOGY PROGRAM.

The Use of Water Soluble Component Retention
Materials in Printed Wiring Assembly Fabrication

Prepared by:

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THE USE OF WATER SOLUBLE COMPONENT RETENTION
MATERIALS IN PRINTED WIRING ASSEMBLY FABRICATION

INTRODUCTION:

At last year's seminar, Dan Niebauer and myself presented a paper which reviewed evaluation of various component hold down systems for soldering, with particular emphasis on the use of polyglycols.

This paper represents a culmination of the evaluation, in that a technique, based upon water soluble polyglycol materials, has been in use at the Litton Guidance & Control Systems Division, Grants Pass facility, for eight (8) months.

This is a relatively simple technique, in which retention material is spray applied to the topside of a loaded assembly, prior to wave solder for retention of components, thereby allowing pre-solder lead cut. This results in a substantial cost reduction (\$\$\$) in terms of both eliminating the necessity of double pass soldering and minimizing touch-up of lifted or tilted components.

MATERIAL APPLICATION:

The sprayer utilized is a hot melt applicator with a heated hose and airless spray gun. The material is placed in the pot, heated to 200°F, and continually cycled through the hose, back into the pot, under a pressure of 17 ± 2 psig. When the

Page 2.

spray is initiated by depressing the trigger on the spray gun, a mist of finely dispersed retention material is uniformly sprayed onto the topside of the assembly. Thickness uniformity is maintained by controlling the spray pressure, spray pattern, material temperature, and utilizing a box spray technique with a minimum of two (2) positions.

The material solidifies to form a strong bond between the components and the printed wiring board. Retention values of 5 lbs/in² have been measured. Solidification occurs in about three (3) minutes with a typical thickness of 100 mils of applied material.

COMPONENT LEAD CUTTING TECHNIQUES:

Once the material solidifies, the assemblies are ready for lead cut. This is easily accomplished, utilizing either:

1. Hand clip via pneumatically operated clippers for lead protrusions of ≤ 0.025 inch or,
2. By lead saw for ≤ 0.025 inch lead protrusion requirements.

Since the assembly has not been exposed to wave solder temperatures, it is not warped and requires no special fixturing, e.g., vacuum, to insure a flat cutting surface.

A minuscule amount of retention material leaks through to the

Page 3.

far side of the printed wiring board. That which does leak through, acts as a lubricant and does not create a mess.

Our procedure allows a twenty-four (24) hour maximum delay between retention material application and wave soldering. Boards which are not immediately wave soldered are stored in desicator cabinets.

SOLDERING:

In order to assure a degree of reproducibility and a successful wave solder operation, each unique assembly part number has an engineering established soldering schedule. (Figure 1.)

This schedule lists pertinent parameter definition for each assembly including, conveyor speed, topside temperature, pre-heater temperature, etc.

When retention material is used on an assembly with a schedule which has been established without the material, the topside temperature is reduced by about 150°F. In order to compensate for this slight decrease, the conveyor speed is decreased from 0.2 to 0.4 ft/minute, depending upon board type.

We have noticed that certain conditions of printed wiring board solder quality deleteriously effects solderability when retention material is used. If the condition is noted before-

hand, retention material is not used. This condition results in marginal solderability under any circumstance, but is accentuated when retention material is used.

We have also noted that the material exhibits a definite pot life in terms of its effects on solderability. Under normal production flow this would not occur since the material would be continuously replenished with fresh material. If, however, the material is allowed to remain at pot temperature of 200°F for extended periods without replenishment with fresh material, solderability defects result when the material is eventually used on assemblies. This degradation can be observed by a shift in the Infrared Spectra and probably results from an oxidation of the material even though the sprayer is a closed loop system. The system pot life is about seventy-two (72) hours and is easily avoided by continual make-up of fresh material or by periodic material change out.

Since the material is applied to the topside of the assemblies, very little drips onto the preheaters during soldering.

CLEANING:

Since the material is soluble in both water and organic solvents, removal from the soldered assembly is easily accomplished. Our cleaning process utilizes an in-line aqueous cleaner immediately after wave solder. Two wash sections insure complete removal of

Page 5.

flux, oil, and retention material. The process is monitored frequently.

Additionally, assemblies are in-process cleaned, utilizing organic solvents, by a combination of IPA soak/brush and vapor degreasing, using a halogenated hydrocarbon/alcohol blend. They are also final cleaned to MIL-P-28809 requirements prior to conformal coat, using aqueous cleaning techniques.

SUMMARY:

This component retention system has been in production use for eight (8) months. No cleaning problems have been observed and few solderability problems have been encountered. Production costs have been reduced due to elimination of the necessity for double pass soldering and reduced touch-up rate due to excessive lifted/tilted parts.

ADDENDUM I.
WAVE SOLDER SCHEDULE

BB/PN
765131-1

ASSEMBLY #
765130-1

P/A #
913

GENERAL MASKING INSTRUCTIONS:

USE FLEX MASK P/N N/A PER MPP-N-107 PAR. 7.1.1 AND 7.2

MASK PER INSTRUCTION BELOW AS CIRCLED PLUS ANY SPECIAL INSTRUCTIONS IF APPLICABLE.

1. MASK ALL UNUSED PLATED-THROUGH HOLES.
2. DO NOT MASK UNUSED PLATED-THROUGH HOLES.
3. MASK ALL MOUNTING HOLES THROUGH GROUND PLANES.
4. MASK ALL GROUND PLANES EXPOSED TO SOLDER WAVE.
5. MASK ALL TEST CONTACT FINGERS.
6. MASK ALL OPEN GAPS IN FIXTURE AFTER BOARD MOUNTING.
7. MASK PER WORK INSTRUCTIONS.

SPECIAL INSTRUCTIONS: (FOR ASSEMBLY NUMBER LISTED AT TOP OF PAGE.)

NO MASKING REQUIREMENTS

MINIMUM CONVEYOR SPEED LIMITED TO $\pm$ 2.0 FT/MIN.

TOOLING:

☐ NO SPECIAL TOOL REQUIRED.

☒ USE FIXTURE TOOL NUMBER T-217038

CONVEYOR SPEED INSTRUCTIONS:

CONVEYOR SPEED WITH WAX $\pm$ 2.1 FT/MIN.

CONVEYOR SPEED WITH WAX 1st Pass 2.4 FT/MIN 2nd Pass 2.8 FT/MIN

SPECIAL INSTRUCTIONS: USE MEDIUM OIL FLOW SETTING

SPECIAL CLEANING INSTRUCTIONS:

☒ TOP PLATE REMOVED

☐ TOP PLUX ALL JUNCTIONS

PREHEAT SETTING 1250 °C

SPECIAL CLEANING INSTRUCTIONS:

183 °F N/A °C

N/A

DATE OF CHANGE:

TOTAL NUMBER OF SOLDER JOINTS:

DATE 1/15/31

505

DATE 1/15/31

MAXIMUM ALLOWABLE DEFECTS:

DATE 1/15/31

15

BOTTOM SIDE TEMP SETTING CHANGED FROM
1150 °F TO 1250 °F 1/15/31

Evolutionary Operations

On The

Wave Solder Process

Glenn Arrant

TRW LSI Products

La Jolla, CA 92038

Evolutionary Operations (EVOP) is a method of investigation of a process where the process is varied to achieve maximum or minimum result of a dependent variable.⁽²⁾ EVOP exploits the best variations of a process by a method which is one step beyond control charting. The math required for this method is simple and can be done by any individual. The advantages of EVOPs is that no capital equipment is required and no increase in personnel is required.

I plan to cover the method of starting an Evolutionary Operation study, the math that you will need to use, what you can expect in terms of problems and where to limit your studies.

Basic Math Requirements

Frequency diagrams will play an important role in your evaluation of the process. It will tell you if your distribution of defects is normal, bimodal or hypergeometric. (See Table I for examples.) The reason I chose to use frequency diagrams is that I wanted a method that was very simple to use. Any person can compare a graph to a standard and tell if the process is maximized (hypergeometric) or out of control (bimodal). This eliminates the need for using χ^2 testing which can introduce errors. It has been my experience that everytime someone must go to a table for a constant there are errors introduced in the early stages of an EVOP process which can be devastating.

The frequency diagram should be interpreted as follows:

The diagram can be assumed to be normal if $s_s < \bar{x}_s$ or $\sigma_o < \mu_o$, there is no more than one space between percentages, and there is a relative peak to the diagram. (See Table II.) This is the type of diagram you may start with but you will want to improve it so that it becomes hypergeometric. Hypergeometric diagrams (single sided) will look somewhat like the function $f(x) = \frac{1}{x}$. Hypergeometric distributions have the following characteristics: $\bar{x}_c \leq s_c$ and the graph looks like $f(x) = \frac{1}{x}$. See Table II for an example.

You will want your process to approach the hypergeometric curve from the normal curve. The bimodal distribution represents a process that is very likely out of control. It can also represent a biased error such as "low preheat temperature" or a "solder wave that is too high". You must be careful in interpreting these results as future defect percentages are based on past experiences. Empirical feedback has its faults.

Referring to the data sheet in Table III I want to define the following terms:

Cycle: A cycle is a production run where the settings controlling the process are not changed.

Phase: A phase is made up of as many cycles as deemed necessary to make a decision about a process setting (usually limited to 8).

$\bar{x}_c$: $\bar{x}_c$ is the mean of the defects found in the solder joints for a cycle (usually expressed as a percent of possible defects).

Example: Three boards that contain 2, 3 and 4 defects respectively and have 100 plated through holes have a 3% $\bar{x}_c$.

$$\bar{x}_c = \frac{\sum_{i=1}^n x_{ni}}{n} \quad (\text{Mean of a cycle})$$

$$\begin{aligned} \underline{s_c}: \quad & \text{Sample deviation for } n \leq 30 \quad s_c = \left[\frac{\sum_{i=1}^n (x_{ni} - \bar{x}_c)^2}{n-1} \right]^{1/2} \quad (\text{Standard deviation of cycle}) \\ & \text{for } n > 30 \quad s_c = \left[\frac{\sum_{i=1}^n (x_{ni} - \bar{x}_c)^2}{n} \right]^{1/2} \end{aligned}$$

Standard Error: The standard error is the method we shall use to make judgments about the process. $se = \frac{s_c}{\sqrt{n_c}}$

$$\mu_p = \text{phase mean} = \frac{\sum_{c=1}^n \bar{x}_{cn}}{n_c} \quad (\text{The average of all the cycle means})$$

$$\sigma_p = \left[\frac{\sum (x_{cn} - \bar{x}_{cn})^2}{n_p} \right]^{1/2} \quad (\text{Standard deviation of all the cycles})$$

$$\bar{x}_{cn} = \mu_p = \text{Mean of all the cycles.}$$

n_p : The number of cycles run.

There are some aspects of statistics with respect to hypergeometric distributions that will be apparent at the outset. The standard deviation does not hold as much significance in calculations for standard error and

it is more difficult to find out if a process has improved (significantly) when the frequency diagram and the statistical tests ($\bar{x}_c = s_c \pm 10\%$ of x_c or $\mu_c = \sigma_c \pm 10\%$ of μ_c) indicate that the process defects have approached a hypergeometric distribution. The test for significance will change the amount of significance we place in the measurements. If your process is at a point of being hypergeometric it is in all likelihood under control.

I want to introduce the concept of acceptable percentage of errors. Error (defects) will occur regardless of the process. You will need to decide on how many errors are acceptable, 1%, 3%, 5%. This is a decision that must be made by the EVOP committee. This is when the committee agrees that the machine is producing minimum defects. When the committee sets a defect goal then the goal is μ_p for the hypergeometric function. By this time control charting may take over and I suggest no more than two sigma limits for the control chart.

The primary reason for my redefining the EVOP method from the one in Box and Draper is that the method in Box and Draper is complicated and it is geared to the chemical industry. There are infinite independent variables and minor changes in any one of them could cause cross product changes. I don't feel that this is the case with a wave solder machine. The cross product changes are insignificant (in my experience) and I needed a method that was statistically sound and one in which any person could work the data sheets.

EVOP is not an overnight answer to solder defect problems. It is slow but it works extremely well. It gives a method for determining the next logical step in process maximization. Continental Controls (a division of Bendix) was getting zero defect boards in three phases using these methods.

EVOP Method

The first thing that will need to be done is that you will have to define the defects that you consider critical. This may vary from product to product due to customer requirements. The EVOP process with which I was associated defined defects in three classes. Holes, voids and excessive solder were the classes that were used. You must understand that this was on a commercial product with internal solder standards. This same method was used on military products to MIL-S-45743 standards but the process took much longer to perfect due to inspection standards, board geometry and MIL inspection requirements.

Board geometry is a tool that you can use to your advantage. You can use the same EVOP settings and study for boards of approximately the same geometry so long as the following conditions are met:

1. The difference in packing densities are less than 6%.
2. The surface area and thickness of the PCB are the same.
3. The types of components do not vary greatly. (This is discussed more in the next paragraph.)
4. The board top temperature does not vary more than 10% when measured at the center of the PCB.

As you run your process there may be things in the board configuration that present special problems. Large transistors and heatsink or connectors with large posts present a biased error. These types of errors should be ignored. The reason for this is if you tried to solder these from the wave solder machine you would probably destroy the rest of the components on the board. The rule is to gear your evaluations to the majority of the types of solder joints that are represented on the PCB.

EVOP Committee

An EVOP committee will have to be formed. This committee will make judgments on what parameters are to be varied and how much (independent variables) and if the defects are significantly less (or more) than past phases. Defects are considered dependent variables. The committee should be a minimum of 2 people but not more than four. It is the option of the various managers as to who will be on the committee. I would suggest that a Quality Engineer and a Manufacturing Engineer be on the EVOP committee.

EVOP Process

The actual method of EVOP is that 3 dependent variables are varied in a consistent, orderly manner. Dependent variables are any machine setting that could affect the solder process. (Examples: belt speed, solder temperature, flux density.) The reason that you vary in three's is that your mind is a three dimension device and it can't picture more than three variables at one time. The data is taken after wave soldering and before touch up. Data is gathered by board type and correlated that way also. Defects should be expressed in terms of percentage defective. Therefore one data sheet will be required for each run. Eight cycles should be run and then a decision should be made on whether a change in independent variables is beneficial or not. When a change is beneficial the present method gives a confidence of approximately 75%. (This number was chosen because any process will vary one standard deviation (65%) and to wait until one is 90% confident that a process was changed is too stringent.) Thus 75% was picked because

results would be immediate.

Referring to Table III I shall explain how the EVOP cycle work sheet is filled out.

(a) (b) You will need to keep track of which part numbers have been run on the particular process. EVOP should run regular production material otherwise you may never get enough boards for a statistically significant result. (You may want to consult ASTM pamphlet E122 for more information.)

(c) The cycle mean is entered here and (d) the deviation is also entered. The frequency diagram is plotted in the area (e) and the cycle number is written in at (f). The box at (g) is the setting of your machine. These boxes are only a suggestion; the mandatory information is $\bar{y}$, s and cycle number. There is no reason to limit yourself to eight cycles per phase but you should not run less than eight.

The phase data sheet has the same information essentially except that the data from the cycles is entered and analyzed. If you are setting a base line (initial run) then no computation is required. The formulas for the computations are written at the bottom as a reminder. A phase data sheet is on Table IV.

Each type of defect you are examining requires a cycle sheet and phase sheet. Analysis between phases of the defects should be done as outlined in the next paragraph. I sometimes choose a visual method for managers because I find it is more readily understood and retained. Pictures sometime give a larger view of what the process is really doing. Bar graphs or frequency diagrams usually work best. I do not recommend them for everyday use.

To compare phases you may run into the following problem. Assume that

you are looking at a total of three types of defects. Two of the defects show reductions but the third shows no change (or in some cases is worse).

How do you proceed?

The first step is to check the EVOP work sheets to ensure that the process controls were set on the points indicated by the EVOP committee.

Second, check to see that the coefficient of correlation for each of the cycles is the standard error of the phase divided by the deviation of the cycle. The values should approach zero (perfect correlation). There should be no more than 25% difference between any two values of correlations or between the high and low values. If there is a difference, discard the whole test because there are biased errors in the experiment (if the settings were changed or the operator has made an error in loading or logging).

It has been my experience that the defects (of all types) will become better or worse in unison. They do not appear to function independently. I want to caution the reader that my data is somewhat limited but after three tries and getting zero defect boards, it does give me some confidence about my methods.

Possible Sources of Error

I want to list (statistical) major and minor errors and how they can affect the outcome of the EVOP process.

1. Operator Errors

- | | |
|---|--|
| a) Incorrect loading | Statistical effect. Frequency diagram shifts to different mean, correlative coefficient is too high. |
| b) Operator changes one or all settings | This could vary from a small improvement to the same answer in a). The process engineer should audit the process to ensure the conformance to the EVOP plan. |
| c) No change in the process between two phases | There are two possible answers; the settings were not changed or the process is at maximum condition. |
| d) The process is not changing; is it at a maximum? | After two phases of eight cycles, if the defects do not change there is a 75 to 90% chance that the process has maximized and it will not continue to improve. |

A wave solder machine is not a black box or a known function. We are just beginning to realize all the scientific aspects of the wave solder process. I do not believe in black clouds over a process or person, causes without effects or processes that can't be understood. The EVOP committee should move the process in a logical manner toward the goal of zero defects.

Managers should understand that EVOP takes time and man power to operate. It is not a quick answer. It is the best way I know to get the people who are operating the wave solder machine involved in the decision making process about the machine.

The EVOP committee should answer the following questions:

- a) What is our goal?
- b) What is the acceptable percentage of defects per board?
- c) What is our current status?
- d) Are there any alternatives that we have not considered such as sending out the work to be soldered by an outside vendor?

The EVOP committee should set reasonable timetables to accomplish the goals agreed upon by management.

When the goals are complete, control charting should take over.

Conclusion

The method I have outlined is the method I developed for use at my last position at Bendix. It worked for them and it can work for you. I used this method because it was the best one for me. I'm a firm believer in what works for you is best. That is what this conference is about, sharing ideas and methods. My method worked for me. If you can't see it, or you don't like it, change it and come tell us next year.

TABLE I

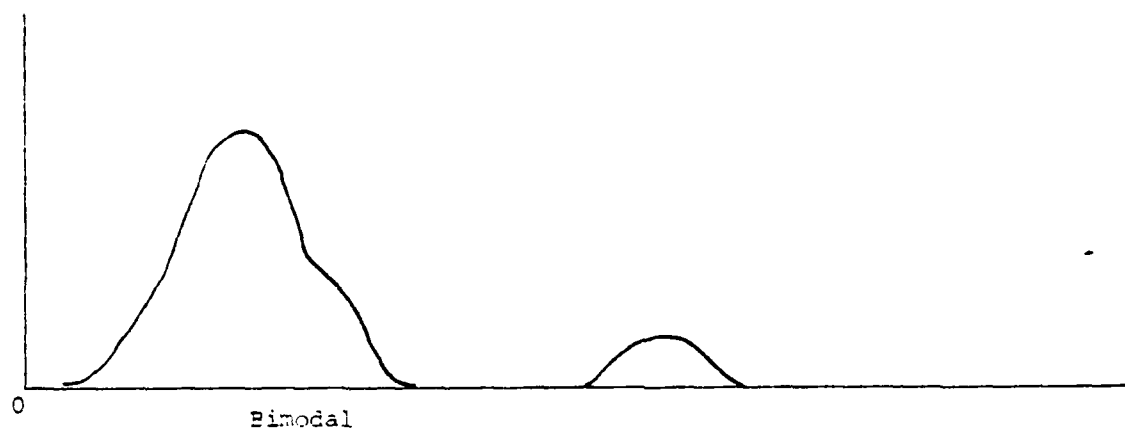
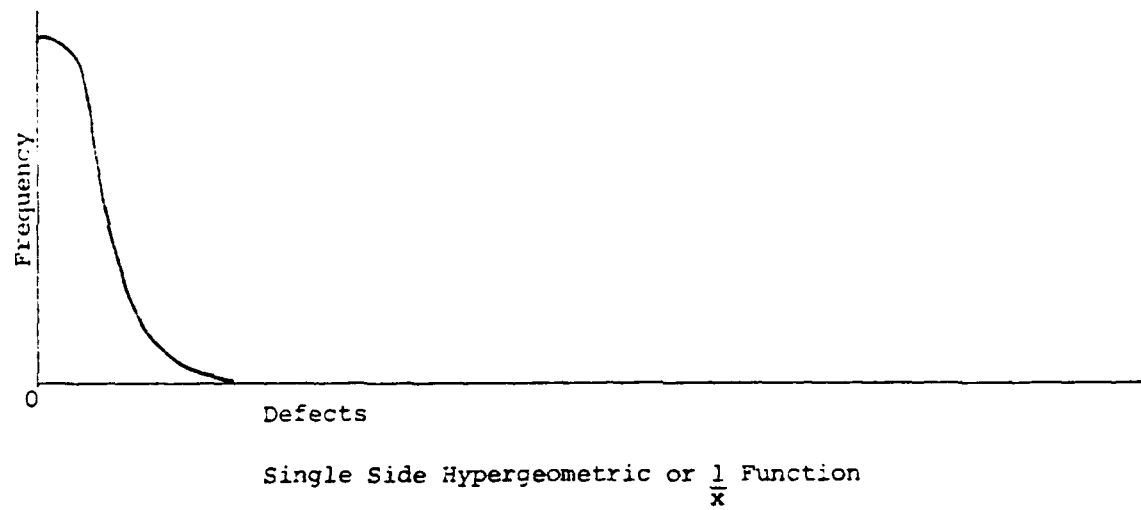
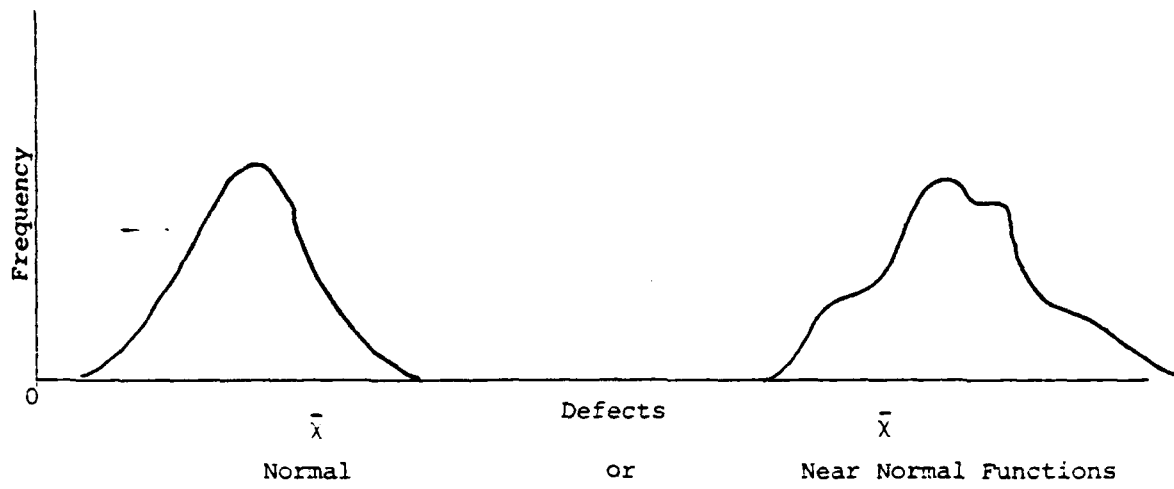
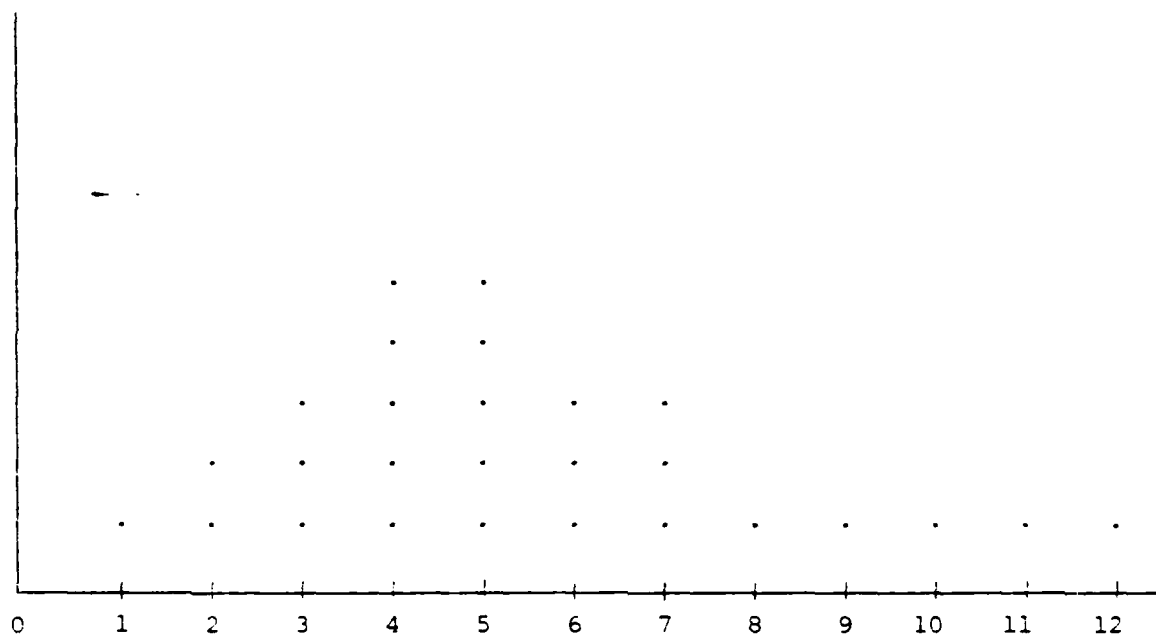
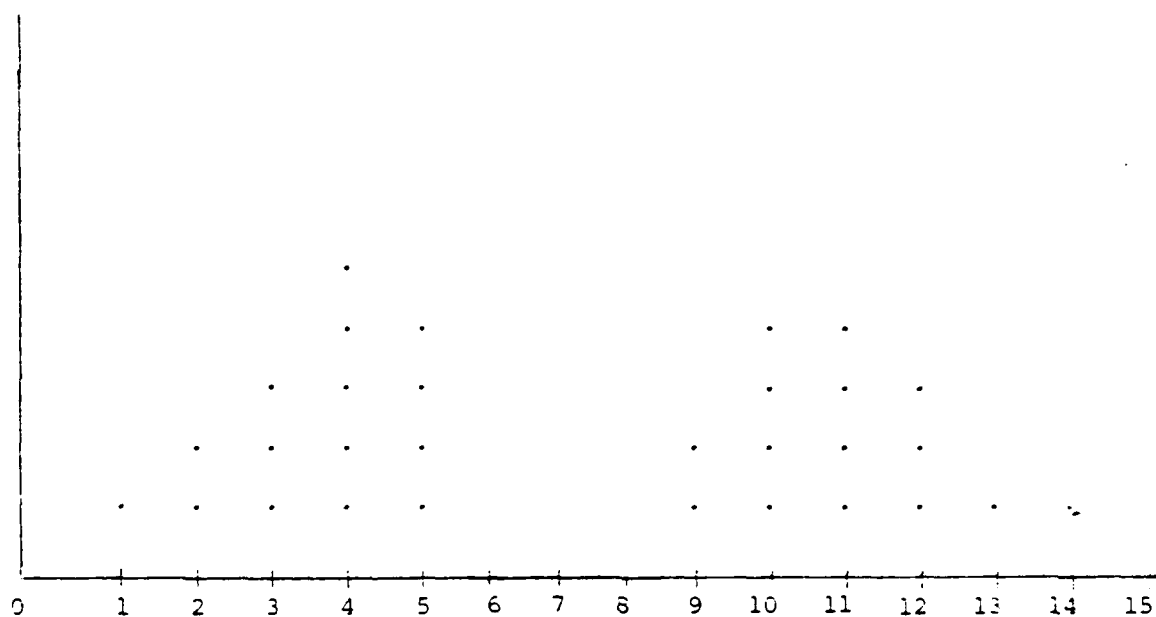


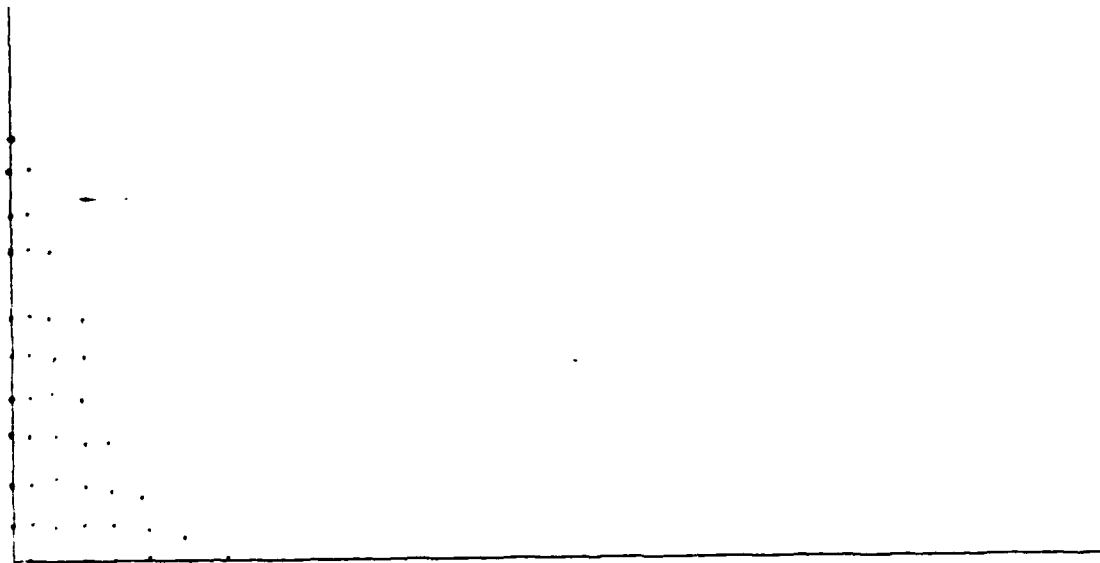
TABLE II



Near Normal



Possible Biased Error



0

TABLE III

EVOP CYCLE WORK SHEET

P/N _____ a _____
W/O _____ b _____
Cycle $\bar{X}$ = _____ c _____
s = _____ d _____

Settings

Wave Height = _____
Solder Temp. = _____
Flux Density = _____
Belt Speed = _____
Preheat Temp. = _____
Flux Temp. = _____

9

e

0

% Defective

TABLE IV

EVOP WORKSHEET

Worksheet # _____

Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8
$\bar{x}_s =$	$\bar{x}_s =$	$\bar{x}_s =$	$\bar{x}_s =$	$\bar{x}_s =$	$\bar{x}_s =$	$\bar{x}_s =$	$\bar{x}_s =$
$s_s =$	$s_s =$	$s_s =$	$s_s =$	$s_s =$	$s_s =$	$s_s =$	$s_s =$

Phase $\bar{x} =$ _____ $s_p =$ _____ $se_p =$ _____Last Cycle $\bar{x}_p + 2se_p =$ _____ to _____ Present $\bar{x}_p$ _____ from worksheet # _____
 $+ \Delta = \bar{x}_p + 1.15se_p - \text{present } \bar{x}_p =$
If $+ \Delta > 0$ Process Has Improved

Notes:

Settings

Present	Present	Δ From All Settings
Wave Height =	Wave Height =	
Solder Temp. =	Solder Temp. =	
Flux Density =	Flux Density =	
Belt Speed =	Belt Speed =	
Preheat Temp. =	Preheat Temp. =	
Flux Temp. =	Flux Temp. =	

$$\mu_p = \frac{\frac{n_p \sum \bar{x}_n}{1}}{n_p}$$

$$\sigma_p = \sqrt{\frac{(\bar{x}_x - \mu_n)^2}{n_p}}$$

$$se_p = \frac{\sigma_p}{\sqrt{n_p}}$$

P/U _____

W/U _____

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ABSTRACT

When vapor phase reflow techniques were used to solder components onto polyimide multilayer circuit boards, "frosty" - appearing solder joints were a regular occurrence on the leadless ceramic chip resistors and capacitors. Components with through-hole-mounted axial leads rarely exhibited the problem. A thorough analysis of the solder joint revealed a final metallurgy which was substantially different from both the intended final result the initial joint make-up.

In this paper, kinetics of intermetallic compound formation, and of base metal dissolution into molten solder are evaluated to explain the cause of the problem and to implement a solution. Resulting revisions to the components' procurement specifications, and to the vapor phase equipment are discussed.

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SOLDERABILITY DEFECT ANALYSIS

by

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SOLDERABILITY DEFECT ANALYSIS

Introduction

The following is a typical scenario between a systems manufacturer and a component vendor. We will call them Joe Radar and Charlie Chips.

Joe says, "I want to buy 200,000 Zip 7 op amps and here is my spec."

Charlie answers, "Swell! I can supply them in the 4th quarter 1982 at \$100 each."

Joe replies, "Great! I can't wait to get them. I will schedule production so that they will be needed at the exact time they come in."

Six months pass and both Joe and Charlie are on schedule. When Joe receives the op amps, he solderability tests them at incoming and they fail. He then gets on the phone to Charlie and this is what we hear.

Joe: "Those damn op amps you sent me won't pass solderability. What are you going to do? I've got production stopped and sent all the line people home."

Charlie replies, "What's wrong with the solderability?"

Joe answers, "I don't know; they just won't pass! I won't pay you til I get good stuff!"

Now we have an impasse. Neither Joe nor Charlie knows what's wrong, in a technical sense, and both are in trouble. This scenario happens all too often. It is this exact problem that solderability defect analysis attacks. To explore the problem a little deeper, we find that the component manufacturer may be small and does not have high technology packaging or analytical resources in-house. The user or systems house often has elaborate research resources or knows where to get them. We will talk of this later.

The point of the above dissertation is that if the component vendor knows exactly where his process has gone out of control, he could offer a logical and expeditious fix.

Solderability Defect Analysis

What is solderability defect analysis? It is the analytical evaluation of a particular solderability defect. This evaluation results in a characterization of the defect which in turn can be combined with other information to determine the cause of the defect.

Why defect analysis?

First, solderability defects cause increased costs and field failures. The maximum strength of a solder joint is decreased. Also, complex environments which result in fatigue stresses will result in early failure of joints with solderability problems. A recent case showed a joint which should sustain at least 3000 thermal cycles failed in less than a hundred because of a solderability problem.

Second, the nature of a defect can be used to pinpoint a component manufacturing problem. Examples of this will be demonstrated later in this paper. In addition, the hard analytical evidence is difficult for a component manufacturer to refute. This can go a long way in establishing a useful relationship with that vendor.

Third, if a component manufacturer knows what to fix, he will usually fix it. It is advantageous for him to do so from both a cost standpoint as well as good from a public relations standpoint. If a fix is made, it will often be across the product line. Therefore, a fix for user "A" will be a fix for all customers.

From this, one can see that solderability defect analysis is as much a philosophy as a technical approach. It is also a commitment from both a corporate standpoint as well as an industry standpoint. The implications here are quite evident. The problems are industry-wide and must be attacked on a cooperative basis. We see solderability defect analysis as an effective tool.

Analytical Method

The premise in solderability defect analysis is that all such defects have a physical and metallurgical meaning. This could mean a lack of metallurgical bond, gas evolution, etc., which result in a pre-service crack in the solder joint.

In order to determine the true nature of the defect, a "method" can be employed. This method is analytical and can follow a set procedure.

The tools used are available in most modern, moderately well-equipped laboratories today. The first line tool is the optical microscope. Two types are needed; a stereomicroscope capable of magnification of 5-50X (10-30X is acceptable), a metallurgical microscope (and ability to prepare samples) capable of up to 800X magnification. The second major tool is a scanning electron microscope. While they may sound exotic, it is really not in today's technology. In fact, most semiconductor manufacturers of modest size or larger have one in-house. They just don't use it to full capabilities.

The last major piece of analytical equipment is an electron microprobe analyzer. This also may sound like an exotic technique but it is fact that most scanning electron microscopes are equipped with one of the energy dispersive type.

In addition to the above, one also needs the ability to solderability test samples. Preferably, the equipment should be able to test to MIL-STD-202, Method 208, using type "R" flux.

The actual method of solderability defect analysis follows the steps as outlined below.

1. Solderability test a sample while retaining an untested sample.
2. Examine using a stereomicroscope and note characteristics of the defect in detail. Document defects.
3. Prepare a sample of surfaces with defects for SEM/EMA analysis.
4. Document characteristics of defect in detail. Determine if base metal is exposed in defect.

- 4.a. If appropriate, examine a new, untested sample. Look for defects in surface deposit or excess contaminants on surface.
5. Remove from the SEM/EMA and metallographically section through a typical defect in the appropriate plane. Also, prepare a new, untested sample.
6. Examine sections in a metallurgical microscope for abnormal interface characteristics (lack of metallurgical bond, dirt under plated deposit, etc.). Document.
7. Examine all data and interpret. Review with manufacturer's processing steps in hand. Make decision.

Once step 7 has been completed, several things can now happen. One of these is a decision to rework or not. Another is a summit meeting with the manufacturer to map out a program to put his process back in control.

The cost of a typical solderability defect analysis is \$500 or less. This expenditure could save thousands and up. In one extreme case, we spent about \$50,000 in a total program and saved possibly \$3 million.

Defect Analysis

In a solderable system, a continuous metallurgical bond must be easily made to the solderable surface of the parts to be joints. To review a basic concept, this surface should be defined. In most solderable components (leads, PWB's, etc.) a surface deposit such as tin, tin-lead, gold is used. This deposit is either over the actual base metal or over an underplate such as nickel or copper. When exposed to molten solder, these "solderable" deposits either melt or alloy with the solder. The end result is that the metallurgical bond is made to either the underplate or to the lead or run base metal. Based on this knowledge, one can list the basic defects which can occur. This list is amazingly small.

1. A surface deposit which prevents melting or alloying of the coating. Epoxy or paint on the lead will cause this type of defect. A thoroughly oxidized, too thin coating also falls in this category. An example is a very thin tin deposit which has seen extensive, high temperature burn-in.

2. The wrong surface coating. This is a variation on the first defect creating condition. Examples of this are alloy golds which may have an oxide film on the surface or an out of control tin-lead coating which may not melt or alloy properly.
3. Entrapped or co-deposited materials in the coating. The most common is co-deposited organics which result in a dewetting condition.
4. Dirt at the coating/base metal or underplate interface. This prevents a metallurgical bond from being properly made. Causes non-wetting.
5. Oxides at the coating/base metal or underplate interface. This again causes non-wetting. It is the result of improper cleaning or plating procedures. It is also the most common defect seen in devices with glass to metal seals.

This list covers 95% of all the solderability defect causes found in real life. However, it must be recognized that the iterations and the intensity of the specific conditions may vary widely. This is where knowledge of the component manufacturing process comes in. Comparing the above list, defect analysis data and the component manufacturing process, one can pinpoint the problem causing the solderability defect.

Hint to the Handyman

In solderability defect analysis, one of the keys is getting the maximum information from the analysis. This can be done by using the right detailed technique. The following is a hint for obtaining the maximum information.

In the examination of defects which occur in nickel or Kovar based leads, it is nearly impossible to optically discern non-wetting due to the fact there is no color difference. The SEM is useful here using elemental contrast. The non-wet nickel or nickel-iron surface will appear darker than the surrounding solder. The technique can be used to separate low atomic number organics from the metallic background.

Problem Components

It has been found that certain classes or generic types of components are more susceptible to solderability defects than others. Of these, semiconductor devices, with glass or ceramic to metal seals are at the top of the problem list. There are several reasons for this, one of which is the basic manufacturing process of making a glass or ceramic to metal seal. The following is typical:

- 1) pre-oxidize leads
- 2) assemble with glass bead
- 3) make oxide seal to glass
- 4) clean oxide from leads
- 5) plate

The solderability problems which are found on components which have seen such a manufacturing process is usually related to the incomplete removal of the oxides prior to plating. In many cases, the manufacturer over-oxidizes the leads which results in a thicker, harder to remove oxide. In addition, the oxides which might not have been removed can be easily plated over as they are conductive enough.

Examples of Solderability Defect Analysis

Case #1

This case involved the solderability failure of a glass bead diode. The leads are copper. Figure 1 shows the SEM view of the solderability tested surface. Microprobe analysis of the defect areas showed exposed and incomplete formation of copper-tin intermetallic compounds. Examination of a new, untested lead showed a dense, uniform electroplate of bright acid tin. The information indicated a problem at the electroplate/base metal interface.



Figure 1

A sample of the diodes just prior to tin plating was requested. Upon receipt of these samples, it was immediately evident what the problem was (see Figure 2). The leads were covered with black spots (cupric oxide). Glass bead diodes see considerable thermal processing which oxidizes the leads. This oxide must be removed prior to plating. If not removed, the oxides can be easily plated over as they are conductive enough. The exact cause of the problem was that nobody was inspecting the leads prior to plating to see if they were properly cleaned.

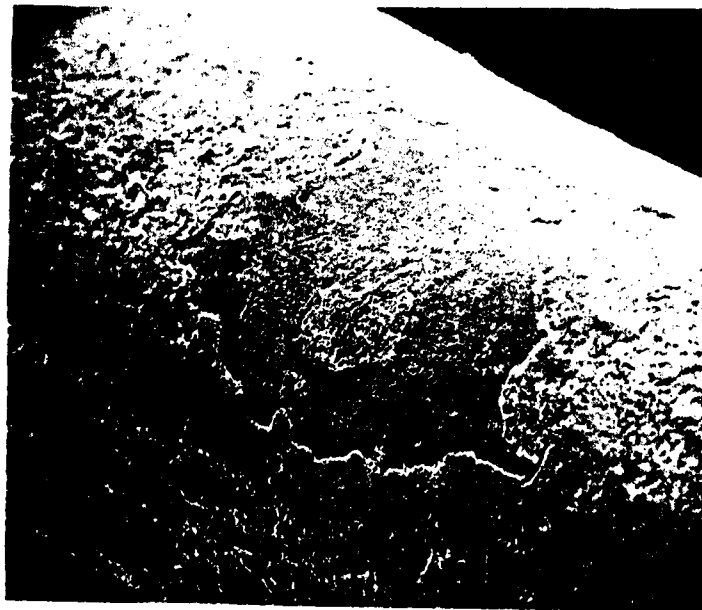


Figure 2

Case #2

This case involved a Kovar leaded microelectronic device. Figure 3 shows the solderability tested surface and the defects. Microprobe analysis showed exposed Kovar. Metallographic sections showed a lack of bond of the solder to the base metal. This is shown in Figure 4. Sections of new, untested leads showed defects at the plating/base metal interface. As in the previous case, the cause of poor solderability was a lack of proper cleaning prior to application of the solderable finish. In this case also, it was tin plate.

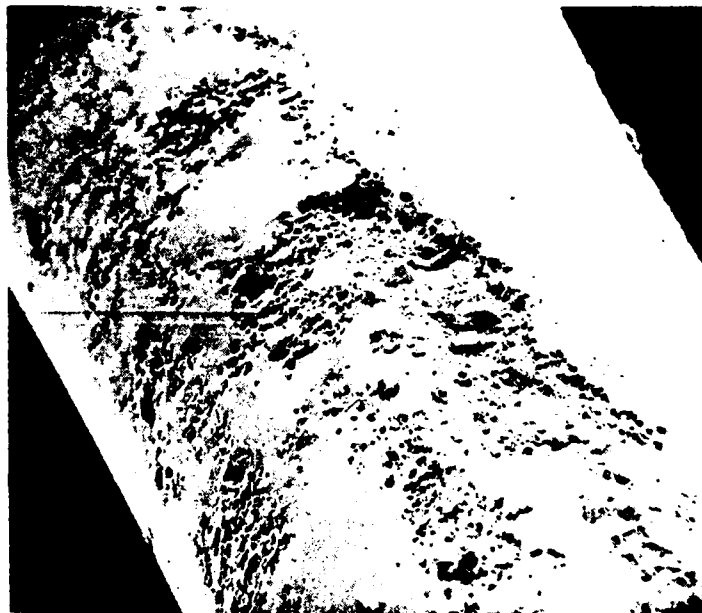


Figure 3



Figure 4

Case #3

This case also involved a Kovar leaded microelectronic device. Figure 5 shows the solderability tested surface with the defects. Microprobe analysis showed there was no exposed Kovar in the defect areas. Metallographic cross-sections (see Figure 6) showed a good bond of the solder to the base metal. However, the solder is loaded with gas voids. Examination of new, untested leads showed that the surface coating was bright acid tin electroplate. This type of plating is loaded with co-deposited organics.



Figure 5



Figure 6

From the evidence, the indicated source of the problem was that the co-deposited organics were breaking down and resulting in vigorous gas evolution when exposed to molten solder. In addition, the surface coating was extremely thick (1000 μ in). Therefore, it was not completely flushed from the surface during the 5 sec of solderability testing.

Case #4

This case involved severe solderability defects in a dipped mica capacitor. The leads are hot tinned brass with copper underplate. Figure 7 shows the untested lead with the defect. Lumps of organics are seen on the surface. Microprobe analysis found these lumps to be high in titanium. Titanium oxide is the most often used pigment in white paint.

The capacitor bodies are marked with a white epoxy paint. Therefore, it was concluded that the cause of the defect was improper control in marking which resulted in epoxy coating of the leads.



Figure 7

Rework

One of the benefits of solderability defect analysis is the information needed to prescribe a rework method. In many situations, the components which are bad are needed to maintain manufacturing schedules. The obvious tactic is to rework the components in-house.

The most difficult defects to correct are oxides or contamination at the surface coating/base metal interface. The presence of the surface coating prevents easy removal. Rework to eliminate this type of defect involves exposure of the interface and removal of the oxides or contamination. One procedure is to double hot solder dip, fluxing before each dip. The first dip exposes and the second removes. A more extreme procedure is to strip, clean, and replate.

Rework of defects within the surface coating can usually be corrected by hot solder dipping with the appropriate flux.

Rather than expounding on all the rework procedures which could be used, a general guideline can be stated. Any rework method selected should be the gentlest necessary to remove the defect causing poor solderability. Also, each case should be studied separately for determining the appropriate rework.

Summary

1. Solderability defect analysis is a useful tool in pinpointing a component manufacturer's process problem. The keys are the use of analytical tools in conjunction with knowledge of the component manufacturing process.
2. Solderability defect analysis is a useful tool in describing the proper rework method to improve solderability.

Paper given at the 6th Annual Soldering Technology Seminar, Naval Weapons Center, China Lake, Cal., 18 February 1982

EUROPEAN SOLDERABILITY CONTROL.

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INTRODUCTION

Last year when I was at the China Lake Soldering Seminar I was very much impressed by the serious work which was laid down here in the field of soldering. I was impressed by a picture in Mr. Rabys location which was taken when the first printed wiring board without faults was celebrated. This is a really remarkable performance.

This picture and the fact, that the American Military invited me to give this lecture, gave me the idea to tell you about my first soldering job, which resulted in zero defect soldering joints too and to tell you how this problem was solved, what we learnt from it and what consequences this work had.

THE SOLDERING PROBLEM

Our laboratory has worked with the solder globule method, which is a solderability test method since 1959. But at that time we actually did not know so well how to use this method in reality. It was only, when we had to use the method in practice that we were able to get a good understanding of it. In 1965 LM Ericsson had to deliver a code switch system to the US Military. This system did not work correctly. After a thorough investigation it was found that the solder joints in the multiple, were the reason. This was a surprising fact, because LM Ericsson had at that time delivered many code switching systems without any complaints. They were manufactured precisely in the same way as the equipment for the US Army was. What was the difference? We found out that the equipment was used in a way it was not intended for. It was operated at 4V instead of the normal 48V. As it was stated that the solder joints did not meet these new requirements we started an investigation. The multiple wires were soldered in a

high frequency apparatus with a maximum temperature of 380°C and a soldering time of 1.8 s. We tested the multiple wires in our solder globule tester and found that the round 0.6 mm diameter tinbronze wire should not be solderable. This was at least some agreement with the fact, that the solder joints caused trouble. A sectioning of the solder joint, see fig 1, confirmed the findings.

Before I continue the story I have to explain briefly the solder globule test and the evaluation system we use.

THE SOLDER GLOBULE TEST AND THE EVALUATION SYSTEM

In the solder globule test, which is an internationally recognized method and standardized by IEC, a solder pellet is heated to the temperature of 235°C on the top of an iron pin. The sample is dipped into the solder globule and the time is measured when the sample touches the solder until the solder elapses over the sample, fig 2. This test has to be carried out repeatedly. The measured times are then plotted in sequence into a logarithmic normal distribution paper, where the x-axis gives the measured soldering times and the y-axis the number of the conducted tests, or the probability, see fig 3.

In the course of the work which I am describing we found that the curve in the diagram, which is derived from the measured solderability values directly can be compared with production and quality demands. The workshop requires that a solder joint shall be produced within a given time, e.g. 1 s and the quality department requires that e.g. no more than 1 out of 10 000 solder joints shall be defective, which means, that 99.99 % of all solder joints must be perfect.

If you repeat the solderability measurement you will get other values, and other curves, which means that you get a spread for your first curve. Statistics will tell you what spread you can expect and that the spread of the curve depends on the number of samples, fig 4. This is very important for you who want to sell components but even for you who want to solder them. In the diagram we see that a material with an average soldering time of 1 s at the 99.99 % level can have such long soldering times as 1.5 s but even such short ones as 0.74 s. If the agreed soldering time is 2 s for a seller's risk of 5 %, here 5 % confidence, at the 99.99 % level, you have to accept material which needs a soldering time up to 12 s. In normal cases this is unbearable.

The diagram even shows that it is not possible to predict exactly the number of soldering faults. At an average of 1 faulty solder joint out of 10 000 you may expect in our case as few faults as only 1 per 200 000, but it can be as bad as 1 faulty solder joint for every 900 joints.

SOLUTION OF THE PROBLEM

Now back to our problem. When we used the described method we found a curve as curve 1 in fig 5 for the material tested. Curve 1 shows that only 80 % of the material will solder within 1.8 s. And this value corresponded well to the magnitude of number of faulty solder joints found in the workshop. We discussed the problem together with our material supplier and together we improved the material. The exiting point in this development was that we tested the material in every stage of the improvement both with the solder globule method and by practical soldering in the workshop. And the predictions we made on the failure rate were confirmed by the workshop. So we started with 1 bad solder joint out of 300, this is curve 1 in fig 5 improved the material, reached curve 2 and ended up finally at curve 3. Within a very short time we were able to improve the tinning process so much at the wire manufacturer that we obtained curve 3, which tells us that at a soldering time of about 1 s no more than 1 faulty solder joint out of 1 000 000 solder joints could be expected. We followed up our figures with the figures in the workshop, but when we found after 15 000 000 solder joints, that no single solder fault was detected we considered that we had solved this problem. Not only that, the improved solderability did not cost us a cent more.

SOLDERABILITY - ELECTRICAL CONTACT RESISTANCE

However we were not quite satisfied with our work yet. It puzzled us that a solder joint could work satisfactorily when a relatively high voltage was involved but was deemed to fail when a low voltage was applied. So we designed a test, where different solderable wires were soldered into a 60/40 SnPb sample, see fig 6 and measured the contact resistance from the one wire through the solder to the other wire according to the scheme in fig 6. The samples were measured before and after ageing. The ageing was either an oxidation of the samples for four weeks, or an oxidation and salt spray for four days. The results in fig 7 speak for themselves. A well solderable wire did not change the contact resistance even after hard ageing. A bad solderable wire however

showed after ageing an increase of the contact resistance by a factor of 10^6 microohms. From this investigation on we knew exactly what good solderability means and that we needed this good solderability.

SOLDERABILITY OF COMPONENT LEADS

At that time we had even started up the solderability testing of component leads. So we had a certain experience when we got a problem with a printed wiring board. As usual, all other factors were blamed for the bad soldering result except the solderability of the component leads. By the way, the printed wiring board was soldered within 0.8 s. We measured the solderability of all the components on the board. The result is given in fig 8. The first thing which can be seen is that an increase of the soldering time will decrease the number of soldering faults. Anyhow, three components were left which accounted for the rest, a considerable amount of soldering faults. The bad solderability of the transformer leads could be eliminated by changing from brass tag to German silver tag. It was more difficult to improve the solderability of the capacitor leads. The capacitors were not made in our factory. And to the supplier they had an excellent solderability according to MilStd-202. So it was very hard to convince this manufacturer that the solderability of the capacitors had to be improved. And when he finally was convinced he never used the Mil-Std-202 for solderability testing again. He switched over completely to the IEC Solder Globule Method.

THE SOLDER JOINT CONSIDERED AS A COMPONENT

Through all the solderability problems we have had, the discussions what bad solderability means for the function of the electronic equipment, through the statistics we applied for the evaluation of the solderability results, it became obvious for us that we had to regard a solder joint as a component with all the consequences. And the consequences are shown in fig 9 where you can relate the probability that your equipment will work to the number of components and their probability to work. If you have 100 parts, solder joints, and every joint works only with a probability of 99 %, the chance that your equipment will work is then 37 %. If you can increase the chance that your 100 solder joints work correctly to 99.99 % you have raised the chance that your equipment with the 100 solder joints will work correctly to 99%. This consideration in combination with others as pro-

duction volume, production costs which include reparation has made that LM Ericsson has chosen as a general quality level for solder joints the probability of 99.99 %. It has turned out that due to this philosophy the really achieved quality level in many cases is much higher.

SPECIFYING THE SOLDERABILITY REQUIREMENT

When specifying quality criteria for solderability one of the criteria to be specified is the soldering time. Already in the very beginning we requested on good grounds for hand soldering a soldering time of maximum 1 s and for machine soldering a time of 2 s.

As the solderability testing at our company was started in combination with problems in the workshop, we soon found out, that the workshop had problems when we measured soldering times greater than 3 s at the 99.99 % level. Workshops with more sensitive soldering tasks and more accurate soldering operators already started to complain about the solderability when the soldering time which we measured exceeded 2 s.

Our experience gathered on a huge number of solderability tests on component leads showed us, fig 10, that the soldering times were distributed in a certain manner. We found that good solderable material had soldering times shorter than 1 s and the spread for these times was rather small. About 45 % of passive and 70 % of active components belonged to this group. Then we had another group, the material which was difficult to solder or not solderable at all. The group which was difficult to solder started at 2 s, the group which was unsolderable had values above 3 s. This group had a very large spread in the soldering time and amounted to about 20 % for the active and 50 % for the passive components. Then we had a third group where the soldering times were between 1-2 s and this group amounted to 5 - 10 %. Our collected experience from the solderability testing showed us that there is a border line between good and bad solderable material and that this should lie between 1 and 2 s. Statistical investigations showed that it was reasonable both from the view of the buyer as well as from the view of the seller to establish as a solderability requirement a value of 1.5 s.

As small companies, and LM Ericsson is from the viewpoint of the output of a component manufacturer a small company, have difficul-

ties to claim such a solderability from component manufacturers, the industries in Scandinavia agreed in the early seventies on a mutual standard for solderability which in principal is the IEC Solder Globule Method, but defines exactly the solderability requirements in terms of soldering time, 1.5 s, related to an AQL level of 0.01 % and a risk level of 5 %.

SOLDERABILITY AND ECONOMY

Good solderability means even good economy, fig 11.A production volume of 1 000 000 solder joints a year is not large. Let us assume that 40 % of the material has a soldering time longer than 1 s, say 2 s. With a production cost of 27 USD per hour you have to pay 3 000 dollar more for 400 000 joints.

With an estimated failure rate of 1 out of 1 000 000 solder joints and the assumption

75 % repaired for	6 USD / defect in the workshop
15 % repaired for	17 USD / defect in the final check
10 % repaired for	110 USD / defect at the customer

the failure costs will total to 1 800 USD per year and a production volume of 1 million solder joints.

We have tested the solderability of component leads with the Solder Globule Method since 1966. First in special cases. Then the method was introduced for type - testing of components and later for normal incoming test. We have about 30 solder globule testers at LM Ericsson today. It is true that solderability testing is expensive. But the savings are far greater. In one case we could not buy a diode from a certain manufacturer, even though all electrical values were found to be satisfactory in the type - testing. The only property which was insufficient was the solderability. We helped the manufacturer to improve the solderability to the desired level. Then we could buy the diode from this manufacturer and this saved us only in one factory 1 million dollar per year.

THE WETTING BALANCE METHOD

The solder globule method has one disadvantage. You can not detect dewetting effects with it. Therefore it is requested in the IEC

that the solder globule test has to be complemented with a dewetting test, which is a simple dip test, if the globule test shall be valid. This problem does not exist when you test the solderability with the Wetting Balance Test (Meniscograph Test). The IEC has worked out a testing procedure for this test and defined the demands on the testing apparatus. In the wetting balance test the wetting forces acting on the sample are measured over the test time. It has taken a considerable time before recommendations could be made as how to evaluate the obtained wetting force versus time curves.

Even for the wetting balance test it is important to realize the statistical character of the result. This means that you have to test a sufficient number of samples, otherwise you will not get a valid result.

I will give one example. Our workshop complained about the solderability of one component. The problems of the workshop were verified by the solder globule test. After contact with our supplier he told us that he had carried out solderability tests as well but could not confirm our findings. The problem became a real problem when we found out that our supplier used the wetting balance test. The question arose if both test methods were giving comparable results. After a thorough discussion of the test methods and the statistics with the supplier he agreed on that he should carry out as many tests as we have carried out on the solder globule. The result of this was that the supplier himself found his material unsolderable.

By the way, we had not to pay a higher price for the component after the improvement of the solderability. Actually to me no case is known where our company had to pay a higher price for improved solderability, when we complained on solderability and helped other companies to improve the solderability of their component leads.

THE SCANNING SOLDERABILITY TESTING METHOD

The wetting balance test is a good test, but as it is specified in the IEC with a dipping speed of 20 mm/s it has the same disadvantage as the solder globule test and that is that the test is carried out only on a small area of the component lead. Based on an idea of the Siemens Corporation we have developed the wetting balance test with a slow dipping speed of 1 mm/s, fig 12, which

we call the Scanning Solderability Test Method to indicate that we measure the solderability over the whole length of the component lead. The dipping speed is chosen so slow that the sample at the solder interface always has the soldering temperature and thus enables the solder to form a positive meniscus. The formation of the meniscus and the obtained wetting force thus is only dependent on the surface properties, the solderability of the surface. This method has shown an other advantage too.

With the scanning method it is possible to detect decreased solderability on the component lead as a function of the thermal demand of the component body, acting as a heat sink. This can give us two informations. The one is whether the component is suitable for flush mounting or not, in other words if the component is correctly designed with respect to solderability. If the component can not be flush mounted, the obtained solderability curves gives you a measure for the distance with which the component body has to be mounted on the printed wiring board, when a reliable solder joint shall be achieved fig 13.

PRETINNING

We had a problem with the solderability of one component lead. As it was not determined at what place of the lead the soldering should be carried out we used the scanning solderability method. We tried different methods, to restore the solderability of the lead. From fig 14 we see that the solderability really was bad over the whole length of the lead, curve 3. A brutal tinning with zinc chloride did not improve much the solderability, curve 2 neither did so the many other fluxes we used. The only solution in this case was the use of a mildly activated flux in combination with ultrasonics, curve 1. With this method we obtained a nearly perfect solderability.

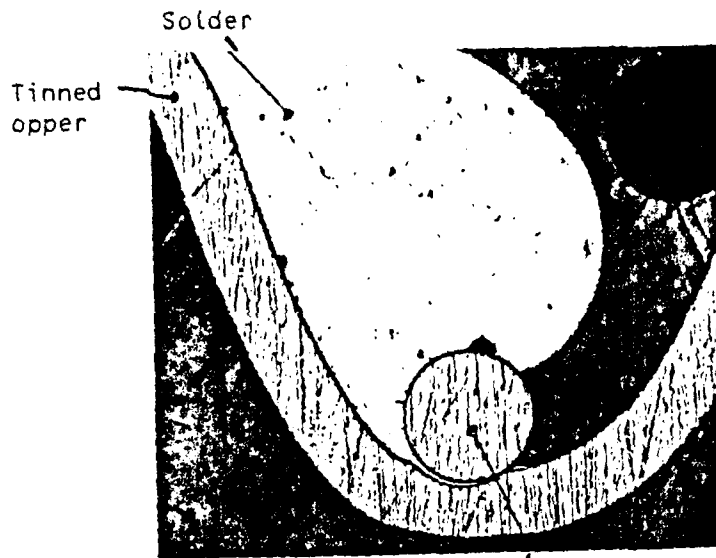
Very often it is claimed that if you have solderability problems that you only need to pretin your components and then you have solved your problem. I can not agree with this. It is absolutely necessary that you evaluate your solderability problems and check the improvements you intend to introduce with a solderability test. In most of the cases a simple pretinning only will cover your problems, not solve them. It is only very seldom that you can solve your problem correctly in such a simple way.

~~Glücks~~

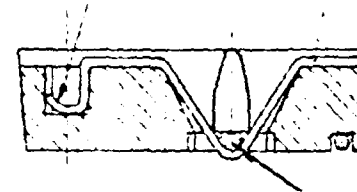
Dokument - Document

Blad Sheet

Uppgjord - Prepared	Datum - Date	Rev	Dokumentnr - Document no
Godkänd - Approved	Kontroll - Checked		Filhanvisning - File reference



Tinned tin-bronze



The design of the joint

x 30

The soldered joint



Tinned tin-bronze

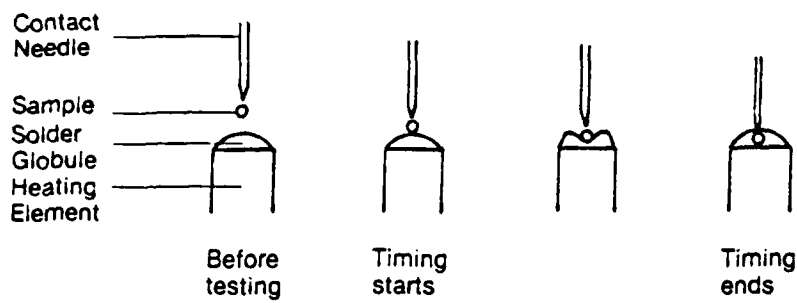
x 600

Bad wetting



Tinned copper

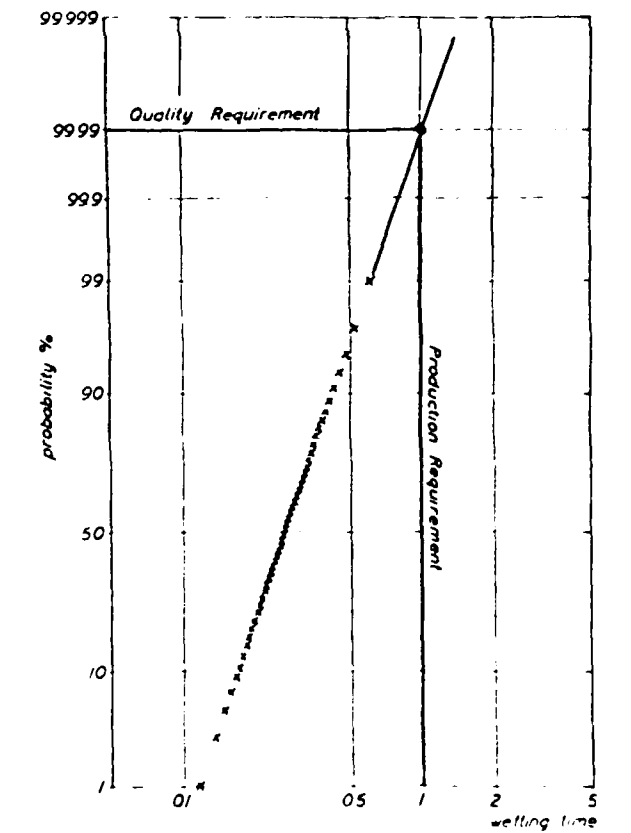
x 600



IEC Publication 68-2-20, Part 2, Test T
Solder Globule Method

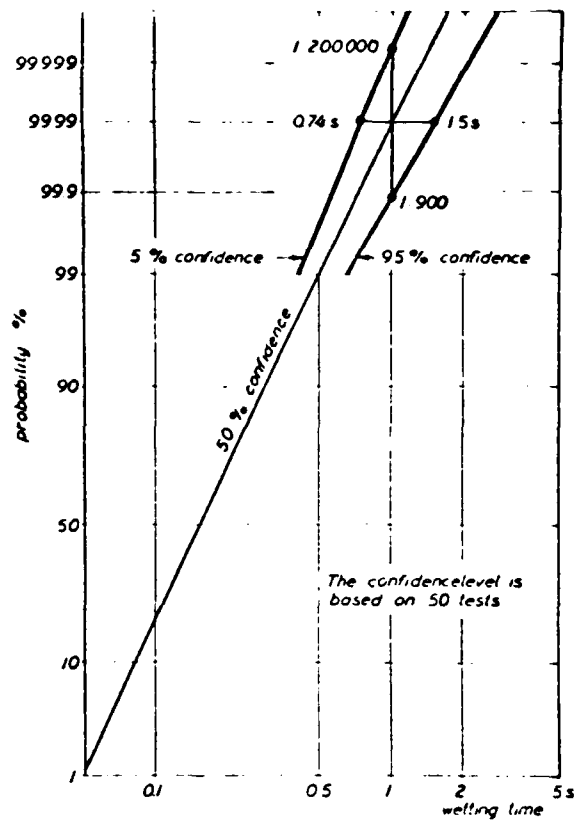
Solderability testing of component lead

ERICSSON 
620202



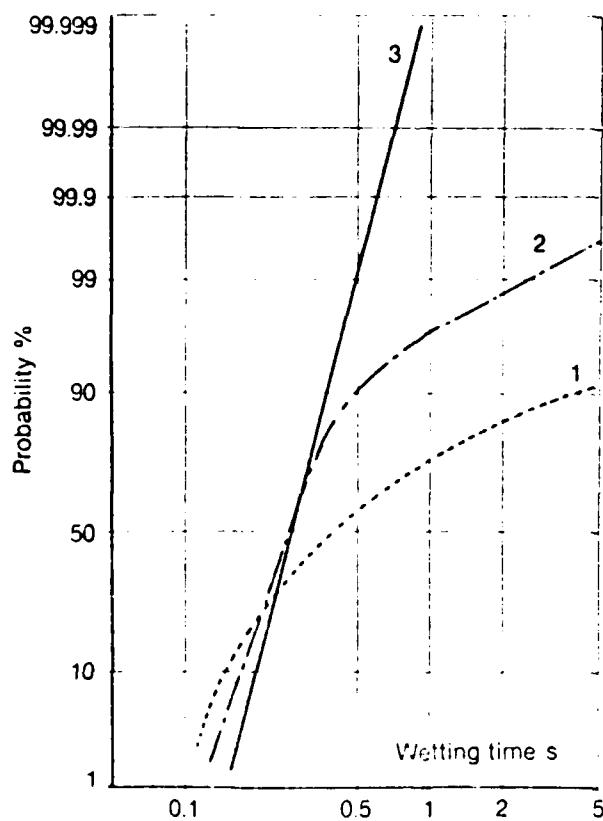
Evaluation of the results
of the solderability tests

ERICSSON 



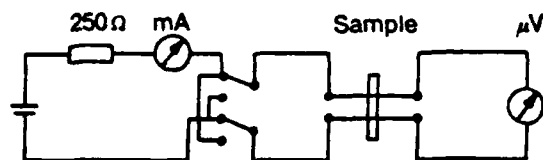
The confidence interval
for the solderability curve

ERICSSON 

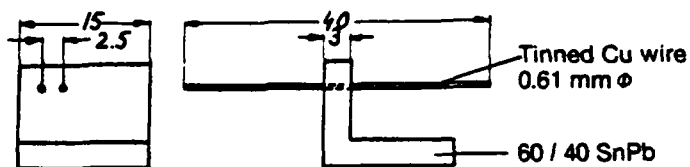


Solderability curves

ERICSSON 



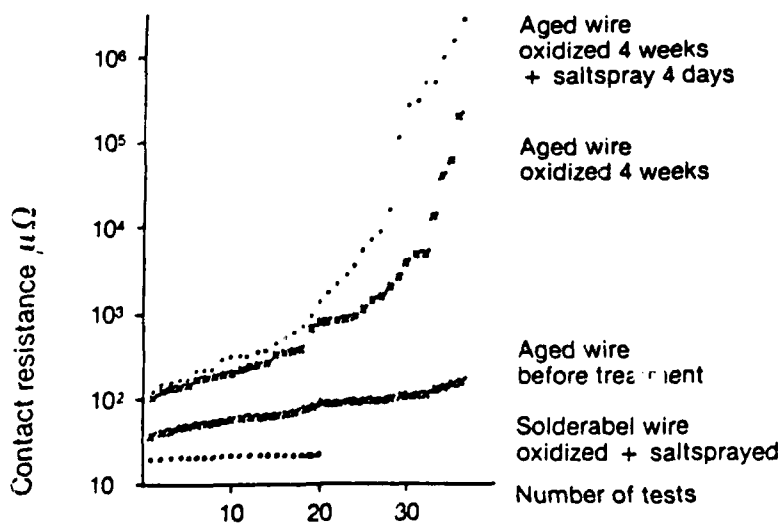
Measuring scheme



Sample

Solderability — Electrical contact resistance

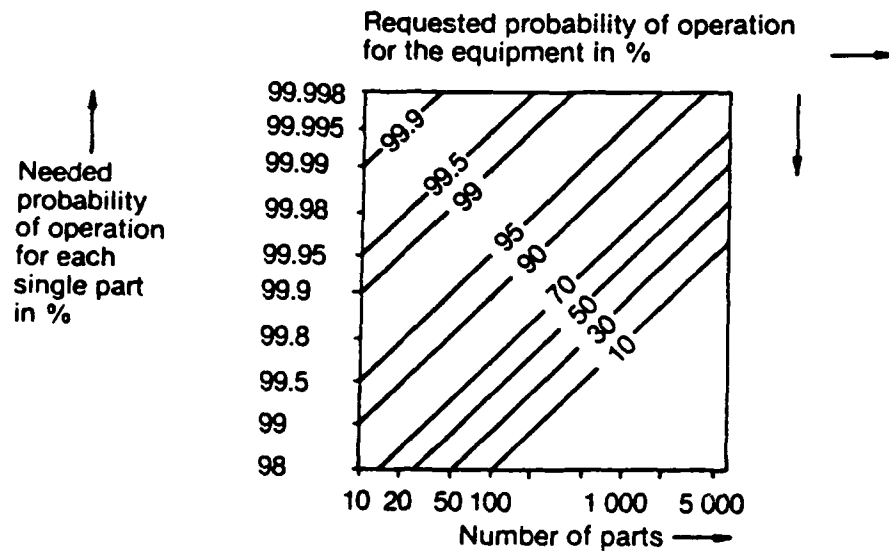
ERICSSON 
S20206



Result of electrical contact resistance measurements versus solderability

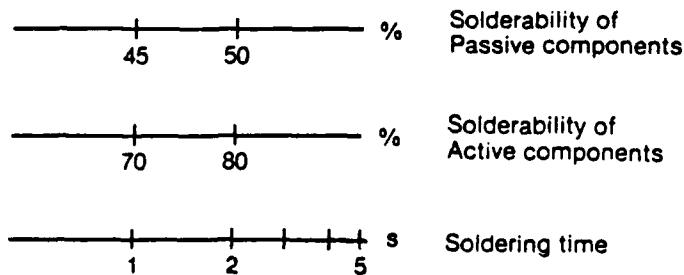
ERICSSON 
S20207

Component	Number of component leads on 10.000 boards	Expected number of sol- dering defects when sol- dering 10.000 boards at a soldering time of	
		0.8 sec	2.0 sec
Capacitors	20.000	0	0
	20.000	18.800	8.400
	60.000	9.600	1.800
Resistors	20.000	20	0
	40.000	20	0
	20.000	10	0
	20.000	600	0
Diodes	40.000	0	0
	20.000	160	10
	20.000	400	10
	20.000	0	0
Relay (tabs).	130.000	0	0
Transformers	60.000	0	0
	60.000	19.200	16.000
Expected number of soldering defects		48.810	26.220
Number of soldered connections		550.000	



A solder joint is a component

ERICSSON 
820208



Distribution of component solderability

ERICSSON 
820210

Production volume 1 000 000 solder joints / year

40% have soldering times <1s

With a soldering time of 2 s this means 111 h more
and with 27 \$ / h this means 3 000 \$ more

Failure rate: 1 bad joint among 10 000 joints

75% repaired for 6 USD / defect in workshop

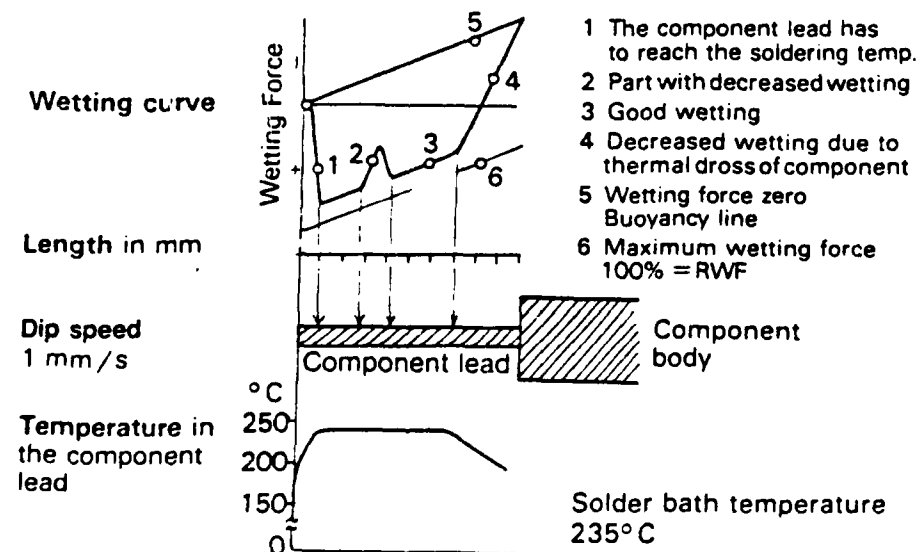
15% repaired for 17 USD / defect in final check

10% repaired for 110 USD / defect in at customer

The failure costs will be 1 800 USD / year

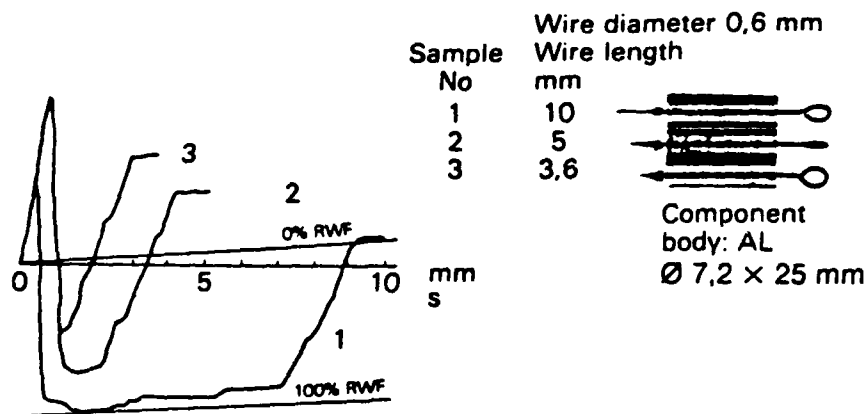
Economics of solderability

ERICSSON 
620211



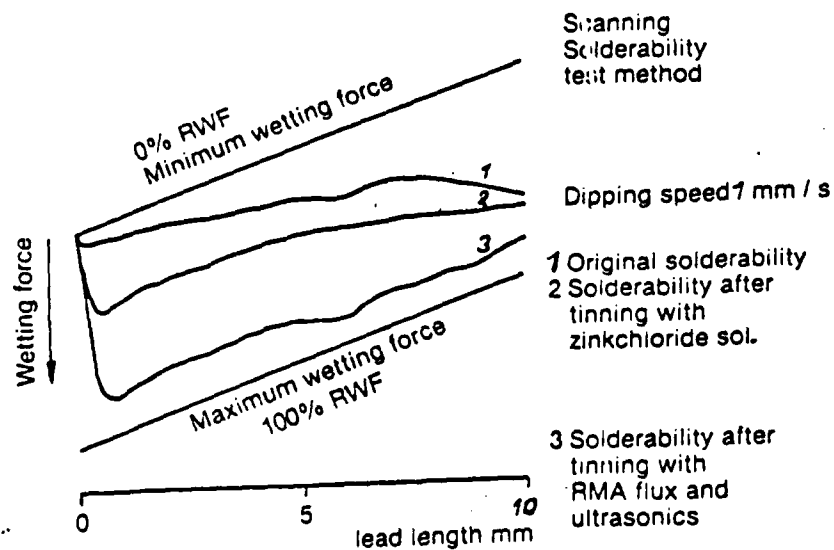
The scanning solderability test method

ERICSSON 
600802



Influence of component body heat drain
on the wetting of the component lead

ERICSSON 
820807



Solderability curves of pretinned component lead.

ERICSSON 
820214

THE ULTIMATE IN AUTOMATIC INSPECTION

By

Riccardo Vanzetti, Alan C. Traub and Laura Supino
Vanzetti Systems, Inc.
Stoughton, Massachusetts

ABSTRACT

In mass-production of PCBs, visual inspection of soldered joints is probably the last major operation still carried out manually.

Among the problems typical of this approach are the following:

- accept/reject decision is based on personal judgment of the inspector;
- only surface visible characteristics are available to make a decision. Subsurface defects (voids, inclusions, discontinuities, etc.) being invisible, remain undetected;
- setting the threshold level between accept and reject is affected by the production's prevalent quality level;
- human operation is slower than automated, and subject to fatigue and other variables.

The paper describes a novel system, designed to:

- ensure that the accept/reject threshold is firmly held at a pre-set level, regardless of the prevalent production quality;
- detect solder-joint defects, regardless whether they are on or under the surface;
- identify said defects by type, severity and precise location;

- carry out this inspection at high speed (10 joints per second or faster);
- allow full automation of the inspection process.

In essence, the system's operation is based on:

- a laser firing a pulse of radiation onto a solder joint;
- an infrared detector monitoring the joint's temperature increase during the laser's pulse, and its decrease afterwards;
- a programmable XY table holding the board to be inspected;
- a computer running the whole operation, and having in its memory the thermal signatures of acceptable and rejectable soldered joints;
- an input-output device for programming, displaying and recording all necessary data.

PCB reliability enhancement and cost savings afforded by automated soldered joints inspection are discussed in the final section of the paper.

INTRODUCTION

Every year in the U.S.A. billions of soldered connections are made on printed circuit boards by computer manufacturers and others. For example, last year, one hundred seventy five billion (more or less) of such soldered connections were made. With a study conducted by a major computer manufacturer, it has been observed that, under the best conditions, there are approximately two defective soldered connections every thousand. This gives one an idea of how important and conspicuous can be technical and economic problems related to quality (each joint should meet a certain standard of mechanical quality), reliability, maintenance, warranty, rental and even number of spares to stock.

In an attempt to solve this problem, we describe in this paper a newly developed system that is able to inspect automatically the quality of the solder joints in printed circuit boards. This system works on the basis of the new concept of "infrared signature". As a matter of fact, the Laser/INSPECT System includes a Nd:YAG laser which emits a pulse of radiation directed onto each solder joint in turn. During the pulse duration, the joint temperature rises and as soon as the pulse is over it decreases again. A HgCdTe detector monitors the rise and decay patterns which together form the joint infrared signature (Fig. 2). This signature is uniquely typical, just as a fingerprint, and contains relevant information about the thermal mass, the internal structure and the surface condition. Figures 1 and 2 show some

heating and cooling curves of solder joints and indicate the relations between the characteristics of the joints and the rate at which the temperature varies.

Based on these principles, the Laser/INSPECT System is able to test both lap type and feed-through joints, and to detect not only visible but even invisible defects such as:

1. Bubbles
2. Cavities
3. Porosities
4. Delamination discontinuities
5. De-wetted leads (partial or total)
6. Inclusions or impurities.

Quite often these defects are not so severe to cause an open circuit, but make the joints just liable to break or to cause intermittences in the circuit functions. Thus they cannot be identified by means of an electrical test.

Figure 3 shows some of the defects that can characterize either lap type or feed-through joints, while Figure 2 and Figures 4 through 10 show some typical solder joints' infrared signatures.

DESCRIPTION OF THE LASER/INSPECT SYSTEM

As can be seen in the schematic representation shown in Figure 11, the Laser/INSPECT System comprises a HeNe laser and a Nd:YAG laser. The first emits 0.0005W of red light ($\lambda = 0.6328\mu$) and the second emits an infrared beam ($\lambda = 1.06\mu$) whose power is

kept between 5 and 10 watts according to the physical mass of the target and to the pulse's preferred duration.

By means of two small mirrors these two beams are made parallel and very close together and then focused into a special optical fiber, which acts as a beam coupler and homogenizer. The resulting beam is then directed by the injection head over the solder joint which is being analyzed (see Figure 12).

In Figure 11 you can also see an InSb infrared detector. This one is cryogenically cooled by liquid nitrogen at 77°K.

The detector is always directed toward the target and can measure its temperature variation both during the laser pulse when the joint is warming up and after the laser pulse when the joint is cooling down. This temperature measurement is done with an accuracy of $\pm 1^{\circ}\text{C}$ and with a resolution of 0.05°C .

The analog output of the infrared detector is first processed through very low noise electronics, then converted into a digital signal by a high speed analog converter whose input rate can be as high as 16 KHz and finally sent to a microprocessor where, besides other things, it is compared to the signal expected from that joint.

During the inspection process the printed circuit board rests on an XY table where each joint in turn is placed at the focused image of the infrared detector.

Figure 13 shows a prototype of the Laser/INSPECT System.

DIGITAL PROCESSORS

The Laser/INSPECT System uses two digital processors that

share the task of controlling and regulating all main functions of the system itself (see Figure 14).

One is an 8-bit microprocessor common to all Laser/INSPECT Systems. It controls the motion of the XY table and collects all data monitored by the optical system during the inspection process of the boards. It can operate its functions only on one X-Y point at a time and it has no capabilities in making decisions on the solder joint quality. In case it might be necessary to intervene in the process the microprocessor is interfaced with a keyboard and a display that allow manual operation of the system.

The other is a general purpose computer communicating with the system through an RS232 ASCII high speed universal interface. In operation this interface is used to position the XY table and receives information regarding the solder joint which is being analyzed at that particular moment.

The main processor software permits one to describe and to record on tapes or disks new board configurations and to analyze and to make decisions on the qualities of the solder joints themselves.

The reason for a system with two processors is to give the system and thus the user the greatest flexibility. As a matter of fact, different users may have different requirements or needs. Some, for example, may already have their own general purpose computer. Others may require some sophisticated computer peripherals, and so on.

The application software of the main processor is written in Fortran so that changing computers becomes easy. In fact any computer with 64KB and a Fortran compiler can be connected to the system and can make it run. Besides, one may add to the program in order to fit some particular needs. Some user could, for example, want to develop statistics concerning failures or to analyze possible manufacturing problems.

SYSTEM OPERATION

The procedure for inspecting printed circuit boards with the Laser/INSPECT System consists of several steps.

First of all, it is necessary to prepare a profile for each type of printed circuit board that has to be inspected. This is done by assigning a number to each component of the board and then by introducing the coordinates of the first and last pin on each component. The position information is automatically entered with the component number. Then all data are arranged and memorized in a file that will serve as a guide to follow during the inspection process of boards with that particular configuration.

Once the pattern of a type of board is ready, it is necessary to define the ideal temperature values and tolerances of each solder joint contained in it. This is done by scanning a certain number of reference quality boards. During each reference scan, the detected temperature values are stored into a disk file. When all scanning is over, the main processor reads back the disk files, computes a mean and a tolerance for each solder joint and stores them on the board profile already prepared.

AD-A168 245

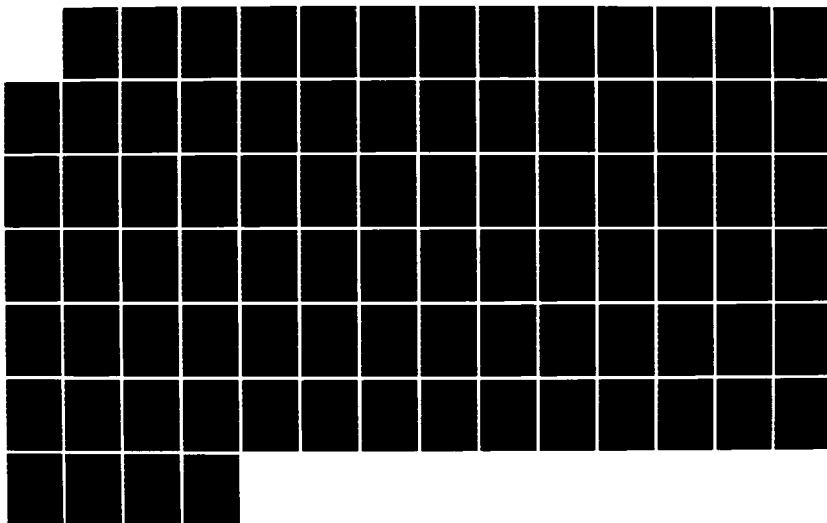
SOLDERING TECHNOLOGY (6TH) PROCEEDINGS OF ANNUAL
SEMINAR 17-18 FEBRUARY 1982(U) NAVAL WEAPONS CENTER
CHINA LAKE CA FEB 82 SBI-AD-E900 564

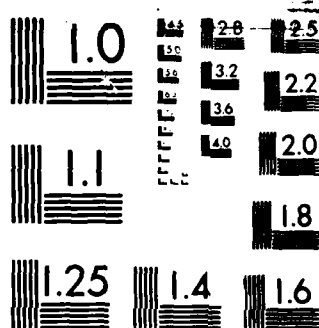
2/2

UNCLASSIFIED

F/G 13/8

NL





MICROCOPY RESOLUTION TEST CHART
 NATIONAL BUREAU OF STANDARDS-1963-A

Now the Laser/INSPECT System is ready to test any unknown quality board with that particular pattern. It will be sufficient to place the board in the correct position on the XY table and to start the system. One by one, all joints' effective infrared signatures will be compared with the data contained in the profile and in case an abnormal temperature value is detected the location of the presumably defective joint is memorized and later (when the testing is over) displayed on a peripheral device. In such a way it is easy once the inspection process is over to find and repair all defective joints.

To facilitate the pointing out of the faulty joints to the repair operator, a dye marker could be applied at or near the joint itself. Eventually also several other methods could be devised for the visual display of the exact defective joint locations. In any case, once their coordinates are known, suspect solder joints can be easily brought into visual observation by manually moving the XY table.

THE XY BOX

Figure 15 shows the operator panel of the Laser/INSPECT System from which the mechanical and optical functions can be manipulated.

It is seen that this operator panel comprises several sets of push buttons.

The set on the left must be used for entering position information during profile preparation or for bringing a suspect

solder joint into view for visual observation. Four of the push buttons are associated with the XY table axes; these are X, ΔX , Y and ΔY . The X and Y commands always display the current position while the ΔX and ΔY commands cause a changing of the values of the table position relative to its current position. The other commands of this set are useful when testing and in manual operation of the system. The set on the right serves for "jogging" or moving the table continuously. All front panel operations of the instrument can be simulated via the computer interface similar to an IEEE 688 operated instrument. However, that is where the similarity ends. The interface is ASCII serial instead of ASCII parallel and contains no hardware and handshaking as in the IEEE 688 interface. The commands are coded ASCII characters with their associated handshake or response.

The computer program that regulates the operator board is written in PLM, a high level structure language. As can be seen from the brief flow chart shown in Figure 16 the program has two states. It can either run a loop and execute the jog functions or it can serve an interrupt. Interrupts can be started by key commands, key data and the computer to computer interface. The latter have the highest priority and initiate the same routines as the key command interrupts.

SIGNAL PROCESSING SOFTWARE

There are two types of board scan commands. One is used on the reference quality printed boards to input all thermal information necessary to create first the data file and then the

board file. The other is used in actual production to scan unknown printed circuit boards that have to be compared with the reference profile.

Most commands are associated with the preparation and updating of board profiles. As a matter of fact, for this operation it is necessary to identify all components and to enter information about the locations of their first and last pins and the number of pins themselves. Only then if the components are laid perpendicular to the board edge, the computer will be able to compute their orientations and all other information needed.

There are two different methods of entering the pin locations. The first is direct and implies that the XY coordinates of the location points referenced to the corner of the printed board are known. This information can be obtained either from the drilling tape or scaled from the artwork.

The second method is based on the use of a low power visible HeNe laser as a pointer. It consists in manually spotting and jogging the printed circuit board on the XY table. Both methods allow one to add or delete components by number. Using the keyboard it is also possible to manually recompute or modify the profile limits.

Profiles can be displayed at any time and in two different formats. One is a format that shows names, locations, size and tolerances for each pin of the components.

The other is a short format that shows only names, locations and sizes. During the actual inspection process the Laser/INSPECT

System examines the solder joints of the printed circuit board one at a time. The procedure is always the same: during the laser pulse the joint's thermal data are read by the infrared detector and delivered to the general purpose computer that makes its decision about the joint's quality and sends instructions for the inspection of the next joint.

The main computer decisions about the joint are displayed or printed on peripheral devices, but in any case all data may be stored on a disk and retrieved when needed.

The printing of the data collected from the board can be done either in an absolute or in a comparison format.

The absolute format produces a report on all solder joints, while the comparison format causes the printout of the suspect solder joints only.

There is a set of commands also for data retention and retrieval for both data and profiles.

LASER DAMAGE PREVENTION

Most substrate materials are more highly absorbent of the infrared laser beam than is a normal solder joint. Should there be a small programming error in the position of a given joint or should some system malfunction occur, a part or all of the laser beam could impinge on the board material. Discoloration and charring can result within 10 or 20 milliseconds, increasing absorption further and causing a runaway heating situation in which the board can sustain severe local damage. The same can be true if a properly positioned test joint holds any foreign matter on its surface.

In any case, such laser damage is preceded by an abnormal rate of temperature rise, with the infrared detector observing excessive thermal signals and their time derivatives several milliseconds before the onset of actual damage. (Detector response times of the order of microseconds are typical.)

A separate logic circuit has been implemented to close the laser shutter prematurely when abnormally high thermal signals are seen. The threshold level for closure is adjusted to be somewhat higher than the highest thermal peak which would normally be seen in a defective solder joint and yet low enough to be below the damage level for ordinary materials. Moreover, an anticipation circuit further lowers the threshold if the thermal signal rise rate is excessively high. The shutdown signal is delivered to the shutter control within microseconds of the threshold being reached. The mechanical action of the electromechanical shutter in present use requires just over one millisecond to block the laser beam. Thus far, this has been sufficiently fast to prevent all laser damage to boards.

TYPICAL APPLICATION AND COST

The average inspection speed of the automated system is many times faster than that of the human inspector. The principal advantage of the system, however, is that it is a more reliable decision maker than the inspector. Moreover, the inspector's judgment is always limited to the visible features of the items.

The potential cost/effectiveness of an operational system is illustrated by a hypothetical case. Assume that a given military circuit board manufacturer produces 30,000 boards a year costing \$1,000 each or \$30,000,000 a year to produce. Several such producers report that about 9% of the total production cost is for solder joint inspection. For our hypothetical case that is \$2,700,000 a year, almost entirely for labor. Inspection labor costs about \$27,000 annually per person, including benefits and overhead, so up to 100 inspectors and supervisors are needed to do the job.

Visual inspection of military board solder joints is slow and tedious averaging only 10 joints a minute. Laser/INSPECT can easily inspect two joints per second, and more, or 12 times faster than the human inspectors. Put another way, one Laser/INSPECT can replace 12 inspectors.

To allow for some supervision, an operator and to make the math easier, say we only replace 10 inspectors. That means our hypothetical company will need 10 Laser/INSPECT Systems to replace all 100 inspectors for a one-shift operation. For two and three shift operations, only seven or four systems are needed respectively.

If each Laser/INSPECT System costs \$200,000 complete and installed, payback rate per year for our hypothetical company from labor savings alone is:

1 Shift

$$\frac{\text{labor savings}}{\text{equipment cost (10 systems)}} = \frac{\$2,700,000}{2,000,000} = 135\% \text{ or } 9 \text{ mo.}$$

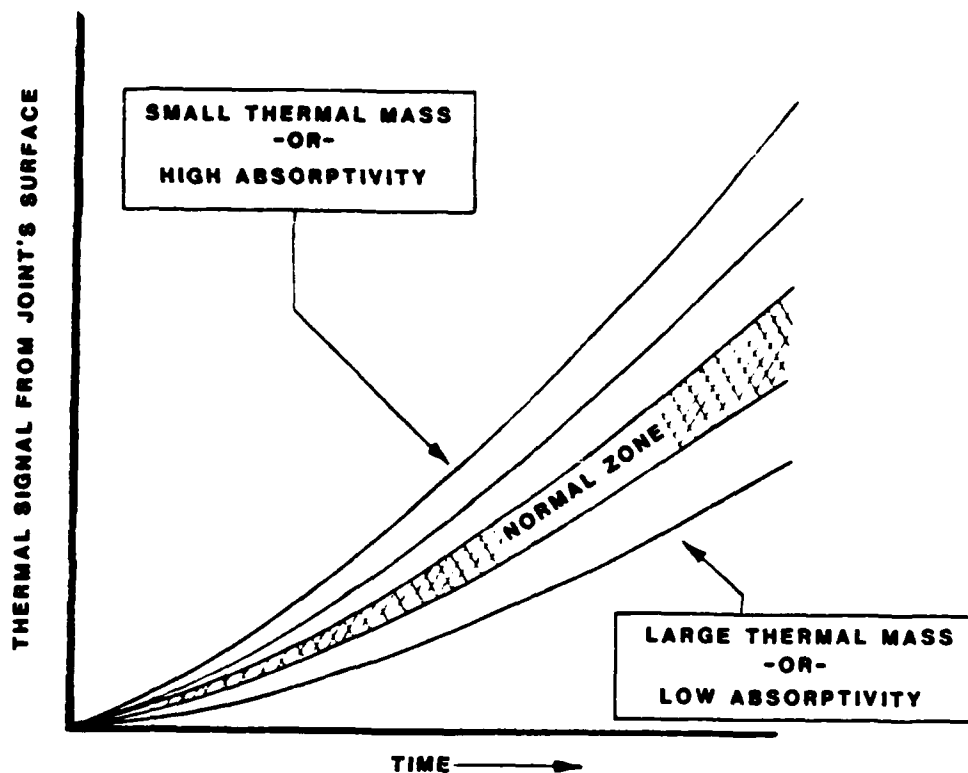
2 Shift

$$\frac{\text{labor savings}}{\text{equipment cost (7 systems)}} = \frac{\$2,700,000}{1,400,000} = 193\% \text{ or } 6 \text{ mo.}$$

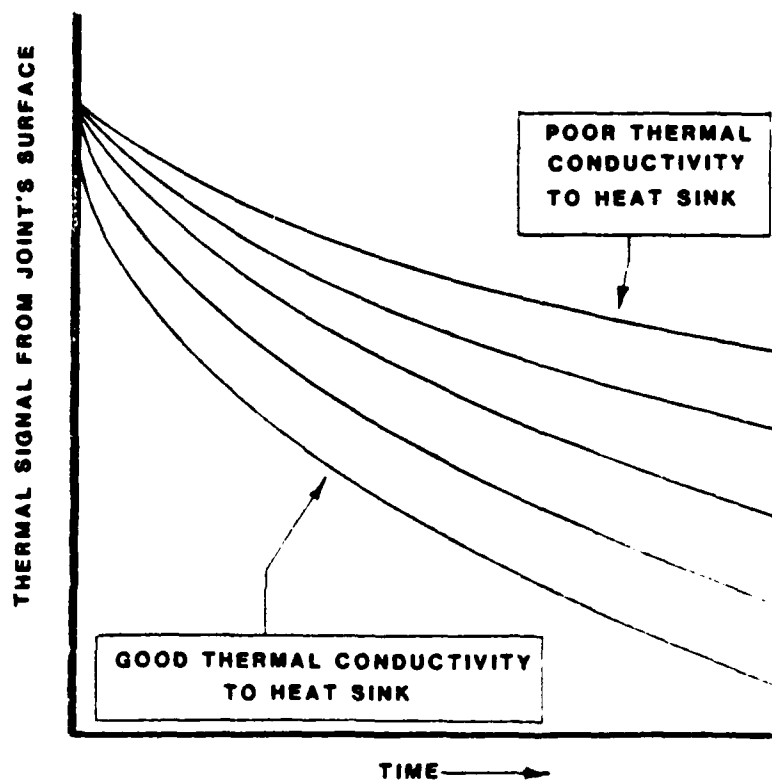
3 Shift

$$\frac{\text{labor savings}}{\text{equipment cost (4 systems)}} = \frac{\$2,700,000}{\$800,000} = 300\% \text{ or } 4 \text{ mo.}$$

Add to labor savings the warranty cost savings possible with consistent and objective Laser/INSPECT inspection and there can be no doubt which way to go.



TYPICAL HEATING CURVES DURING LASER-BEAM EXPOSURE.



TYPICAL COOLING CURVES AFTER EXPOSURE.

Figure 1. Heating and cooling curves for laser-heated solder joints.

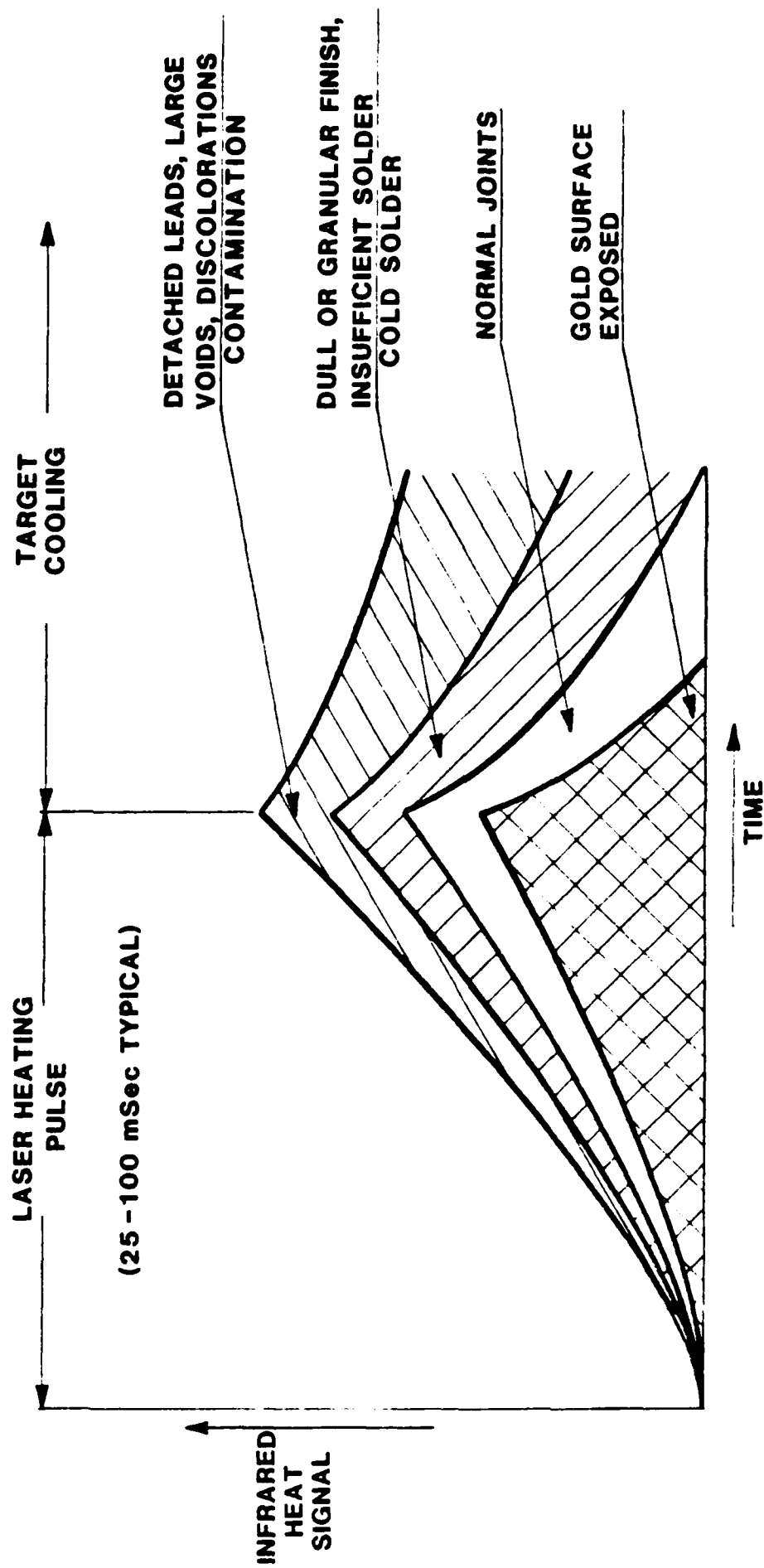
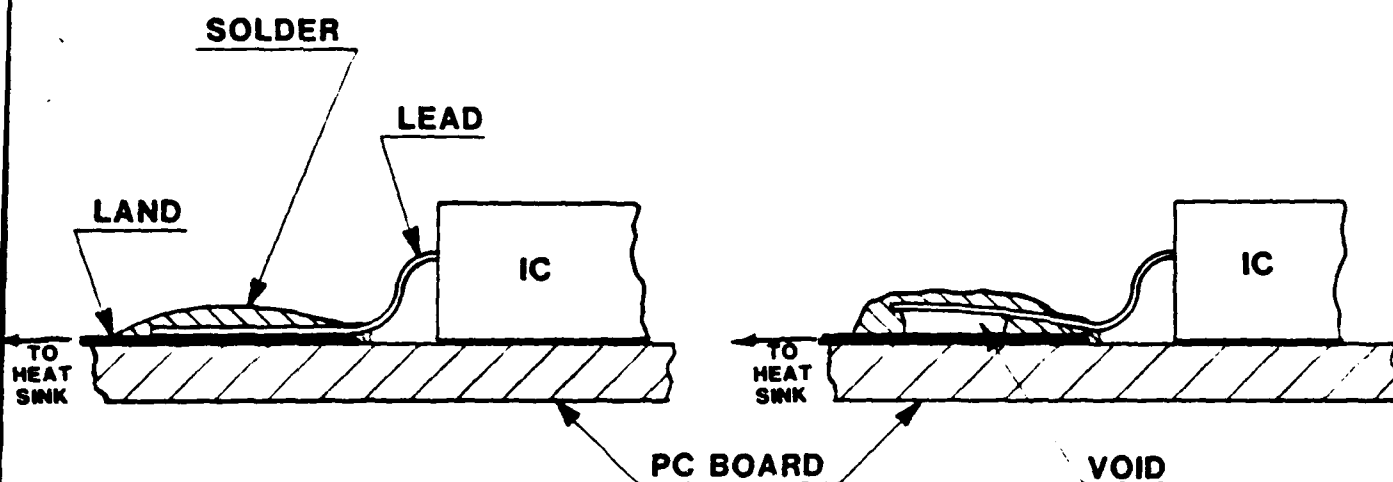
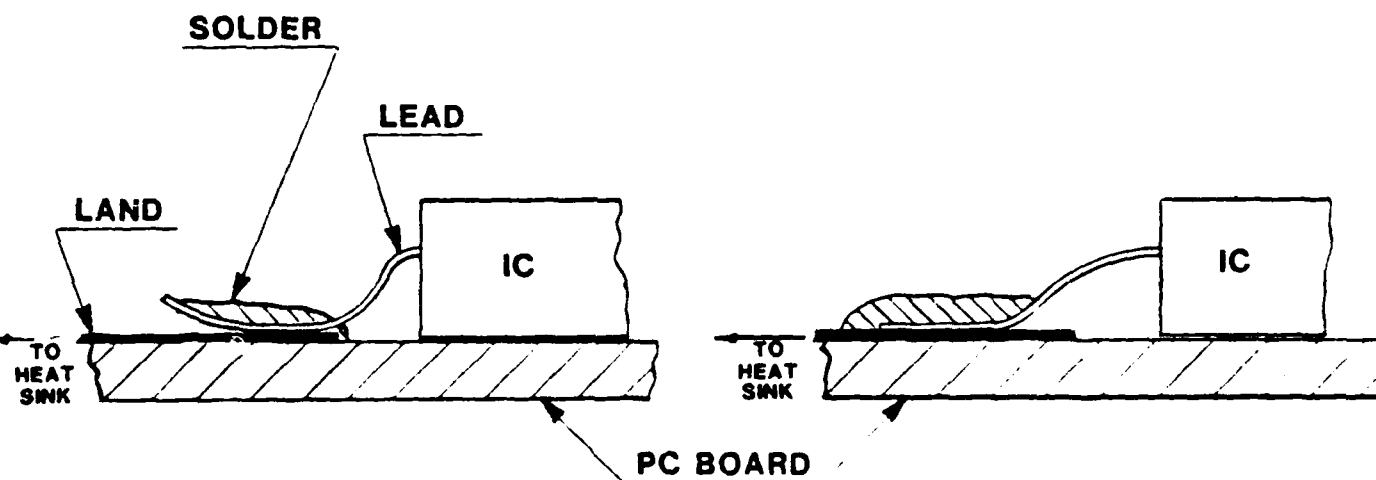


Figure 2. Typical solder-joint infrared signatures.



1: NORMAL

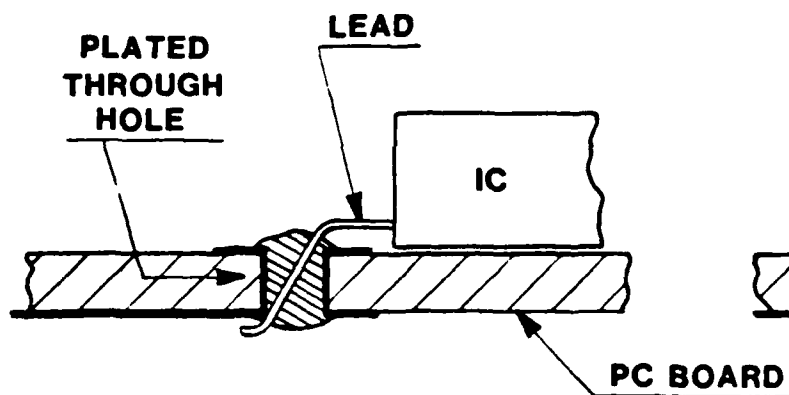
2: INSUFFICIENT SOLDER
WITH VOID



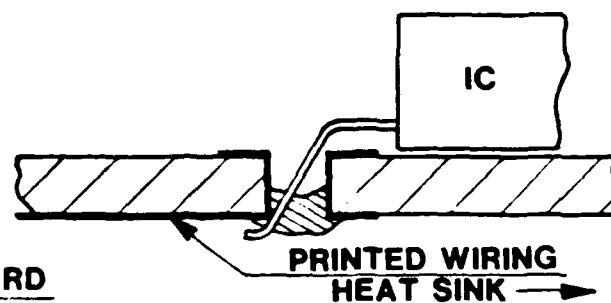
3: LIFTED TIP

4: HEEL CRACKED

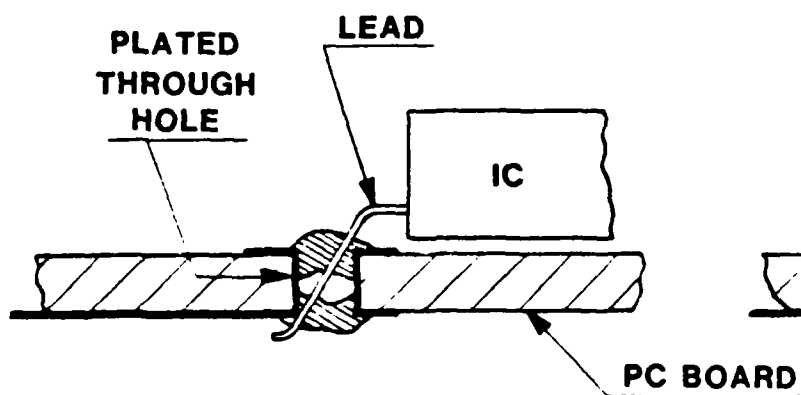
Figure 3a. Examples of good and bad lap joints.



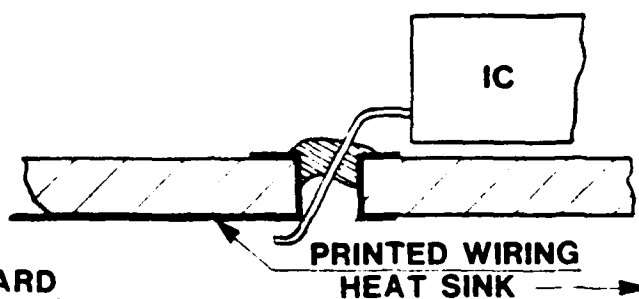
1: NORMAL



2: INSUFFICIENT SOLDER TOP



3: INTERNAL VOID



4: INSUFFICIENT SOLDER BOTTOM

Figure 3b. Examples of feed-through joints.

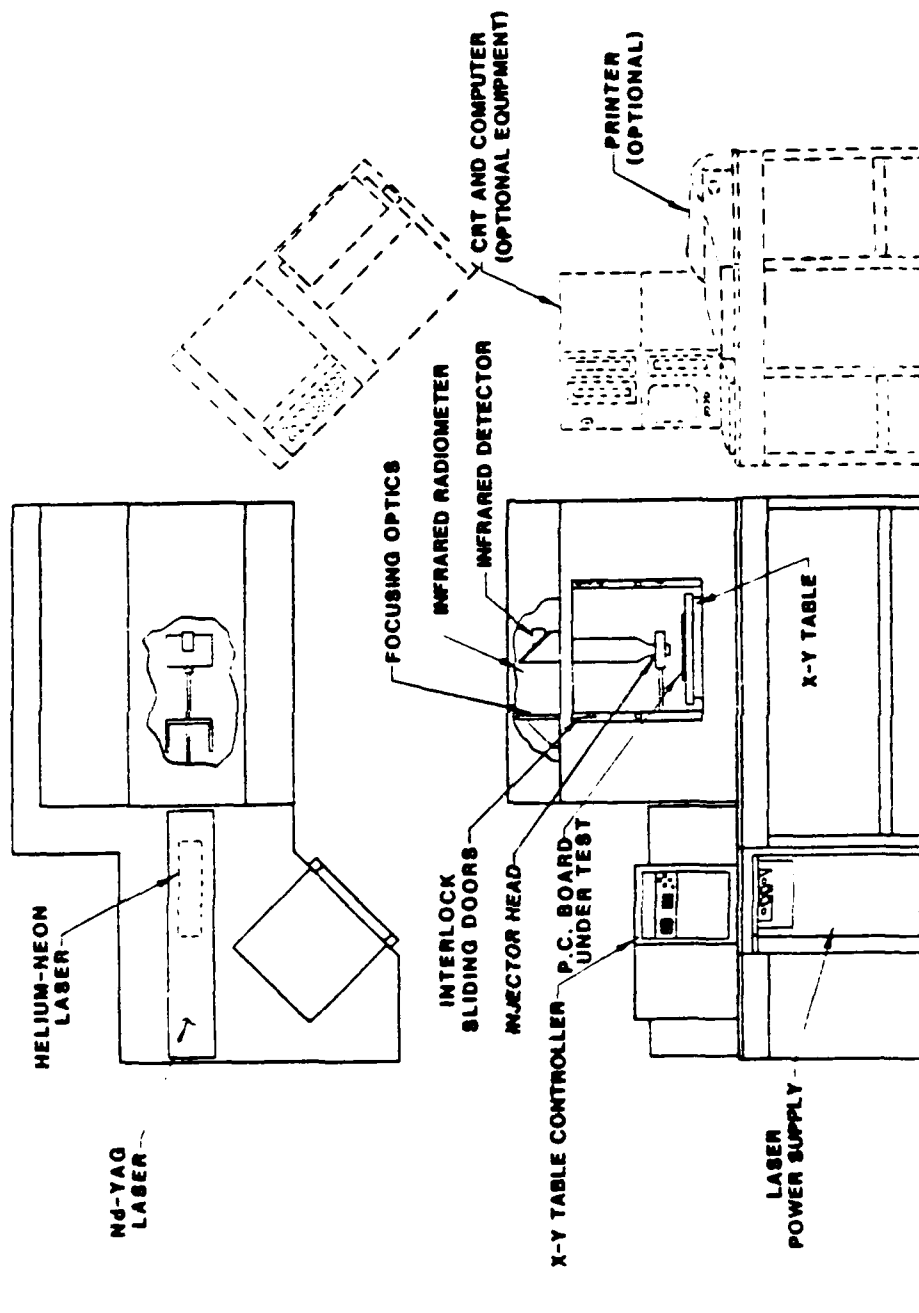


Figure 11. Laser/INSPECT system configuration.

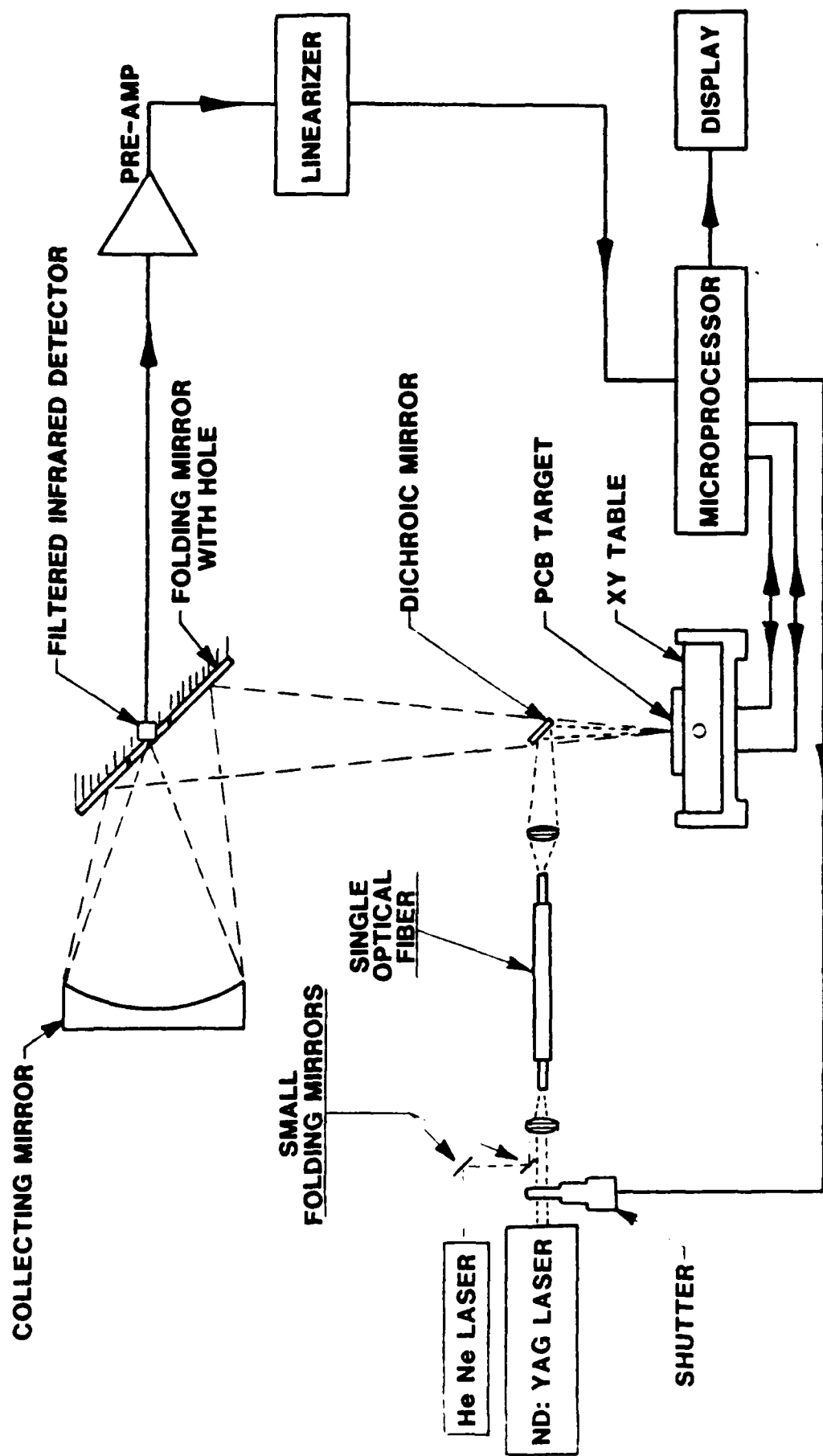


Figure 12. Laser/INSPECT optical system diagram.

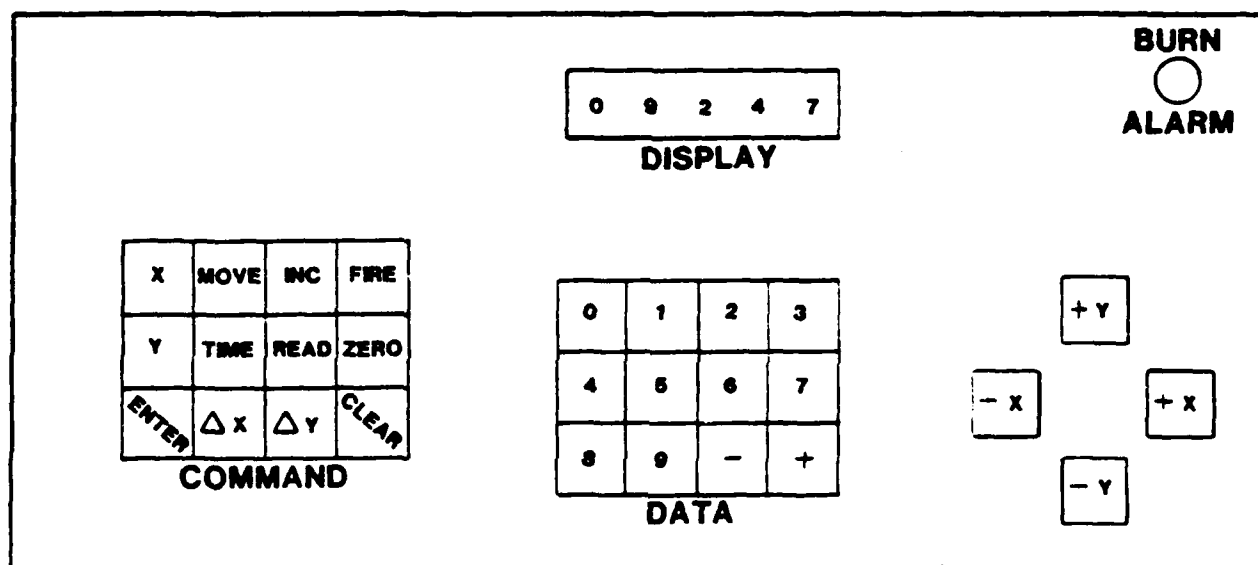


Figure 15. Laser/INSPECT processor panel configuration.

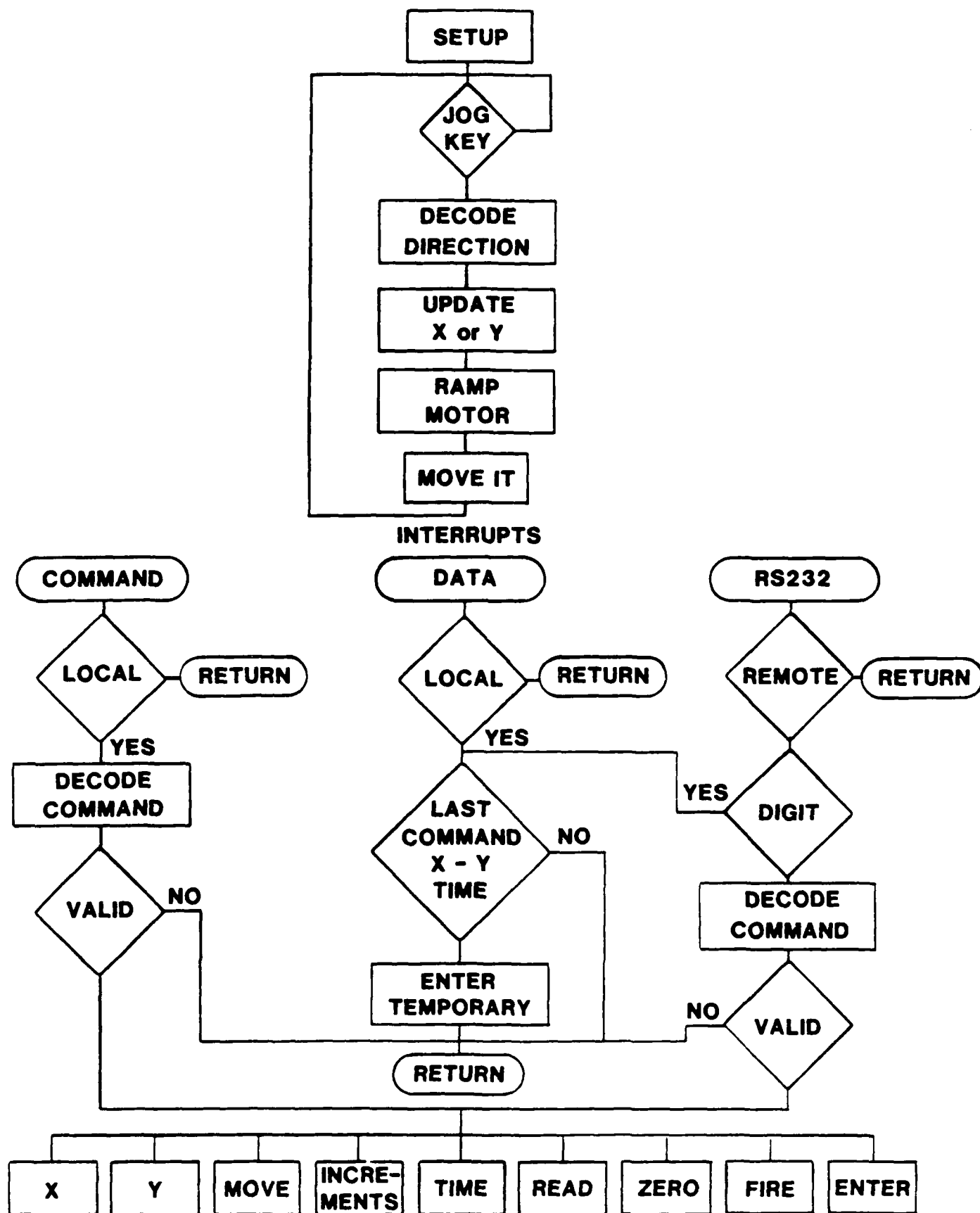


Figure 16. Microprocessor flow chart.

PRINTED WIRING BOARD
PLATING TANK CONTROL AND TEST

PREPARED BY:

DENNY J. BEROIZ
PROCESS QUALITY ASSURANCE
GENERAL DYNAMICS
POMONA, CALIFORNIA

Printed Wiring Board
Plating Tank Control And Test

The types of hardware processed in the plating and process tanks at General Dynamics, Pomona Division include metal castings, machined parts, rigid and flexible two sided and multilayer printed circuits and ceramic hybrid microelectronic substrates.

Before the computer system was established in 1972 there were 65 tanks with 131 parameters being controlled by chemical analysis in two locations in the factory building. At the present time, there are 83 tanks with 183 parameters being controlled in three locations in the factory and in two locations in Engineering. A record of all analysis and corrective actions taken must be maintained for all tank parameters for a least one year.

It took from one to 24 hours to make corrective actions after an analysis on a given tank was completed. The reason for this was that all corrective actions were manually calculated. There were a total of five people performing analysis, making calculations, making solution adjustments and plotting the solution control charts for the 65 tanks. No out-of-tolerance or other types of overall performance reports were prepared from the data. The percentage of tanks found out-of-tolerance when analyzed averaged 28 percent in 1971.

Computerized chemical process control system uses two computer systems: a batch system and an on-line timeshare system. The batch system is used to plot solution control history charts, record corrective action taken, perform statistical calculations on the solution analyses, prepare daily solution analysis and tank maintenance schedules for each employee on each shift and prepare daily tank out-of-tolerance reports with it accompanying weekly summary.

The timeshare system calculates solution analysis results from raw data, calculates required corrective action to bring concentrations to within specified control limits and causes cards to be punched for input into the batch system. A flow chart representing the computer system can be seen in Figure 1.

Working from the daily solution analysis schedule (Figure 2), an analysts will perform a variety of tests, both physical and chemical on solution, a plating deposit or some other parameter that would indicate tank activity. The raw data from these tests are recorded directly on the schedule.

The solution control analysis and corrective action list (Figure 3) is prepared from raw analysis data obtained by the chemical analyst and is printed on a computer timeshare terminal. Raw data such as milliliters of standard solution used in a volumetric analysis are typed into a timeshare terminal. The computer processes the raw data, calculates final analysis values, compares these values with corrective action limits, and calculates chemical additions or dilutions as required to maintain the solutions within the preselected limits. The results of all these calculations are printed immediately on the teletype terminal. The data tape can be punched in about 15 minutes, and the computer calculations and print-out on the teletype take about 12 minutes. The chemist responsible for chemical control of the solutions reviews the printed list and makes any changes necessary. The list then is given to the technician who makes the required solution adjustments.

The computer program includes the ability to calculate a dilution and determine its effect on all parameters in the tank, and then calculate additions for all parameters that are put below the lower corrective action limit by the dilution. The program will determine if liquid additions are too large to add without removing some solution. If some solution must be

removed, the program calculates the optimum amount to remove, and the amounts of the liquid and solid concentrates to add to adjust the parameters to their optimum values.

The analysis and any corrective action taken are then made part of the solution control history chart.

The solution control history chart (Figure 4) is a graphic display that plots analysis values by M-day. The M-day scale is shown on the ordinate and the analysis scale on the abscissa. Descriptive information about the tank and solution parameter, such as code number, description, tank volume, manufacturing process specification (MPS) on which tank is used, solution parameter specification limits and tank location, are given in the heading.

The mean value of all points plotted is shown as a dashed line across the middle of the graph and its value is indicated as the middle value on the abscissa. The upper parameter specification limit is shown as a series of U's and the lower limit as a series of L's across the graph. Initial analyses points are indicated with an A, retest values with an R and multiple analyses with approximately the same value obtained on the same M-day are shown with an M.

The results of various statistical calculations are shown at the bottom of the chart. These include $\pm$ three sigma statistical limits (UCLX and LCLX) about the latest week's mean value, six sigma range between these limits (range between limits for individuals) and corrective action limits. Corrective action limits are obtained by adding the mean moving range, $\bar{R}^3$, to the lower parameters specification limit and subtracting it from the upper specification limit. Thus corrective action limits are affected by the average analysis-to-analysis changes caused by analysis errors, usage of the solution and accidents.

The process engineer uses the corrective action limits as a guide to decide when to adjust the solution parameter concentration to keep it within

the specification limits when it is next analyzed. He makes a chemical correction whenever these limits are exceeded. The mean value of all analyses up through last week and net change in the mean for this week also are shown here. The days on which the solution parameter is analyzed are shown at the bottom of the chart. A list of solution analyses and corrective actions by M-day accompany every parameter that is controlled (Figure 5).

The daily out-of-tolerance report (Figure 6) shows tank solution parameters that are outside of the solution parameter specification limits on each M-day. It lists the actuals reading and the limits. The process engineer and management use this list to detect parameters that are difficult to control within the specification limits.

The weekly out-of-tolerance summary indicates by M-day the number of tanks analyzed, number of tanks out-of-tolerance (i.e., that do not meet the parameter specification limits) and the percent of tanks out-of-tolerance. Five-day moving averages are calculated from the daily number and percent of tanks out-of-tolerance, and are used to measure solution control performance over a long period of time. The effects of various actions taken to improve solution control efforts are revealed quickly by changes in the five-day moving averages.

The following benefits were obtained using the computerized system.

- o Total time for maintaining solution control charts was reduced from 4 hours/day to 1/2 hour/day for manual labor and 15-20 minutes/week for computer run time. Charts are currently maintained for 183 parameters in 83 tanks.
- o Reduced the percentage of tanks found out-of-tolerance when analyzed from an average of 28% and high of 54.5% in February 1971 to average of 5% and a high of 8.7% in February 1972. The average for 1981 was 6.1% out-of-tolerance.
- o Improved the use of the chemical analyst's and process engineer's available time each day. This had been done by adjusting the daily analysis schedule so that a more uniform number of tanks are analyzed each day. Before the computerized solution control system was installed, the number of tanks analyzed/day ranged from 12-28. Now average 27-5 tanks/day and the number ranges from 22-34 (9/81).

- o Visibility of problems (inadequate control limits, erroneous analyses, new employee training, etc.) and associated weekly summary.
- o The statistical calculations are used to determine when to increase or decrease analysis frequency and to evaluate effects of analysis methods.
- o Eliminated many errors made when adjusting solution concentration caused by calculation errors.
- o The corrective action limits are used by the solution calculation program to decide whether to make an adjustment in solution concentration.
- o A maintenance checklist has been generated to complement the chemical and physical testing. This checklist has the analyst verify tank configuration, solution level, equipment operation and cleanliness.
- o An increase in the quantity of records to be kept is easily handled. The growth in the plating areas during the past ten years resulted in 65 tanks becoming 83 tanks while 131 parameters expanded to 183 chemical and physical analyses. Additionally, 150 tank maintenance records are kept along with 50 waste treatment facility records.

The following cost savings were analyzed (1972 dollars):

o Net savings due to computer preparation of solution control charts	\$11,166.00
o Net savings due to computer calculation of analyses and solution adjustments.	5,076.00
o Net savings due to reduced number of tanks found out-of-control when analyzed and elimination of supervision of additions by process engineer. This number dropped from 6 to 3 per day due to the application of computer calculated corrective action limits.	156,935.00
Total Savings	173,177.00
Cost of Writing and Testing Programs	5,402.00
Net Savings	\$167,775.00

Our future plans include a purchase of a laboratory disc-based microcomputer. This will allow us to put both the Batch and Timeshare programs together. This will place all records on-line, will eliminate printing of 770 pages of reports per week, will enlarge our storage capacity to two years on disc and will eliminate the use of keypunched cards.

This proposed system will then be the foundation for a printed circuit board facility where analyses, calculations, tank adjustments, plating current and voltage settings and record keeping are all performed by a computerized, automated system.

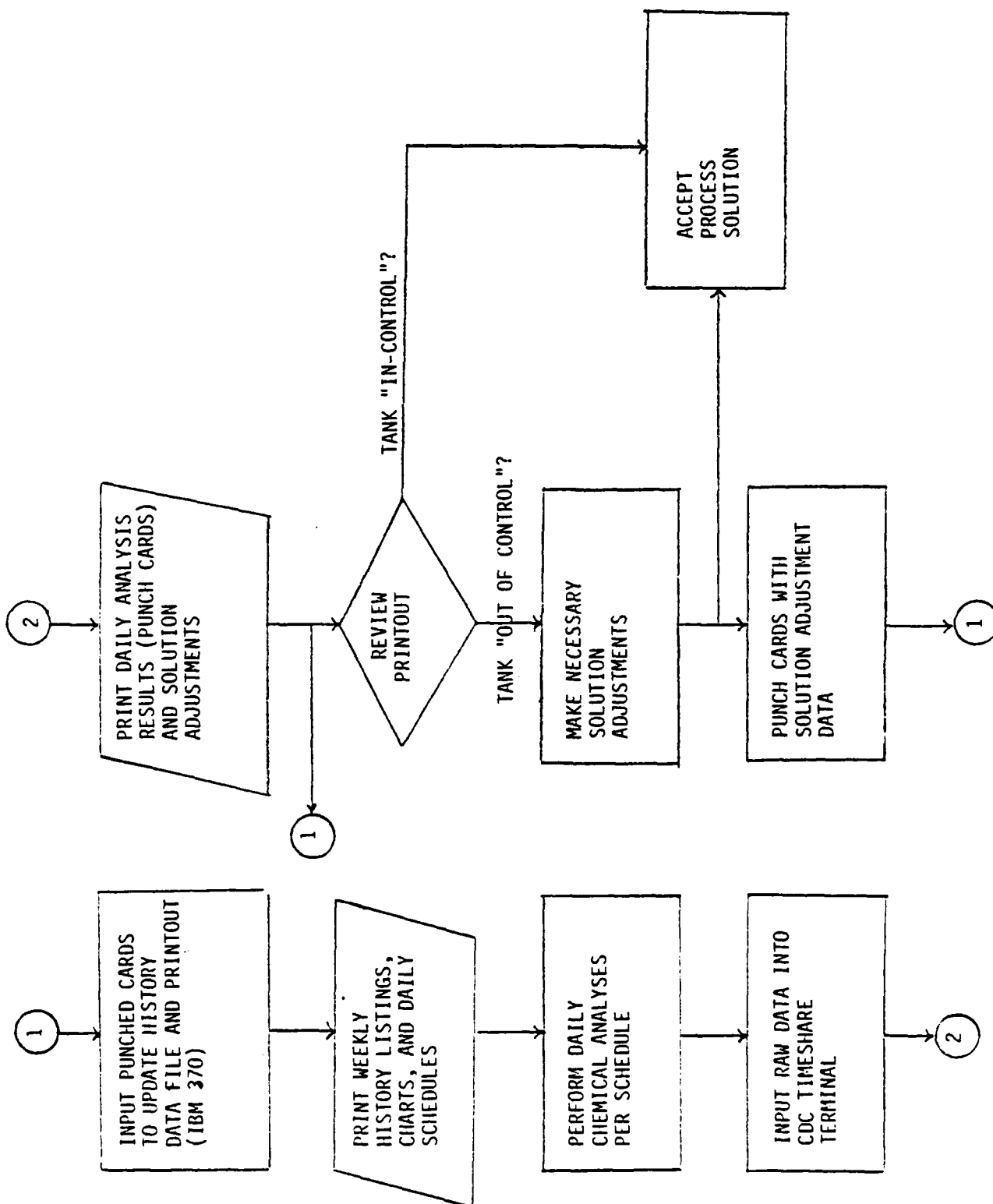
ACKNOWLEDGEMENT

I wish to acknowledge the efforts of W.M. Gross Quality Assurance Specialist, Senior of the Process Quality Assurance Section for his persistence in making this computer system work despite the misunderstanding of every new employee. Also, a sincere appreciation is felt for his efforts in the preparation of this paper.

ABOUT THE AUTHOR

Responsible for management of Process Quality Assurance, including: nondestructive testing, metallurgical analysis, chemical and material testing, solder technology, process surveillance, solution control and industrial waste treatment. Designed many plating, metal finishing and waste treatment systems used in PWB production at General Dynamics, Pomona. Established computer-assisted system for surveillance of plating and waste treatment maintenance.

Activities prior to General Dynamics include: Chemistry Instructor - California State University and author of numerous publications on organic and organometallic electrochemical reaction mechanisms. BS, University of California, Riverside, 1973; MA, California State University, Fullerton, 1976. NWC certified category C instructor/examiner to WS 6536C.



FLOW CHART FOR COMPUTERIZED SOLUTION CONTROL SYSTEM

Figure 1

REPORT NO. D074610004
 QUALITY CONTROL LABORATORIES
 QUALITY CONTROL

QUALITY ANALYSIS SCHEDULE
 ANALYTICAL CHECKLIST

DATE 10/20/84
 PAGE 1

 ITEM NO. PARAMETER
 NUMERICAL NOMENCLATURE

101	2 FREE POTASSIUM CYANIDE. GALI II-003
110	1 COPPER SULFATE. GALI II-010 2 SULFURIC ACID. GALI II-010 4 COPPER SULFATE / SULFURIC ACID RATIO GALI II-010
125	1 GOLD-CROSEVE 999 GOLD SALT. GALI II-011 2 PH. GALI-II-404
152	5 TIN, PLATED PANEL. GALI II-013
160	2 NICKEL CHLORIDE. GALI II-014 3 PHTIC ACID. GALI II-014 4 PH. GALI II-404 5 SURFACE TENSION ANTI-PIT NO. 7 GALI II-014
180	1 COPPER GALI II-015 2 PYROPHOSPHATE GALI II-015 3 AMMONIA. GALI II-015 4 PYROPHOSPHATE/COPPER RATIO GALI II-015 5 PH. GALI II-404
401	1 METEX PTH CLEANER 9076 GALS II-218
404	1 SODIUM PERSULFATE GALI-II-221 2 COPPER GALI II-221
409	1 PALLADIUM GALI II-023
410	1 NORMALITY GALI II-017
416	1 COPPER. GALI II-021 2 SODIUM HYDROXIDE GALI II-021 3 FORMALDEHYDE GALI II-021
444	1 SODIUM PERSULFATE GALI II-221 2 COPPER GALI II-221
449	1 SODIUM CHLORITE GALI II-023 2 SODIUM HYDROXIDE GALI II-023
455	1 COPPER SULFATE.5H2O GALI II-010 2 SULFURIC ACID GALI II-010 7 SULFURIC ACID/COPPER SULFATE.5H2O RATIO II-010 10 BENT CATHODE FOR BRIGHTNERS II-034
463	1 SULFURIC ACID GALI II-004.

Figure 2

SOLUTION CONTROL ANALYSIS AND

CORRECTIVE ACTION LIST

** 125 TANK NO. 125 ACID GOLD PLATE II-011 V. = 231.0 L. **

1 GOLD ANALYSIS = 6.640 G/LITER

2 PH ANALYSIS = 4.480 PH

3 DEGREES BAUME ANALYSIS = 16.500 DEGREES

1 * ADD 1160.78 GMS OROSENE 999 GOLD SALTS

Figure 3

ALBERT M. A. 1004010003
GRAPHIC DISPLAY

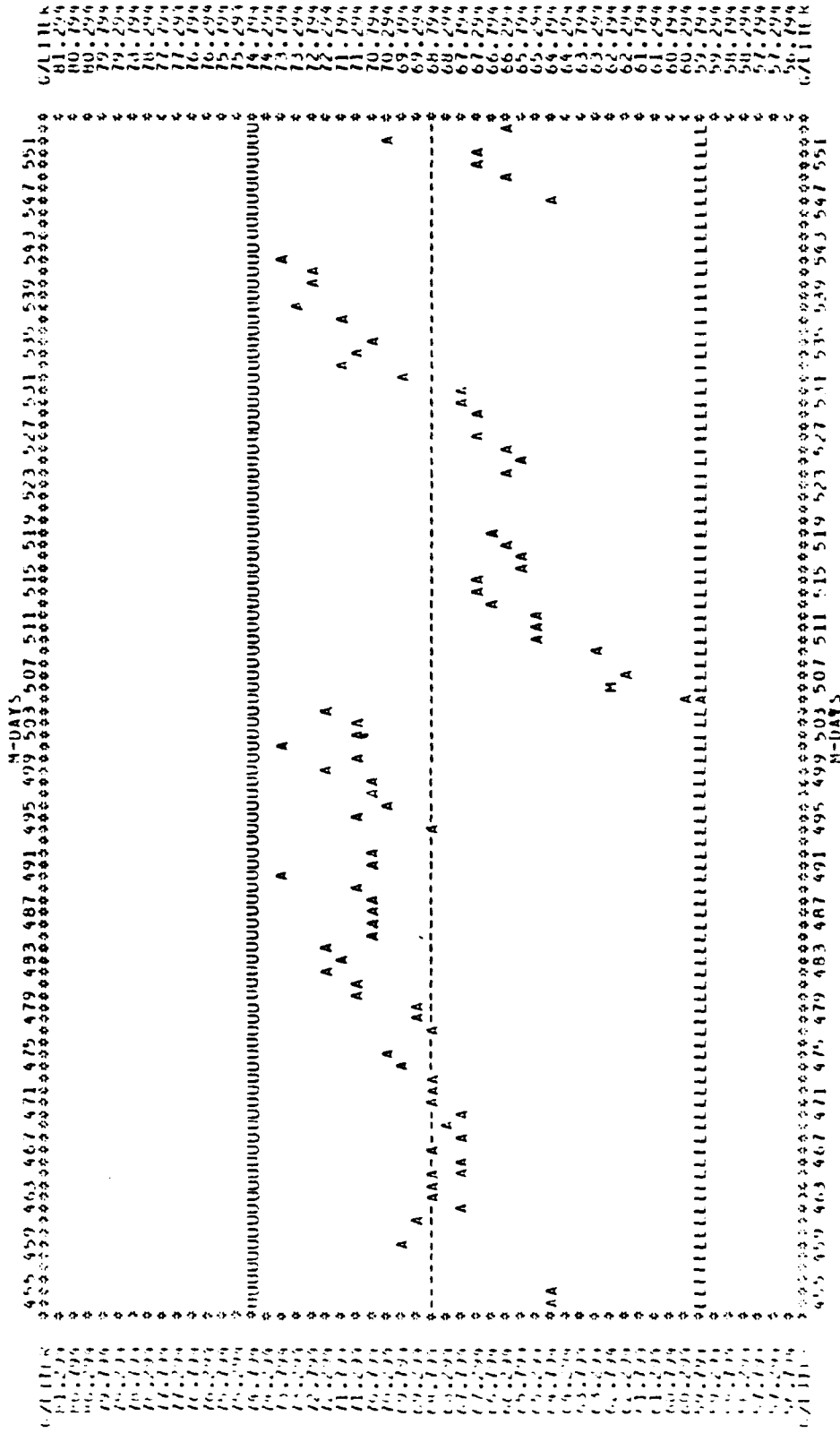
QUALITY ASSURANCE LABORATORIES
SOLUTION CONTROL

PAGE 01/1/1/2

1004010003
TANK NO. 465
CUPPER SULFATE .5M20
QAL1 11-010

M.P.S. 120.12
DEPT. 62
BLDG. 2

60.000 G/LITER
COST CENTER 095
ROOM 625



***** TANK 404 TANK NO. 404 SODIUM PERSULFATE EICH VOL 565L ***** PARAMETER IS SODIUM PERSULFATE QALI-11-221 *****			
M-DAY	CORRECTIVE ACTION	ANALYSIS	RETEST
553		123.606	
552		123.457	
551		122.863	
550		123.444	
549		118.630	
548		125.508	
547		126.390	
546		121.681	
545		121.099	
544		117.454	
543		122.275	
542		112.516	
541		120.453	
540		62.431	
539		122.745	
538		120.511	
537		106.403	
536		120.511	
535		122.275	
534		113.281	
533		119.336	
532		109.930	
531		105.815	
530		104.345	
529		133.444	
528		117.572	
527		118.513	
526		116.984	
525		132.033	
524		116.984	
523		124.626	
522		117.572	
521		126.978	
520		113.751	
519		131.681	
518		121.922	
517		116.396	
516			
515			
514			
513			
512			
511			
510			
509			
508			
507			

Figure 5

QUALITY ASSURANCE LABORATORY

SOLUTION CONTROL SYSTEM

OUT-OF-TOLERANCE REPORT

M-DAYS 689 THRU 693

M-DAY 693

188	3	0.173	A	0.938	TO	2.310	G/LITER
188	4	6.759	A	7.400	TO	8.000	RATIO
822	1	37.600	A	38.000	TO	44.000	DEGREES

SUMMARY TOTALS

M-DAY	TANKS ANALYZED	TANKS 0-0-T	PERCENT 0-0-T
689	36	3	8.3
690	23	1	4.3
691	31	3	9.6
692	29	4	13.7
693	24	2	8.3
TOTALS	143	13	
AVERAGES	28.6	2.6	9.1

Figure 6

NOTE: This draft, dated January 1982, prepared by the Engineering Specifications and Standards Department, Naval Air Engineering Center, Lakehurst, NJ 08733, has not been approved and is subject to modification. DO NOT USE PRIOR TO APPROVAL. (Project No. SOLD-0001)

DOD-STD-2000-1

SUPERSESION DATA
(see Section 6)

MILITARY STANDARD

SOLDERING TECHNOLOGY, HIGH QUALITY/HIGH RELIABILITY



SOLD

DOD-STD-2000-1

DEPARTMENT OF DEFENSE
WASHINGTON, DC 20301

DOD-STD-2000-1

1. This Military Standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commanding Officer, Naval Air Engineering Center, Code 9313, Lakehurst, NJ 08733, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this standard or by letter.

FOREWORD

1. Electrical/electronic equipment and systems used in military applications are continuously becoming more diverse, complex, and sophisticated yet smaller, lighter, denser in internal packaging, sturdier with respect to environment, and more reliable with respect to both function and service life. Such changes in technological posture mandate both definition and standardization of connections and wiring in military electrical/electronic equipment.

2. This standard not only provides for communication between designers, fabricating personnel, and inspectors but also provides for uniformity of soldering processes whether such are manual or automated procedures or whether such are accomplished by any of the many organizations engaged in the production of military electronic equipment. Criteria of this standard are not directed to end-item products per se but are instead directed to part/component solder connections and wiring essential to the said end-item products and should be implemented in conjunction with appropriate documents.

3. This standard addresses that spectrum of solder connections normally defined as standard and miniature, and provides technical criteria essential to electrical connections and wiring within equipment fabricated by or for the Department of Defense. Requirements for microminiature soldering applicable to connections in thin- and thick-film microelectronic assemblies are not specifically defined but are imposed through callout of MIL-M-38510.

4. It is recognized that solder processes other than stipulated herein exist or may exist in the future but it is intended that the requirements of this standard be extrapolated to such noncovered processes insofar as practicable.

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1. SCOPE

1.1 Applicability. This standard is applicable to soldering processes for high quality/high reliability electrical/electronic connections on guided missiles, aircraft, avionics systems, communication equipment, satellites, shipboard weapons systems, ground vehicle equipment, and program critical ground support equipment.

1.2 Classification. The soldering processes specified herein are of the following types.

- a. Manual (5.1)
- b. Automated (5.2)

2. REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. Unless otherwise specified (see 6.), the following specifications, standards, and handbooks of the issue listed in the current Department of Defense Index of Specifications and Standards (DODISS) and the supplement thereto (if applicable), form a part of this specification to the extent specified herein.

SPECIFICATIONS

FEDERAL

O-E-00760	Ethyl Alcohol (Ethanol) Denatured Alcohol, Proprietary Solvents and Special Industrial Solvents
O-T-236	Tetrachloroethylene (Perchloroethylene), Technical Grade
QQ-S-571	Solder, Tin Alloy, Lead-tin Alloy and Lead Alloy
TT-I-735	Isopropyl Alcohol

MILITARY

MIL-I-7444	Insulation Sleeving, Electrical Flexible
MIL-F-14256	Flux, Soldering, Liquid (Rosin Base)
MIL-I-22076	Insulation Tubing, Electrical Nonrigid, Vinyl, Very Low Temperature Grade
MIL-I-22129	Insulation Tubing, Electrical Polytetrafluoroethylene Resin, Nonrigid
MIL-P-28809	Printed Wiring Assemblies
MIL-I-23053	Insulation Sleeving, Electrical, Heat Shrinkable, General Specification for
MIL-M-38510	Microcircuit, General Specification for
MIL-P-46843	Printed Wiring Assemblies
MIL-P-50884	Printed Wiring, Flexible, General Specification for

SPECIFICATIONS (Continued)

MILITARY (Continued)

MIL-P-55110	Printed Wiring Boards
MIL-C-81302	Cleaning Compound, Solvent, Trichlorotrifluoroethane
MIL-T-81533	Trichloroethane 1, 1, 1 (Methyl Chloroform) Inhibited, Vapor Degreasing
MIL-M-83436	Multiwire Interconnection Boards (Plate-through Hole)

STANDARDS

MILITARY

MIL-STD-202	Test Methods for Electronic and Electric Component Parts
MIL-STD-275	Printed Wiring for Electronic Equipment
MIL-STD-429	Printed Wiring and Printed Circuit Terms and Definitions
MIL-STD-1389	Design Requirements for Standard Hardware Program Electronic Modules
DOD-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically- Initiated Explosive Devices)
DOD-STD-1866	Soldering Process, General (Non-Electrical)
DOD-STD-2000-2	Acceptance Criteria for High Quality/High Reliability Soldering
DOD-STD-2000-3	Component Mounting, Handling and Storage, Printed Wiring Board

HANDBOOKS

MILITARY

DOD-HDBK-P04	Soldering of Electrical and Electronic Connections
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(Copies of specifications, standards, handbooks, drawings, and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Other publications. The following document(s) form a part of this specification to the extent specified herein. The issues of the documents which are indicated as DOD adopted shall be the issue in the current DODISS and the supplement thereto, if applicable.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D 1193 Reagent Water

(Applications for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

CFR, Title 29, Code of Federal Regulations,
Part 1900 to 1919, Occupational Safety and Health Administration,
Chapter XVII Department of Labor

(Application for copies should be addressed to the Superintendent of Documents, US Government Printing Office, Washington, DC 20402.)

Industrial Ventilations, Manual of Recommended Practices

(Application for copies should be addressed to: Committee of Industrial Ventilation, P.O. Box 16153, Lansing, MI 48902.)

3. DEFINITIONS

3.1 Terms and definitions. The definitions applicable to this standard shall be in accordance with MIL-STD-429 and the following additions and modifications.

<u>Term</u>	<u>Definition</u>
Coining	
Ground	A point of common potential in an electric circuit used for common connections and reference voltages.
High quality/high reliability soldering	A soldering technique whereby the probability of obtaining perfect metallic joining, product cleanliness, and optimum electrical conductivity without damage to components or equipment has been statistically proven. These statistics are obtained by using controlled processes, environments and facilities, approved applications, and trained certified personnel.
Hook terminal	A terminal formed in a hook shape.
Lead	A length of insulated or uninsulated solid or stranded wire used for electrical interconnection.
Mechanical wrap	The securing of a wire or the lead of a component around a terminal prior to the soldering operation.
Perforated or pierced terminal	A terminal containing a hole through which leads or wires are placed before soldering.
Plated soldering iron tip	A solid copper tip that has been plated or clad with iron, nickel, chromium, or similar metal that will extend the service life of the tip.
Solder cup	A hollow, cylindrical terminal, open on one end to accommodate one or more leads or wires.

<u>Term</u>	<u>Definition</u>
Step soldering	Technique for sequentially soldering connections on the part or terminal without impairing any of the prior connections. The first connection is made with a solder alloy having a higher melting temperature. The next is made with a solder alloy having a lower melting temperature. Additional solder connections are made with solder alloys having successively lower melting temperatures.
Stress relief	The forming of a slight curve in the leads of components to avoid stress between terminations.
Transfer soldering	A process wherein a measured amount of solder in the form of a ball, chip, or disc is picked up on a specially configured tip of a hand soldering iron and transferred to the prefluxed element of a connection to be soldered. The process was initially designed for soldering leads of planar mounted devices and miniature through-board connections and is equally suitable for other connections as well.

4. GENERAL REQUIREMENTS

4.1 Acceptance criteria. Acceptance requirements and illustrations for use as comparison criteria for high quality/high reliability soldering shall be in accordance with DOD-STD-2000-2.

4.2 Visual inspection. One hundred percent visual inspection of all soldered connections and assemblies shall be performed using the magnification aids of paragraph 4.11.3.5. The soldered connections and assemblies shall conform to the requirements specified herein.

4.3 Conflict. In the event of any conflict between the requirements of this standard and the applicable engineering drawing(s), one copy each of the drawing(s) shall be submitted to the contracting officer or his designated technical activity with information justifying the deviation(s), and with a request for approval of the deviation(s). When approved, the provisions of the engineering drawing(s) shall govern.

4.4 Hybrid microelectronic modules and assemblies. Hybrid microelectronic processing, modules, and assemblies shall be in accordance with MIL-M-38510.

4.5 Multiple termination modules. Acceptance criteria for Multiple Termination Modules (MTMs) shall be in accordance with DOD-STD-2000-2.

4.6 Standard electronic modules. Acceptance criteria for Standard Electronic Modules shall be in accordance with MIL-STD-1389.

4.7 Multiwire interconnection design. Multiwire Interconnection Boards shall be in accordance with MIL-M-83436. Solder connections of assemblies incorporating multiwire interconnection boards shall be in accordance with detailed requirements herein.

4.8 Non-electrical soldered connections. Soldered connections utilized to join surfaces in non-electrical applications shall be in accordance with DOD-STD-1866.

4.9 Electrostatic discharge. Electrostatic sensitive devices, assemblies, and equipments shall be protected in accordance with DOD-STD-1686 at all times.

4.10 Vapors control. Areas used for cleaning parts and areas where toxic or volatile vapors are generated shall employ a local exhaust system for removing air contaminants from the area in which they are generated. The exhaust unit utilized shall be in accordance with the recommendations or guidelines of the "Industrial Ventilation Manual of Recommended Practices" and applicable OSHA requirements.

4.11 Facilities, tools and equipment.

4.11.1 The soldering facility.

4.11.1.1 Environmental controls. An enclosed soldering facility, maintained at a slight positive pressure, shall be required if the soldering area is not air conditioned.

4.11.1.2 Temperature and humidity. The temperature shall be maintained at 24°C plus or minus 5°C (75°F plus or minus 9°F) and the relative humidity shall not exceed 65 percent. When humidity is 30 percent or lower the requirements of 4.8 shall be emphasized.

4.11.1.3 Cleanliness. Work areas shall be maintained in a clean and orderly condition. All dirt, grease, flux, solder spatter, chips and other contaminating foreign material shall be promptly removed. Eating, smoking or drinking at the soldering work station shall not be permitted, and precautions shall be taken to preclude contamination by prohibiting products of such activities from the work area.

4.11.1.4 Lighting. Working surface lighting of soldering stations shall be 100 foot-candles minimum (1077 Lm/m²).

4.11.2 Soldering tools. Tools used in the soldering process shall be cleaned prior to use and shall be free of dirt, grease, flux, oil and other foreign matter and shall be kept clean during use.

4.11.2.1 Thermal strippers. Thermal strippers utilized to remove insulation from stranded and solid conductor wires shall be of a type that can be regulated to provide the required temperature. (See figure 1.) Temperature controls shall be sufficient to prevent damage to the wire or unstripped insulation.

4.11.2.2 Mechanical strippers. Mechanical strippers utilized to remove insulation from stranded or solid conductor wires may be of the hand operated or automatic high-volume machine type. Hand-operated strippers shall be of a fixed-die configuration (see figure 2). Automatic high-volume machine strippers shall be of a type utilizing either fixed dies, dies adjustable to calibrated stops, or roller cutters adjustable to calibrated stops. Dies, whether adjustable or fixed, shall be properly maintained to assure consistently sharp and even cuts without damage to the wires or unstripped insulation.

4.11.2.3 Chemical strippers. Chemical solutions, pastes, and creams used to strip hookup and magnet wires shall be suitable for removal of the insulation to be stripped and shall be limited to those that: (1) cause no degradation of the base metal of the wire; and (2) allow wires or conductors to be neutralized and cleaned of both ionic and non-ionic contaminants.

4.11.2.4 Wire and lead cutting tools. Tools used to cut component leads shall not cause damage to those components. Shear type rotary cutters or tooling which cuts squarely without leaving burrs, excessive ridges, or sharp points on the leads shall be used. Holding fixtures shall be used to absorb any shock which might otherwise be transmitted to the component.

4.11.2.5 Clinching tools. Clinching tools or clinching devices shall be of such design and made of a material which will not cause damage to printed wiring boards, printed circuitry, and component leads or components mounted thereon.

4.11.2.6 Anti-wicking tools. Anti-wicking tools shall be of a type marked with conductor gage size.

4.11.2.7 Bending tools. Bending tools used for component wire or lead bending may be automatic or hand implements and shall be of a material that will not cut, nick, or otherwise damage solid or stranded wires, leads, any integral insulation or any other insulation or insulators added prior to the bending operation. Bending tools shall impart no stress to the component bodies or seals.

4.11.3 Soldering equipment. Soldering equipment shall not produce levels of electromagnetic, electrostatic, electromechanical, electrical or other forms of energy which will be detrimental to the item(s) being soldered. Protective devices to prevent potential differences greater than 2 millivolts (mV) shall be used when voltage sensitive devices are being soldered. Transformer type soldering guns shall not be used.

4.11.3.1 Soldering irons. The size and shape of the soldering iron and tip shall permit soldering with maximum ease and control without causing damage to adjacent areas or connections. The soldering iron or resistance heating element shall heat the connection area rapidly and maintain proper soldering temperature at the connection throughout the soldering operation.

4.11.3.2 Soldering iron tips. The soldering iron tips or resistance soldering element shall be sized to the operations involved. Soldering iron tips shall be made of commercially pure copper, tellurium copper, or lead copper and shall be plated/coated with another metal that prevents degradation of the tip in molten solder.

4.11.3.3 Soldering iron holder. A soldering iron holder satisfactory for the soldering iron utilized shall be provided. The holder shall leave the soldering iron element and tip unsupported.

4.11.3.4 Solder pots. Solder pots shall be capable of maintaining the solder temperature within $\pm 5.5^{\circ}\text{C}$ ($\pm 10^{\circ}\text{F}$) of the preselected temperature specified in 5.1.2. Solder pots shall be grounded.

4.11.3.5 Magnification aids and lighting. Magnification aids used for assembly and inspection shall be commensurate with the size of the item being processed and conform to the following requirements:

- a. Magnification aid of 2X to 4X, for use during the assembly and inspection of other than solder connections.
- b. Magnification aid of 4X to 10X, for use during the inspection of solder connections.
- c. Be suitable to permit inspection of each solder connection in its entirety.
- d. Utilize only glass optical elements.
- e. Light source for shadowless illumination of the area being viewed. A clear incandescent light shall be used for detection of nontinned copper.

4.11.3.6 Thermal shunts. Thermal shunts shall be of such material, size, shape, and design as to permit rapid application and removal with minimum interference to the soldering procedure, and to facilitate rapid heat dissipation from the area being soldered.

4.12 Machine soldering systems. Machine soldering systems shall be of the automatic or automated type of such design to provide (a) a capability for preheating printed wiring assemblies to within 38°C (100°F) of the soldering temperature immediately prior to contact with the molten solder; (b) the capacity to maintain the temperature at the printed wiring assembly within $\pm 5.5^{\circ}\text{C}$ ($\pm 10^{\circ}\text{F}$) of the established bath temperature throughout the span of any continuous soldering run; (c) an exhaust system (either integral or separate) (see 4.10) adequate to assure conformance with applicable OSHA health and safety requirements.

4.13 Carriers. Devices used for the transport of printed boards through preheat, soldering, and cooling stages shall be of such material, design, and configuration that they shall not contaminate, mar, or otherwise damage the printed board nor transmit sufficient vibrational or shock stress from the conveyors or other such mechanisms to cause board, part, or component degradation.

4.14 Soldering equipment for reflow soldering of planar mounted components. The soldering device and machine used shall be of such design to rapidly heat the surfaces to be joined and shall have the capacity to maintain the correct temperature during repetitive solder operations with a maximum temperature variation of $\pm 5.5^{\circ}\text{C}$ (10°F) from

the nominal soldering temperature. The heat source shall not cause damage to the board or components or contaminate the solder when direct contact is made between the heat source and the metals to be joined. Reflow soldering equipment includes those which utilize parallel-gap resistance, shorted-bar resistance, hot air, infrared or thermal transfer soldering techniques.

4.15 Condensation (Vapor Phase) reflow. The condensation (Vapor Phase) reflow system shall be mechanized to provide for smooth transition of the work piece. The nonflammable, inert, chemically and thermally stable liquid used to produce the vapors shall be maintained to produce consistent high quality metallurgical bonds. The level of vapor in the equipment shall be controlled so that the dwell-time of the work piece is minimal while insuring that the solder and work piece have reached a temperature sufficient to produce the metallurgical bonds.

4.16 Materials. Materials used in the soldering processes stipulated in this standard shall be as specified herein. It is possible that the materials and processes specified may in some combinations be incompatible. It shall be the responsibility of the manufacturer to select those materials and processes that will produce acceptable high quality/high reliability products.

4.16.1 Solder. Solder composition Sn60, Sn62, or Sn63, solder form optional, conforming to QQ-S-571 shall be used. Sn5, Sn10, or Sn96 may be used for high temperature soldering. Cored fluxes shall be type R or RMA. Type RA flux of QQ-S-571 may be used only if approved by the procuring activity.

4.16.2 Flux. Rosin based fluxes conforming to types R or RMA of MIL-F-14256 shall be used for making soldered connections. Other types of fluxes shall not be used except by approval of the procuring activity.

4.16.3 Solder creams (paste) and solder preforms. Solder creams (paste) and solder preforms shall meet the requirements of 4.16.1 and 4.16.2.

4.16.4 Cleaning solvents. The solvents or aqueous cleaners used for removal of grease, oil, dirt, flux, and other debris, shall be selected for the ability to remove both polar and nonpolar contamination. The solvents or cleaners used shall not degrade the materials or parts being cleaned. Flux solvents used in solder creams (paste) shall not be harmful to the work piece or solder joint and must be easily removed after the soldering operation. A list of typical solvents are:

<u>Solvent</u>	<u>Specification</u>
a. Ethyl alcohol (Ethanol)	O-E-00760
b. Trichlorotrifluoroethane	MIL-C-81302

<u>Solvent</u>	<u>Specification</u>
c. Isopropyl alcohol	TT-I-735
d. Perchloroethylene	O-T-236
e. 1, 1, 1-Trichloroethane (vapor degreasing)	MIL-T-81533
f. Reagent water (Type II)	ASTM D 1193
g. Detergent cleaners	As approved by the Government procuring activity
h. Thinner, paint, mineral spirits	TT-T-291F

Mixtures of solvents may be used. Solvents used shall be selected for compatibility with the materials being cleaned. To prevent contamination of parts and to provide for personnel safety, areas for cleaning parts, and areas where toxic or volatile vapors are generated, shall have an exhaust system to remove the vapors as they are generated (see 4.10).

4.16.5 Tubing. Polytetrafluoroethylene tubing shall conform to MIL-I-22129.

4.16.6 Heat shrinkable tubing. Heat shrinkable tubing shall conform to MIL-I-23053.

4.16.6.1 Heat source. Devices used for shrinking heat shrinkable tubing shall be temperature controlled to prevent damage to components.

4.16.7 Extruded vinyl plastic tubing. Extruded vinyl plastic tubing shall conform to MIL-I-7444, type I, or MIL-I-22076.

4.16.8 Printed wiring boards. Printed wiring board (PWB) design shall conform to MIL-STD-275 and MIL-P-55110.

4.16.9 Flexible printed wiring. Flexible printed wiring shall conform to MIL-P-50884, Type B.

4.16.10 Storage containers. Containers shall be of a material that does not introduce gases or chemicals that could be detrimental to the solderability of the printed wiring board or its components. Bags or containers shall not be made of silicones, sulphur compounds, polysulphides, or be processed with these or other detrimental compounds.

4.16.11 Wiping pads. Cellulose sponge pads for wipe-cleaning the soldering iron tip shall be finely textured, and of low sulphur content.

4.16.12 Maskant. The maskant material shall keep masked areas free of solder and shall not degrade mounted parts. When removed after soldering, the maskant shall leave no residues or contaminants. A maskant compatible with all PWB requirements, including contamination, conformal coating, and residue, need not be removed.

4.17 Solderability.

4.17.1 Solderability of leads and terminals. Leads and terminals of all components and end caps of chip components, shall be tested and conform with the solderability tests specified in MIL-STD-202, Method 208, within 120 days prior to being soldered into an assembly. Component leads, terminals and end caps shall either be pretinned with a solder coating process to provide a minimum of 0.0001 inch to a maximum of 0.0004 inch thickness on the lead or, if held in storage beyond 120 days, they shall be solderability tested and conform with MIL-STD-202, Method 208, prior to release for production.

4.17.2 Solderability of boards. Printed wiring boards shall meet the solderability requirements of MIL-P-55110.

4.18 Preparation for soldering.

4.18.1 Insulation removal. Insulation shall be removed from wire conductors by one of the following methods, using the tools specified in 4.10.2.

4.18.1.1 Thermal. Thermal type insulation strippers are preferred for wires of size 20 and smaller.

4.18.1.2 Mechanical. When extruded insulation is removed using a mechanical stripping tool, the lay of the wire strands shall be restored, if disturbed, without using bare finger contact. A device that utilizes fiberglass stripping wheels may be used for magnet wire.

4.18.1.3 Chemical. Insulation removal from magnet wire shall be accomplished by the use of chemical stripping agents, in accordance with the manufacturer's recommendation.

4.18.1.4 Solder dip. Polyurethane or similar type coatings may be removed by dipping the insulated wire to the required depth into a solder pot at the temperature recommended by the manufacturer. Stripping of solder strippable magnet wire (with polyurethane or similar insulation) on the termination of coils and windings wound with such wire may be performed by hot solder application in compliance with the wire manufacturers recommendations.

4.18.2 Removal of gold from areas to be soldered. Prior to use gold shall be removed from to-be soldered areas of component leads and connectors by any of the three tinning methods outlined below and shall be accomplished in such manner to prevent physical or functional degradation of the component.

Method 1. Static bath.

Immerse the fluxed gold plated lead in solder bath number one for 2 to 5 seconds. Only the portion of the lead to subsequently be soldered shall be immersed. Gold contamination level in solder bath number one shall be maintained at less than 4 percent. Immerse the fluxed tinned lead in solder bath number two for 2 to 5 seconds. Gold contamination in bath number two shall not exceed the limits specified in Table I.

Method 2. Agitated bath.

Immerse the fluxed gold plated lead in a flowing solder bath for 2 to 5 seconds. Only the portion of the lead subsequently to be soldered shall be immersed. Gold contamination in the solder bath shall not exceed the limits specified in Table I.

Method 3. Special processes.

Solder cups, gold plated in excess of 0.0001 inch, shall be prefilled as follows:

- Step 1: Clean solder cups using solvents specified in 4.16.4.
- Step 2: Place sufficient solder in the solder cup to completely fill the solder cup, to the milled lip, after melting.
- Step 3: Heat solder cup sufficiently to melt solder and allow all gases and flux to escape (cups should be at approximately a 45 degree angle to prevent entrapment of gases and flux).
- Step 4: Remove solder by wicking or extraction device.
- Step 5: Inspect inside of cup to ensure complete tinning of solder cup.
- Step 6: Place sufficient solder in the solder cup to allow proper fillet after wires are inserted into the cup (see 5.1.12).
- Step 7: Heat solder sufficiently to melt solder and allow all gases and flux to escape.

For solder cups that are not gold plated or are gold plated less than 0.0001 inch, only steps 1, 6, and 7 are applicable.

Upon conclusion of the gold removal process, the solder coated portion of the component lead shall conform to the acceptance criteria of MIL-STD-202, Method 208. Parts/components may be procured with tinned or solder coated leads to preclude this operation.

4.18.3 Component lead forming. Component leads shall be preformed to insertion or attachment configuration before installation into an assembly using a bending tool as described in 4.11.2.7. The lead forming process shall not cause damage to the component body or lead by stressing, nicking or deformation of the lead exceeding 5 percent of the diameter. Welded leads, when being bent, shall be firmly held by a suitable tool on the side of the weld away from the component body. Footed areas of leads coined for planar mounting are excluded from the 5 percent deformation requirement.

4.18.4 Automatic lead forming devices. Automatic lead forming devices are acceptable. Smooth impressioned marks due to bending tool holding forces shall not be cause for rejection.

4.18.5 Lead bends. The distance between the body of the component or weld and the bent section of a lead shall be in accordance with mounting criteria specified in DOD-STD-2000-3 and acceptance criteria of DOD-STD-2000-2. Lead bends shall be such that solder fillets shall not extend into the bend radius.

4.18.6 Stress relief. Wires and component leads terminated at a solder connection shall have slack in the form of a slight loop or gradual bend. The bending in the lead shall serve to minimize tensile or shear forces at the soldered connection. When the stress relief is in the horizontal plane, the lead shall wrap and shall continue around the terminal in the same direction as the stress-relief bend (see figure 3).

4.18.7 Lead trimming. Wires and leads shall be cut to their proper length prior to final soldering. When leads are cut after insertion in the printed wiring board, the cutting action shall not damage the printed wiring board or components mounted thereon. When automatic lead cutting is performed, a maintenance program shall be implemented to provide assurance that blades (saws) are monitored for wear, and that the feed system is calibrated to match the needs of the materials and density of leads being cut. Automatic cutting shall not bend the lead nor leave sharp spurs on lead ends.

4.18.8 Tinning of stranded wire. Prior to the soldering operation, that portion of stranded wire to be soldered to another surface shall be tinned (see figure 4) with the solder penetrating to the inner strands of the wire. Tinning of stranded wire shall not obscure the wire contour and the entire stripped end shall be tinned to within approximately 0.0625 (1/16) inches (1.588 mm) of the end of the insulation.

4.18.9 Precleaning. Items shall be clean or cleaned to fully accept flux and solder.

4.18.10 Handling and storage of printed wiring boards. Surfaces of printed wiring boards to be soldered shall not be handled with bare hands. If the board cannot be handled without touching its surface, protective devices such as clean nylon or cotton gloves, finger cots, or special tooling shall be used. Printed wiring boards that have been in storage may have absorbed moisture and shall be baked (see DOD-HDBK-P04) prior to being used in any soldering process.

CAUTION: Finger cots and nylon gloves shall provide static discharge protection in accordance with DOD-STD-1686.

4.18.11 Printed wiring board condition. Before components or terminals are mounted on a printed wiring board, the board shall have been examined for conformance to the requirements of 4.16.8 and 4.17.2. There shall be no evidence of any of the following defects:

- a. Pits, scratches, or inclusions.
- b. Separation of the conductor pattern (including terminal areas) from the base laminate.
- c. Blisters in the conductor pattern.
- d. Measling/crazing.
- e. Delamination of the base material.
- f. Wrinkles in the conductor pattern.
- g. Dirt, grease, or other foreign matter on the printed wiring board.

4.18.12 Mounting of component parts. Components shall be mounted in accordance with DOD-STD-2000-3. Specifically, component/part leads shall be of the clinched or straight-through configuration in accordance with the following:

- a. Leads in unsupported holes in single-sided boards (or in any single-sided section of a printed wiring board) shall be clinched (see figure 5A).
- b. Leads in unsupported holes in double-sided boards (or in any double-sided section of a printed wiring board) shall be clinched (see figure 5B) or, if the connection is to be step-soldered in accordance with DOD-STD-2000-1, the leads may be unclinched.
- c. Leads in plated-through holes in printed wiring boards may be unclinched (see figure 6A) unless otherwise specifically stipulated on the applicable engineering drawing. For the U.S. Army Missile Command, all leads shall be clinched (see figure 6B) unless

otherwise specified on the drawing (does not apply to modules, DIPs or pins). For the National Security Agency, leads shall be unclinched unless otherwise specified or if mechanical support is needed for large components.

d. One or more leads of multileaded components (DIPs) may be bent (rather than clinched) to the termination area to retain parts during soldering operations but such bent leads shall conform to all requirements applicable to unclinched (straight-through) leads (see figure 7). Bends shall be limited to approximately 15° ; for the National Security Agency, bends shall be limited to 45° and to a maximum of 4 leads per component.

4.18.13 Tempered leads. Unless otherwise specifically stipulated on approved engineering drawing, untempered leads that are smaller than 0.050 inch in diameter shall be clinched when installed in unsupported holes. Tempered leads (sometimes referred to as pins) and untempered leads 0.050 inch or greater in diameter or thickness shall not be bent nor formed for mounting purposes inasmuch as body seals and connections internal to the component may be damaged thereby. Neither shall tempered leads be cut with diagonal cutters or other tools which impart shock to connections internal to the component.

4.18.14 Lead extension. Component leads terminated "straight-through" shall protrude through the printed wiring board a minimum of 0.020 and a maximum of 0.060 inch (see figure 8), unless otherwise specified on the drawings. This is an exception to MIL-STD-275.

NOTE: Lead extension shall be identical for leads mounted in eyelets when such are utilized (such as in new-built-to-existing-design projects).

4.18.15 Metal cased components. All metal cased components that lay on conductor wiring shall be insulated.

4.18.16 Insulation clearance. Clearance between the solder of the connection and the end of either separable or fixed insulation on the wire in the connection shall be in accordance with DOD-STD-2000-2.

5. DETAILED REQUIREMENTS

5.1 Manual soldering. Manual soldering shall be accomplished using the facilities, tools and materials specified in paragraphs 4.11 through 4.16.

5.1.1 Preparation of the soldering iron. The soldering iron tip shall be fully inserted into the heating element casing, which shall be tightly attached to the handle. The soldering iron shall be heated and upon reaching a temperature which causes solder to melt, the tip shall be first tinned with a light coat of solder and then cleaned by wiping lightly on a clean, moist wiping pad (see 4.16.11). A thin, bright, tinned surface shall be maintained on the working surface of the tip to insure proper heat transfer to the connection being soldered. Oxidation scale shall not be allowed to accumulate on the tip or between the heating element and the tip.

5.1.2 Use of solder pots. Solder pots may be used for cleaning and tinning of areas to be soldered. Solder pots shall be temperature controlled, and, unless otherwise specified, shall be set at a preselected temperature within the range of 260 to 302°C (500 to 575°F). Solder purity shall be controlled in accordance with 5.2.2.1. Immersion time in the solder pot of areas to be soldered shall be less than 5 seconds.

5.1.3 Use of thermal shunts. Thermal shunts (heat sinks) shall be used to protect heat sensitive components such as semiconductors, transistors, ceramic capacitors, crystal devices, and insulating materials from damage due to heat, while soldering (see figure 9). Thermal shunts so utilized shall not otherwise damage the component being soldered.

5.1.4 Heat application. The elements to be soldered shall be sufficiently heated by the soldering iron tip to cause melting of the solder and wetting of the surface. Excessive heating time, pressure, and temperature shall be avoided to prevent unreliable joints or damage to parts, printed circuitry, insulation, or adjacent components.

5.1.5 Solder application. Except for transfer soldering, the area to be soldered shall first be properly heated and then the solder, in accordance with 4.16.1, shall be applied at the junction of the soldering iron tip and the parts or components being soldered (solder bridging, figure 10). Precautions shall be taken to prevent any change in wire or lead positioning within the solder connection before the solder has completely solidified. Solder bridging shall be maintained throughout the soldering process.

5.1.6 Flux application. Flux in accordance with 4.16.2, shall be utilized for all soldered electrical connections. Liquid flux, when used, shall be applied in a thin, even coat to those surfaces to be joined prior to application of heat. Cored solder wire, when used, shall be placed in such a position that allows the flux to flow and cover the connection elements as the solder melts.

5.1.7 Cooling. The molten solder shall be cooled at room temperature only; forced air or liquid material shall not be used to accelerate solidification.

5.1.8 Bifurcated terminals. The order of preferred terminations of bifurcated terminals are as follows:

5.1.8.1 Side route connection. The wire or component lead shall be dressed through the slot and wrapped to either post of the terminal (see figure 11). The wire or lead shall be wrapped to the terminal post a minimum of 180 degrees and a maximum of 270 degrees (1/2 to 3/4 turn). The wire or lead shall be wrapped on the terminal post to assure positive contact of the wire with at least two corners of the post. The wire or lead shall also be in firm contact with the base of the terminal or the previously soldered wire. The number of attachments shall be limited to three per terminal post and shall be maintained such that: (a) there is no overlapping of wraps and wires; (b) spacing between wires and between wires and terminal board or panel is a minimum consistent with the diameter of the wire insulation; and (c) the wraps are dressed in alternate directions.

5.1.8.2 Bottom route connection. The wire shall be inserted through the terminal base and wrapped to either post a minimum of 180 degrees and a maximum of 270 degrees (1/2 to 3/4 turn) (see figure 12). The wire shall be wrapped on the terminal post to assure positive contact of the wire with at least two corners of the post. The wire lead shall also be in firm contact with the base of the terminal or the previously installed wire. When more than one wire is to be attached, they shall be inserted at the same time but shall be wrapped separately around alternate posts.

5.1.8.3 Top route connection. The stripped wire shall be positioned such that it extends the full length of the terminal forks. When the ratio of slot size to wire size is greater than 2:1, the wire may be doubled back (see figure 13) to help hold the wire in position.

5.1.8.4 Continuous run connections. When a series of terminals are mounted in a row, with the post pairs parallel with all others, and the terminals are to be connected each to the other, such interconnection shall be made in accordance with a, b, c, or d below:

a. Individual solid jumper wires shall be wrapped between corresponding posts of adjacent terminals in the row (see figure 14). Individual wraps shall be in accordance with 5.1.8.1.

b. A solid jumper wire shall be wrapped to one post of the initial terminal in the row and continued from terminal to terminal with 360 degree wrapping (see figure 15) at the post corresponding with the first until the last terminal is wrapped. The first and last wraps shall be in accordance with 5.1.8.1.

c. A solid jumper wire shall be wrapped to one post of the initial terminal in the row, dressed through the slot of each subsequent terminal without wraps, and wrapped to that post of the last terminal which corresponds with the post of the initial terminal wrapped. The first and last wraps shall be in accordance with 5.1.8.1. The unwrapped portion of the jumper shall include a curvature for relief of tension caused by thermal expansion/contraction (see figure 16).

d. If wires are to be attached to a group of terminals such as on transformers, certain relays, and rotary switches, the wires shall be neatly arranged around the terminals in such a manner that they do not cross one another. When a continuous run is more practicable than would be the application of individual jumpers, intermediate terminals of a series to be connected with each other shall be joined with a solid jumper wire threaded through the openings (see figure 17). The jumper wire shall contact at least two non-adjacent contact surfaces of each intermediate terminal.

5.1.9 Hook terminals. The bend to attach wires and leads to hook terminals shall be 180 to 270 degrees ($1/2$ to $3/4$ turn). Insulation clearance shall be as specified in 4.18.16 and the maximum wire fill shall not exceed the end of the hooks (see figure 18). Not more than three conductors shall be permitted. For size 30 or smaller wire, a maximum terminal wrap of 3 turns may be used. In no case shall wires be wrapped on each other.

5.1.10 Pierced or perforated terminals. For wiring to a single terminal, the wire must pass through the eye and shall be wrapped around the terminal 180 to 270 degrees ($1/2$ to $3/4$ turn), as applicable (see figure 19). Insulation clearance shall be in accordance with DOD-STD-2000-2.

5.1.11 Turret terminals. The bend to attach a wire or lead to a turret terminal shall be not less than 180 degrees ($1/2$ turn) and no more than 270 degrees ($3/4$ turn) (see figure 20). Not more than three conductors for each section shall be permitted. The first wire shall be attached to the base and vertical post in the lower section or the shoulder and vertical post in the upper section. Additional wires shall be attached as close as possible to the preceding wire. When practicable, except for bus wire, conductors shall be placed in ascending order so that the largest wires are on the bottom. Each wire shall be in contact with the terminal for the full curvature of the wrap. The side route shall be used on all solid-post, turret-type terminals.

5.1.12 Cup and hollow cylindrical type terminals. Solder cup terminals shall be cleaned and pretinned/pre-filled prior to insertion of the wire. Use sufficient solder to fill the cup or receptacle when the wire is inserted. Sufficient heat shall be applied during filling of the cup to assure that all of the flux has risen and is not trapped at the cup bottom. No more than three (3) wires shall be installed in the cup, and in no instance shall the lay of the strands of any wire be disturbed, nor shall strands be removed to permit multiple wire insertion.

After filling, the wire(s) shall be inserted straight into the cup (see figure 21), touching the terminal (along the back side for scoop-cut cups) for its full length until it strikes the bottom of the cup. Continuous soldering iron control shall be maintained throughout the soldering operation.

The solder should rise slightly above the top of the cup and follow the contour of the cup entry slot. The contour of the wire shall not be obscured at the termination end of the insulation. Solder should not spill over and adhere to the sides of the terminal. Excess solder that spills over the terminal or from a weep hole shall be removed, such that the solder remaining on the outside of the solder cup is only in the form of a thin film.

5.1.13 Termination of shielded wires. Termination of shielded wires shall be as specified by the engineering drawing.

5.2 Automated soldering systems.

5.2.1 Machine soldering. Machine soldering shall be accomplished using any integral system (see 4.12) which also incorporates: (1) temperature-controlled preheating and soldering stages (see 5.2.2.8 and 5.2.2.9, respectively); (2) an automatic fluxing stage (see 5.2.2.7); (3) a cooling stage (see 5.2.2.10); and (4) a speed-controlled conveyor stage per 5.2.2.5. Components shall be constrained by lead configuration or by devices or materials in accordance with 5.2.2.3 to assure that the leads do not move during the flux-preheat-solder-cool cycle.

5.2.1.1 Machine maintenance. Machines incident to the automated soldering process shall be maintained such as to assure capability and efficiency commensurate with design parameters established by the original equipment manufacturer.

5.2.2 Solder bath. The solder bath shall be set to a preselected temperature (T) between 249° and 271°C (480° and 520°F). The temperature and the time of contact between the printed wiring assembly and the solder shall be dependent upon such factors as preheating, thickness of board, number of contacts or conductors, and the type of parts. The period of exposure of any printed wiring assembly to a solder bath shall be limited to a duration which will not cause damage to the board or parts mounted thereon. In no case shall the temperature or length of time be such as to cause damage to sensitive parts. The solder bath shall be periodically analyzed to insure that contamination levels do not exceed the limits specified in Table I.

5.2.2.1 Maintenance of solder purity. To maintain the proper purity of solder, the following procedures shall be adhered to in machine soldering of printed wiring assemblies:

a. Before the start of soldering operations, dross shall be removed from the solder bath surface. Dross shall be periodically removed from the solder bath to assure that dross does not mix with the liquid solder. Automatic or manual methods are acceptable provided that dross does not come in contact with the printed wiring assembly during any portion of the soldering process.

b. The solder utilized within the machine soldering system shall be maintained to assure that contaminants do not exceed the percentages specified in Table I.

c. Solder in solder baths shall be chemically or spectrographically analyzed or renewed at the testing frequency levels shown in Table I, column B. These intervals may be lengthened to the 8 hour operating days shown in column C when the results of analysis provide definite indications that such action will not adversely affect the purity of the solder bath. If contamination exceeds the limits of Table I, intervals between analyses or replacement shall be shortened to those 8-hour operating days shown in column A, or less, until continued purity has been assured by analysis. Records containing the results of all analyses and solder bath usage shall be readily available for review by the procuring activity.

5.2.2.2 Masking. Areas of printed wiring boards not to be soldered (including plated-through holes in which leads or wires are to be later inserted and soldered) shall be masked prior to the application of solder flux. The maskant materials used shall not cause fire or create fire or health hazards (see 4.16.12).

5.2.2.3 Holding fixtures and materials. Devices or materials used to retain components and parts to the printed wiring board through preheat, fluxing, soldering, and cooling stages shall not contaminate, mar, or otherwise damage or degrade printed wiring boards, parts, or components. The devices or materials shall not only be adequate to maintain positioning but shall permit solder flow through plated-through holes and complete coverage of terminal areas on the component side of the printed wiring board. If used, skin packaging should be vented to assure hole fill and terminal area coverage.

5.2.2.4 Carriers. Devices used for the transport of printed wiring assemblies through preheat, fluxing, soldering, and cooling stages shall be in accordance with 4.13.

5.2.2.5 Conveying. Preloaded and precleaned printed wiring assemblies shall be transported through the fluxer and preheater to the solder bath and on through the cooling stage at a rate preselected to assure compliance with 5.2.2.9. The speed shall not vary more than 1 inch (25.4 mm) per minute. Immersion time of terminations in the molten solder wave shall not exceed 5 seconds.

5.2.2.6 Lead trimming. Leads may be trimmed provided the cutters used are such to impart no physical shock to the components and the leads are cut square with no spikes, peaks, or drag. Trimming may be accomplished prior to or after exposure to the solder bath. When leads are cut after the soldering operation, reflow is required.

5.2.2.7 Fluxing. Flux shall be applied by the dip, spray brush, wave, foam, or other method which will produce an even coated surface. Any thinner used shall be a product of the flux manufacturer, which the manufacturer recommends for the particular flux, or shall be a Government approved substitute.

5.2.2.8 Preheating. Printed wiring assemblies shall be preheated to a temperature compatible with the flux, conveyor speed, solder temperature, and time of board contact with the solder bath (to remove volatile solvents, to improve solder flow and wetting, and to reduce temperature shock).

5.2.2.9 Solder application. Solder shall be applied to the printed wiring assembly through machine contact with a solder bath (or wave) compatible with the type of soldering machine being used. The time of contact between the printed wiring assembly and solder shall be preselected, dependent upon preheating, thickness of board, number of connections and conductors, and the type of components. The temperature of the solder at the point of contact with the surface of the printed wiring assembly shall be the preselected temperature (T) $\pm 10^{\circ}\text{F}$ (see 5.2.2). The height of the wave (or depth of immersion for systems designed for board float) shall be maintained to assure effective contact and a solder pressure sufficient for hole fill and solder spread to terminal areas on the component side of the printed wiring assembly. The assembly/solder time at temperature shall be such to preclude damage to heat-sensitive components.

5.2.2.10 Cooling. The printed wiring assembly shall be retained on the conveyor until the solder has solidified. There shall be no forced cooling.

5.2.2.11 Interface holes. Double-sided printed wiring boards, with plated-through holes for interfacial connections, shall have a continuous plug of solder from one side of the board to the other (see figure 22A), or have a solid, tinned, copper feed-through lead through the holes. The solder plug shall fill the plated-through hole, completely wetting the walls 360 degrees around the periphery of the hole and extending a minimum of 0.005 inch outward from the hole. The solder in the hole may be depressed on both sides of the printed wiring board but the depression shall not exceed 25 percent (25%) of the hole depth measured at the terminal area. Plated-through holes, with leads, shall have a maximum depression of 25 percent of the board thickness on the component side of the board.

Unplated-through hole interfacial connections shall be made by the use of uninsulated, solid, tinned copper wire (Z-wire) extending through the hole and clinched (see figure 22B). The lead shall make contact with the conductor pattern (foil) on each side of the printed wiring board and the ends shall not extend beyond the end of the terminal area or its electrically connected conductor pattern.

5.2.3 Planar (Reflow) soldering.

5.2.3.1 Solder application. Solder shall be deposited or plated on both metal surfaces to be joined prior to positioning the components in place.

5.2.3.2 Solder thickness. The thickness of the solder coating on component leads or ribbon conductors plus the solder thickness on the termination area shall be 0.0381 mm to 0.0889 mm (0.0015 to 0.0035 inches). The coating shall extend from the end of the flat pack lead up to and including the radius of the heel bend but shall not extend past the radius of the knee bend (see figure 23).

5.2.3.3 Flux application. Prior to the soldering process, a thin uniform coating of flux shall be applied to the pad surfaces or joint area where the component leads are to be soldered.

5.2.3.4 Component positioning. The component shall be positioned such that the body is centered between terminal areas (see figure 24). Mounting shall be in accordance with DOD-STD-2000-3.

5.2.3.5 Soldering. The leads to be soldered shall be heated to the flow temperature of the solder. The application of heat shall be controlled during the soldering operation to prevent damage to the assembly (e.g., base material, adjacent connections, electrical components). The surfaces being soldered shall be restrained to preclude movement relative to the terminal area as solder is solidifying.

5.2.4 Condensation (Vapor Phase) reflow. The condensation (Vapor Phase) reflow soldering method is generally used for back planes and connector reflow soldering. Prior to using this method for component soldering, supportive information that no damage will occur to the components shall be submitted to the procuring activity. The condensation reflow system shall be mechanized to provide for smooth transition of the work piece, control of temperature, level of vapors and dwell-time. There shall be a smooth transition out of the vapors after completion of the soldering operation to prevent disturbed solder connections prior to solidification.

5.2.5 Machine controls. The contractor shall have operating procedures describing the soldering process and the proper operation of the automatic soldering machine and associated equipment. For the soldering machine, these procedures, as a minimum, shall define the preheat temperature, solder temperature, rate of travel, frequency of temperature verification measurements and frequency of solder bath analysis. If any of the above mentioned characteristics must be adjusted

for different printed wiring assemblies, the procedure shall identify by printed wiring assembly, drawing number, or other positive identification means, the setting to be utilized.

5.3 Post soldering operations.

5.3.1 Rework of unsatisfactory solder connections.

Nonconforming solder connections shall not be reworked until inspection personnel have recorded each discrepancy. This information shall be used to provide corrective action to reduce future rework.

5.3.1.1 Reheat method of rework. Solder connections shall not be reheated more than once during rework. The reheating and addition of flux and solder, if required, may be used to correct the following defects:

- a. Rosin solder connections.
- b. Cold solder connections.
- c. Fractured (disturbed) solder connections.
- d. Solder points, peaks, or icicles.
- e. Unsoldered connections.
- f. Insufficient solder.
- g. Pin holes.

5.3.1.2 Resolder method of rework. Defective solder connections which cannot be corrected in accordance with 5.3.1.1 shall be reworked by removing the solder with a vacuum device or by wicking. After the solder has been removed, the connection shall be cleaned and the defect corrected. All connections shall be cooled to room temperature before reapplying heat. Soldered joints reworked to correct deficiencies must meet the requirements of this specification.

5.3.2 Cleaning. Solvents or combinations of solvents (see 4.15.3) shall be used to remove all residual flux and other contaminants as soon as practicable but not later than one (1) hour after solidification of the solder connection. When activated fluxes are used, the printed wiring assembly shall be cleaned immediately upon completion of the soldering operation and in such a manner to prevent damage to the printed wiring assembly or components mounted thereon. The use of ultrasonic cleaning devices on printed wiring assemblies is prohibited. Acceptable cleaning methods are provided in DOD-HDBK-2000-X.

5.3.3 Cleanliness testing. After cleaning, in accordance with 5.3.2, the printed wiring assemblies shall be subjected to a cleanliness test before the end of the production shift. The methods of measuring the resistivity of solvent extract (greater than 2,000,000 ohm-centimeter) or the salt equivalent ionic contamination (less than 10.06 micrograms per square inch) are provided in DOD-HDBK-2000-X.

5.4 Certification of personnel.

5.4.1 Certification. Certification as to the ability of personnel to meet the requirements of this standard shall be made available to the procuring activity. Personnel shall be certified, in accordance with the requirements specified herein, prior to performing or inspection of soldering on engineering or experimental models, prototype models, or deliverable articles. Each individual's certification card shall be on his person or visibly displayed at his work station.

5.4.2 Visual acuity. All candidates for certification in any category (see 5.4.4) shall meet the following vision requirements:

- a. Far vision: Snellen chart 20/50, or better.
- b. Near vision: Jaeger 1 or 0.50 meter at 14 inches or better.
- c. Color perception: Normal as determined by means of standard color plates.
- d. Depth perception: Normal binocular vision for fine, close work as determined by standard testing methods.

All personnel certified to this standard shall be given an eye test annually by an accredited eye examiner to determine their ability to meet these vision requirements. Use of prescription lenses to meet the vision requirements is permissible. When such lenses are required, the certification card shall so state and such lenses shall be used whenever soldering or inspection is being performed. Failure to meet any of these requirements shall disqualify a candidate for training and certification or shall result in revocation of any certification previously granted.

5.4.3 Achievement of certified status. To be certified in categories A, B, and C, personnel shall attend and successfully complete an 80 hour formal training program at a Government approved school, as specified by the procuring activity. To be certified in categories D and E, personnel shall attend and successfully complete a 40 hour formal training program conducted by a category C instructor/examiner. To be certified in category F and G, Government personnel must attend a special course at an approved school (see 5.4.7.4).

5.4.4 Certificate categories. Certificates shall be issued in the following eight categories: Government personnel, (categories A and B), and contractor personnel, (category C), shall be certified by an approved school; contractor personnel, (categories D, E, and R), shall be certified by the contractor; Government personnel, (categories F and G), shall be certified under the cognizance of an approved school.

5.4.4.1 Category A - senior examiner.

5.4.4.1.1 Government personnel. Category A senior examiners shall be Government personnel who are actively involved in research and development of soldering methods, techniques, and standards and have been certified by a Government approved school. Currency shall be maintained and shall be reviewed on an annual basis.

5.4.4.1.2 Category A authority. Category A personnel are authorized to train, or to require recertification of personnel of all other categories. Category A personnel are also authorized to monitor soldering processes, workmanship, training programs and facilities for conformance to this standard.

5.4.4.2 Category B - Government instructor/examiner.

5.4.4.2.1 Category B Government personnel. Category B personnel shall be Government personnel who have been certified after satisfactory completion of an 80 hour soldering course conducted in accordance with 5.4.7.4.

5.4.4.2.2 Category B authority. Category B personnel are authorized to require recertification of personnel of categories C, D, E, R, F, and G, to inspect contractor soldering processes and workmanship for conformance to this standard and to perform soldering operations and inspections at Government facilities for conformance with this standard.

5.4.4.2.3 Category B training authority. Category B personnel are authorized to train other Government personnel, (category F and G), to this standard. To perform this training, the same requirements which are imposed on the contractor, must be met (see 5.4.4.2.2). This authority is granted by the procuring activity after review and acceptance of the training program plan facilities.

5.4.4.3 Category C - instructor/examiner.

5.4.4.3.1 Category C contractor personnel. Category C personnel shall be contractor personnel certified after satisfactory completion of an 80 hour soldering course (see 5.4.7.4). Category C personnel certification and performance shall be reviewed on an annual basis.

5.4.4.3.2 Category C authority. Category C personnel are authorized to train or require recertification of personnel of categories D, E, and R; to monitor soldering processes and workmanship for compliance to this standard; to perform inspections for conformance with this standard; and to determine the operations or procedures that are appropriate for a category R inspector or operator.

5.4.4.4 Category D - inspector.

5.4.4.4.1 Category D contractor personnel. Category D personnel shall be certified by the contractor after satisfactory completion of a 40 hour soldering course conducted by a certified category C instructor/examiner.

5.4.4.4.2 Category D authority. Category D personnel are authorized to perform inspections for conformance with this standard.

5.4.4.5 Category E - operator.

5.4.4.5.1 Category E contractor personnel. Category E personnel shall be certified by the contractor after satisfactory completion of a 40 hour soldering course conducted by a certified category C instructor/examiner.

5.4.4.5.2 Category E authority. Category E personnel are authorized to perform soldering operations in conformance with this standard.

5.4.4.6 Category R - restricted operator/inspector.

5.4.4.6.1 Category R contractor personnel. Category R personnel shall be selected by the contractor for performance of a limited number of operations or procedures. The training program shall, as a minimum, include the operations or procedures for which the category R personnel are to be certified. Functions or operations using a category R operator or inspector at the contractor facility require prior approval of the procuring activity. Similar operations conducted by a subcontractor requires approval of the prime contractor and is subject to review by category A or B personnel in accordance with 5.4.4.1.2 and 5.4.4.2.2.

5.4.4.7 Category F - Government inspector

5.4.4.7.1 Category F Government personnel. Category F personnel shall be certified by the Government after satisfactory completion of a 40 hour soldering course with prime emphasis on inspection criteria conducted by a certified category B instructor/examiner.

5.4.4.7.2 Category F authority. Category F personnel are authorized to perform inspections for conformance with this standard.

5.4.4.8 Category G - Government operator.

5.4.4.8.1 Category G Government personnel. Category G personnel shall be certified by the Government after satisfactory completion of a 40 hour soldering course conducted by a certified category B instructor/examiner.

5.4.4.8.2 Category G authority. Category G personnel are authorized to perform operations in conformance with this standard.

5.4.5 Contractor training program.

5.4.5.1 General. The contractor shall establish and maintain an effective written training program to qualify, certify and recertify all personnel performing operations applicable to this standard under the cognizant procuring activity contracts and shall include subcontracts, interplant work orders, and purchase orders. The program shall provide for training using the methods, equipment and materials described in this standard. Upon satisfactory demonstration of proficiency, personnel shall be issued a contractor certificate. The contractor shall prepare and maintain records of personnel training and performance.

5.4.5.2 Training records. The contractor's training records shall be maintained for the term of the contract and shall include, for each trainee during the time of his/her certification, the following:

- a. Trainee-fabricated test specimen depicting satisfactory conformance to the applicable requirements of this standard.
- b. Graded copies of written tests.
- c. Employer, plant division, and location of employment.
- d. Certification category.
- e. Date of certification or recertification.
- f. Records of latest visual acuity examination.

5.4.5.3 Program evaluation. The training program is subject to review by a category A senior examiner to assure that the program is compatible with this standard. The category A senior examiner reserves the right to disapprove the training program at any time the objectives of this standard are not being met.

5.4.5.4 Government training program. The training program for Government personnel shall, as a minimum, meet the criteria detailed in 5.4.5.1.

5.4.6 Maintenance of certified status.

5.4.6.1 General. Based on a quality audit, review of inspection data, or observation of quality of articles fabricated, soldering personnel involved may be required to either demonstrate proficiency or be retrained in the category concerned and be recertified (see 5.4.7).

5.4.6.2 Continuous performance evaluation. Category D, E, F, and G personnel shall be subjected to a continuous performance evaluation as specified in 5.4.7.2.

5.4.7 Recertification.

5.4.7.1 Requirements. Recertification shall be required under the following circumstances:

- a. Proficiency requirements herein are not met.
- b. New techniques have been developed which require new skills.
- c. Certificate holder changes employment.
- d. There is a reason to question proficiency or workmanship.
- e. Work period interruptions exceed 90 days (categories B, C, D, E, R, F and G).
- f. Twelve months after last certification.

5.4.7.2 Procedures. The recertification procedure shall be as follows:

- a. Category B and C personnel shall annually demonstrate proficiency to a category A senior examiner, and failing to demonstrate proficiency shall be required, prior to further performance, to attend a recertification course. Personnel passing the recertification course shall be recertified.
- b. When 5.4.7.1b applies, category B and C personnel shall be recertified after attending a recertification course, and demonstrating proficiency in new techniques.
- c. Category D, E and R personnel shall be recertified as specified by category A, B, or C personnel and category F and G by category B personnel.

5.4.7.3 Revocation of certified status. Certifications issued by the contractor shall be revoked when the:

- a. Certificate holder fails to be recertified when required.
- b. Contractor training program fails to meet the objectives of this standard.

c. Certificate holder leaves employment of the contractor for which certificate was originally issued.

d. Certificate holder fails to meet visual acuity requirements.

e. Quality of work has deteriorated as determined by a category A, B, or C instructor/examiner.

5.4.7.4 Certification resources. Certification of personnel to meet the requirements of this standard shall be accomplished by a Government approved school as designated by the procuring activity.

Typical schools: US Navy - Naval Weapons Center
China Lake, CA

Naval Avionics Center
Indianapolis, IN

US Army - U.S. Army locations of approved
Government schools can be
obtained from the procuring agency.

6. SUPERSESSION DATA

This standard is one of a series of documents which, as a composite, covers the entire soldering process and will supersede the documents listed below. The listed documents may remain in effect until DOD-STD-2000-2, Acceptance Criteria for High Quality/High Reliability Soldering, and DOD-STD-2000-3, Mounting Requirements, are approved for use.

MIL-STD-1460	Soldering of Electrical Connections and Printed Wiring Assemblies.
MIL-S-45743	Soldering, Manual Type, High Reliability, Electrical and Electronic Equipment.
MIL-S-46844C	Solder Bath Soldering of Printed Wiring Assemblies.
MIL-S-46860B	Soldering of Metallic Ribbon Lead Materials to Solder Coated Terminals, Process for Reflow.
MIL-S-50826B	Soft Soldering Electrical Connections for Special Weapons Items.
MIL-S-50827A	Soft Soldering Electrical Connections for Conventional Weapon Items.
WS-6536	Process Specification Procedures and Requirements for Preparation and Soldering of Electrical Connections.

DOD-STD-2000-1

WS-4554	Wave Soldering of Printed Wiring Assemblies, Automatic Machine type
NSA 756	High Reliability Manual Soldering of Electrical Connections.
NSA 757	Automatic Machine Flow Soldering of High Reliability COMSEC Printed Wiring Assemblies.

Custodian:

Air Force - 11
Army - MI
Navy - AS
NSA - NS

Preparing Activity:

Navy - AS
Project No. SOLD-0001

Reviewers:

AF - 15, 17, 19, 99
Army - AR, CR, ER, MR
Navy - EC, OS
DLA - ES

Users:

Army - AV
DLA - DH

TABLE 1. Solder bath contaminate levels.

Contaminant	Maximum allowable percent of contaminate per solder operation		Testing frequency 8 hr operating days <u>5/</u>		
	Pre-conditioning (lead/wire tinning) <u>1/</u>	Wave soldering <u>2/</u>	Columns		
			A	B	C
Copper	0.75	0.30	15	30	30
Gold	0.50	0.20	15	30	30
Cadmium	0.01	0.005	15	30	60
Zinc	0.008	0.005	15	30	60
Aluminum	0.008	0.006	15	30	60
Antimony <u>3/</u>	0.20 - 0.50	0.20 - 0.50	15	60	120
Iron	0.02	0.02	15	60	120
Arsenic	0.03	0.03	15	60	120
Bismuth	0.25	0.25	15	60	120
Silver <u>4/</u>	0.75	0.10	15	60	120
Nickel	0.025	0.01	15	60	120

1/ The tin content of the solder shall be from 59.5 to 63.5 percent tin and tested at the same frequency testing for copper/gold contamination. The balance of the solder shall be lead with one or more of the listed contaminants.

2/ The total of copper, gold, cadmium, zinc and aluminum contaminants shall not exceed 0.4 percent for soldering.

3/ The minimum amount of antimony present in the solder for either operation (column 1 or column 2) shall be 0.20 percent.

4/ Not applicable for Sn62 solder - limits to be 1.75 - 2.25 (both operations).

5/ An operating day constitutes any 8-hour period, or any portion thereof, during which the solder is liquified and used.

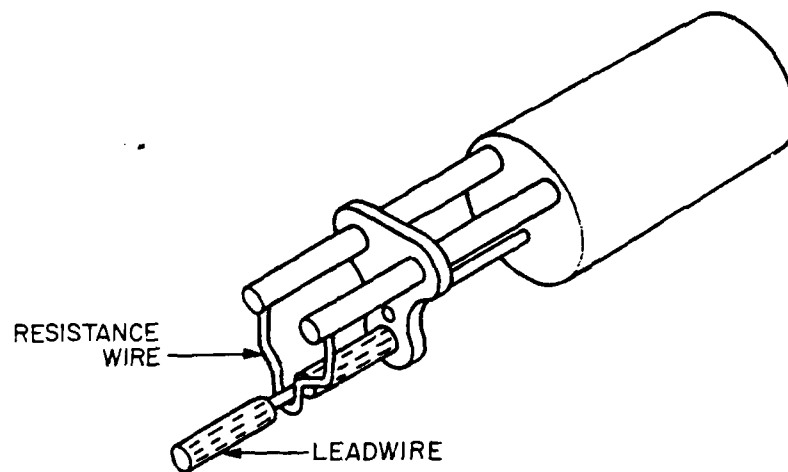


FIGURE 1. Typical thermal stripper (see 4.11.2.1).

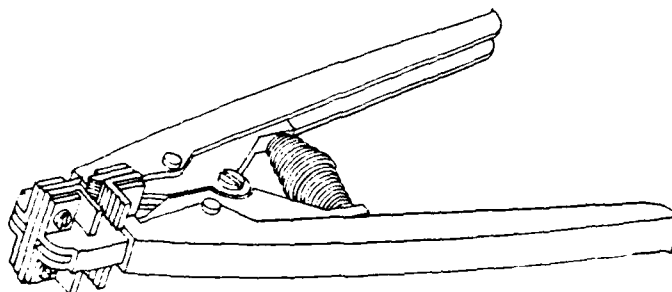


FIGURE 2. Mechanical hand wire stripper (see 4.11.2.2).

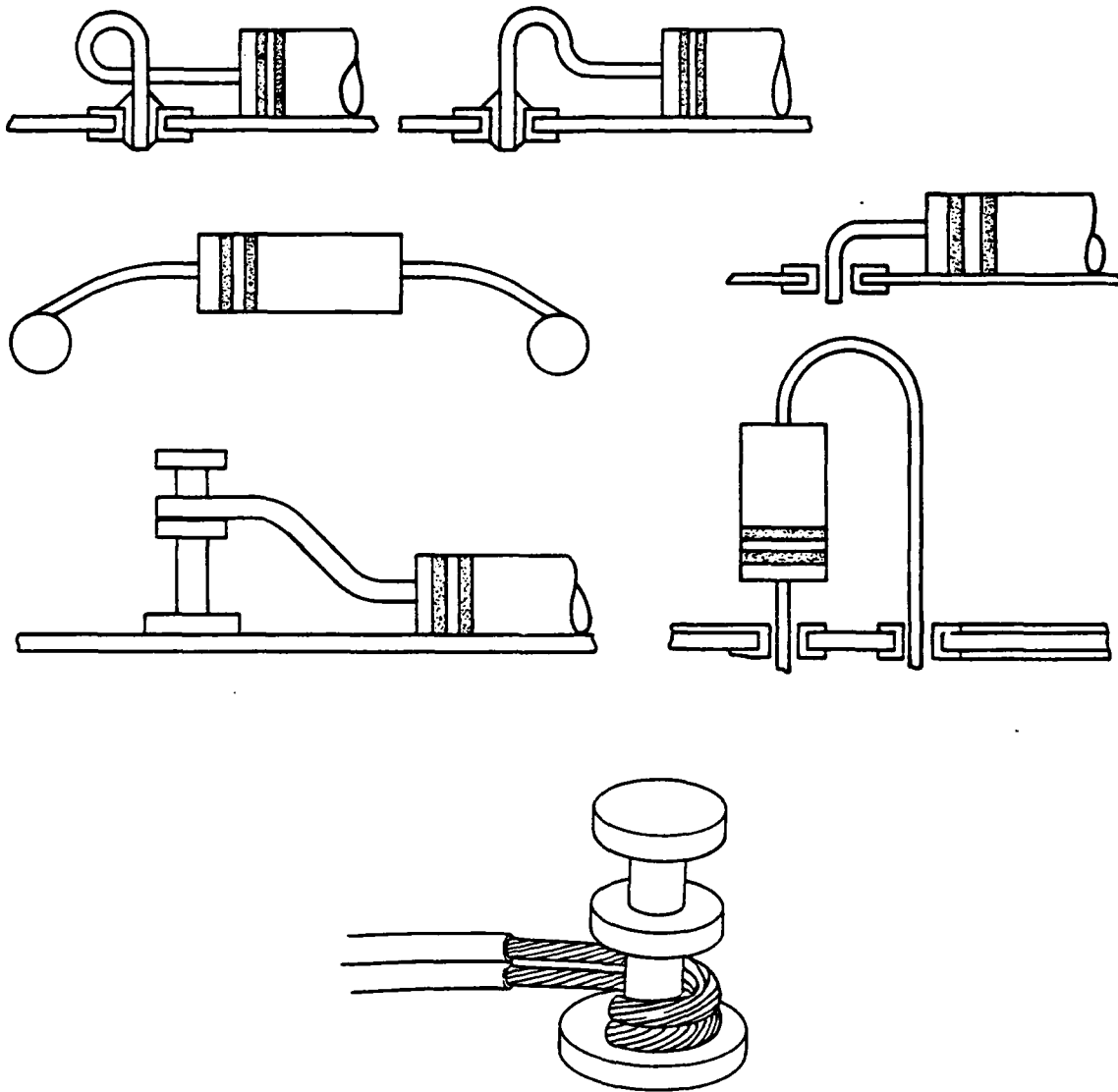
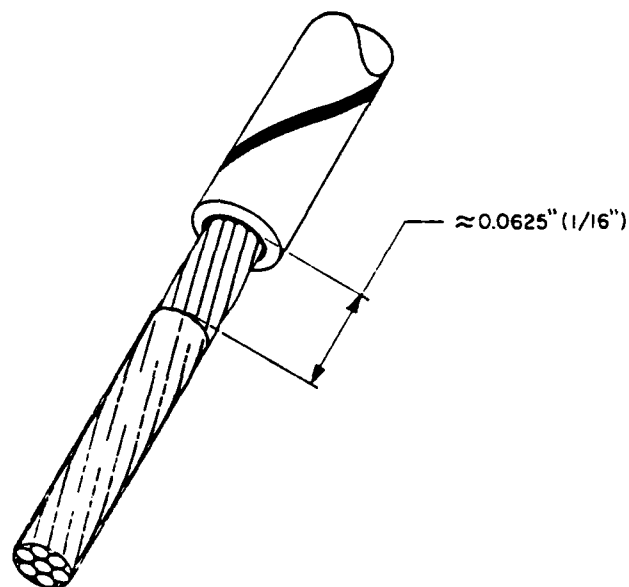


FIGURE 3. Typical examples of stress relief (see 4.13.6).



NOTE: THIS IS AN IN-PROCESS
CONFIGURATION. WICKING IN
FINAL CONNECTION SHALL
CONFORM TO DOD-STD-2000-2

FIGURE 4. In-process step for tinning stranded wire (see 4.18.8).

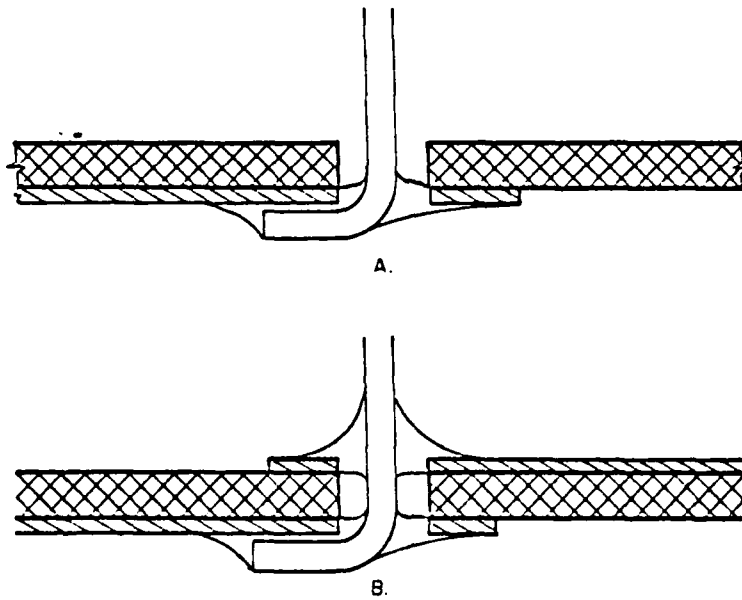


FIGURE 5. Clinched lead termination (see 4.18.12.a & b).

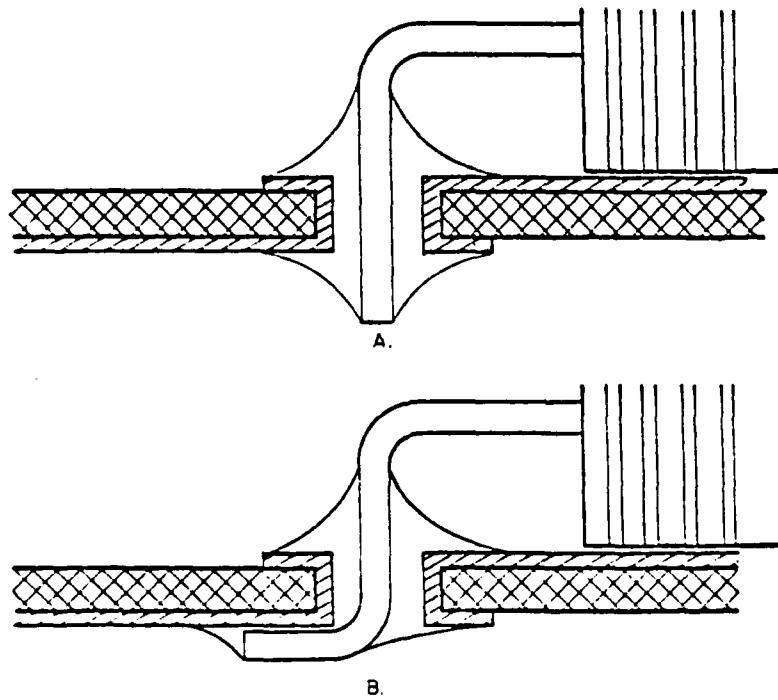
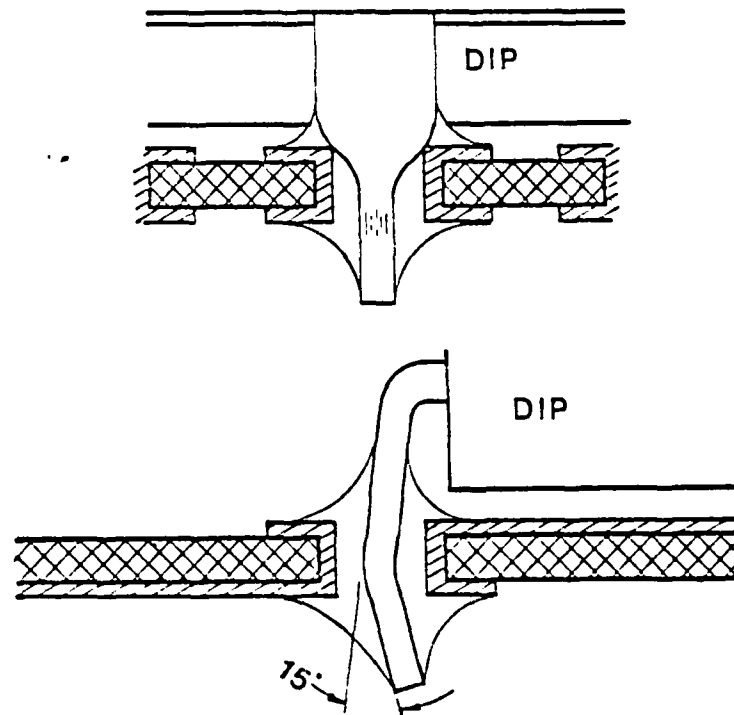


FIGURE 6. Plated-through hole lead termination (see 4.18.12.c).



NOTE: LEAD BENDS LIMITED TO 45°
FOR NSA USAGE

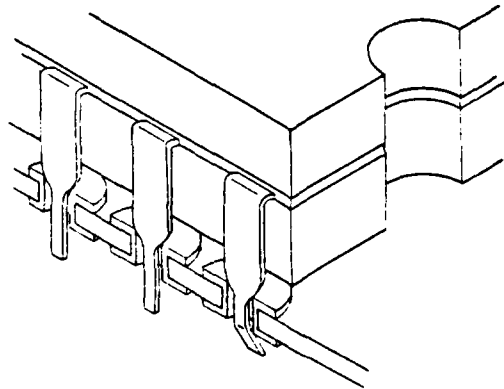


FIGURE 7. Lead bends for multileaded components (see 4.18.12.d).

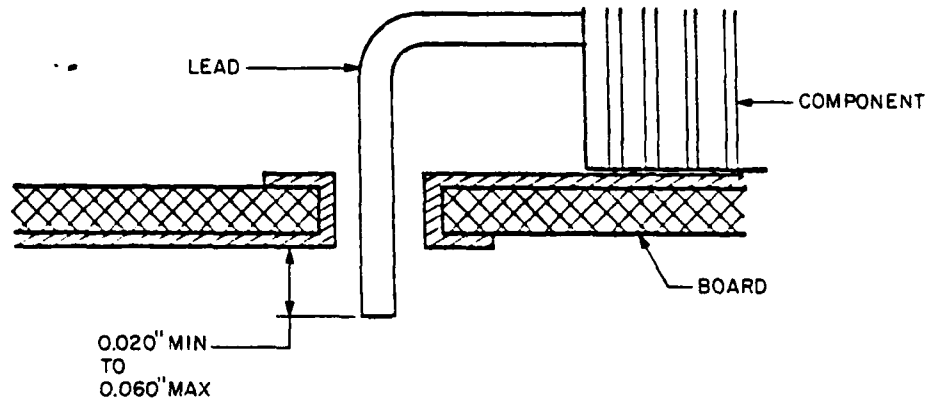


FIGURE 8. Straight through lead extension (see 4.18.14).

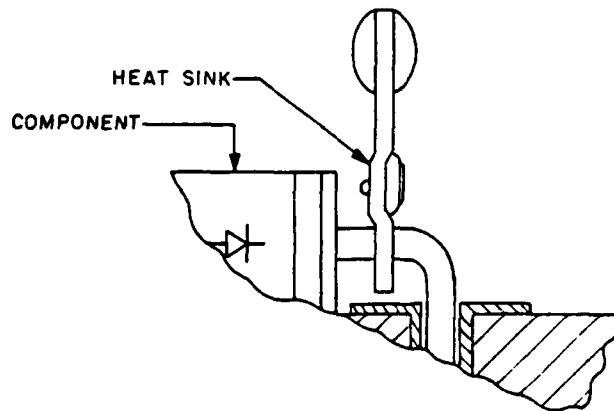
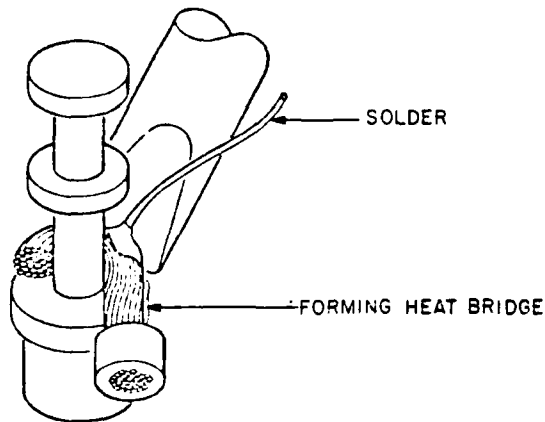
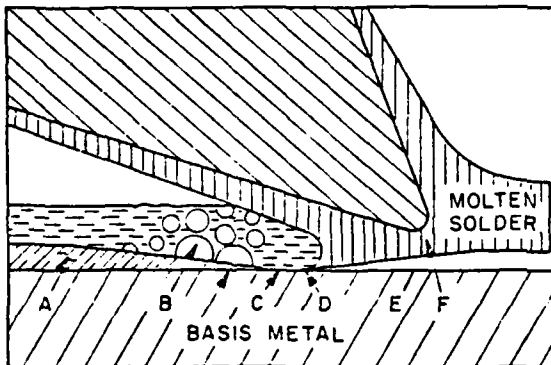


FIGURE 9. Heat sink (thermal shunt) (see 5.1.3).



INITIAL BRIDGING
BEING FORMED



- A. FLUX SOLUTION LYING ABOVE OXIDIZED METAL SURFACE.
- B. BOILING FLUX SOLUTION REMOVING THE FILM OF OXIDE.
- C. BARE METAL IN CONTACT WITH FUSED FLUX.
- D. LIQUID SOLDER REPLACING FUSED FLUX.
- E. TIN REACTING WITH THE BASIS METAL TO FORM A NEW ALLOY.
- F. SOLDER BRIDGING

NOTE:
SOLDERING IRON TIP SHOWN NOT
TOUCHING BASIS METAL FOR CLARITY.

FIGURE 10. Solder application and bridging (see 5.1.5).

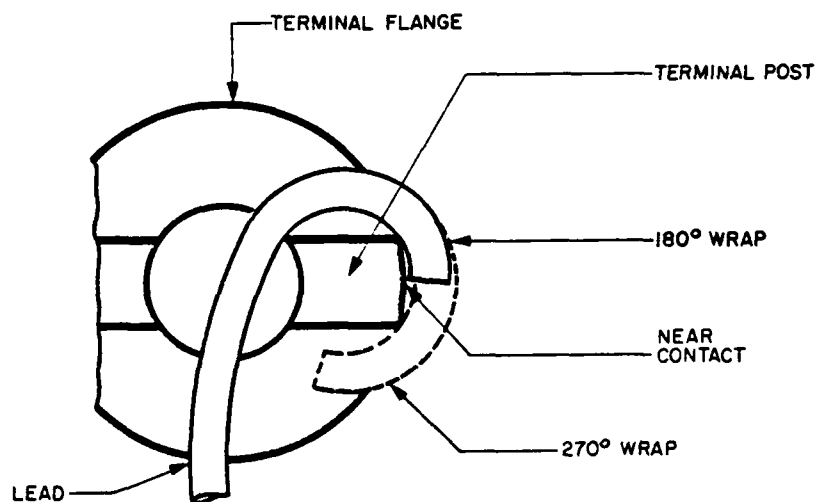
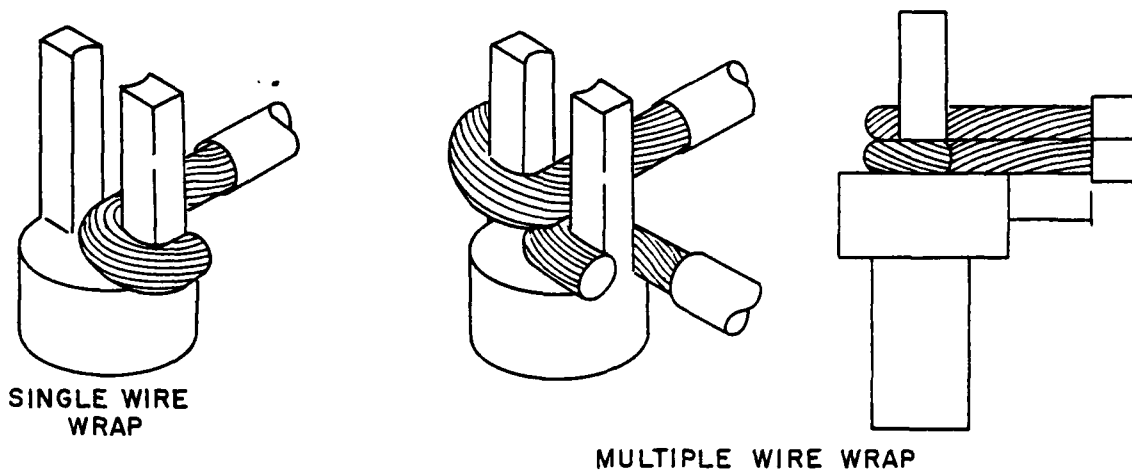


FIGURE 11. Side route connections and wrap on bifurcated terminal (see 5.1.8.1).

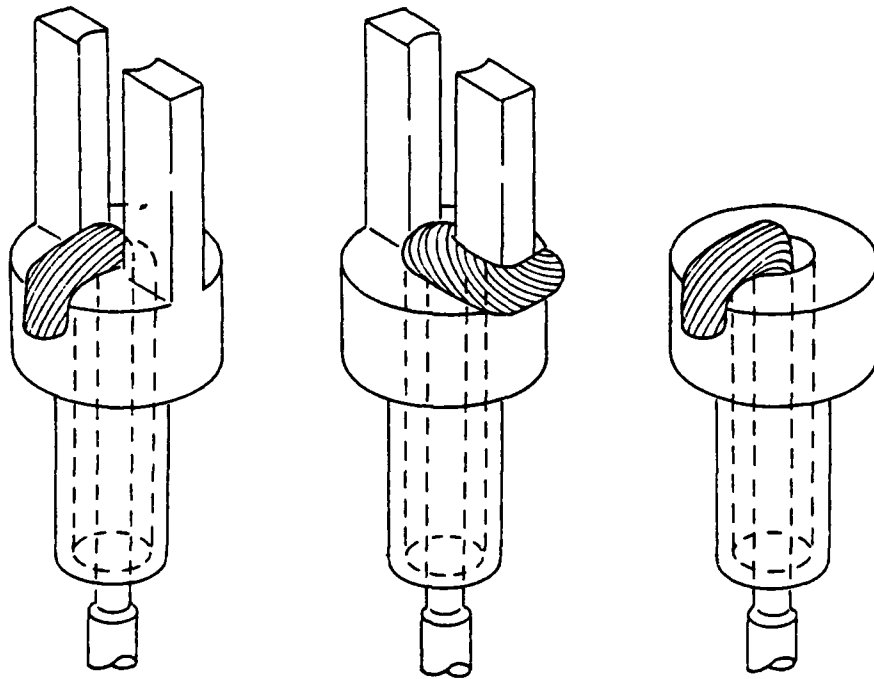


FIGURE 12. Bottom route terminal connection (see 5.1.8.2).

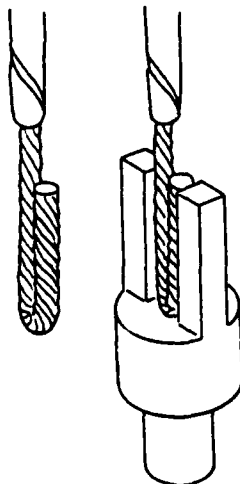


FIGURE 13. Top route connection (see 5.1.8.3).

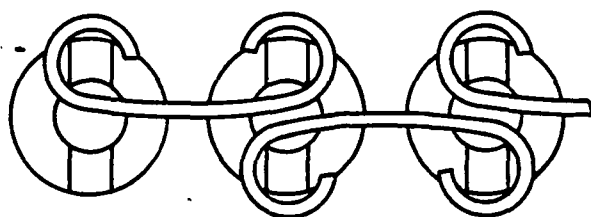


FIGURE 14. Individual wrap; bifurcated terminals (see 5.1.8.4.a).

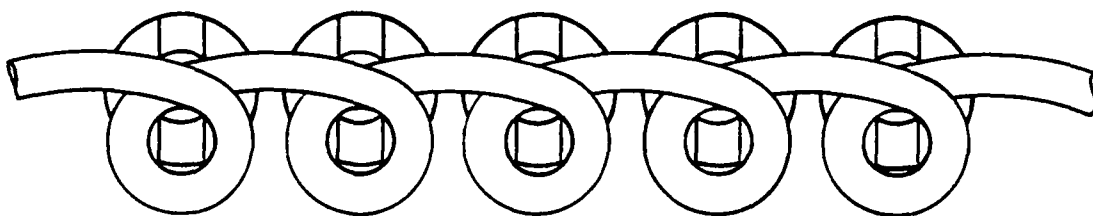


FIGURE 15. Continuous run wrapping: bifurcated terminals (see 5.1.8.4.b).

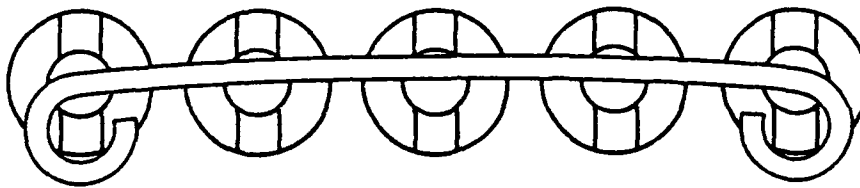


FIGURE 16. Continuous run wrapping: bifurcated terminals, alternate procedure (see 5.1.8.4.c).

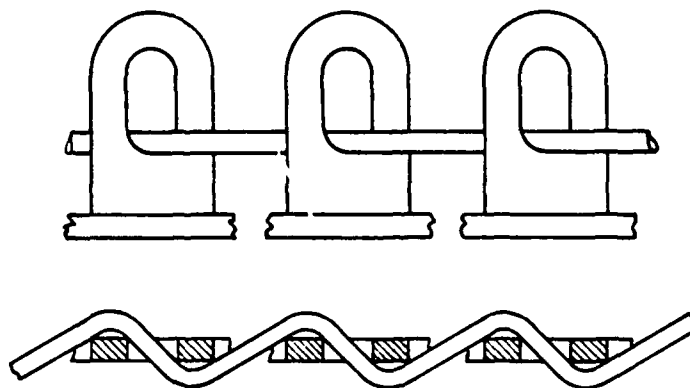


FIGURE 17. Continuous run weaving: perforated terminals (see 5.1.8.4.d).

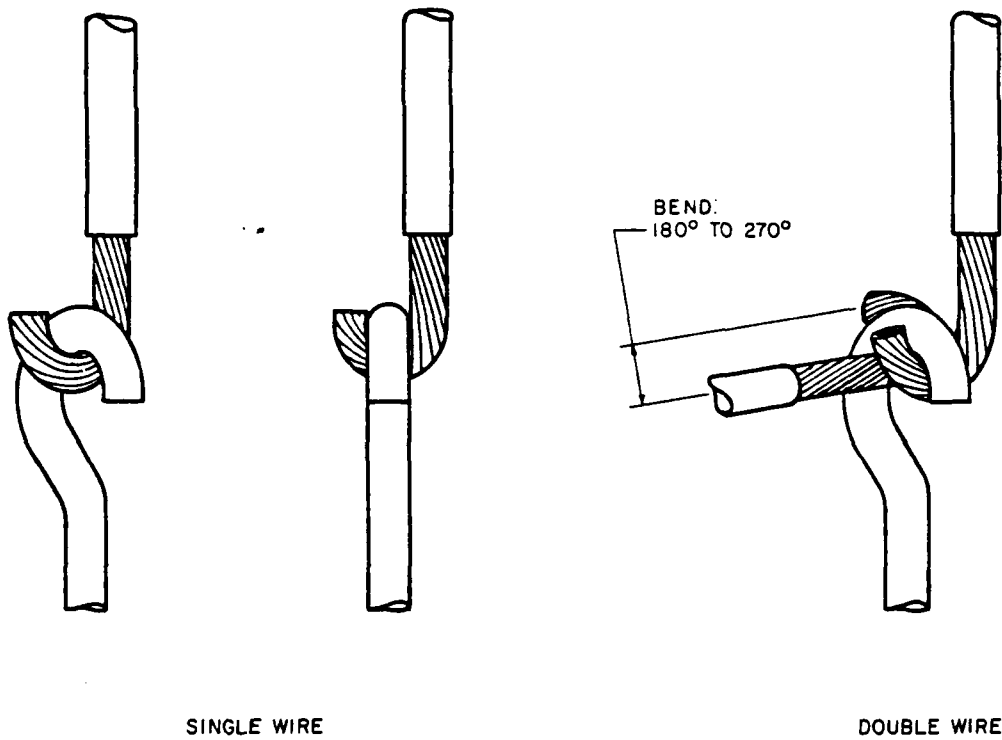


FIGURE 18. Hook terminal connections (see 5.1.9).

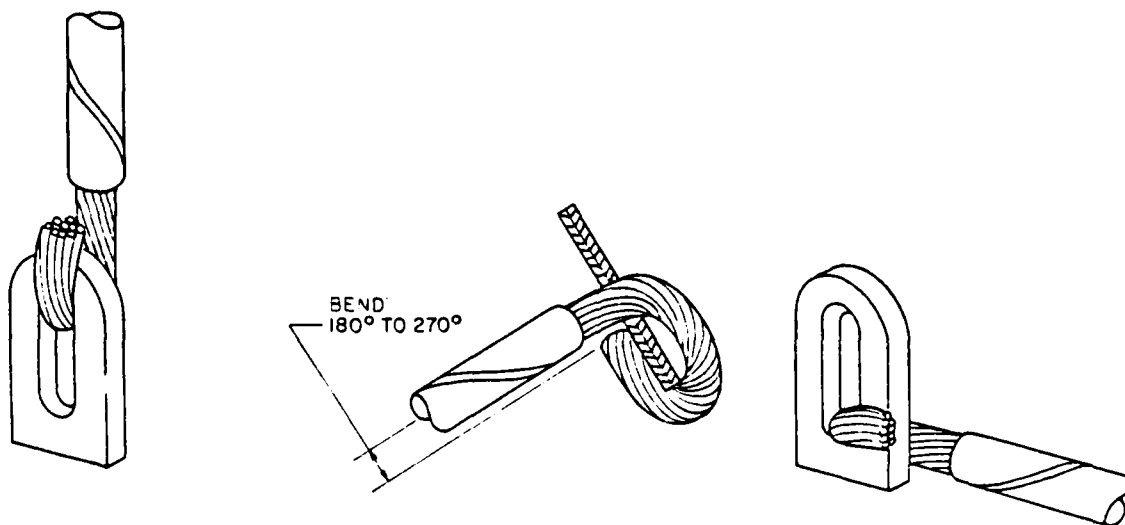


FIGURE 19. Pierced terminal wire wrap (see 5.1.10).

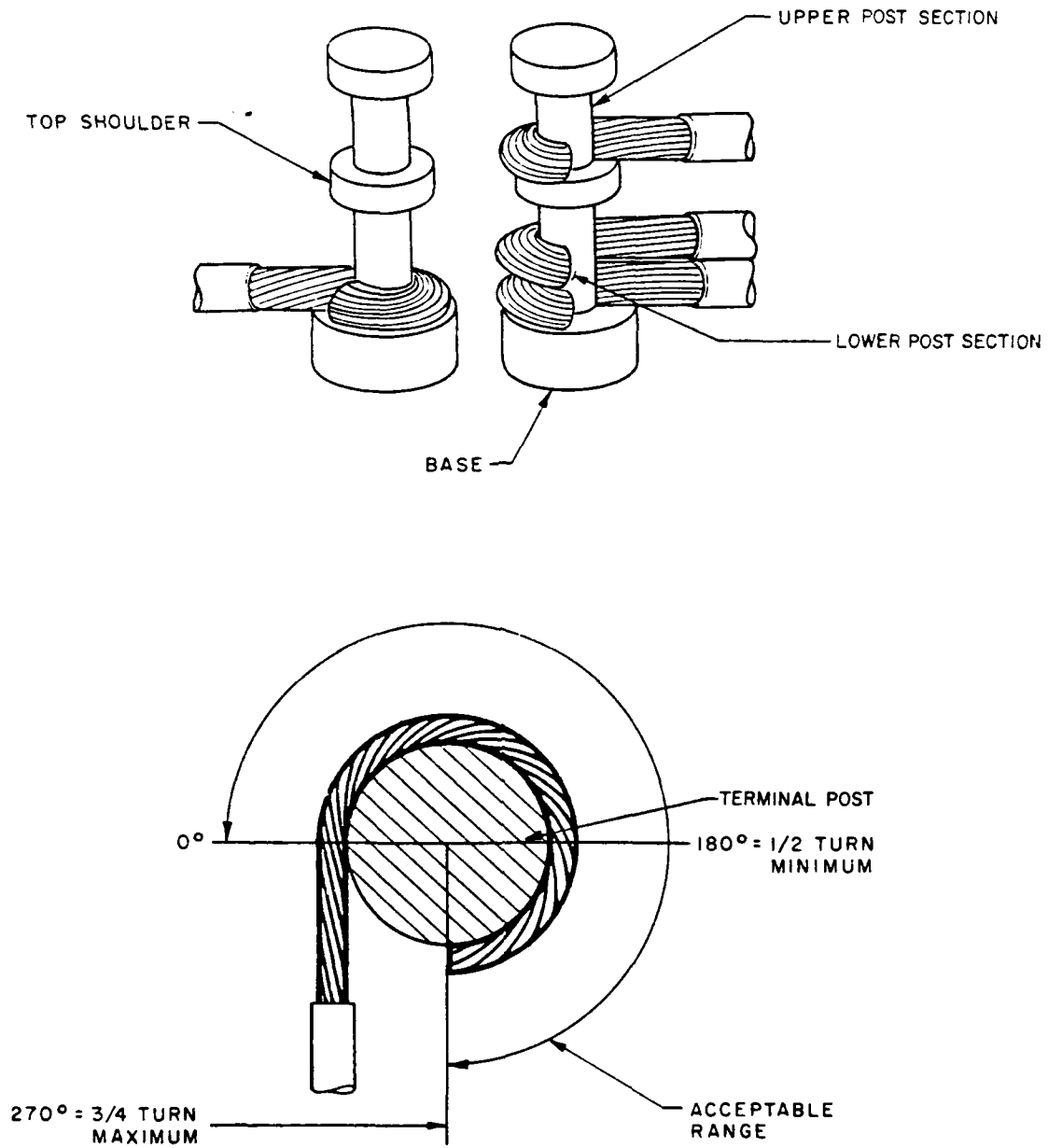


FIGURE 20. Turret terminal wire wrap (see 5.1.11).

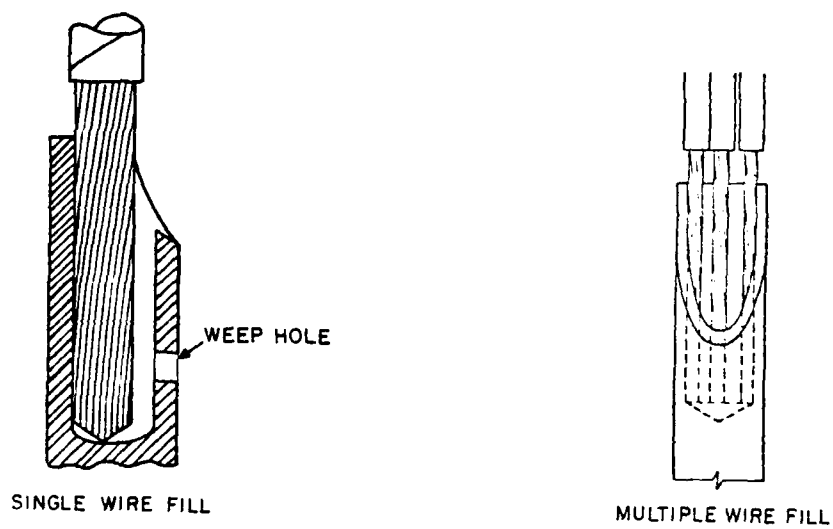


FIGURE 21. Cup-type terminals (see 5.1.12).

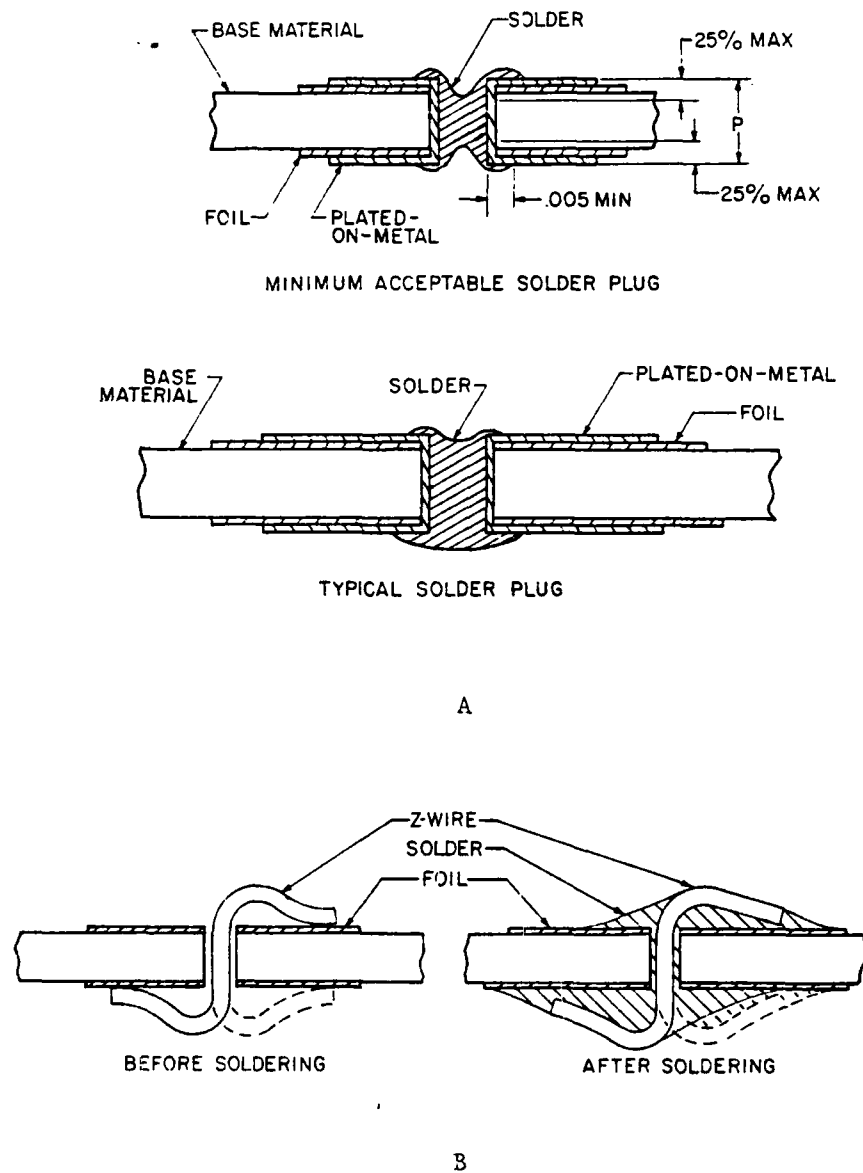
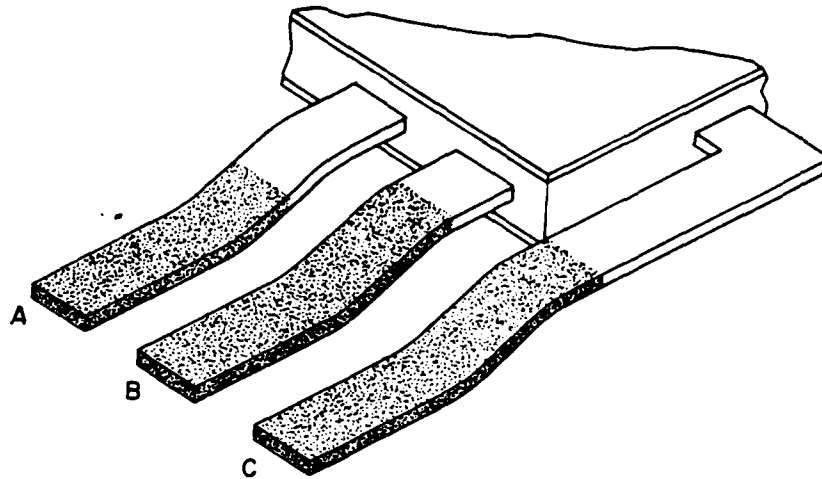


FIGURE 22. Interfacial hole connections (see 5.2.2.11).



- A - Acceptable: Extends past first radius
- B - Minimum Acceptable: Tinning extends to second radius
- C - Reject: Solder extends past second radius
- D - All leads are formed to prevent stress after soldering

FIGURE 23. Lead tinning of ribbon leads (see 5.2.3.2).

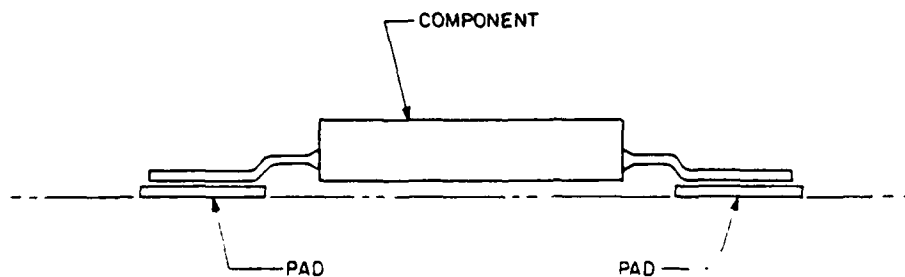


FIGURE 24. Component positioning (see 5.2.3.4).

END

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