METRIC

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MILITARY HANDBOOK

SOLDERING OF ELECTRICAL AND ELECTRONIC ASSEMBLIES

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

AMSC N/A

SOLD

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FOREWORD

1. This Military Handbook 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 5321, Lakehurst, NJ 08733-5100, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

1. SCOPE

1.1 Scope. The scope of this handbook is the range of techniques and practices utilized in the design and manufacture of electrical and electronic assemblies. This includes the physical design of cabling, electronic printed wiring assemblies, the selection of material, and all of the processes utilized to translate the design into functional hardware.

1.2 Applicability. This handbook provides guidance for developing, implementing, and monitoring a soldering program which meets the requirements of MIL-STD-2000. The techniques described herein shall not be considered mandatory requirements. Application of these suggested techniques, within some production systems, may not be compliant with MIL-STD-2000 requirements. The contractor remains responsible for selecting and implementing compliant manufacturing techniques. The subjects addressed in this document include facilities, tools and equipment, materials, part mounting, solderability, cleaning, manual and automatic soldering. It is not the intent of this document to limit users to the techniques described herein since alternative methods may be available.

2. REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards and handbooks. The following specifications, standards and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

SPECIFICATIONS

FEDERAL

QQ-S-571	Solder, Tin Alloy, Tin-Lead Alloy and Lead Alloy

STANDARDS

MILITARY

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-414	Sampling Procedure and Table for Inspection by Variables for Percent Defective
MIL-STD-750	Test Methods for Semiconductor Devices
MIL-STD-883	Test Methods and Procedures for Microelectronics

STANDARDS (continued)

MILITARY (continued)

MIL-STD-1235	Single and Multilevel Continuous Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-1686	Electronic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically-Initiated Explosive Devices) (Metric)
MIL-STD-2000	General Requirements for Soldered Electrical and Electronic Assemblies

HANDBOOKS

MILITARY

MIL-HDBK-106	Multilevel Continuous Sampling Procedures and Tables for Inspection by Attributes
MIL-HDBK-107	Title unknown
MIL-HDBK-263	Electronic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) Metric

(Unless otherwise indicated, copies of federal and military specifications, standards and handbooks are available from the Naval Publications and Forms Center (Attn: NPODS), 5801 Tabor Avenue, Philadelphia, PA 19120-5099.)

2.2 Non-Government publications. The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation.

ANSI/IPC-T-50	Terms and Definitions for Interconnecting and Packaging Electronic Circuits

(Requests for copies should be addressed to the Institute for Interconnecting and Packaging Electronic Circuits, 7380 North Lincoln Avenue, Lincolnwood, IL 60646.)

3. ELECTROSTATIC DISCHARGE (ESD)

3.1 Electrostatic discharge protection. ESD is known to be a source of damage to many components during processing. Damage due to ESD can be particularly troublesome, since it is undetectable by visual inspection and can be in the form of latent defects, thus escaping electrical testing. All personnel coming into contact with ESD sensitive items should be aware of ESD control procedures. MIL-STD-1686 and DOD-HDBK-263 provide requirements and information on ESD control. Tables I, II and III show some of the damage threshold voltages, voltages generated and typical charge sources.

TABLE I. Damage thresholds for various device types.

Device Type	Damage Threshold (Volts)
VMOS	30
MOSFET	100
GaAsFET	100
EPROM	100
JFET	140
SAW	150
OP-AMP	190
CMOS	250
Schottky Diodes	300
Film Resistors	300
Bipolar Transistors	380
ECL	500
SCR	680
Schottky TTL	1000

TABLE II. Typical electrostatic voltages.

Means of Static Generation	Electrostatic Voltages 10 to 20 Percent Relative Humidity	Electrostatic Voltages 65 to 90 Percent Relative Humidity
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes for work instructions	7,000	600
Common poly bag picked up from bench	20,000	1,200
Work chair padded with polyurethane foam	18,000	1,500

TABLE III. Typical primary charge sources.

Object or Process	Material or Activity
Work Surfaces	. Waxed, painted or varnished surfaces . Common vinyl or plastics
Floors	. Sealed concrete . Waxed, finished wood . Common vinyl tile or sheeting
Clothes	. Common clean room smocks . Common synthetic personnel garments . Non-conductive shoes . Virgin cotton 1/
Chairs	. Finished wood . Vinyl . Fiberglass
Packaging and Handling envelopes	. Common plastic - bags, wraps, . Common bubble pack, foam . Common plastic traps, plastic tote boxes, vials, parts bins
Assembly, Cleaning, Test and Repair Areas	. Spray cleaners . Common plastic solder suckers . Solder irons with ungrounded tips . Solvent brushes (synthetic bristles) . Cleaning or drying by fluid or evaporation . Temperature chambers . Cryogenic sprays . Heat guns and blowers . Sand blasting . Electrostatic copiers

1/ Virgin cotton can be a static source at low relative humidities such as below 30 percent.

4. MATERIALS

4.1 Solder. Solder is an alloy used for joining metals which solidifies below 430°C (800°F). The most common alloy is tin and lead. Other alloys used in soldering include tin-silver, tin-antimony, tin-zinc, and indium-based solders. The melting point of the solder depends on the metals in the alloy and the percentage of each. Solder alloys which change directly from liquid to solid and solid to liquid without any intermediate plastic states are eutectic solders. The various solder types and their compositions and melting points can be found in QQ-S-571.

4.1.1 Solder types. Solder is available in a variety of forms to accommodate differing means of applications. The standard designations for these forms can be found in QQ-S-571, and are summarized below. The first symbol is the composition, the second is the form, the third is the flux type, and the fourth is either the core condition and flux percentage for wire, or the powder mesh size and flux percentage for paste type solder. The composition is identified by two letters indicating the critical metallic element, and a number indicating the percentage by weight of that element. Figures 1, 2 and 3 show designations for solder form and flux type, cored solder and solder paste, and solder form samples.

Form

Symbol	Form
B	Bar
I	Ingot
P	Powder
R	Ribbon
S	Special
W	Wire

Flux type

Symbol	Flux type
S	Solid metal (no flux)
R	Rosin flux
RMA	Mildly activated rosin flux
RA	Activated rosin or resin flux
AC	Nonrosin or nonresin flux 1/

1/ Not applicable to flux types R, RMA and RA.

FIGURE 1. Solder form and flux type designations.

Core condition and flux percentage

Condition symbol	Condition		
D P	Dry powder Plastic		
Percentage symbol	Flux percentage		
	Nominal	Minimum	Maximum
1	1.1	0.8	1.5
2	2.2	1.6	2.6
3	3.3	2.7	3.9
4	4.5	4.0	5.0
6 1/	6.0	5.1	7.0

1/ Not applicable to flux types R, RMA and RA.

Powder mesh size and flux percentage

Size symbol	Powder mesh size	
A B C	325 200 100	
Percentage symbol	Flux percentage	
	Minimum	Maximum
1	1	5
2	6	10
3	11	15
4	16	20
5	21	25
6	26	30
7	Over 30	

FIGURE 2. Cored solder and solder paste type designators.

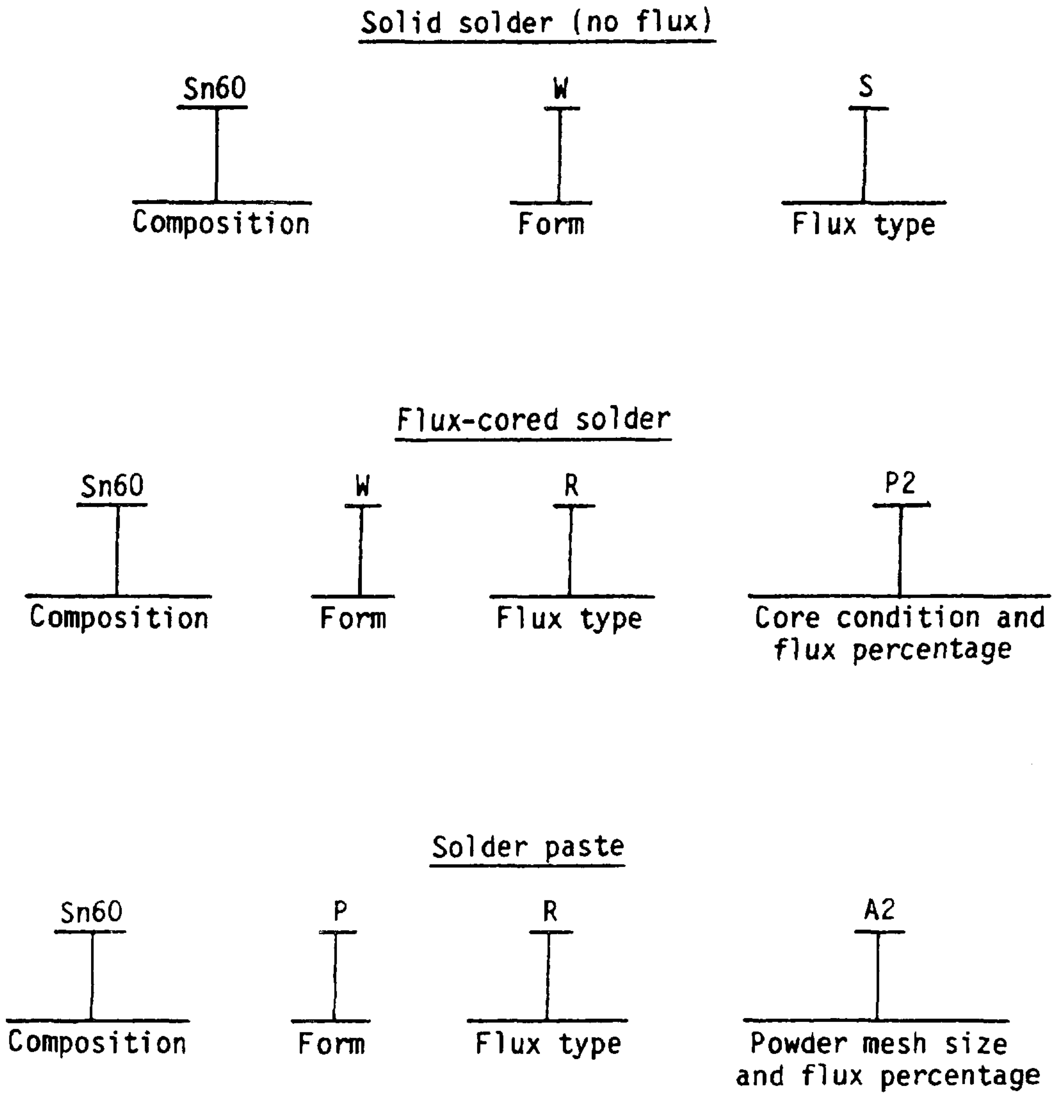


FIGURE 3. Sample type designations of solder forms.

4.1.2 Properties of solder.

4.1.2.1 Strength of solder. The strength of solder is small when compared to other commonly used metals. The measured values of tensile and shear strength are not good indicators of the actual strength of a solder connection, since strength value is lower during conditions of thermal cycling, which occur during actual use. The stresses caused by thermal cycling and those built into the connection cause creep, a slow plastic deformation of the solder. The cyclic plastic deformations of the solder result in fatiguing of the metal, which may eventually result in the formation of cracks.

4.1.2.2 Fatigue properties of solder. The fatigue strength of the solder has a greater impact on the reliability of the connection than the static strength of the solder joint. The creep strength of solder at operating temperatures can be as low as 2.1 MPa (300 psi) rather than the 34.5 MPa (5000 psi) ultimate strength. Different thermal expansion coefficients of the printed wiring board and component cause differential expansion of the board and component, resulting in stresses and strains introduced into the solder joint. The lack of compliant leads on some surface-mounted devices makes them particularly susceptible to thermally-induced stress. The stresses cause strain, which in solder is mostly plastic strain. Creep displacement of the solder relieves the stresses over time. After several strain cycles fatigue-induced cracks can begin to form, usually at the surface with the most bending and at surface irregularities, where the greatest stress concentrations occur. Predictions of the fatigue life of the solder connections are usually based on accelerated thermal cycle testing. Numerical methods of predicting the fatigue life of the connection have been developed and can aid in the design of connections of the required reliability.

4.1.2.3 Static strength. The static strength of a connection is equal to the weakest portion of the connection. Areas of the connection include the board, the land, the barrel of the plated-through hole, the bond between the board and metal, the bond between the solder and other metal, the solder, and the lead. The following example of strength calculation only considers the initial static strength and does not take fatigue into account.

4.1.2.4 Calculating bond strength. The strength of the bond between the board and the conductor is usually the weakest link in the connection unless the lead is small or the solder connection is defective. The strength of the bond between the board and the copper laminate is called the peel strength and is expressed in pounds per millimeter (inch). The total strength of the board-conductor bond may be expressed by:

Bond Strength (S) = peel strength X conductor width

Note: The peel strength may be determined experimentally on a test sample or be provided by the board vendor.

4.1.2.5 Calculating ultimate strength. The ultimate (breaking) strength of the solder in a connection can be calculated if the dimensions of the joint and shear and tensile strength of the solder are known. The calculated strength provides an estimate of the strength of a connection which has not been subjected to thermal cycling or other environmental stresses, which will degrade the mechanical properties of the properties considerably. The strength of a lap joint subjected to a shearing force is (see Figure 4):

4.1.2.6 Sample lead in plated-through hole calculation. As an example, the strength of a connection with a straight-through lead (see Figure 5) will be calculated. Since the shear strength of copper is higher than that of solder and on a properly wetted joint the adhesion of solder to copper is greater than the cohesion of solder, the assumption is made that the connection will fail either in the solder or the board-laminate bond. This assumption would not be valid for poor wetting or defective laminate.

Joint Strength (S) = Shear strength X solder area

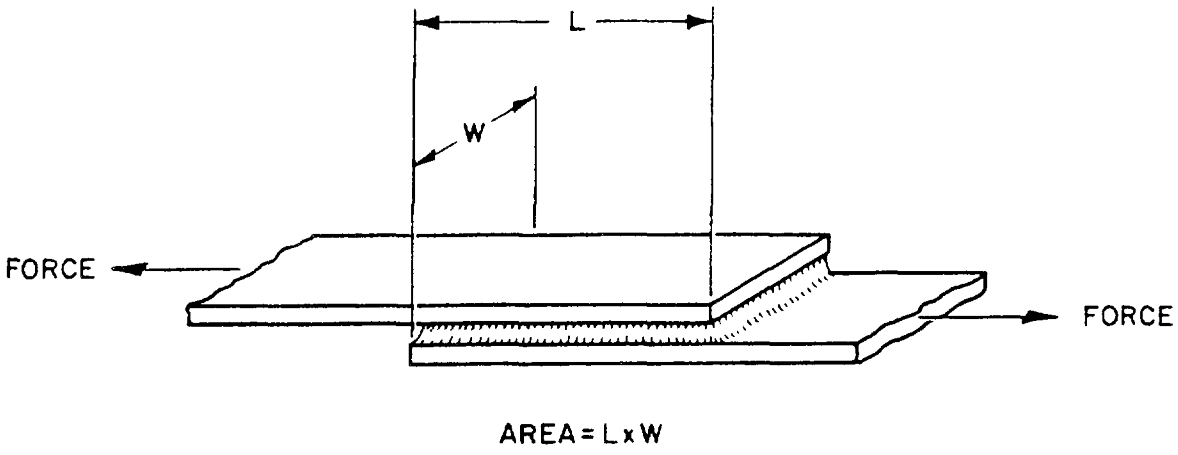


FIGURE 4. Solder joint area (see 4.1.2.5).

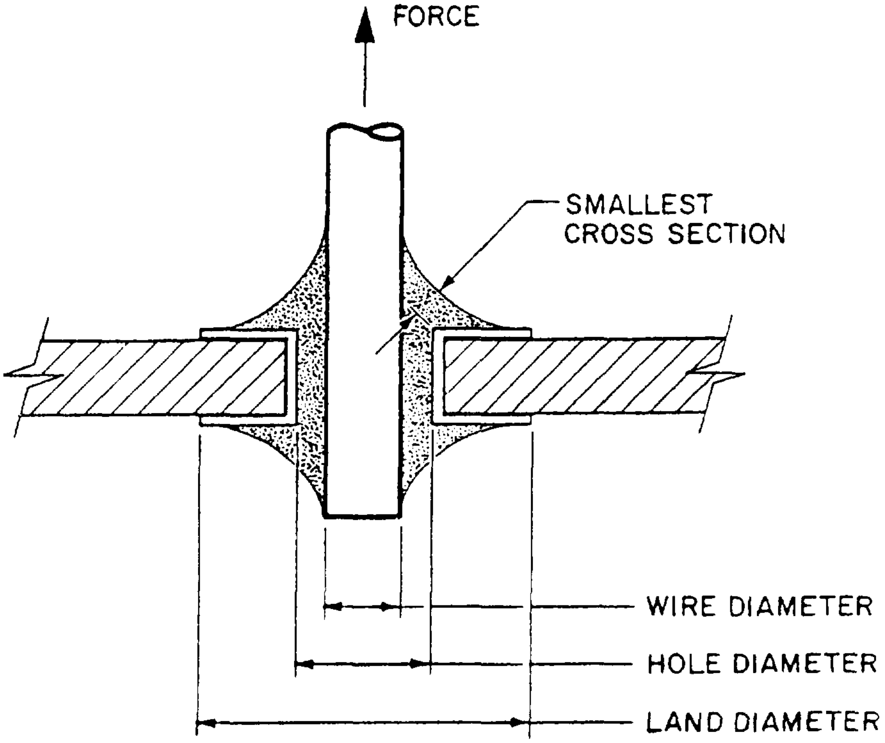


FIGURE 5. Joint strength, straight-through lead (see 4.1.2.6).

4.1.2.7 Simplified strength calculations. The solder strength is most easily calculated by dividing it into three sections, the solder side fillet, the component side fillet, and the solder in the hole, calculating the strength of each and adding them up. With a force on the lead in the component side direction all sections of the solder will be under shearing force. The solder area in the hole will be:

Area = Wire Diameter X Pi X Hole Length

The solder area in each of the fillets will be:

Area = Hole Diameter X Pi X Smallest Cross Section

The smallest cross section is the shortest distance between the edge of the hole and the top of the fillet. The following values will be used for the calculation:

Hole length	1.52mm = 0.06"
Wire diameter	0.76mm = 0.03"
Hole diameter	1.02mm = 0.04"
Smallest cross section (top side)	0.18mm = 0.007"
Smallest cross section (bottom side)	0.36mm = 0.014"
Shear strength of solder	37.2 MPa = 5400 psi

The strength of the solder in the hole will be:

(0.76 mm)(3.14)(1.52 mm)(37.2 MPa) = 135.4 (newtons)
(0.03 inches)(3.14)(0.060 inches)(5400 pounds/inch^2) = 30.5 pounds

The strength of the solder side fillet will be:

(1.02 mm)(3.14)(0.36 mm)(37.2 MPa) = 42.2 N
(0.04 inches)(3.14)(0.014 inches)(5400 pounds/inch^2) = 9.5 pounds

The strength of the top side fillet is:

(1.02 mm)(3.14)(0.18 mm)(37.2 MPa) = 20.9 N
(0.04 inches)(3.14)(0.007 inches)(5400 pounds/inch^2) = 4.7 pounds

The total solder strength is:

135.4 N + 42.2 N + 20.9 N = 198.5 N
30.5 pounds + 9.5 pounds + 4.7 pounds = 44.7 pounds

The peel strength of the top side land is:

(2.54 mm)(3.14)(68.9 KPa) = 13.8 N
(0.1 inches)(3.14)(10 pounds/inch^2) = 3.1 pounds

The peel strength of the barrel of the hole is:

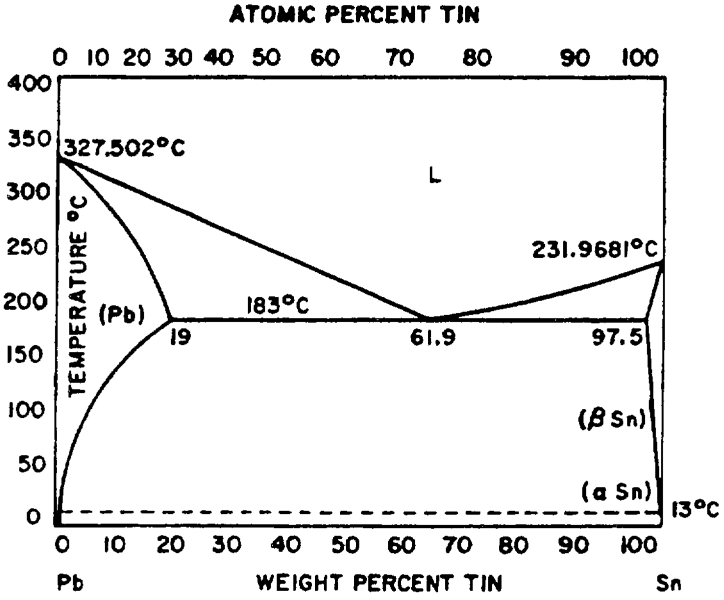
(1.02 mm)(3.14)(20.67 KPa) = 1.8 N
(0.04 inches)(3.14)(3 pounds/inch^2) = 0.4 pounds

With the force pulling in the component direction, the solder side fillet will add strength without loading the copper-board bond. The strength due to the laminated copper and the bottom side fillet is then:

13.8 N + 1.8 N + 42.2 N = 57.8 N
3.1 pounds + 0.4 pounds + 9.5 pounds = 13.0 pounds

The amount of upward force on the lead the connection can withstand before breaking is 57.8 N (13 pounds). The actual damage threshold would be lower than this figure.

4.1.2.8 Phase diagram. The phase diagram shown in Figure 6 is a representation of the relationship of the solidus and liquidus of solder for varying percentages of tin and lead. The liquidus is the locus of points at which the components of the system begin to freeze upon cooling, or finish melting on heating. The solidus is the locus of points at which the components begin melting upon heating, or finish freezing on cooling. Those points between the solidus and liquidus are known as the intermediate or plastic state. In the intermediate state the solder exists in both liquid and solid states, where the tin or lead in excess of that required to make eutectic solder solidifies before the rest of the solder. When the solidus and liquidus lie on the same point the alloy is said to be eutectic. This representation is based on the theoretical ratio of tin and lead with no impurities. When impurities are present the intermediate phase increases and affects melting temperature.



TIN-LEAD ALLOYS

FIGURE 6. Tin lead phase diagram.

4.1.2.9 Time in a phase state. The time the solder spends in the intermediate state or at the transition point is dependent on the rate of heat flow into or out of the solder. Once the solder reaches the state transition temperature, the heat required to produce a change of states must be added or removed from the solder. Although eutectic solder does not have a temperature band for the intermediate state, it is susceptible to disturbance during the time spent changing states.

4.1.3 Effect of impurities on the properties of solder. The following is a compilation of metallic impurities (which are known to decrease solderability) and their effect on solder connections. It is noted that the addition of a certain amount of bismuth, nickel, and copper to the eutectic tin-lead solder alloy improves the wetting ability of the solder, whereas the addition of cadmium and zinc decreases the wetting power of the eutectic solders.

4.1.3.1 Aluminum. Aluminum does not have any solid solubility in either tin or lead at room temperatures, and only a small amount of aluminum is dissolved in liquid tin at an elevated temperature. Aluminum in molten solder usually causes sluggishness in the melt, with a considerable amount of grittiness and lack of adhesion. Very little aluminum is used in electronic soldering because of the large galvanic potential present between aluminum and the tin-lead alloy (1.53V). Aluminum surfaces which must be exposed to molten solder, even for a short time, should be hard anodized.

4.1.3.2 Antimony. The solubility of antimony in tin at room temperature is about 6 to 8%, while little antimony is dissolved in lead at room temperature. In some specifications the presence of 0.2% to 0.5% antimony is mandatory to retard the transformation of tin into its gray state (tin-pest). Excessive antimony may cause a spread reduction in lead termination.

4.1.3.3 Arsenic. No solubility of arsenic in either tin or lead has been observed. Two intermetallic compounds, Sn_3As_2 and SnAs appear as a long needle in the microstructure. Arsenic may cause poor wetting.

4.1.3.4 Bismuth. At room temperature bismuth has a solubility in lead of up to 18% and solubility in tin of about 1%. Concentration of less than .25% causes reduction in working temperature. Bismuth causes a gray appearance.

4.1.3.5 Cadmium. The solubility of cadmium in both tin and lead is negligible. There is an intermetallic phase at elevated temperature. Cadmium surfaces can deteriorate rapidly and cause spotty connections with poor adhesion (poor wetting).

4.1.3.6 Copper. Copper has negligible solubility in both tin and lead. Two intermetallic compounds, Cu_3Sn and Cu_6Sn_5 are formed between copper and tin. As the copper content of the molten solder increases, higher temperatures are needed to overcome sluggishness and grittiness of the liquid metal. This increases the rate of solution of additional copper from the surfaces to be soldered, degrading the soldering conditions rapidly.

4.1.3.7 Gold. The solubility of gold in tin-lead at room temperature is negligible. Several intermetallic compounds are formed between tin (Au_6Sn, AuSn, $AuSn_2$ and $AuSn_4$) and lead (Au_2Pb and $AuPb_2$). Unless the soldering is completed rapidly the gold intermetallics will rise to the surface of the connection, causing an extremely dull gray and grainy surface. Above 0.340 percent, gold contamination in the solder pot may cause embrittlement of the solder connection.

4.1.3.8 Iron. Iron has some solubility in tin at elevated temperature, forming two intermetallic compounds, $FeSn$ and $FeSn_2$, manifesting themselves as needle shaped crystals. The presence of iron in solder is detrimental and causes grittiness.

4.1.3.9 Magnesium. Magnesium has the same effect as aluminum on solders, having no solubility in lead and negligible in tin at room temperature. It can form the intermetallic compounds Mg_2Sn and Mg_2Pb.

4.1.3.10 Nickel. Nickel shows no solubility in either tin or lead. Intermetallics formed with tin are Ni_3Sn, Ni_3Sn_2 and Ni_3Sn_4.

4.1.3.11 Silver. There is no solid solubility in either tin or lead, but tin and silver form the intermetallics Ag_6Sn and Ag_3Sn. When silver content rises over 2.0% the silver-tin intermetallics will segregate upon cooling.

4.1.3.12 Phosphorus and sulphur. These contaminants have a detrimental effect on wetting at levels exceeding 0.03% (frosty appearance).

4.1.3.13 Zinc. Zinc has little solid solubility in tin and none in lead. No intermetallic compounds are formed with either tin or lead. Zinc is detrimental to the solder alloy. As little as 0.005% of zinc is reported to cause lack of adhesion, grittiness and susceptibility to grain boundary weakening.

4.2 Flux. The purpose of flux is to remove oxides and penetrate films, prevent oxidation during heating, and lower interfacial surface tensions. In addition, flux should be thermally stable, be easily displaced by molten solder, be non-injurious to components, and be easily removable.

4.2.1 Rosin fluxes. Rosin flux, Type R, is an organic material distilled from pine tree sap. The active ingredients in rosin flux consist primarily of abietic and pimaric acids. Pure rosin is a solid at room temperature and chemically inactive and insulating. Rosin melts at about 72°C (160°F) and the organic acids become active at around 108°C (225°F). Peak fluxing ability occurs around 262°C (500°F) when the rosin begins to decompose into reducing gases. At temperatures above 346°C (650°F), the flux becomes inactive and polymerizes, causing difficulty with residue removal.

4.2.2 Mildly activated rosin. Activators are added to rosin to increase its fluxing action. Mildly activated rosin, Type RMA, may contain a variety of activators, (typically less than 1%) but have limits placed on their electrical and chemical properties before and after soldering.

4.2.3 Activated rosin. Activated rosin flux (typically containing 1-5% activators), Type RA, is used for purposes where Type RMA is not strong enough. For military purposes their use is usually limited to component tinning of sealed components and solid wire. When warm, these fluxes can conduct electricity and can leave residues which can cause corrosion or shorting paths to form.

4.2.4 Organic fluxes. Organic acid fluxes are a group of fluxes that have as their active ingredients materials such as organic acids, organic hydrohalides, amines and amides. These fluxes are water soluble since they contain no rosin. Good cleaning is critical with this type of flux since the salt residues it leaves are corrosive and conductive.

4.3 Cleaning solvents. Qualities of solvents which affect their ability to clean include wetting, solvency, capillary action and cleanliness of the solvent. Other factors affecting a solvent's ability to clean are type and density of components, the cleaning equipment, and the type of contaminant to be removed.

4.3.1 Solvent wetting. Wetting is the ability of the solvent to spread quickly by low wetting surface tension over a surface with a small contact angle. As the contact angle increases, the solvent spreads more slowly and tends to bead. The solvent's wetting characteristics are determined by the solvent and the material it is intended to clean.

4.3.2 Capillary action. Capillary action is the tendency of the solvent to be drawn into small spaces by surface tension. The capillary action of a solvent is necessary for a solvent to clean under components and on densely populated boards. Low surface tension improves wetting by capillary action.

4.3.3 Solvency. The solvency is the ability of a material to dissolve the contaminants. It depends on the match of solubility of the solvent to that of the contaminant.

4.3.4 Solvent stability. The stability of a solvent is its ability to resist breakdown from the chemicals it must clean, its ability to withstand elevated temperatures and other process conditions, and its flammability.

4.3.5 Film drying properties. This quality is determined by the solvent's ability to carry off contaminants and its rate of evaporation. Solvents which evaporate before carrying off all the contaminants will cause streaking or a patchy surface.

4.3.6 Types of solvents. Solvents may be classified as single component solvents or azeotropic or non-azeotropic blends. Since polar solvents are most effective at removing polar contaminants and non-polar solvents remove non-polar contaminants, a blend is often most effective for removing both types of contaminants.

4.3.6.1 Azeotropic blends. Azeotropic blends are mixtures which have the same composition in the vapor and liquid state. This allows for distilling for reuse without changing the composition.

4.3.6.2 Non-azeotropic blends. When non-azeotropic blends are boiled, one component vaporizes more quickly than the other, causing the vapor blend to be a different composition than the liquid. Non-azeotropic blends must be monitored for correct composition, and must be analyzed and reblended if it is distilled for reuse.

4.3.6.3 Water-based cleaners. Water is a good cleaner for removing polar contaminants. Other materials, such as rosin and oils, are insoluble in water. Water can be made to dissolve these materials by the addition of a saponifier, which is an alkaline material which reacts with the non-polar residues to form a soapy material easily removed by water wash. Caution must be used in this method since the saponifier is highly ionic, and if not thoroughly rinsed with clean water can leave ionic contamination on the assembly.

4.4 Conformal coating. Conformal coating is a thin protective film, applied to the printed wiring assembly to protect it from its environment. Table IV summarizes some of the properties of different conformal coatings.

4.4.1 Conformal coating materials. Materials used for conformal coating include acrylic, epoxy, polyurethane, silicone, and parylene. Each has its own advantages and disadvantages in terms of durability, effectiveness, cost, ease of application and repairability.

TABLE IV. Conformal coating characteristics.

	CHARACTERISTICS																				
CONFORMAL COATING	HARD	MEDIUM HARD	SOFT	HEAT REACTION	SURFACE BOND - VERY STRONG	SURFACE BOND - STRONG	SURFACE BOND - MEDIUM	SURFACE BOND - LIGHT	SOLVENT REACTION	SMOOTH SURFACE	LUMPY SURFACE	NONPOROUS SURFACE	GLOSSY SURFACE	SEMIGLOSSY	DULL SURFACE	RUBBERY SURFACE	BRITTLE	CHIPS OFF	PEELS AND FLAKES	STRETCHES	SCRATCH AND DENT BEND AND TEAR
EPOXY	X			X	X					X		X	X	X			X	X			
ACRYLIC LACQUERS		X		X		X			X	X		X	X				X	X	X		
POLYURETHANES	X	X	X	X			X			X		X	X						X	X	X
SILICON			X		X	X	X	X		X					X	X				X	X
PARYLENE	X				X					X		X			X				X		X

4.4.2 Acrylic coatings. Acrylic coatings are usually a solvent based fast drying system. Advantages of acrylic coatings are that they dry to a tack-free finish in 10 to 15 minutes at room temperature, are fungus resistant, and are easily removed for repair. A disadvantage of acrylic coatings is that their resistance to solvents and chemicals is poor. Acrylics have an operating range of -65° to 130°C (-85° to 266°F).

4.4.3 Epoxy coatings. Epoxy coatings are normally a two-part system and may contain a solvent for thinning. Some epoxies cure to a tack-free state at room temperature in 30 minutes to an hour, while others may require an elevated temperature cure. Epoxies exhibit excellent chemical, solvent and abrasion resistance. These properties also make the epoxy coated board very difficult to repair. The curing of epoxies is from 60° to 135°C (140° to 275°F). Since epoxy coatings cure to a rigid state buffer material must be added to prevent component damage.

4.4.4 Polyurethane coatings. Polyurethane coatings may be either one or two component systems with or without a solvent used for thinning. They have excellent chemical and solvent resistance and good abrasion resistance. Their operating range is from -70° to 135°C (-94° to 275°F).

4.4.4.1 One component polyurethanes. The single component polyurethanes usually cure to a tack-free state in 20 to 30 minutes. Complete curing at room temperature requires 4 to 5 days. This time can be reduced to about three hours by curing in an oven at 60° to 80°C (140° to 176°F). Since the moisture in the air acts as part of the curing mechanism, these coatings should be used where relative humidity is over 30%. Placing a pan of water in the curing oven will keep the humidity at an acceptable level. (Note: Different manufacturers may have different curetimes.)

4.4.4.2 Two component polyurethanes. At room temperature, two part polyurethanes cure to a tack-free condition in 3 to 5 hours and completely cure in 5 days. Using an oven at 60° to 80°C (140° to 176°F) can reduce the times to 20-35 minutes for tack-free and 3 hours for complete curing.

4.4.5 Silicone coatings. Silicone coatings are one part coatings which can be thinned with a solvent. Normal room temperature curing times are an hour for a tack-free finish and 5-7 days for full cure. Oven curing at 60° to 80°C (140° to 176°F) will reduce the time for complete curing to 1 to 3 hours. A minimum relative humidity of 30% is necessary for proper curing. Silicone coatings are fungus and flame resistant, have fair solvent and chemical resistance, and have an operating range of -65° to 200°C (-85° to 392°F).

4.4.6 Plating processes. The material interactions of copper and the plating materials are similar to the interactions which occur during soldering. When tin is plated onto copper, a very thin diffusion layer forms between the copper and the tin. This diffusion layer is typically much thinner than the intermetallic layer which occurs during solder wetting. After formation of the diffusion layer, the plating process bonds atoms of tin together forming the characteristic tin plating.

4.5 Material and process interactions.

4.5.1 Solubility of tin and copper. Tin is soluble in lead. Solder is a tin/lead solution. There is no molecular formation between the tin and lead. Copper, however, is more soluble in lead than it is in tin. When heated copper and melted solder are brought into contact, atoms of copper diffuse from the basis metal into the solder. This forms the characteristic intermetallic layer between the solder and the copper. Copper oxides and other contaminants prevent the diffusion of the copper into the solder. Most nonwetting and dewetting conditions are caused by impurities on the surface of the copper.

4.5.1.1 The process of wetting. The angle θ formed between the liquid and solid is called the dihedreal angle (see Figure 25). This angle is a function of the surface tensions of the solder, the metal and the interface between the solder and the metal. The relationship of these quantities is expressed by Young's equation:

$$\gamma_{ls} + \gamma_{l} \cos\theta = \gamma_{s}$$

γ_{l} = liquid surface tension

γ_{ls} = surface tension of liquid solid interface

γ_{s} = surface tension of solid

4.5.2 Formation of oxides by cutters. Rotary cutters must be properly maintained and the feed rate properly set to ensure quick, clean cutting. Rotary cutters, especially when used in solder-cut-solder systems, have been known to heat and form oxides on the surface of the cut leads; this prevents subsequent wetting.

4.5.3 Oxidation at elevated temperatures. When metals are heated, they oxidize more rapidly. Rosin fluxes are used to prevent oxygen from reaching the copper when it is at elevated temperatures. This prevents formation of oxides which would inhibit wetting. As as alternative, some manufacturers are tinning parts in an inert atmosphere so that they can obtain the same oxidation prevention as fluxes without the cleaning problems. A second function of flux is the removal of surface oxides. Active fluxes, containing varying quantities of acids, remove the oxides and similar contaminants from the surface of the copper. This cleaning action promotes the diffusion of copper into the solder (i.e., the formation of the intermetallic layer).

4.5.4 Intermetallic layers. Solder bonds or "wets" to metals in a process in which it is joined by a metallurgical reaction with the base metal. This is a totally different mechanism than that which takes place when water wets a surface. This metallurgical bonding mechanism results in the formation of an intermetallic compound layer between the solder and the base metal. For example, if a molten Sn-based solder is placed in contact with clean Cu, the metallurgical reaction between Sn and Cu will result in the formation of a layer of Cu_6Sn_5. This intermetallic layer is the "glue" that holds the solder joint together. In normal soldering, the thickness of the intermetallic layer is on the order of 0.5 to 1.0 micrometer. It will rarely grow thicker than this in a liquid-solid reaction. However, solid-state metallurgical reactions can progress after solidification of the solder joint, especially at elevated temperatures. In the Sn-Cu system, a second intermetallic compound can form between the Cu and the Cu_6Sn_5 layer. This is Cu_3Sn which has quite different (non-solderable) properties than the Cu_6Sn_5 compound.

Intermetallic compounds have much different physical and mechanical properties than the metals which make them up. Typical intermetallics are very brittle and have poor electrical conductivity. In addition, if they are exposed to air, they will passivate (oxidize) very rapidly.

Chemically, these passivated intermetallic surfaces are very stable and can not be reduced by the typical fluxes used in electronic soldering. Therefore, it is usually advisable to keep the layers as thin as possible, (generally between 1 and 2 micrometers) and protected from the atmosphere by a layer of solder. The reaction rate involved in intermetallic formation during solder wetting will vary considerably in different metal systems. For example, the Sn-Ni intermetallic formation rate is slower than the Sn-Cu formation rate, which the Sn-Ag formation rates are orders of magnitude faster. Stability of the different intermetallic compounds also varies between the metal systems.

Intermetallic compounds can be found in two places in a solder joint. Preferably, they are in a thin continuous layer between the solder filler metal and the base metals. Sometimes, intermetallic compounds can be found as particles, needles, or other forms within the solder matrix of the joint. This is not mechanically nor metallurgically desirable and process conditions leading to such intermetallic inclusions should be avoided.

In surface mount technology (SMT) the majority of interconnections are made between active or passive components, (leaded or leadless) and Printed Wiring Boards (PWB). The PWB metallization is typically copper which has been solder coated. Therefore, the bond will actually be made between the solder and the copper. Leaded chip components will typically have Kovar or alloy 42 leads. Therefore, the bond will be between the solder and nickel contained alloy, with the main intermetallics formed being Sn-Ni. In leadless parts, technology dictates that all silver metallization be coated with a barrier layer of nickel. Again, the solder bond will be between the Sn in the solder and the nickel barrier, forming Sn-Ni intermetallics. The process can literally use up one of the two metals making up the intermetallics. This process is commonly known as "leaching". On a chip component, this can lead to exposed ceramic, or an underlying, non-solderable, refractory metallization. If solder coating is used up, this can lead to exposure of the intermetallic to the atmosphere, and non-solderability of the surface. This is the cause of "weak knees" in printed wiring boards.

4.5.4.1 Solder joint microstructure. The microstructure in solder alloys is becoming more important as the applications become more severe. A basic principle in physical metallurgy is that the properties of an alloy are dependent on the microstructure, and solders are not an exception.

Sn and Pb solders are binary alloys with a strong two-phased microstructure. The eutectic structure of 63/67 Sn/Pb solder is the finely divided mixture of Sn and Pb rich solid solutions. Cooling the solder more slowly results in solid and Pb rich solid solutions and in solid state diffusion, which results in a "course grained" structure. The "fine grained" structure is more desirable from a strength and fatigue-resistance standpoint. Subsequent thermal exposure can and does alter the "as cooled" microstructure. Also, different solders develop different microstructures based on composition. Departure from the eutectic composition results in increased proeutectic phases. These will, if on the Pb side of the eutectic, increase the ductility and lower the creep resistance of the solder. If on the Sn side of the eutectic, the creep resistance and hardness will increase slightly. In contrast, 96/4 Sn/Sb are mainly single-phase solders which contain lattice pinning intermetallic compound particles. Being basically single-phased, the microstructure does not significantly change during thermal cyclings and thermal exposure. For this reason they are stronger, lower in ductility and thermal exposure. For this reason they are stronger, lower in ductility and more creep-resistant. The fatigue life also can be improved since most fatigue (plastic strain) damage occurs at phase boundaries. There are a number of ways to enhance the life of a surface mount or any other joint. They are:

a. Reduce CTE mismatch.

b. Strain reduction by solder joint geometry.

c. Leaded components (strain reduction) against leadless components.

d. Solder alloy selection.

These are listed in order of overall effectiveness and take into account producibility plus microstructure resulting from thermal exposure. Processes such as vapor phase soldering tend to result in course microstructure.

4.5.5 Plating porosity. The plating process, depending on a range of factors, may deposit either porous or fine textured platings. Generally, the faster the metal is plated, the more porous the plating. Porous platings typically allow subsurface oxidation which may result in the appearance of dewetting or nonsolderable parts. If reflowed, the plating will lose its porous nature, will fully cover the copper and will perform much better.

5. TOOLS AND EQUIPMENT

5.1 Soldering irons. Some performance variables which should be considered when selecting a soldering iron include temperature, heat capacity, tip size and shape, recovery time, and ease of use. When selecting a soldering iron, one should evaluate how well the iron will perform specific tasks and how long it will perform those tasks (i.e., how durable is it relative to its cost). In evaluating how well the iron performs its tasks, one needs to consider the following:

a. Board design. The number of interconnects to a plated through hole will affect the amount of heat drawn from the iron by the board. As the number of interconnects increases, it will greatly increase the heat transfer from the tip. Specific board design concerns are:

    1. Pad size and hole diameter. This is a copper quantity issue. As such, a small pad and a narrow barrel, plated with a thick layer of copper, may draw more heat than is expected.

    2. Boards with internal heat sinks. Heavy internal heat sinks with plated-through hole feed through will draw large quantities of heat from the soldering area.

b. Number of tip sizes available. Tip sizes affect what type of connections can be made. The iron should be selected for its heat capacity with respect to the tips which will deliver that heat.

c. Ease of tip changes. If tips are readily changeable this will limit the need for multiple irons at a work station.

d. Durability. Both the soldering iron station and the tips need to be evaluated for durability. As the tip surface oxidizes to where it needs replacement, the ability of the tip to transfer heat during soldering is reduced. As such, if frequent tip replacements are required, it may reduce the overall life of the soldering station. In addition, if the temperature controller in the soldering station has degraded, the lack of proper tip temperature control may require excessive tip replacement.

e. Ability to meet MIL-STD-2000. Before soldering equipment is purchased for use on MIL-STD-2000 programs, it should be tested by the potential customer. Unfortunately, as is possible with any product, not all soldering irons perform in the manner described.

f. Digital read-out of tip temperature and switch selectability for the operating temperature. A thermocouple-based calibration system (i.e., a thermocouple embedded in the tip of the soldering iron) is recommended for calibrating the tip temperature to the read-out on the soldering station. A digital read-out is preferred as they are generally capable of displaying the tip temperature in fine gradations. The need to be able to rapidly change the tip temperature (and accurately know its value) is more critical in fine pitch soldering. During fine pitch soldering the operator will need to change the tip temperature based on the lead size and connection elements. In this way the operator can rapidly compensate for the differences in thermal capacity between fine pitch and standard size leads. This compensation is required to minimize the occurrence of measling and lifted lands and maximize the occurrence of proper connection formation (i.e., add enough heat to form the connection).

g. Cord flexibility. The flexibility of the soldering iron cord affects ease of iron use. Operators generally find flexible cords are better for reaching the desired relative positions of the soldering iron and the connection elements.

h. Operator bias. The selection of soldering irons should be based on as many objective factors as possible. The way the iron is used, especially relative to operator technique, is a critical factor which may bias results found while evaluating iron performance. Depending on their personal operating techniques, different operators may get different performance from the same iron.

5.1.1 Soldering iron tips. The effectiveness of the tip is determined by the length, mass, cross-sectional area and the contact area. The construction of the soldering tip affects all the performance variables of the iron.

5.1.1.1 Range of available tips. Soldering iron manufacturers frequently have a range of tips available. Soldering iron tips are generally made of a copper, tellurium copper, or lead copper because copper is both economical and a good material for heat transfer. This base material is then coated or plated to reduce oxidation and tip reactivity. The material composition and shape of the tip should be considered during tip selection. The goal is to select a tip which will rapidly transfer heat without reacting to the solder.

5.1.1.2 Selection of tip materials. The primary material consideration in tip selection relates to the plating material. For most electrical and electronic soldering applications, an economically priced iron-plated tip is used. As long as the iron tip is maintained properly, it will perform adequately in most applications. Proper tip maintenance generally involves only keeping the tip cleaned and tinned during soldering operations. Tip oxidation may become a problem if the tip is not maintained clean and tinned. Soldering operations involving low tin solders (less than 10% tin) are generally best performed using iron-plated tips. Nickel-plated tips are also effective general operation tips. They tin easily and the nickel forms a thin, nonreactive surface layer of oxide. In addition to these general purpose tip materials, there are other specialty materials available. Ceramic-coated tips are used when soldering is performed on adjacent, electrically active terminals. Copper tips with a stainless steel bonded surface are also available. Stainless tips usually have longer working lives, do not freeze onto iron and are generally easier to change.

5.1.1.3 Tip selection criteria. There are three basic parameters to consider in selecting the soldering iron tip, length, diameter and shape. For maximum iron operating efficiency, the shortest tip which meets the application requirements should be used. As the tip length grows, the working temperature of the tip is reduced. In addition, the tip must always be fully inserted into the iron to maximize the heating element-to-tip heat transfer. The tip diameter affects the heat transfer of the tip and is directly related to the soldering iron life and maintenance requirements. The larger the tip diameter, the less maintenance is required and the longer the iron life.

5.1.1.4 Tip contours. Lastly, the shape of the soldering iron tip is important. The shape of the tip should be selected to minimize the soldering operation dwell time. For the shortest dwell, use the broadest point with largest area of contact between tinned surface and terminal. Conical tips are most effective when soldering eyelets. Full chisel tips are best for soldering terminals, leads and wires. Radius or grooved tips are best for soldering (gold cup) pin connectors. Some soldering iron tip manufacturers will supply tip blanks, allow users to shape a custom tip, and then supply plated custom tips. To maintain the effectiveness and life of the soldering iron tip, users should keep the tip tinned at all times. Excess solder should be allowed to sit on the iron tip while the iron is idling in the holder. Flux residues and plastic wire insulation residues should not be allowed to accumulate on the tip. If the tip becomes excessively oxidized or contaminated, it will not transfer heat well. Oxidized and contaminated tips should be replaced or reconditioned in accordance with the tip manufacturer's instructions.

5.1.2 Heat capacity and mass. The heat capacity of the tip is the specific heat of its material times its mass. High heat capacity allows the tip to pour more heat into a connection for a given temperature drop in the tip. Large connections require tips with more heat capacity rather than simply higher tip temperatures.

5.1.3 Tip length. The length of the tip affects the recovery and response time of the iron. The length of the heat path from the heating element to the working area of the tip determines the response time of the iron, with a shorter heat path providing quicker response.

5.1.4 Contact area. All of the heat provided to the connection by the iron must pass through the tip contact area. The largest practical tip contact area will keep the dwell time to a minimum.

5.1.5 Thermal profile of a soldering iron. Figure 7 shows the variation in tip temperature during a typical soldering sequence.

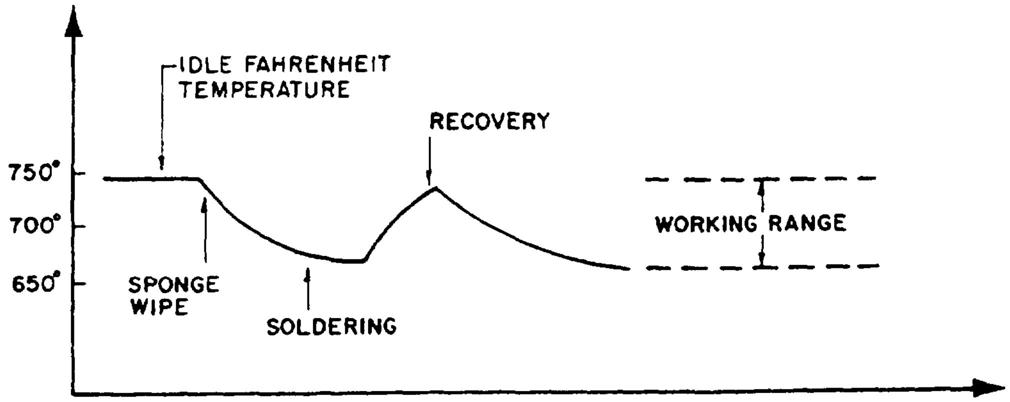


FIGURE 7. Thermal profile of a soldering iron tip (see 5.1.5).

5.1.6 Soldering iron tests.

5.1.6.1 Tip voltage test. The following test may be used to determine whether potentially damaging voltages are present at the tip of the soldering iron.

Equipment required:

a. RMS voltmeter with an accuracy of ±10% at 2 mV RMS, a frequency range of 50-500 Hz, input impedance of 10M ohms and the proper shielded cables and clips for attachment to shim stock and ground pin of plug.

b. A piece of 0.20-0.5 mm (0.008-0.020 inch) thickness brass or copper shim stock approximately 3.81 x 1.90 cm (1.5 x 0.75 inch).

c. Rosin core solder.

Procedure:

a. Remove any oxidation and corrosion from the shim stock.

b. Bond a small pool of solder to the shim stock using sufficient heat to ensure a well wetted bond between the shim stock and solder.

c. Turn on the voltmeter and the unit under test. Use the maximum temperature or the unit under test and allow it to warm up for 15 minutes. Select the proper range and measure and record the measurement system voltage, V1.

d. Remove the voltmeter negative cable and the ground cable from the conduction plate and attach them to each other as depicted in Figure 9.

e. Place the tip of the soldering iron in the solder and allow solder to melt. Wait approximately 30 seconds for the temperature to stabilize. Measure and record the voltage level V2.

f. If the voltmeter is not battery operated, it must be plugged into the same duplex wall receptacle as the unit under test.

g. Attach a cable with an alligator clip end or other suitable means to the ground pin of the unit under test.

h. Attach the positive and negative cables of the voltmeter and the ground cable to the conduction plate as indicated in Figure 8 using alligator clip ends on the cables. Ensure that a good electrical connection is made.

i. The voltage level of the unit under test is the difference of the two voltages, V2 - V1.

5.1.6.2 Tip to ground resistance test.

a. Equipment: Same as the voltage test, with an ohmmeter in place of the voltmeter.

b. Using an ohmmeter in place of the voltmeter in Figure 9, with the soldering iron hot and the solder melted, measure the resistance between the tip of the iron and ground.

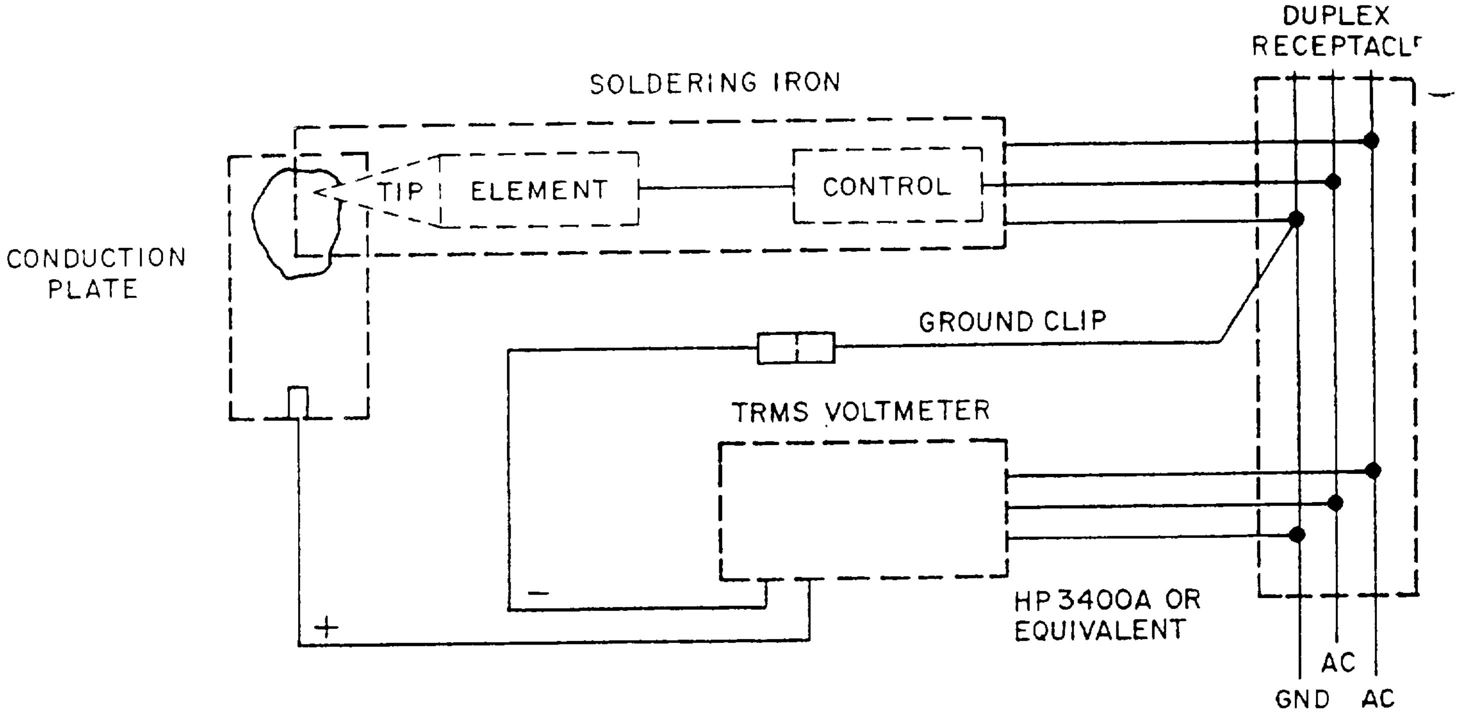


FIGURE 8. Measurement of UUT RMS voltage level.

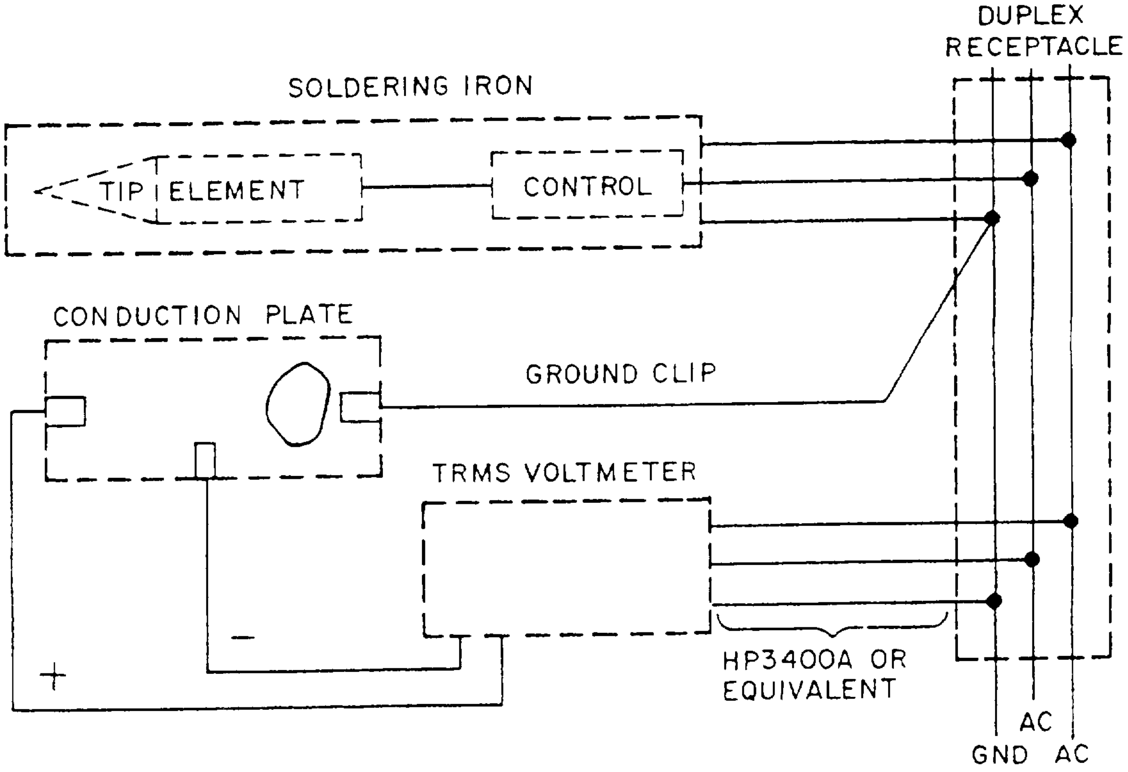


FIGURE 9. Measurement of test systems RMS voltage level.

5.1.6.3 Tip temperature test. The tip temperature can be measured using a contact pyrometer, an infrared pyrometer, or an embedded thermocouple. The procedure for using an embedded thermocouple is as follows:

a. Using a No. 55 drill, drill a hole approximately 3.2 mm (1/8 inch) deep in the tip of the soldering iron. Ensure no molten solder may enter the hole or get on the thermocouple.

b. Insert the twisted thermocouple so the last twist is exactly at the edge of the hole. Wedge a small piece of copper into the hole to hold the thermocouple in tight contact with the iron and trim off the excess copper.

c. Ensure the resistance of the thermocouple wires matches the calibration of the pyrometer. Attach the thermocouple wires to the pyrometer and heat up the iron. After the iron reaches operating temperature, record the temperature several times over a few minutes to determine the variance in tip temperature.

5.2 Constant output soldering irons. This type of soldering iron is typically used in the soldering of connections to chassis, RF shields, transformers, and other high thermal mass applications where large quantities of heat are required. Temperature controlled irons are designed for rapid responsiveness to changes in the tip temperature. To gain this responsiveness, the tips and heating elements of temperature-controlled irons are usually lighter in thermal mass. As such, constant output irons may be effective where temperature controlled ones are not.

5.2.1 Selection of constant output soldering irons. The same basic tests for temperature controlled irons should be used for constant output irons. Imbed a thermocouple in the tip of the iron and measure the tip of the iron after the last of a series of connections or operations. This will give you an indication of how well the iron will perform with the specific mass to be soldered. Another consideration is the dwell time of the soldering operation. For soldering printed wiring with a temperature controlled iron, a maximum of five seconds of dwell are all that is usually required. During some chassis soldering operations, however, the dwell time for a constant output soldering iron may extend up to 30 seconds. To assure proper connection formation, the measure temperature of the soldering iron tip, measured at the thermocouple, should stay at approximately 150°F above the melting temperature of the solder alloy during soldering. Also, the connection appearance will show if enough heat was applied (grainy, good wetting, good solder flow, good solder quantity, etc.).

5.3 Lighting. When selecting light sources for use during inspection, the color spectrum should be evaluated to ensure inspectors are able to see untinned copper. A good red spectrum is needed to spot bare copper. Fluorescent lights, projecting a white light with a large blue spectrum, are generally not as effective as incandescent lamps for spotting bare copper. New "warm" fluorescent light systems, however, are being developed with a greater red spectrum and may be successfully used. Within reasonable limits, small pitch inspection and operation is easier to perform with brighter light sources. When selecting light sources one must balance resolution capability against glare. If the light is too bright everything appears white. Fiber optic ring lights using a tungsten filament (halogen) light source (incandescent) have a higher red spectrum and seem to perform better than fluorescent tube lights on microscopes.

5.4 Microscopes. Microscopes should be binocular systems. When users are properly trained in their use, binocular systems are usually less fatiguing for long inspection operations. Greater exit pupil size (final image size) microscopes are easier to use. In addition, factors such as depth of field, field of view, and clarity will affect the users' ability to inspect. The effective aperture (i.e., the feedback of light) is a critical factor and should be maximized. Microscopes used for inspecting a variety of assembly types should be easily adjustable to differing working heights relative to the work inspected. To reduce operator fatigue, the microscope eyepiece height should be relatively easy to adjust. This will enable inspectors to move to different comfortable positions throughout the day. When inspecting products at higher magnification limits (10X and greater), tables and should be individual work stations isolated since minor bumps and vibrations will cause a significant appearance of motion within the view of the microscope. Zoom capacity is very desirable as it allows rapid adjustment to accurately identify defects. Some of the newer inspection systems (microscopes) have prismatic systems which will show the sides of parts. Video projection systems are also developing. Buddy microscopes are effective tools for defect analysis, contractor/auditor discussion aids, etc.

5.5 Work station and furniture selection. Basic human factors analysis principles should be applied to the manufacturing environment. Many studies have shown that as personnel fatigue, their ability to concentrate and perform tasks is reduced. Informal studies in several manufacturing facilities have shown that when a minor investment is made in improving operator comfort, there is a reduction in errors made by operators and inspectors. The adjustability of chairs and the ability to properly interface the height of the chair relative to the table significantly affects operator comfort. Cushions on the top side surfaces of tables is preferred. Hard table surfaces, if the board is moved on it, may cause basis metal to become exposed on the end of leads. This may also cause conformal coating to be removed from the end of leads.

5.6 Automatic lead-forming equipment. When choosing lead forming equipment, users need to evaluate the number of different part sizes and lead forms to be manufactured. Many users have found that a range of fixed dies are more cost-effective than many floating anvil dies systems. Floating anvil dies systems should be selected carefully as some systems tend to drift out of position more frequently than others. Floating anvil dies generally are more maintenance intensive than fixed dies. For fine pitch applications, minor variations in the anvil position may have adverse effects on the final lead configuration. Fixed dies generally produce consistent lead forms for a longer period of time. Fixed dies appear less sensitive to variation in packaging changes (part variations). Some parts (quadpacks, etc.) which have leads emanating at different heights on the side of the part may need to be shimmed during forming operations to achieve a consistent lead height (i.e., so only the part lead is in contact with the board and the part body is off the board). Consistent lead forming is especially critical in applications that use vapor phase reflow applications that use reflowed solder deposition rather than printed solder paste.

5.7 Wire strippers. Durable wire strippers with fixed dies that have been manufactured to tight tolerances will increase the probability of a clean insulation stripping without damaging the underlying wire.

5.8 Selection of vapor phase reflow systems.

5.8.1 Preheating and paste drying. Prior to the vapor phase reflow, the solder paste must be dried and the assembly preheated. Vapor phase systems need either a separate oven drying step in the assembly preparation process or an integral infrared preheat and drying stage. Preheating may be done in a dry nitrogen oven. Dry nitrogen baking minimizes oxidation of the solder paste. Inline vapor phase systems typically include inline infrared preheaters.

5.8.2 Inline vs batch systems. Inline systems are more costly than batch from a power consumption standpoint and should be used only when the volume of work requires them. Inline systems lose more fluid than batch systems and recovery is more difficult. Curtains (i.e., stainless steel covers) may be used to limit fluid loss when the system is not processing the product. Flexible curtains are not recommended as they tend to sweep parts off the board. As the assembly translates through the inline system, it is heated. If the solder paste reaches a flow point (i.e., paste liquification without solder reflow) while the board is on the down slope of an inline system, the parts may slide off their lands. Some of the newer inline systems use a batch type configuration with an inline work flow.

5.8.3 Acid neutralization systems (batch reflow system). Acid neutralization is needed to limit the acidity of fluid due to hydrochloric acid formation. The interaction of the primary and secondary vapors frequently causes formation of acids which while they appear within the limits for acid in the system, will cause degradation of the cooling coils. Acid formation is often the cause of premature cooling coil failure. Scrubbing systems can also remove some other contaminants, although it is not their primary purpose.

5.8.4 Heat capacity. The capacity of the vapor phase system (rated in kilowatts, heat capacity in Joules) needs to be evaluated against the heat required for the assembly. The mass of the elements (both the assembly and the fixture) going in and the rate of through-put should be considered to determine if the power rating of the heaters (vapor phase system) is adequate. If necessary, through-put rates may be adjusted when the inline vapor phase system is only marginally capable. This is not possible in batch systems.

5.8.5 Fault detection systems. A burn-out of a heater in a vapor phase system will cause the reflow vapor to condense (collapse). Many of the newer systems utilize current monitors on the heaters to detect burn out. Newer systems also include thermocouples at various levels to detect the loss of reflow vapor.

5.8.6 Vapor recovery systems. Due to the cost of reflow vapor fluids, recovery systems are an important part of the vapor phase machine. Recent model recovery systems have improved to the point where only a few grams per hour of fluid is lost.

5.8.7 Cleanability. Periodic cleaning of all vapor phase systems is required. The vapor phase system should be selected in a manner which minimizes both the frequency that cleaning is required and the amount of time required to clean the system. Environmental factors such as altitude can affect vapor loss and boiling point.

5.8.8 Limited selection of reflow vapor. Vapor phase machine manufacturers will provide guidelines on the boiling points that should be used in the machines. Differing fluids will have differing loss rates (i.e., loss from the machine) and differing chemical breakdown rates. The heat transfer properties vary between fluids as well. The heat transfer property of the fluid must be evaluated both in terms of the heat capacity of fluid and the heat transfer rate of the fluid. During reflow, the reflow vapor will condense on the assembly. Variations in the thickness of this condensate layer and its heat transfer rate will affect how long the assembly must dwell within the vapors. There have also been some rare occurrences where the flux and reflow vapor has been incompatible. This incompatibility has resulted in the flux being soluble in the reflow vapor and the assembly is "degreased", inhibiting the reflow process. Some solder pastes are manufactured specifically for vapor phase.

5.8.9 Field support. An often overlooked selection criteria is the quality of field support provided by the system manufacturer. Field support is essential during the initial integration of the equipment into the manufacturing facility.

5.9 Selection of infrared reflow systems.

5.9.1 Preheating and paste drying. Infrared systems typically have a preheat and paste drying section integral to the unit. This obviates the need for a separate preheating and drying step or process. After parts are placed on the assembly, the assembly can be directly loaded into a properly configured infrared reflow system.

5.9.2 Combination of convective and infrared heating. All infrared systems heat the atmosphere around the assembly. Some systems incorporate convective heating elements as well. When evaluating infrared reflow systems, potential users should examine their assemblies and the system operation to estimate what percentages of infrared and convective heating are required for effective process operation. In infrared reflow, the emissivity of parts (i.e., the infrared absorption characteristics) will affect the heat absorbed during reflow process. If some parts have a much higher absorption rate than others, hot spots may develop on the assembly. Infrared reflow systems which use a greater percentage of convection heating will help reduce the occurrence of localized hot spots. As an alternative, aluminum or other similar heat shields may be used. The addition of these heat shields, however, is time-consuming and undesirable.

5.10 Selecting pick and place equipment.

5.10.1 Part variations. The number of different type of parts to be placed is a critical selection criteria. Users should attempt to limit the number of parts available for use in design to maximize the utility of pick and place equipment. Both through-put rates and the requirement to change part trays or reels should also be considered in evaluating the flexibility of the equipment and the number of parts to be loaded into the machine.

5.10.2 Interface with CAD systems. Depending on the number of different assemblies to be processed, users may wish to have their pick and place equipment compatible with their computer-aided design. The pick and place equipment should be tested with actual output data from the computer-aided design system to ensure it will accept the data.

5.10.3 Integral part testing systems. Some pick and place machines will perform a variety of tests on the selected part and determine whether or not to place the part on the assembly. Some machines will test only a sample of the parts; others will test all parts as they are picked. The machine should test both whether the correct part has been placed in the reel position and whether the part is within its tolerance limits. Some of these test systems are not very efficient and may make errors in the part testing process.

5.10.4 Feed systems. Users need to match the part packaging system to the pick and place equipment. Prior to the purchase of pick and place equipment for specific parts, potential users should verify the desired packaging structure is available. Parts used infrequently should be bought in a packaging structure that does not require large quantities of parts to sit on the production floor. Depending on the tolerance of the feed system, variations between similar packaging systems (i.e., package tolerance variations) may make it difficult to accomplish alternate source part substitutions. Generally, fine pitch leaded parts must be handled very carefully to avoid unnecessary lead reforming operations and should be bought in matrix tray (waffle) packaging systems. Tape and reel systems are most effective for axial leaded parts.

5.10.5 Part issuance (material control). The use of complete kitting systems precludes the need for stocking of parts on the machines. The packaging structure may be determined by the kitting or part issuance system.

6. DESIGN

6.1 Design control and development. All design activities must include considerations for producibility. A large amount of time and money is wasted when manufacturing personnel are required to compensate for poor designs. Equipment manufacturers who do not include manufacturing personnel as part of the design team or who limit the communication between the design and manufacturing divisions will rarely design readily producible products. New equipment design teams should include personnel from all corporate departments including purchasing, manufacturing, and quality. The use of design and producibility guidelines is a generally less effective alternative to the integrated design team concept.

6.2 Part numbering. For traceability during production and testing, part numbering which is based on part location rather than device numbering based on logic design (circuitry design) may be used. When common board layouts are used for functionally different boards, similar part numbering schemes (based on location) between common board layouts speeds part identification. For example, a series of different assemblies that utilize a five row by five column flatpack design should have identical part numbering for identically located flatpacks. CAE may require that parts be numbered by their schematic location.

6.3 Use of adhesives. Adhesives make rework and repair operations more difficult. The use of adhesives, except for applications where surface mounted chip devices will be moving through a solder wave, should be limited to designs where heat transfer or additional mounting strength is required.

6.4 Component density. For producibility, the layout of the components on the board is critical. The spacing of parts determines producibility. Over approximately 85% component density, the assembly becomes significantly more difficult to produce.

6.5 Mixed technology designs. In general, a mixture of through-hole and surface mounting significantly increases the difficulties associated with assembly processing. Mixed technology assemblies should be avoided wherever possible.

6.6 General printed wiring design. There are two basic steps in the design of printed wiring assemblies. These are the electrical circuitry design and the design of the circuitry "packaging." This handbook focuses on the packaging of the circuitry and is not concerned with the schematic level design of the circuitry. Packaging design, involving the design of the printed wiring board as a component (i.e., the number of layers, location of ground and power planes, etc.) and the layout of the board (relative location of components) should stress producibility of the final assembly.

6.6.1 Development of standard design practices. There are many techniques for designing printed wiring assemblies which will meet the requirements of military contracts, specifications and standards. As such, most manufacturers have developed their own design guides and internal design rules. Often these are incorporated into computer-aided design systems. These design requirements should be developed by manufacturing in conjunction with printed wiring manufacturers. Proper design can significantly reduce the overall costs to produce an assembly. As the production lot size increases, the cost savings associated with removing the obstacles to producibility increases. As such, producibility is the most critical element in developing design requirements.

6.6.2 Solder mask over melting metals. To ensure solder mask adhesion, solder mask may only be applied over nonmelting metals. Solder, however, is often used as an etchant resist when etching copper patterns for the printed wiring boards. When used on outer layers, either another etchant resist must be used or the solder must be stripped away. If stripped away, the printed wiring must then be masked and solder deposited on the pad areas. Printed wiring manufacturers find it easier to produce boards with a "pads only" outer layer. These boards have fewer conductors on the outside so there are fewer problems associated with respect to electrical clearance spacings during subsequent assembly processing.

6.6.3 Hole fill requirements. Since partially filled plated-through holes may contain contaminants, plated-through holes are best left completely empty or completely filled. When plated-through holes are used to provide inner and outer layer connections without part leads inserted, narrow aspect ratio plated-through holes permanently tented with solder mask are an effective technique. Unfilled narrow aspect ratio holes will require the least strength from the solder mask tent. Tenting is generally ineffective on holes larger than 0.64 mm (.025 inches). Many solder masks are not well suited to tenting. Solder masks should be evaluated for this. These holes may be used in lieu of blind via holes which may also become a collection point for contaminants.

6.6.4 Inner layer connections. Buried via holes and "copper columns" are an effective way of providing inner layer connections without increasing the conductive surface area on the outside of the board. Buried vias require greater board processing than through-holes (there is an interim masking, etchback and plating process required to connect the layers). Also, multiple copper plating operations may be used to create an interconnecting column of copper between layers of the board between laminations.

6.6.5 Thermal stress. Thermal stress is an essential design consideration for both end-item service life and production. Differing thermal expansion coefficients and wide temperature variations may cause component cracking. Glass diodes and the glass seals of dual-in-line packages may fracture during processing. Proper assembly design and part selection is required to avoid introduction of failure modes during assembly. Parts such as glass diodes also need to be protected from conformal coatings. When coatings get between the part and the printed wiring board, their different expansion rate may result in cracked components.

6.6.6 Ability to clean under parts. Cleanability is another important design concern. The design must allow sufficient spacing between the part and the board to ensure that the cleaning solvent or aqueous cleaner can flow under the part and remove contaminants. As greater lead numbers and finer lead pitches are used, it is harder to force the cleaning solvents under the part. Where the cleaning process becomes less effective, manufacturers must use less active fluxes to ensure any remaining residues are harmless.

6.6.7 Ability to verify the cleanliness of areas under parts. In a similar manner, the effectiveness of the cleanliness verification system is limited as lead pitches become finer. Most automated cleanliness test systems work by washing contaminants into a solution and measuring a change in resistivity. Just as when the cleaning solvents cannot get under the part to remove contamination, the cleanliness verification solution cannot remove the underlying contaminants. As such, the assembly appears clean when it is not.

6.7 Design for surface mounted technology.

6.7.1 Similar part orientation. Designers should attempt to keep all of the number one pins of multileaded microelectronic devices oriented in the same relative direction within an assembly and over a range of assemblies of similar configuration. This will make it easier to both mount parts and test the assembly. It also reduces inspection time as well. Tanalum capacitors should also be mounted with the same relative orientation.

6.7.2 Orientation of bottom side surface mounted parts. When passive chip devices are mounted on the bottom side of an assembly to be wave soldered, they should be mounted so that the axis of the part is parallel to the leading edge of the wave. This will reduce the incidence of shadowing and will increase the probability of proper fillet formation. The terminal areas of the parts should also make contact with the wave simultaneously to improve fillet formation. The rows of the parts should be aligned along the terminal areas to minimize the potential for shadowing. This is especially important when taller devices are followed by shorter devices. If parts are mounted too closely, bridging may result more often than shadowing. To avoid the potential for shadowing and bridging, high density passive part designs should be used only if a turbulent (agitated) or dual wave soldering system will be used in the soldering process. If parts are designed onto the bottom of assemblies which will be subsequently vapor phase reflowed, epoxy or special fixturing may be required to hold the parts in place (i.e., this design is less producible and should be avoided if possible).

6.7.3 Interrelationship between the land and chip device outline. Variations in the size of surface mounted chip devices, due to either wide tolerances or part substitutions, may result in solder connections of insufficient size and strength if the land is designed at the minimum size limit. The smallest allowable land, when designed for the smallest size part, will probably result in solder connections which are too small (even if properly made). Wherever it is practical, lands should be made as large as possible to maximize that ability of the assembly design to compensate for variations in parts. Land size and interland spacing must be traded-off to maximize solder connection size and minimize bridging potential.

6.7.4 Selecting leaded or leadless components. In general, leadless parts are preferable from a handling perspective. Both lead forming problems are avoided and part coplanarity is easier to achieve. The thermal coefficient of expansion system required for assemblies which incorporate leadless parts, however, may make the overall use of leadless parts less desirable.

6.7.5 Combined via holes and lands. As part of the overall interconnect structure, enlarged lands incorporating via holes have been used for surface mounted part attachment. The addition of these via holes, however, have resulted in less producible assemblies. In general, the solder which is intended to make the surface mount connection will flow into the via hole and will significantly reduce the amount of the solder which remains on the land. This tends to occur whether the hole is solder plugged first or not. Via holes with a surrounding land and an interconnect to the surface mounted part land is the preferred design technique. Tenting of holes and the use of blind vias will prevent solder flow into holes.

6.7.6 Use of conformal coating on surface mount assemblies. Designers must carefully select which surface mount applications require conformal coating. If conformal coating flows under the part, the expansion of the conformal coating during temperature cycling will tend to cause the parts to pop off of the board. Uniform coatings should uniformly coat around the edges of the component without flowing under the part. Parylenes work well in this application. In addition, film epoxy, if properly placed, both help retain the part and prevent conformal coating flow under the part. Where necessary, a potting or sealing compound may be required around the edges of the part to prevent conformal coating from flowing under the part.

6.7.7 Component selection. In addition to their ability to perform their function, components must be selected for their ability to withstand the temperatures and chemicals which will be experienced during subsequent processing. Component manufacturers should be consulted to determine whether or not the parts used on assemblies can survive temperatures associated with all soldering processes. The longer term heat duration associated vapor phase and infrared reflow, while often a lower temperature soldering process, may transmit more heat to the part than the higher temperature hand and wave soldering processes.

6.7.8 Selection of board materials. Use of polyimide outer layer boards may reduce the occurrence of lifted lands. Some boards with greater bond strength between layers or between the glass and fiber are more capable of withstanding the stresses associated with soldering temperatures. The board material may be able to withstand the stresses associated with the expanding water in the board.

7. PART PREPARATION AND MOUNTING

7.1 Solderability. Solderability is the ability of a surface to be wet by molten solder.

7.2 Tests for solderability. MIL-STD-202, Method 208, MIL-STD-750, Method 2026, and MIL-STD-883, Method 2003, are tests used to determine the acceptability of wires and component leads. In MIL-STD-202 parts are steam aged, then the leads are dipped in Type R flux and then dipped in a solder pot set at 245°C (473°F) for five seconds. The less active flux and lower solder temperature than normal soldering conditions make the test more sensitive to solderability problems than the soldering process. 95% coverage of the lead indicates acceptable solderability. Another method for testing solderability is the wetting balance described in MIL-STD-883, Method 2003. The wetting balance measures the force on the lead as a function of time as the lead is dipped in molten solder. Prior to solder wetting the lead, the surface tension of the solder will cause the lead to float on the solder. As the solder wets the lead, the force changes from upward to downward as the solder wets and flows up the lead. This method is quite sensitive and is good comparing the relative solderability of parts. Solderability of PWBs is tested in accordance with IPC-S-804.

7.3 The wetting balance. A typical time versus wetting force plot is shown in Figure 10. The first portion of the plot is the insertion of the cool lead into the solder. The lead tries to float on the solder, resulting

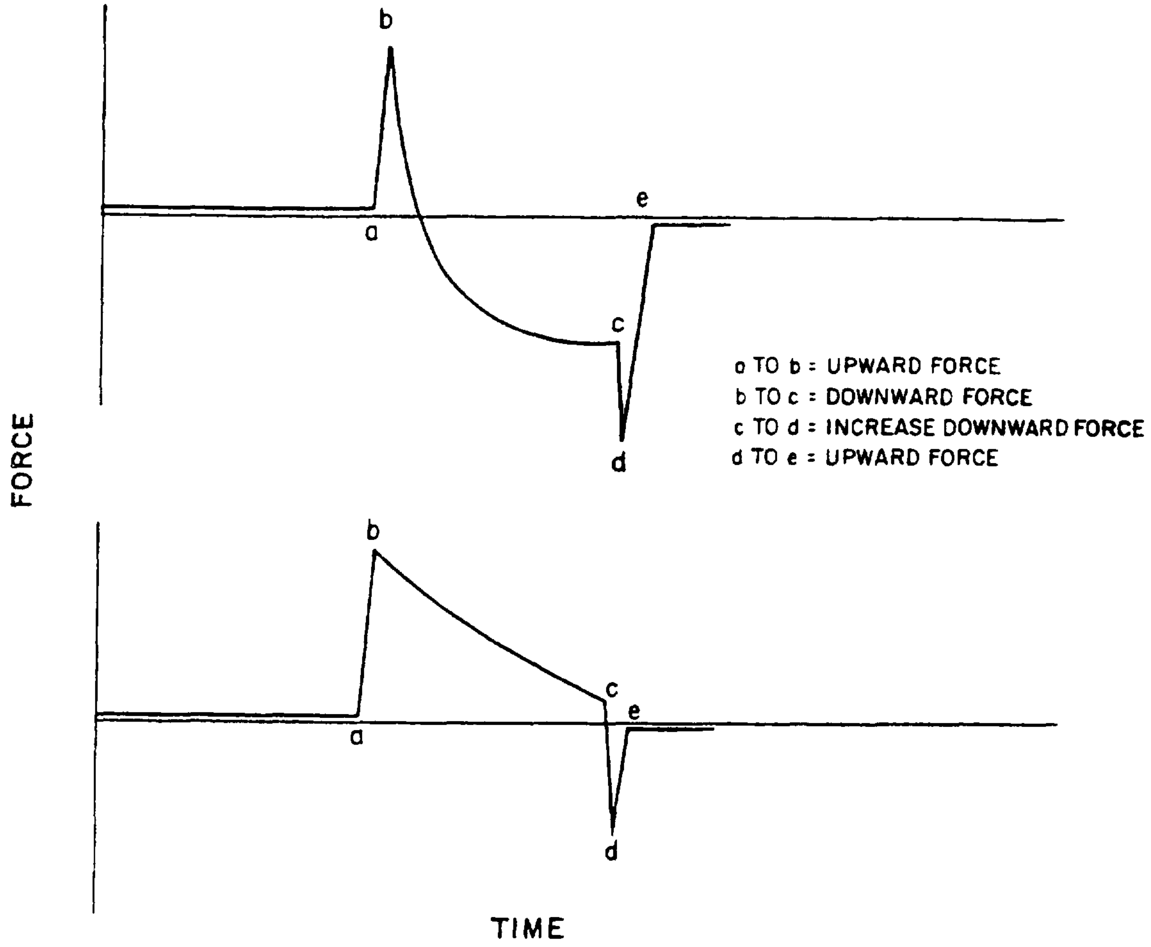


FIGURE 10. Wetting balance plot (see 7.3).

in a positive upward force. In the second portion of the plot the solder begins to wet the lead as the temperature of the lead rises. The force crosses below the zero line as the meniscus changes from convex to concave, pulling the lead down. If it takes an extended time for the force to cross back over the zero point, or if it never does, the solderability is poor or nonexistent. The end of the plot shows the force as the solder is pulled up with the lead and the excess drains off.

7.3.1 Interpreting wetting balance plots. Between points a and b there is an upward force as the lead tries to float on the solder. Between points b and c, the force goes downward as the wetting pulls the lead down. The initial steepness of the curve and the time it takes to level off are indicators of the quality of solderability. From points c to d the lead is being pulled from the solder and pulling some of the solder with it, thus increasing the downward force. The solder then drains off, giving the force line shown from d to e.

7.4 Symptoms of poor solderability. Symptoms of poor solderability on leads include nonwetting, dewetting, foreign material, pinholes, porosity, cratering and blistering, and discoloration.

7.5 Causes of poor solderability. Possible causes of poor solderability include oxidation of the surface of the lead wire, contaminants on the surface, thin solder coating, contamination of the base metal, intermetallic growth, physical damage during manufacture, improper testing, improper flux and inadequate heat.

7.5.1 Oxidation of lead wire surfaces. Oxidation of the lead wire surface is indicated by a dull, discolored appearance. If the oxidation is light and confined to the solder surface only, it will not necessarily destroy the solderability. Light oxidation on the solder surface can be broken up by the flux and reflowing of solder.

7.5.2 Contaminants on the surface of the solder coating. Any contaminant on the surface of the lead will reduce solderability. Common contaminants are salts, skin oils and sulfur.

7.5.3 Thin solder coating. Thin plating or solder coatings may cause solderability problems by allowing oxidation of the underlying base material or by depletion of the coating due to intermetallic growth during burn-in and steam aging. A 60 to 100 microinch coating will insure that a thin coating is not cause for solderability problems.

7.5.4 Contamination of base metal. Contamination of the base metal can occur if the external protective coating is too thin or porous. Contaminated base metal will dewet or blister the solder coating when reflowed.

7.5.5 Excessive intermetallic growth. Intermetallic growth occurs at the interface of solder and copper. Heat accelerates the rate of intermetallic growth. When this happens, tin in the solder combines with copper to form the compounds Cu_6Sn_5 and Cu_3Sn. The depletion of tin from the solder coating can make it lead rich, thus becoming more susceptible to oxidation (see paragraph 4.5.4).

7.5.6 Physical damage during manufacture. Scratches or abrasions on the component lead which expose the base metal will cause solderability problems. The base metal may be unsolderable or may become unsolderable as the exposed metal becomes oxidized.

7.6 Maintenance of solderability. Maintenance of solderability in parts and boards may be best accomplished through controlling the plating on the parts and boards. Porous platings will allow subsurface oxidation of the basis metal. Reflowed tin platings and hot solder-dipped lead finishes will generally provide a longer storage life than plated finishes. The plating process will affect the ability of the finish to resist oxidation. High energy, high speed (blast) platings are generally more porous than lower energy, slower rate platings. Loss of solderability largely results from subsurface oxidation rather than the surface oxidation of the tin or tin-lead. Gold platings may not be solderable because they have organic inclusions (cause loss of solderability by preventing wetting) and porosity (causes electrolytic corrosion).

7.7 Lead finish preparation (conditioning). Parts should be purchased with a fully solderable finish on the lead. Use of parts which do not require reconditioning is preferred. A lead finish of greater than 100 microinches of unreflowed tin or greater than 50 microinches of reflowed tin is typically sufficient to ensure solderability. A hot solder-dipped lead finish, however, has generally been accepted by the military as providing a lead finish that will remain solderable for up to two years in proper storage. Hot solder dipping is a preferred lead finish since it provides a reasonably thick, non-porous finish. Most plating processes in use today use a high energy, "blast," plating system. This plating system will provide 100 microinches of tin plating rapidly. This plating, however, is typically porous and is a poor oxidation inhibitor. The porosity of the plating allows subsurface oxidation of the plated basis metal. If the plating is reflowed in either a hot oil or equivalent bath, then the plating will be less porous (more coherent) and will provide a better oxidation resistance. Some reflow processes use a fusing fluid which contains organic acids as brighteners. The entrapment of these organic compounds in the reflowed plating may result in both corrosion and contaminants on the assembly when the plating reflows during soldering.

7.7.1 Hot solder dipping. The hot solder dipping process generally includes the dipping of the lead or wire to be tinned in type R, RMA or RA flux, followed by the dipping of the lead or wire in hot solder. To assure formation of an intermetallic compound between the basis metal and the solder, the solder pot should be in the range of 257-268°C (500-520°F). The activity of the flux should be selected depending on the level of oxidation of the basis metal. The least active flux should be used to minimize potential contamination problems and simplify subsequent cleaning. When tinning stranded wire, the wire needs to remain in the pot long enough to ensure solder flow into the inner area between the strands. When tinning both stranded wire and parts with lead seals (i.e., dual in-line packages), care should be taken to avoid flowing the flux under the insulation or into the lead seal.

7.7.1.1 Inert atmosphere tinning. Using a wax for dross removal, tinning may be performed in a flowing solder pot with a nitrogen blanket providing an inert environment. This process avoids the need for flux and minimizes the need for cleaning the tinned parts. Bridging of fine lead parts (20 mil pitch) may also be successfully avoided with this process. The formation (or absence) of dross on the surface of the solder pot is an indicator of how well the nitrogen blanket is performing its inerting function.

7.7.1.2 Cleaning of parts tinned with fluxes. Parts should be cleaned shortly after dipping to maximize the effectiveness of the cleaning process. Periodic cleanliness verification (visual and solvent extract testing) should be performed to ensure that parts, when incorporated into a final assembly, will enable the assembly to pass the final inspection requirements.

7.7.1.3 Fine pitch part tinning. Fine pitch components present special cleaning problems. Parts should be cleaned as soon as practical after dipping to maximize the effectiveness of the cleaning process. Spraying or brushing of fine pitch leads may result in undesirable lead deformation in fine pitch parts. Hot air may be used to remove bridging between leads after dipping.

7.7.1.4 Hermeticity. The combined operations of tinning and lead forming may cause the glass seals of hermetically sealed devices to crack. Cracking beyond the limits of the initial part specification may result in a loss of part hermeticity. Once hermeticity is lost, process materials and other contaminants may enter the part, resulting in shortened part life. The potential for hermeticity loss is generally greater in ceramic DIPs and hybrids than in flatpacks or side-brazed DIP packages. Larger packages with larger lead frames (higher pin counts) tend to have a higher potential for glass seal failure at the lead to glass seal in the DIP and hybrid packages. Preheating the package prior to tinning (dipping) and tinning only the area that needs to be tinned may help avoid cracking. Preheat rates should be defined to minimize thermal shock. In addition, cooling rates must be defined to avoid thermal shock. Cooling at room temperature is recommended. Solvent quenching should be avoided. Random leak tests should be performed to verify the tinning process is not causing seal failures.

7.7.2 Lead reconditioning. When leads are not solderable and the solderability cannot be restored using an RA tinning process, specialized techniques are required to restore lead solderability. The lead reconditioning process should consist of stripping away the existing tin or tin/lead finish, fluxing the part, and dipping the part in solder. The stripping process should not remove the tin based finish from the area surrounding the component glass seal (where it exists) to ensure continued viability of the seal. Iron-based leads often require the use of fluxes (typically water-soluble fluxes) not normally approved for operations under MIL-STD-2000. Procuring activity approval should be requested, if necessary.

7.8 Lead forming. Lead forming can be accomplished by using a fixed or an adjustable mechanism. Trimming of the lead can be accomplished either before or after forming to the specified bends. The critical elements of lead forming are support at the lead exit from the component body, the forming itself, and the lead trimming. Figure 11 shows the forces involved in lead forming. Table V is a troubleshooting guide for lead forming.

7.8.1 Hand forming of leads. Hand forming of axial leaded components can be accomplished by carefully bending the leads over rounded jaw pliers or using a lead forming tool as shown in Figure 12.

7.9 Clinching of leads. When clinching of leads is required, leads are left untrimmed until the clinching is accomplished. After the lead is dressed through the hole, use a wood or phenolic tool at the exit point from the hole to bend the lead at a 90 degree angle. Bend opposing leads in opposite directions and along the traces when possible. After the lead is bent, place a small sheet of plastic under the lead to protect the board from the clippers and trim the lead to its proper length.

7.10 Attachment of leads to terminals. Leads attached to terminals should have a wrap of 180 to 270 degrees. Figures 13, 14, and 15 show proper attachment of leads to terminals.

TABLE V. Troubleshooting chart.

Type of Forming Problem	Possible Causes	Corrective Action
Package damaged at exit point	Tooling to support at exit point is inadequate	Support or captivate lead at exit point
	Component body is larger than tooling nest	Customize tooling to accommodate body size changes
Damaged lead	Component damaged at both pre and post forming stages	Improve handling and storing methods
	Tooling will not accommodate lead diameter changes	Tooling must either adjust for variance or dedicated to component lead size
	Worn or damaged tooling	Schedule preventative maintenance on tooling
Component body to circuit card out of tolerance	Component body varies in dimension from component to component	Use tooling that adjusts to accommodate body variance or presort components and direct to set tooling
Flag or burr on trimmed lead	Tool trim edges worn Shear tolerances incorrect	Re-dress tooling

7.11 Connection type designators. Table VI lists the designators for various connection types.

7.12 Solder deposition for reflow.

7.12.1 Selection of solder deposition techniques. There are three basic techniques for placing solder onto printed wiring prior to reflow. These are the use of preforms, selective plating by the board manufacturer (i.e., deposition of a thick solder plating onto the board), and additive processes which include screen and stencil printing and syringe (injection) deposition. When solder must be deposited on significantly differing pitch lands (20 mil vs. 50 mil), different solder thicknesses are required. If a screen or stencil process is used, this will require either multiple printing passes or differing screen thicknesses. As such, selective plating, which eliminates multiple solder addition processes, may be a preferred alternative.

7.12.2 Use of selective plating processes. A primary disadvantage of selective plating boards is that they are usually two to three times more expensive than standard boards. Selective plated boards also have a convex solder top on the lands and parts tend to slide on the land. Automated film bonding of the parts is an effective technique for keeping the parts from moving. A tacky flux used prior to part placement may be effective as well. If an epoxy film is used, the epoxy curing stage (bake) should be combined with a board drying stage (if used).

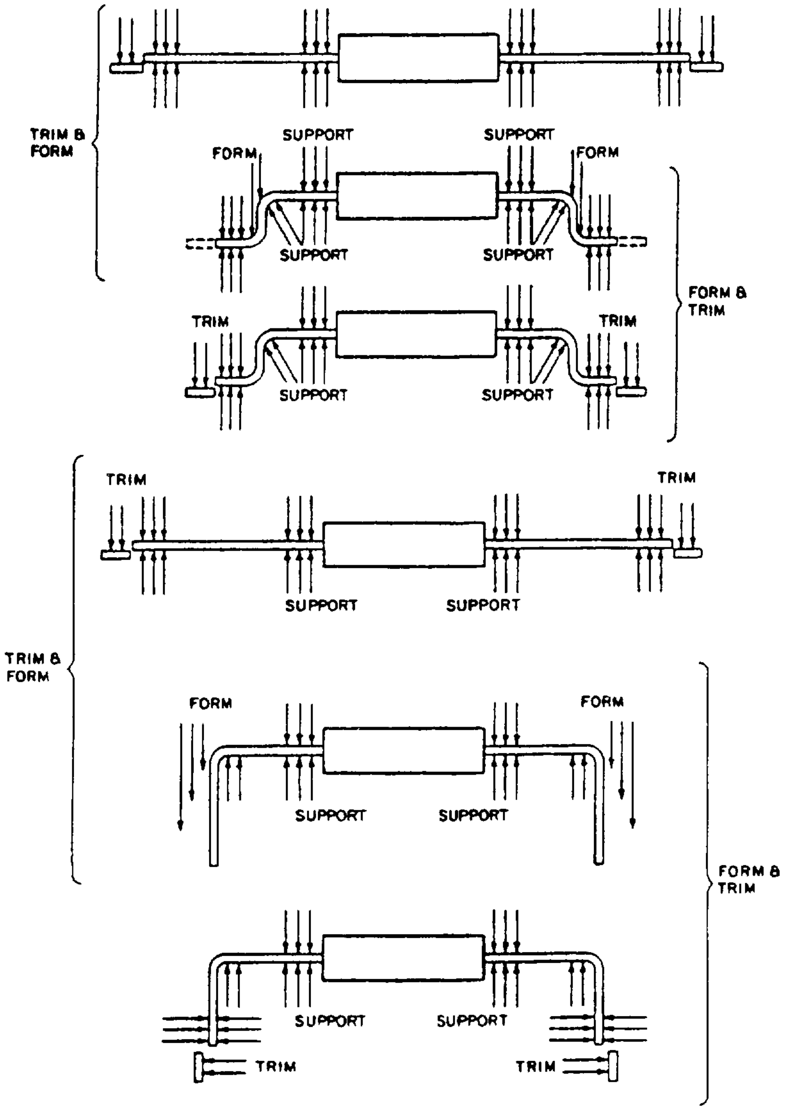


FIGURE 11. Lead forming (see 7.8).

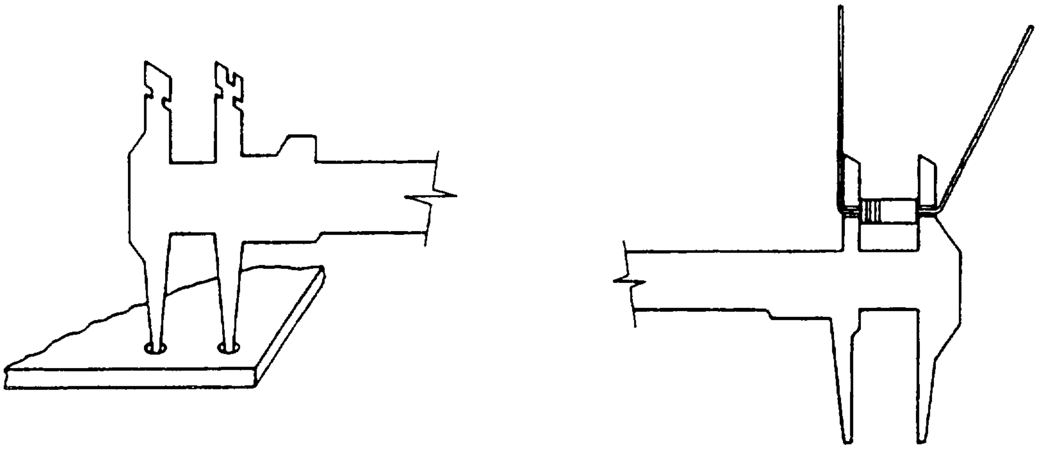


FIGURE 12. Hand forming of leads (see 7.8.1).

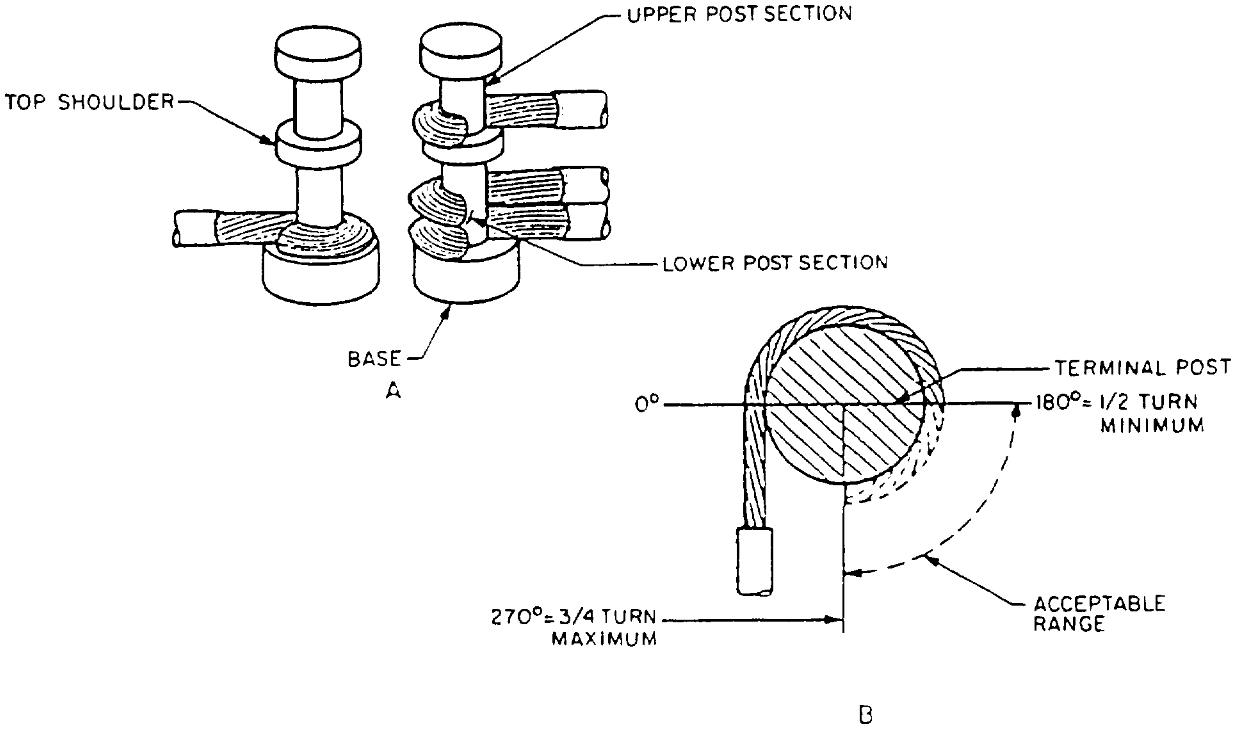


FIGURE 13. Turret terminal wire wrap (see 7.10).

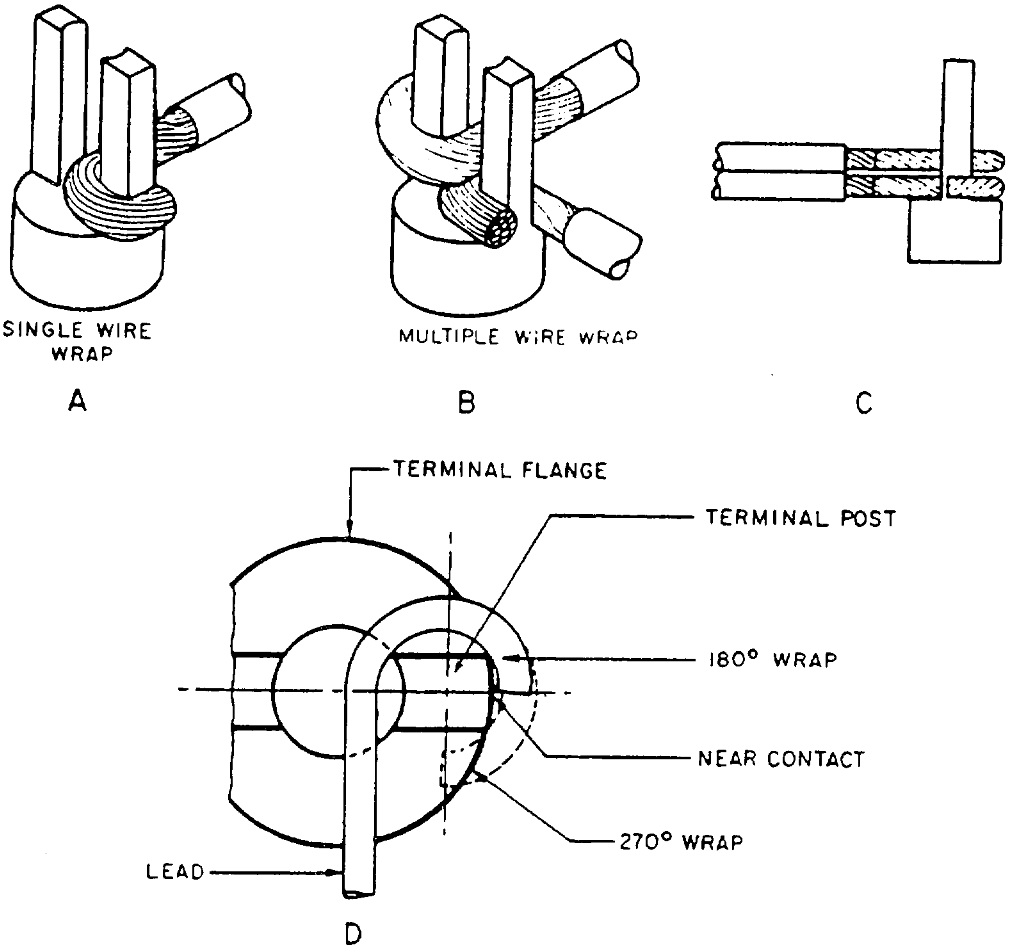


FIGURE 14. Bifurcated terminal side route wire wrap (see 7.10).

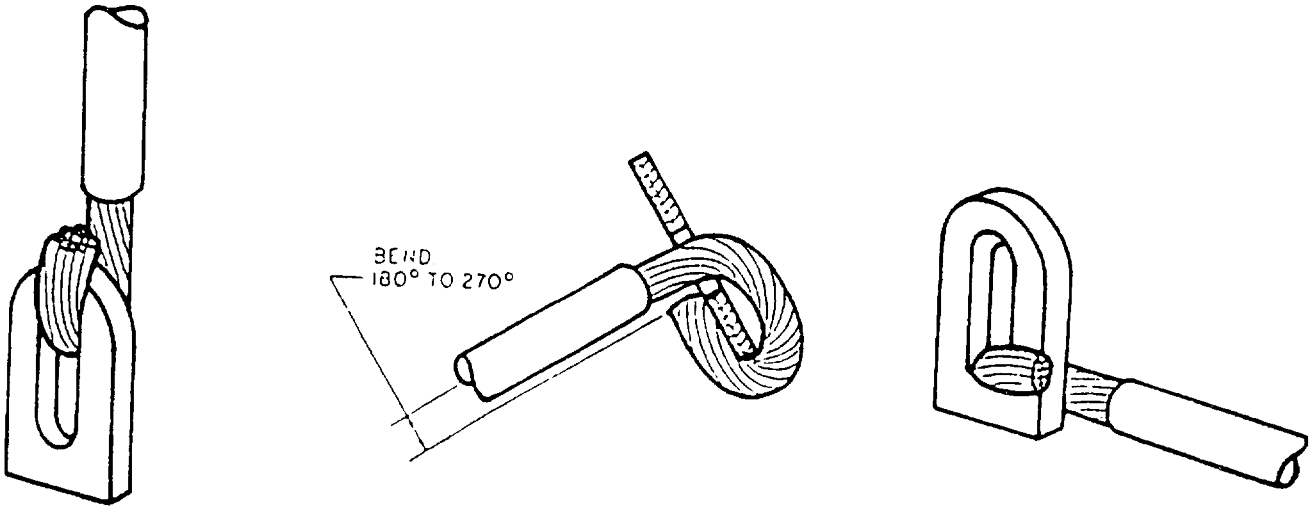


FIGURE 15. Pierced or perforated terminal wire wrap (see 7.10).

TABLE VI. Type designators for solder connections.

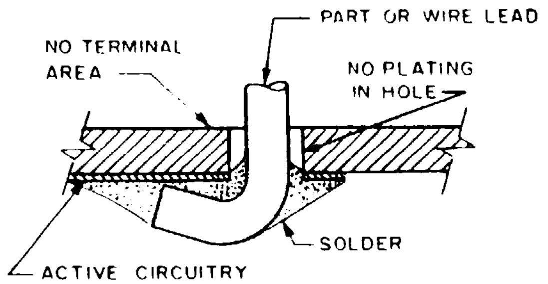
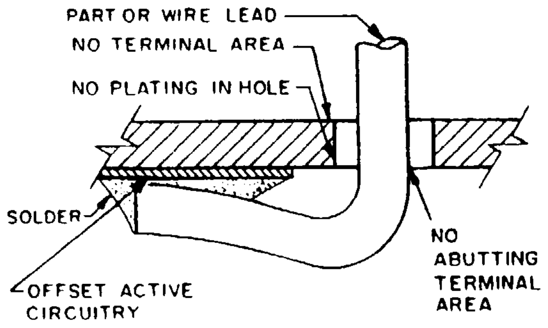
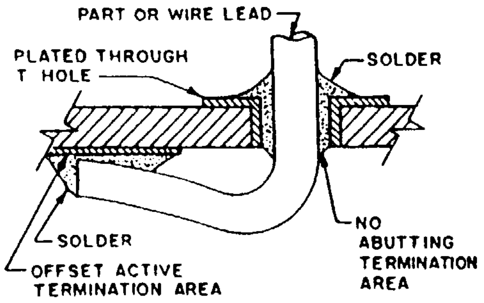
Type Designator	Description	Pictorial	Comments
SS	Connections in single-sided printed wiring boards		
SS-1a	Clinched part or wire lead in unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
SS-1b	Part lead in unsupported hole clinched to an offset termination.		Permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.
SS-1c	Part lead in plated-through hole clinched to an offset termination.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

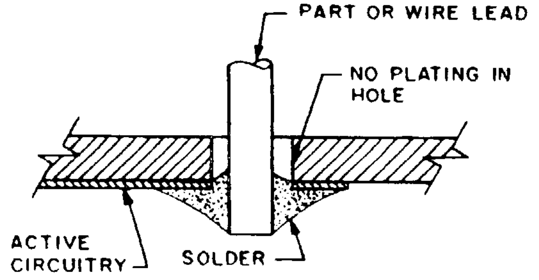
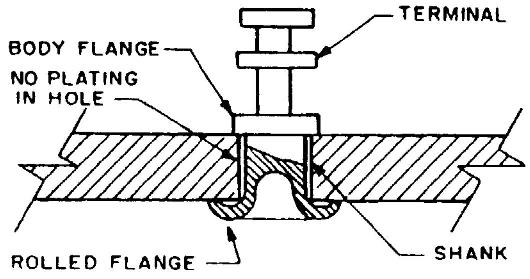
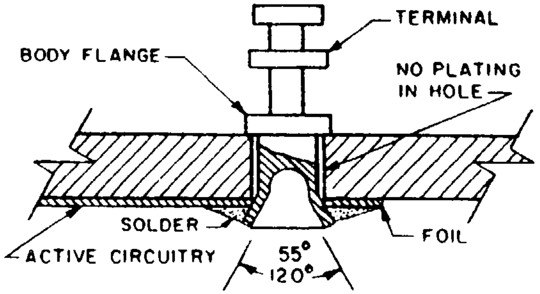
Type Designator	Description	Pictorial	Comments
SS-2	Straight-through part or wire lead in unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
SS-3a	Rolled flange terminal in unsupported hole.		Permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
SS-3b	Flared flange terminal in unsupported hole.		Permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

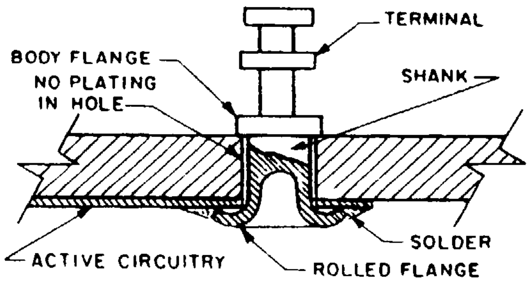
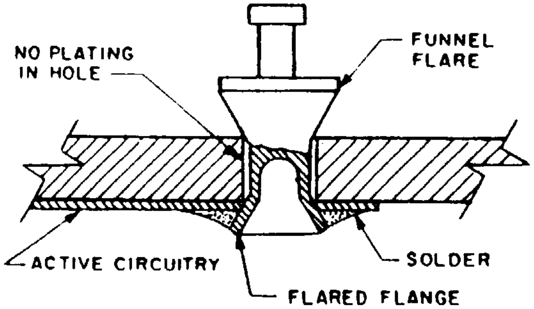
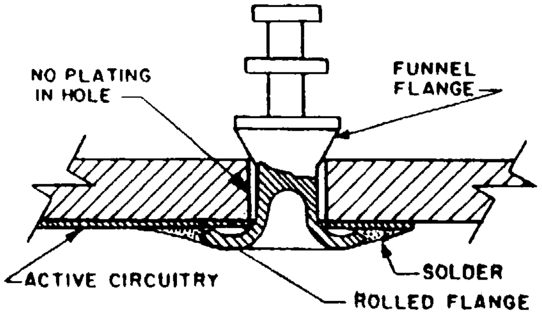
Type Designator	Description	Pictorial	Comments
SS-3c	Terminal in unsupported hole with flange rolled to active terminal area.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
SS-3d	Double flared terminal in unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
SS-3e	Flared terminal in unsupported hole with flange rolled to active terminal area.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

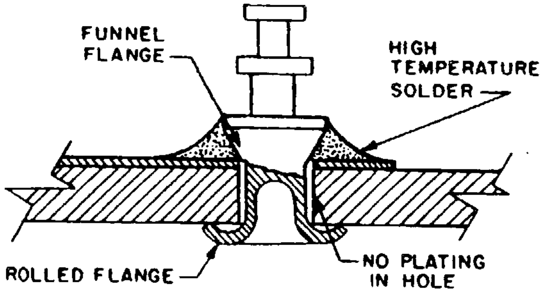
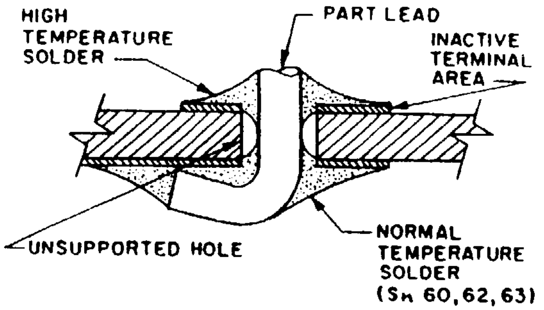
Type Designator	Description	Pictorial	Comments
SS-3f	Flared terminal in unsupported hole with flange rolled to inactive surface of PWB.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275(SHIPS) and subsequent revisions thereof issued prior to 1 January 1987.
DS	Connections in double-sided printed wiring boards		
DS-1a	Step soldered clinched part or wire lead in unsupported hole.		Permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

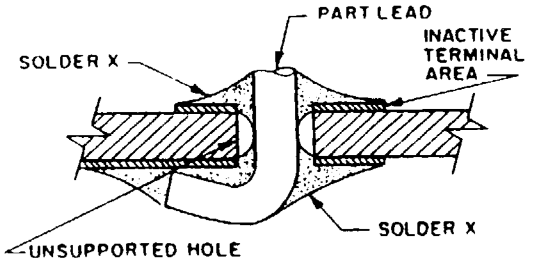
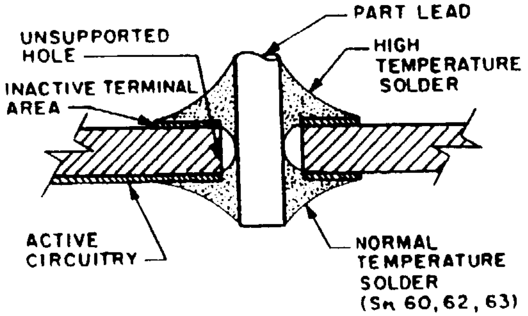
Type Designator	Description	Pictorial	Comments
DS-1b	Clinched part or wire lead in unsupported hole not step soldered.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.
DS-2a	Straight-through part or wire lead step soldered in unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

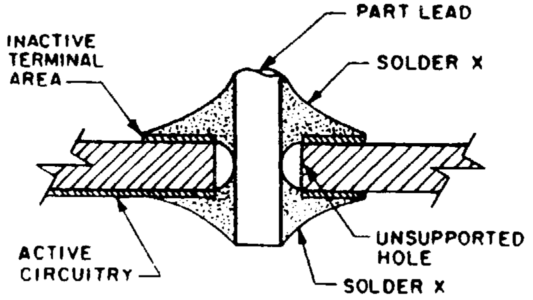
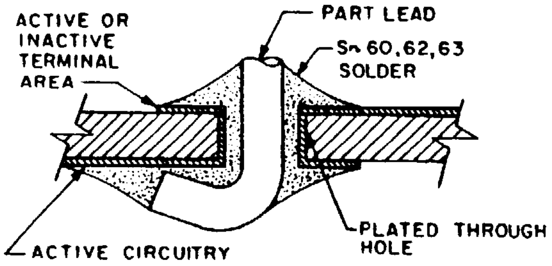
Type Designator	Description	Pictorial	Comments
DS-2b	Straight-through part or wire lead not step soldered but in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.
DS-3a	Clinched part or wire lead in a plated through hole.		Permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

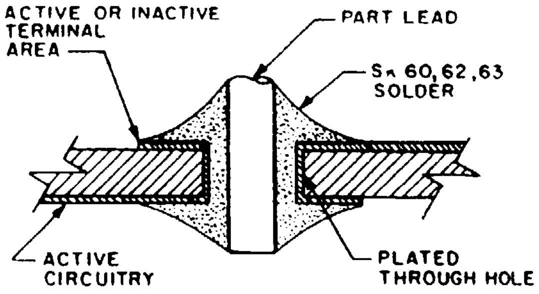
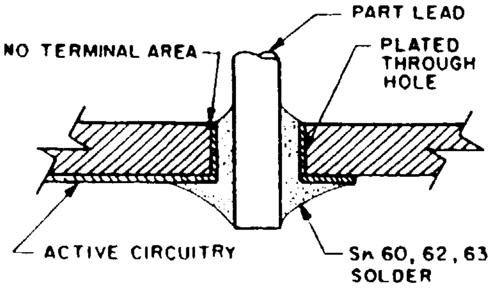
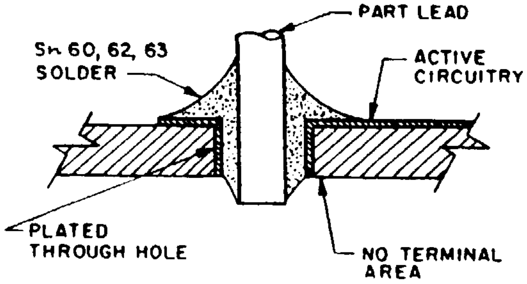
Type Designator	Description	Pictorial	Comments
DS-3b	Straight through part or wire lead in a plated through hole.		Permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
DS-4a	Straight through part lead in an inverted T hole.		Not permitted by any military specification in effect subsequent to January 1965.
DS-4b	Straight through part lead in a plated through T hole.		Not permitted by any military specification in effect subsequent to January 1965.

TABLE VI. Type designators for solder connections (continued).

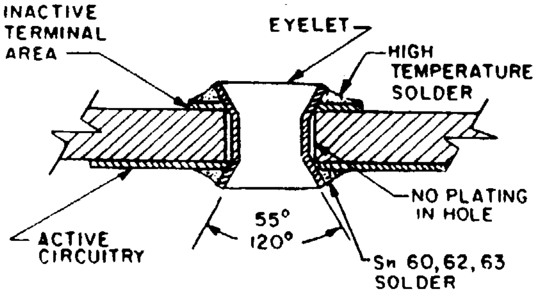
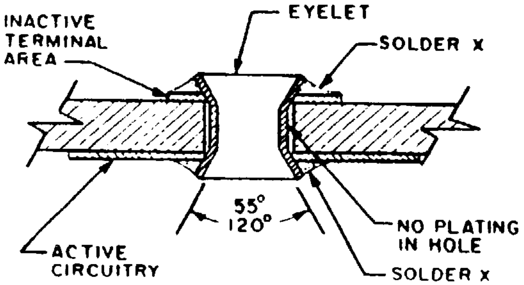
Type Designator	Description	Pictorial	Comments
DS-4b (Continued)	Straight through part lead in a plated through T hole.	NOTE: Types DS-4a and DS-4b have been used in conjunction with one another and with terminal areas for 12 and 14 pin nonaxial leaded parts alternated on opposite sides of the board.	
DS-5a	Noninterfacial hole supported by a step soldered double flared eyelet.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
DS-5b	Noninterfacial hole supported by a double flared eyelet.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

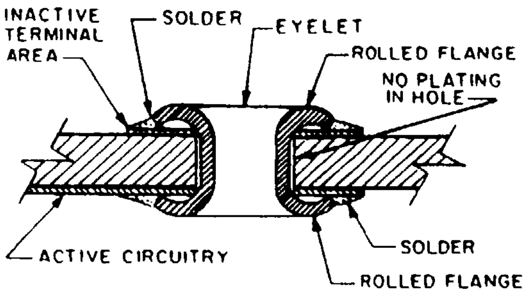
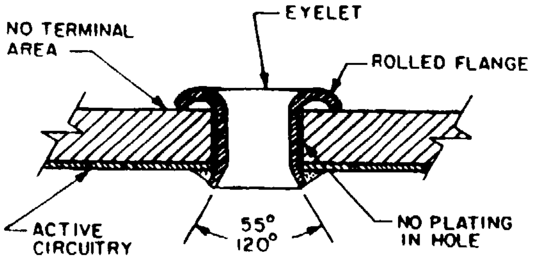
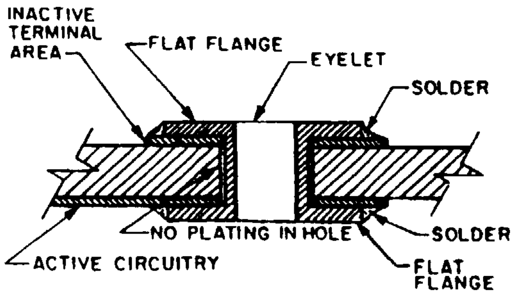
Type Designator	Description	Pictorial	Comments
DS-5c	Noninterfacial hole supported by a double rolled eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
DS-5d	Noninterfacial hole supported by a rolled and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
DS-5e	Noninterfacial hole supported by a double flat flanged eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

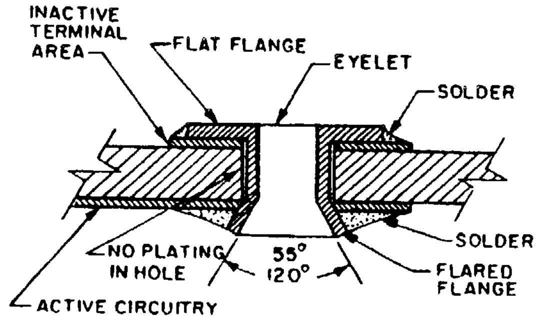
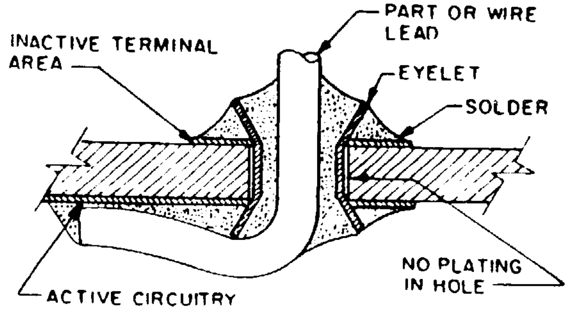
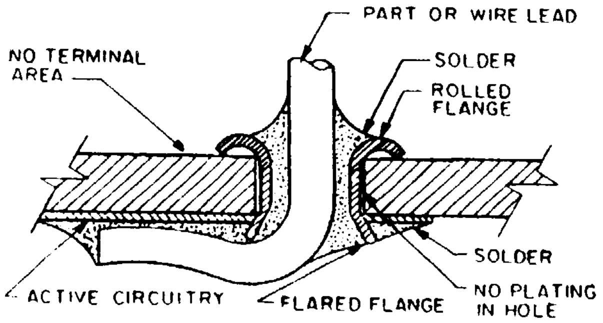
Type Designator	Description	Pictorial	Comments
DS-5f	Noninterfacial hole supported by a flat and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
DS-6a	Clinched part or wire lead in a noninterfacial hole supported by a double flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987.
DS-6b	Clinched part or wire lead in a noninterfacial hole supported by a rolled and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

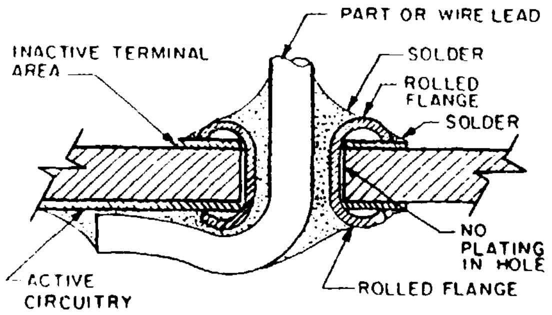
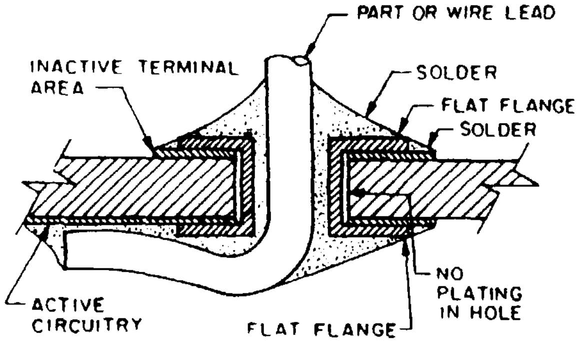
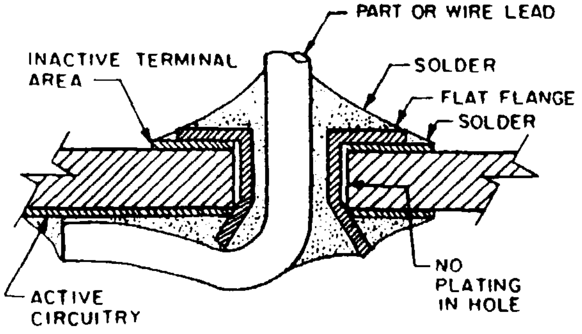
Type Designator	Description	Pictorial	Comments
DS-6c	Clinched part or wire lead in a noninterfacial hole supported by a double rolled eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.
DS-6d	Clinched part of wire lead in a noninterfacial hole supported by a double flat flanged eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.
DS-6e	Clinched part or wire lead in a noninterfacial hole supported by a flat and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and susequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

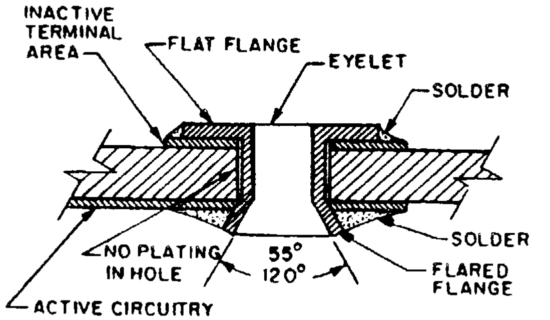
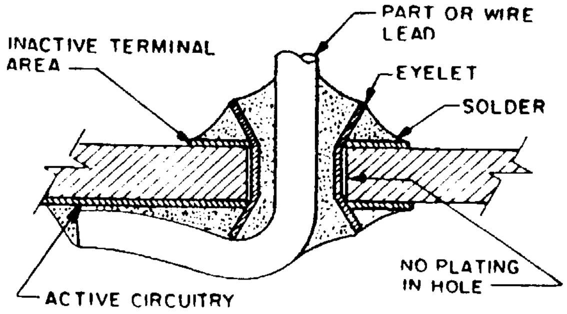
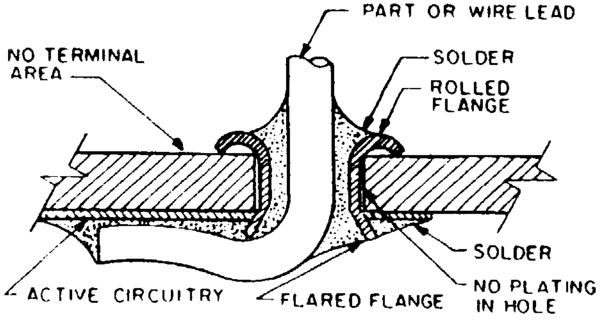
Type Designator	Description	Pictorial	Comments
DS-5f	Noninterfacial hole supported by a flat and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
DS-6a	Clinched part or wire lead in a noninterfacial hole supported by a double flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987.
DS-6b	Clinched part or wire lead in a noninterfacial hole supported by a rolled and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

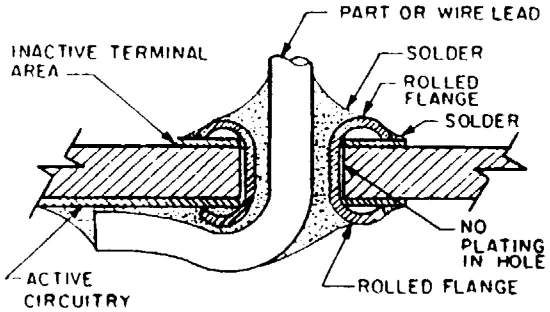
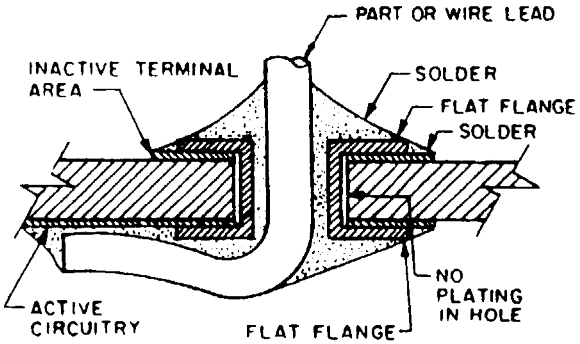
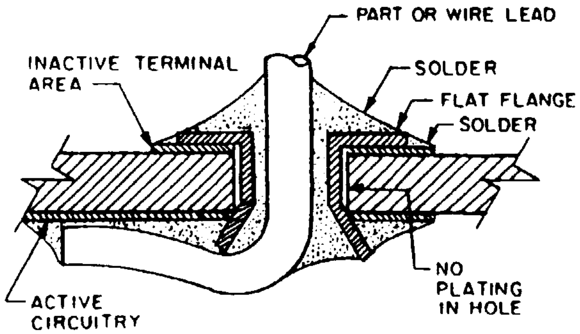
Type Designator	Description	Pictorial	Comments
DS-6c	Clinched part or wire lead in a noninterfacial hole supported by a double rolled eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.
DS-6d	Clinched part of wire lead in a noninterfacial hole supported by a double flat flanged eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.
DS-6e	Clinched part or wire lead in a noninterfacial hole supported by a flat and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and susequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

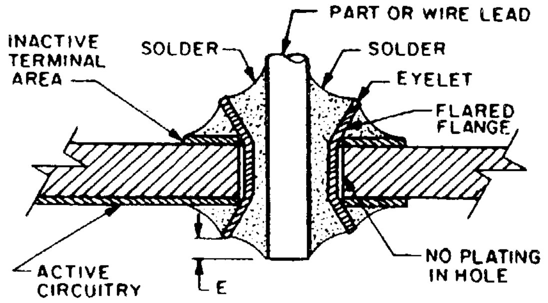
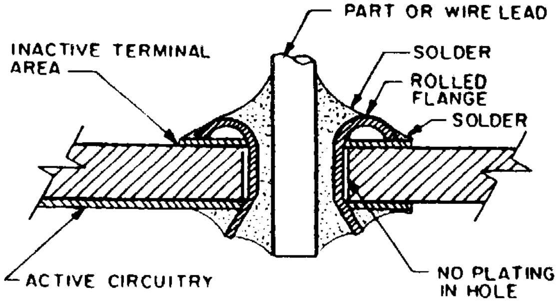
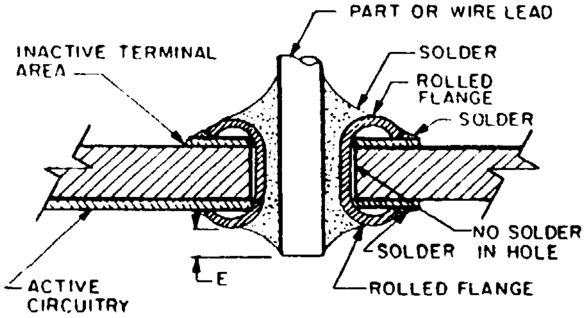
Type Designator	Description	Pictorial	Comments
DS-7a	Straight-through part or wire lead in a non-interfacial hole supported by a double flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987.
DS-7b	Straight-through part or wire lead in a non-interfacial hole supported by a rolled and flared eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987.
DS-7c	Straight-through part or wire lead in a non-interfacial hole supported by a double rolled eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

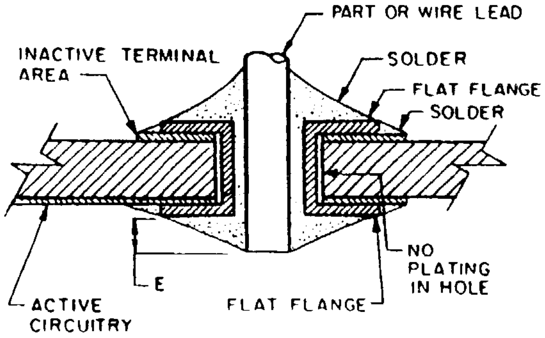
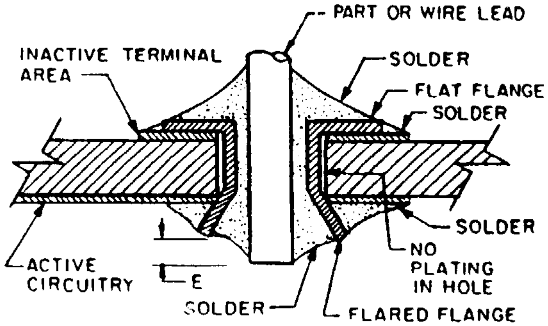
Type Designator	Description	Pictorial	Comments
DS-7d	Straight-through part or wire lead in a noninterfacial hole supported by a double flat-flanged eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987.
DS-7e	Straight-through part or wire lead in a noninterfacial hole supported by a flat and flared flange eyelet.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

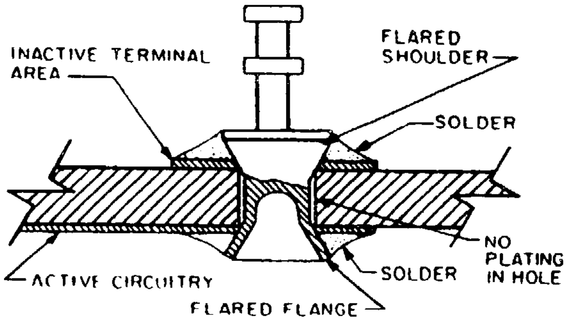
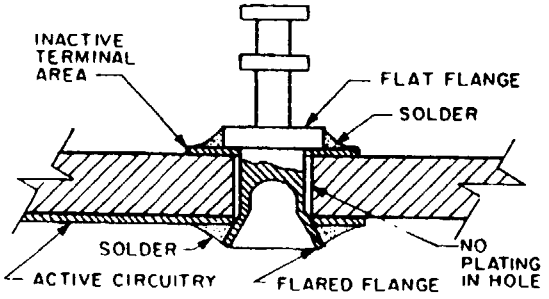
Type Designator	Description	Pictorial	Comments
DS-8a	Double funnel terminal in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275B and prior revisions thereof. Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987 if connection is noninterfacial and is step soldered.
DS-8b	Flat and funnel flanged terminal in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275B and prior revisions thereof. Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987 if connection is noninterfacial and is step soldered.

TABLE VI. Type designators for solder connections (continued).

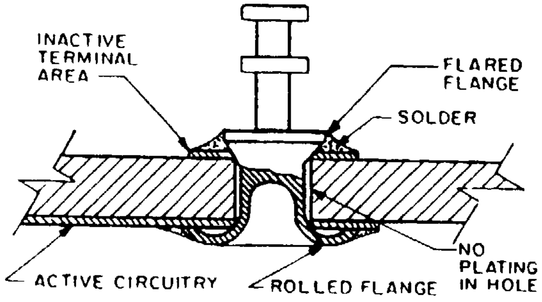
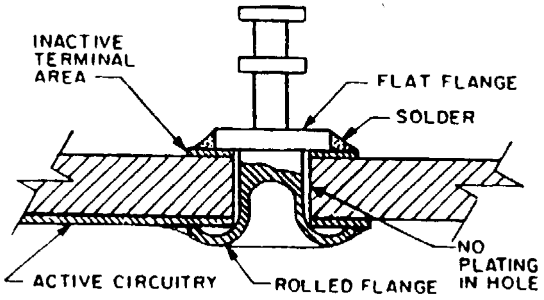
Type Designator	Description	Pictorial	Comments
DS-8c	Rolled and funnel flanged terminal in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275B and prior revisions thereof. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
DS-8d	Flat and rolled flanged terminal in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275B and prior revisions thereof. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

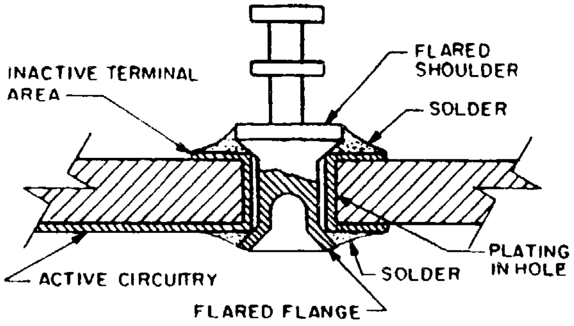
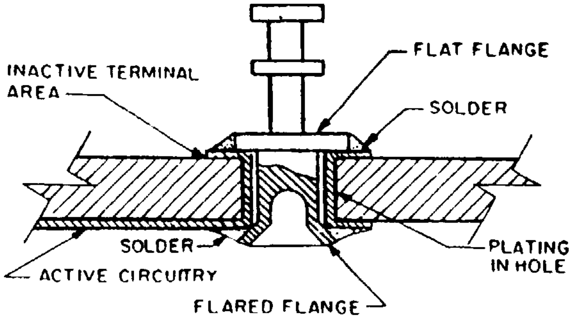
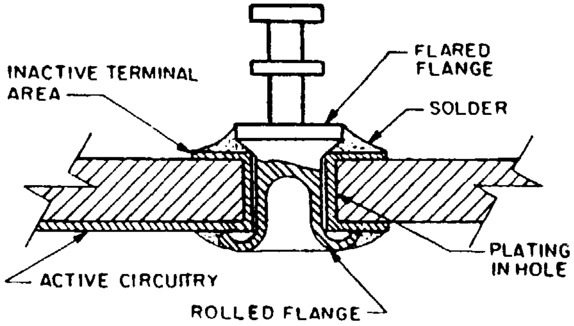
Type Designator	Description	Pictorial	Comments
DS-9a	Double funnel terminal in a plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987. <u>NOT RECOMMENDED FOR ANY APPLICATION</u>.
DS-9b	Flat and funnel flange terminal in a plated-through hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987. <u>NOT RECOMMENDED FOR ANY APPLICATION</u>.
DS-9c	Funnel and rolled flange terminal in a plated-through hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275C and subsequent revisions thereof isued prior to 1 January 1987. <u>NOT RECOMMENDED FOR ANY APPLICATION</u>.

TABLE VI. Type designators for solder connections (continued).

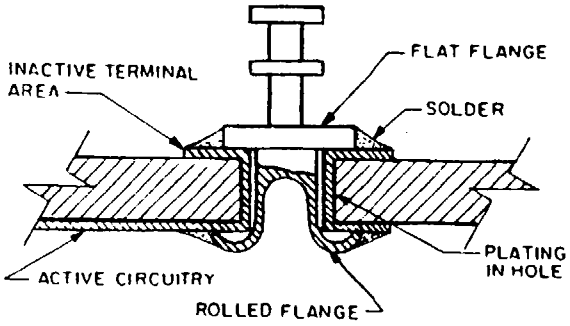
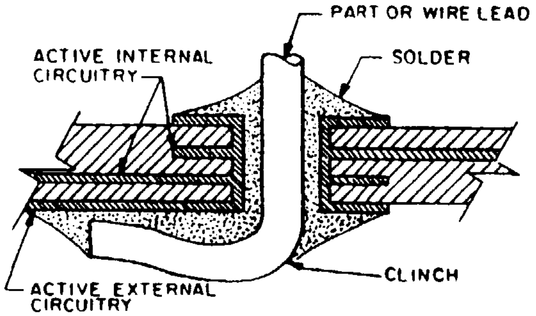
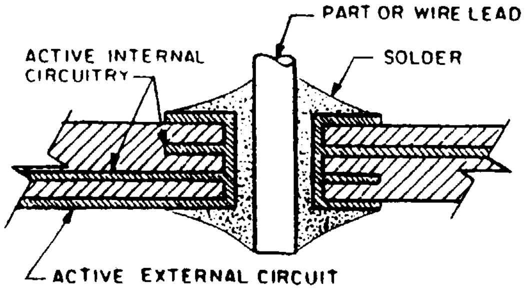
Type Designator	Description	Pictorial	Comments
DS-9d	Flat and rolled flange terminal in a plated-through hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987. NOT RECOMMENDED FOR ANY APPLICATION.
ML	Connections in multilayer printed wiring boards		
ML-1a	Clinched part or wire lead in a multilayer hole.		Permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
ML-1b	Straight-through part or wire lead in a multilayer hole.		Permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

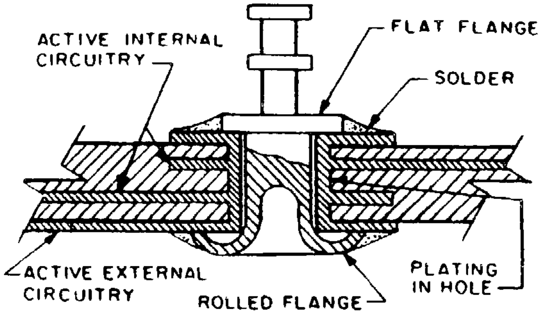
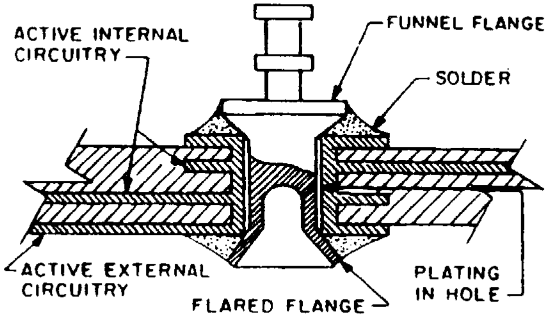
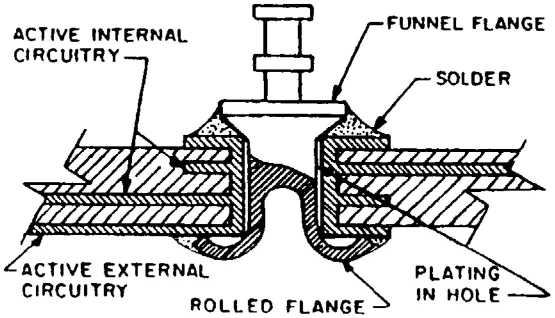
Type Designator	Description	Pictorial	Comments
ML-2a	Flat and rolled flange terminal in a multilayer hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
ML-2b	Double funnel terminal in a multilayer hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
ML-2c	Funnel and rolled terminal in a multilayer hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

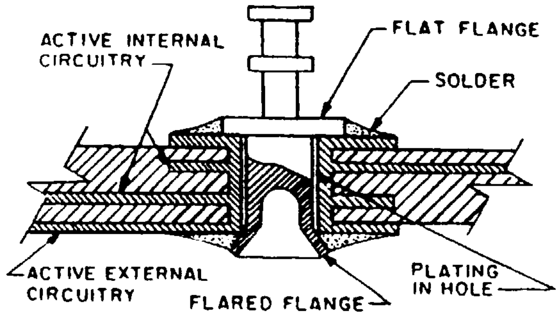
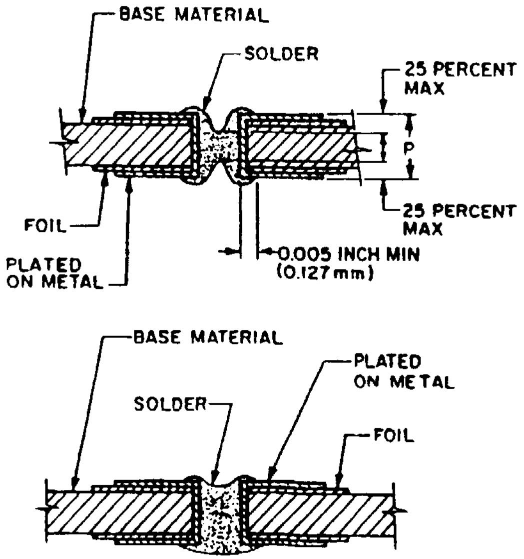
Type Designator	Description	Pictorial	Comments
ML-2d	Funnel and flat flange terminal in a multi-layer hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
IN	Interfacial and interlayer connections in printed wiring boards		
IN-1a	Solder-filled plated-through hole.		Permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

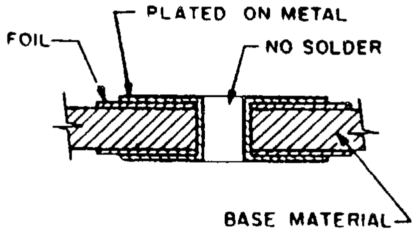
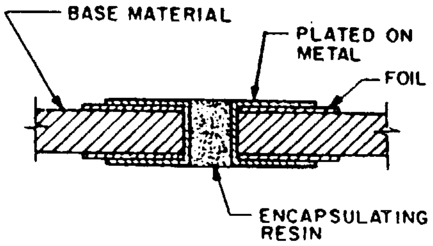
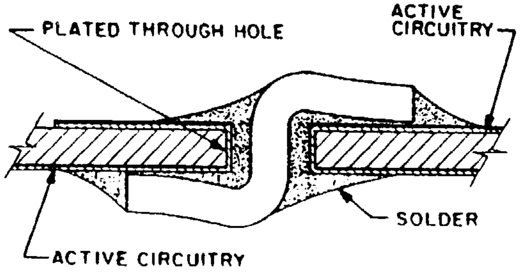
Type Designator	Description	Pictorial	Comments
IN-1b	Plated-through hole without solder fill.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275D and subsequent revisions thereof issued prior to 1 January 1987. NOT RECOMMENDED FOR ANY APPLICATION.
IN-1c	Plated-through hole filled with encapsulating resin.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275E and subsequent revisions thereof issued prior to 1 January 1987.
IN-2a	Clinched jumper wire in a plated-through hole.		Permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

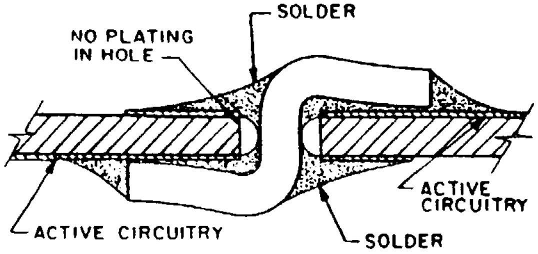
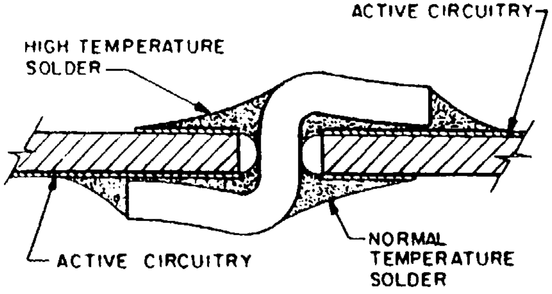
Type Designator	Description	Pictorial	Comments
IN-2b	Clinched jumper wire not step soldered in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275D and prior revisions thereof. Not permitted by MIL-STD-275E and subsequent revisions thereof issued prior to 1 January 1987.
IN-2c	Clinched jumper wire step soldered in an unsupported hole.		Permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275D and prior revisions thereof. Not permitted by MIL-STD-275E and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

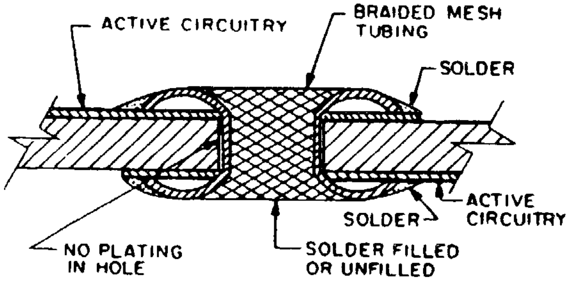
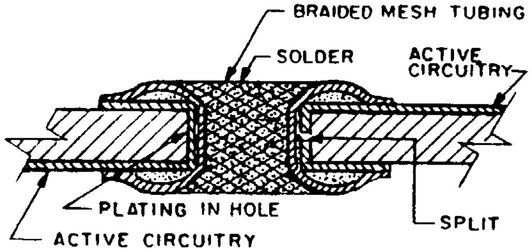
Type Designator	Description	Pictorial	Comments
IN-3a	Mesh braid jumper in an unsupported hole.		Unacceptable for items fabricated to any Military specification.
IN-3b	Mesh braid jumper in a discontinuous plated-through hole in double-sided and multilayer holes.		Unacceptable for items fabricated to any Military specification.

TABLE VI. Type designators for solder connections (continued).

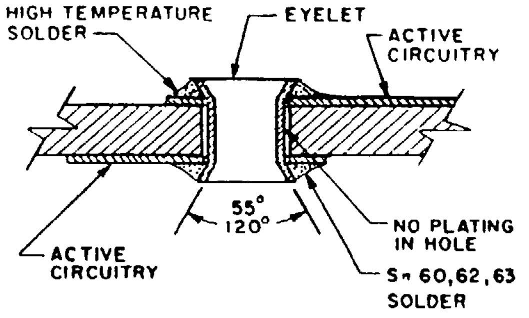
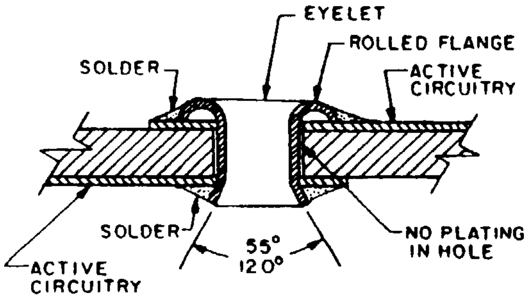
Type Designator	Description	Pictorial	Comments
IN-4a	Double flared eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Permitted by MIL-STD-275B and earlier revisions thereof. Not permitted by MIL-STD-275C andf subsequent revisions thereof issued prior to 1 January 1987.
IN-4b	Rolled and flared eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

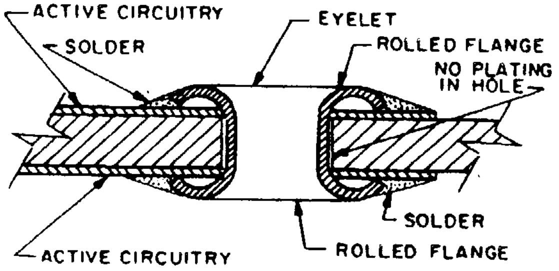
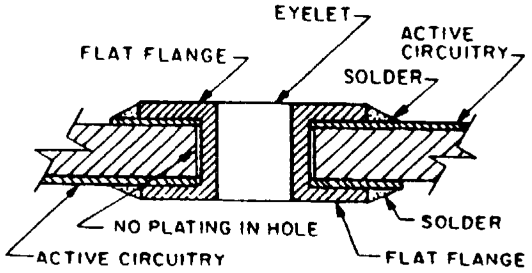
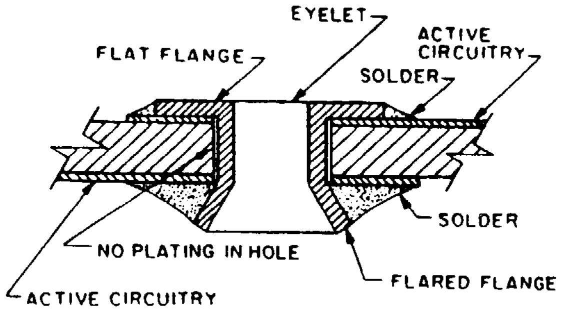
Type Designator	Description	Pictorial	Comments
IN-4c	Double rolled eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
IN-4d	Flat fused-in-place eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
IN-4e	Flat and funnel flange eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

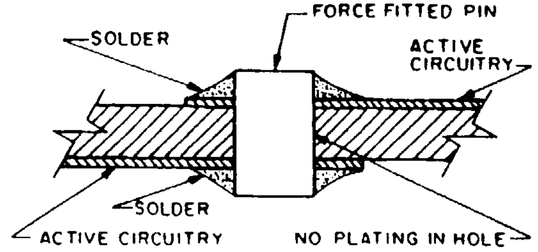
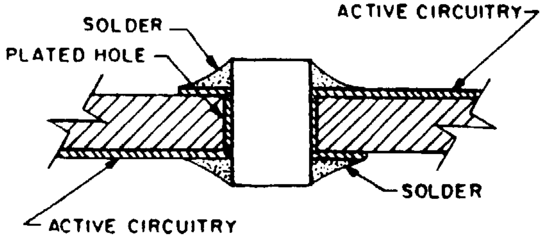
Type Designator	Description	Pictorial	Comments
IN-5a	Force-fit pin in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
IN-5b	Force-fit pin in a plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

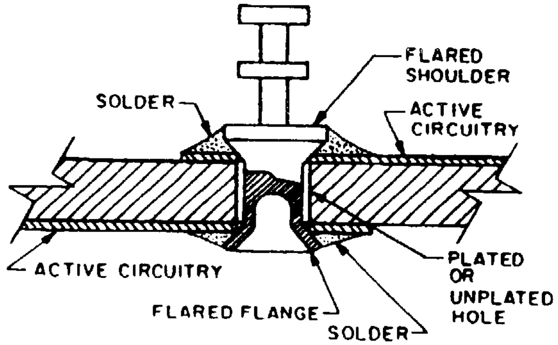
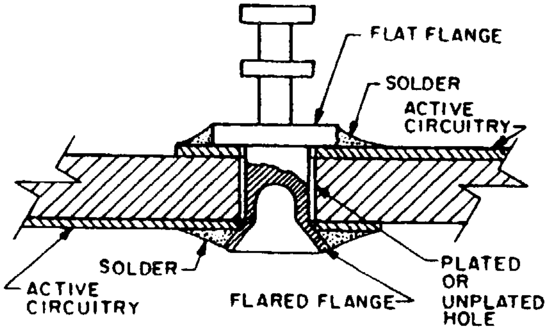
Type Designator	Description	Pictorial	Comments
IN-6a	Double funnel terminal in unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
IN-6b	Flat and flared flange terminal in an unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

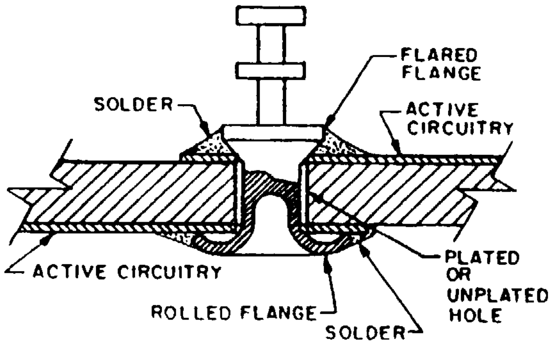
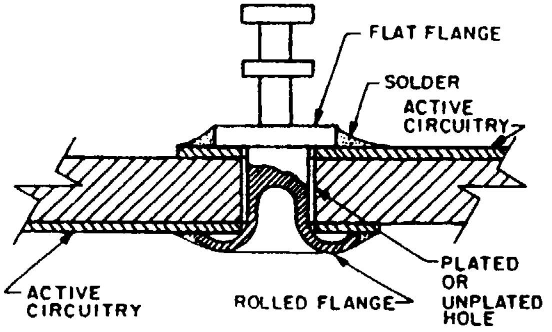
Type Designator	Description	Pictorial	Comments
IN-6c	Funnel and rolled flange terminal in an unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
IN-6d	Flat and rolled flange terminal in an unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

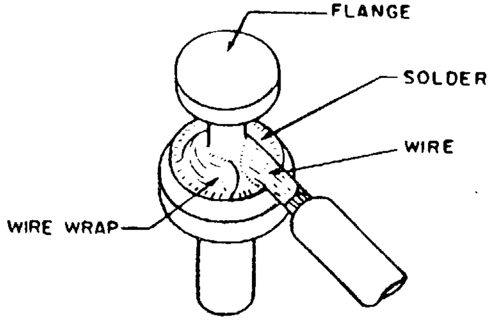
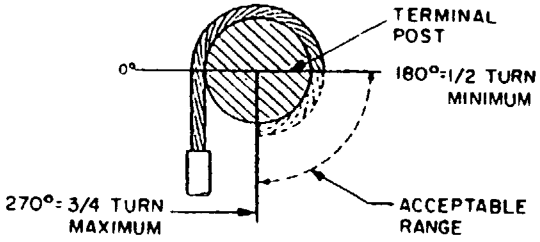
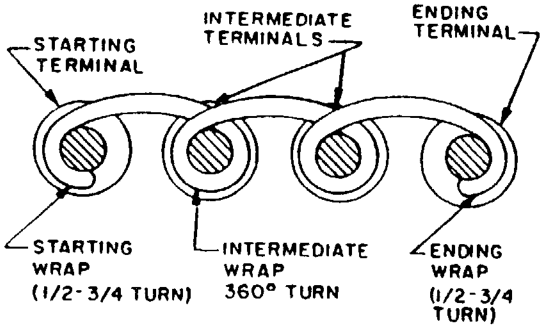
Type Designator	Description	Pictorial	Comments
T	Termination to terminals		
T-1a	Part or wire lead connected to a turret terminal.	 	Permitted by MIL-STD-2000, Task B.
T-1b	Continuous run wrap to turret terminals.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

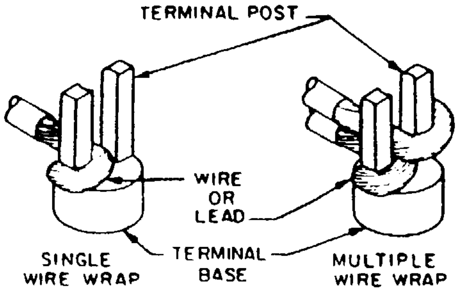
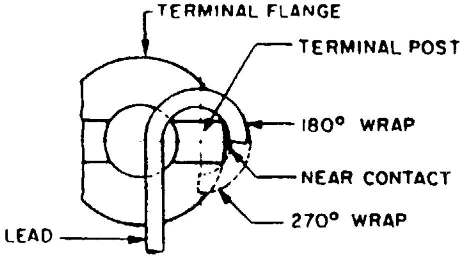
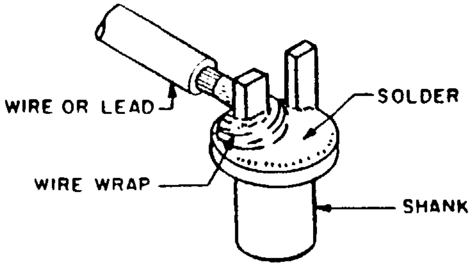
Type Designator	Description	Pictorial	Comments
T-2a	Part or wire lead side mounted to a bifurcated terminal.	  	Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

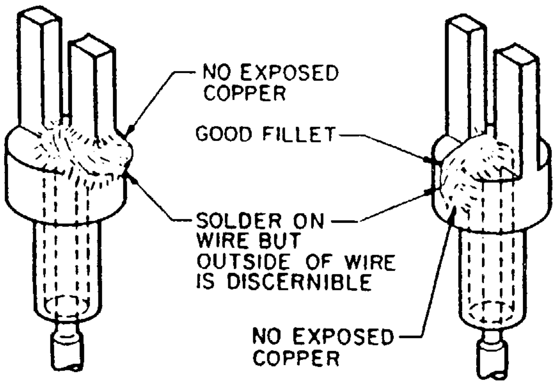
Type Designator	Description	Pictorial	Comments
T-2b	Part or wire lead bottom routed to bifurcated terminal.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

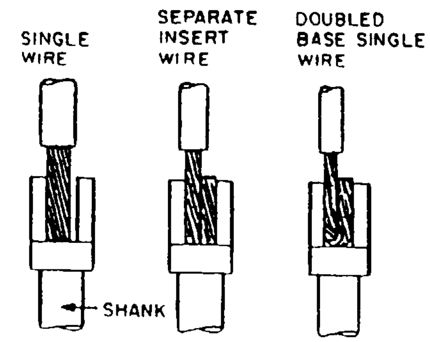
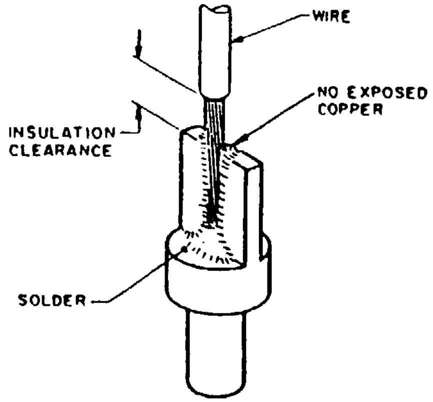
Type Designator	Description	Pictorial	Comments
T-2c	Part or wire lead top routed to a bifurcated terminal.	 	Not permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

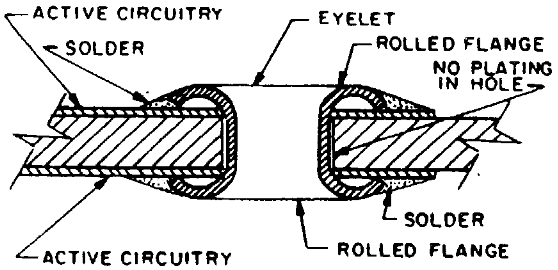
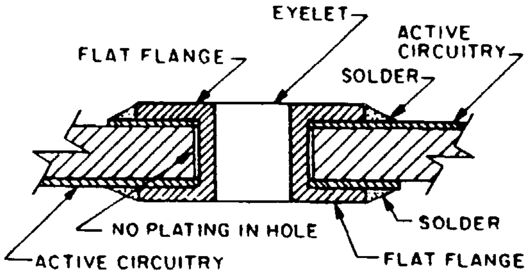
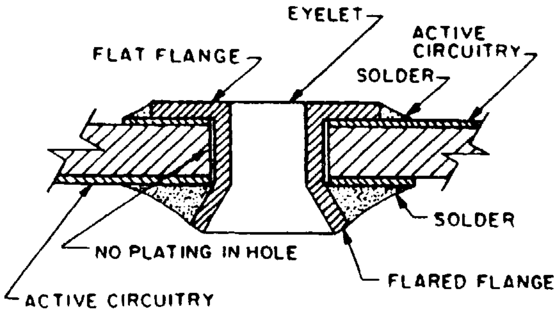
Type Designator	Description	Pictorial	Comments
IN-4c	Double rolled eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
IN-4d	Flat fused-in-place eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
IN-4e	Flat and funnel flange eyelet in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

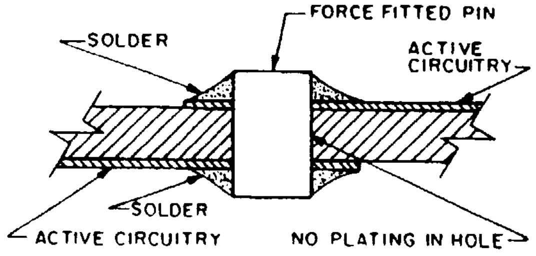
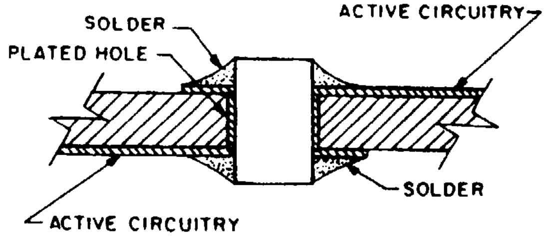
Type Designator	Description	Pictorial	Comments
IN-5a	Force-fit pin in an unsupported hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
IN-5b	Force-fit pin in a plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

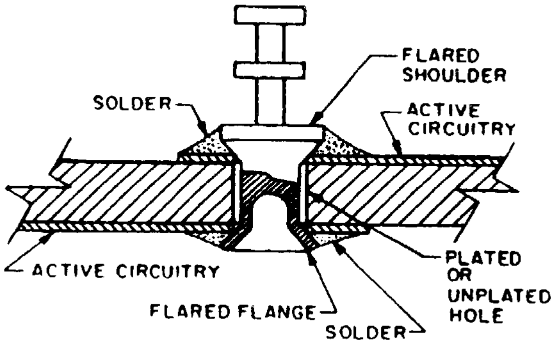
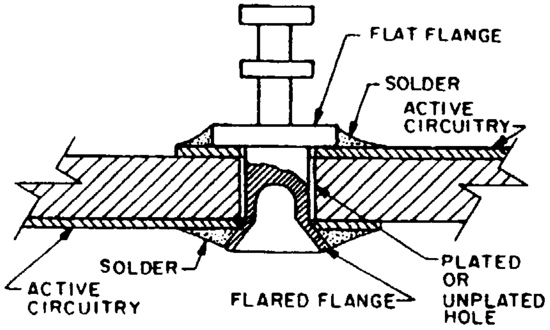
Type Designator	Description	Pictorial	Comments
IN-6a	Double funnel terminal in unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275C and subsequent revisions thereof issued prior to 1 January 1987.
IN-6b	Flat and flared flange terminal in an unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275B and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

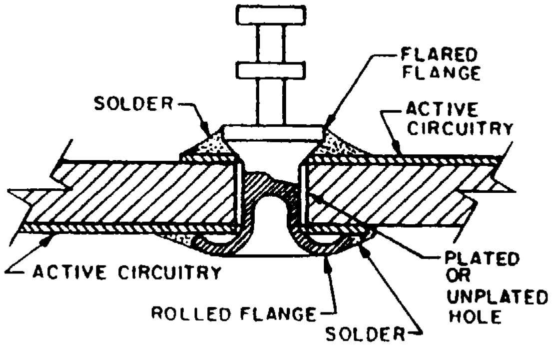
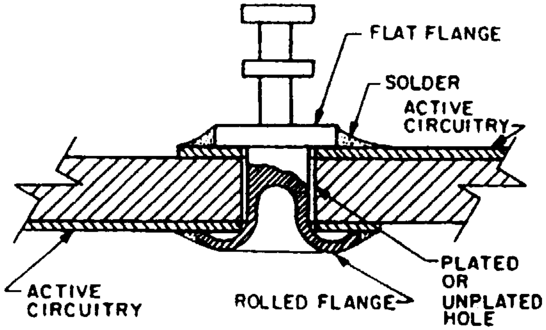
Type Designator	Description	Pictorial	Comments
IN-6c	Funnel and rolled flange terminal in an unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.
IN-6d	Flat and rolled flange terminal in an unsupported or plated-through hole.		Not permitted by MIL-STD-2000, Task B. Not permitted by MIL-STD-275A and subsequent revisions thereof issued prior to 1 January 1987.

TABLE VI. Type designators for solder connections (continued).

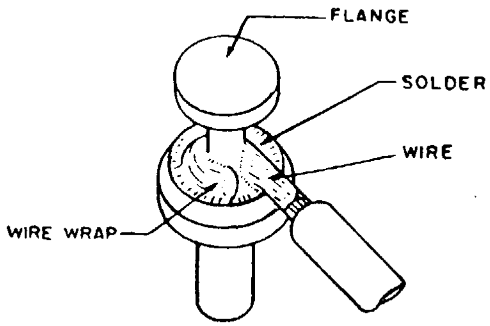
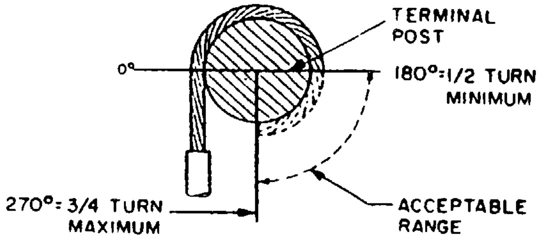
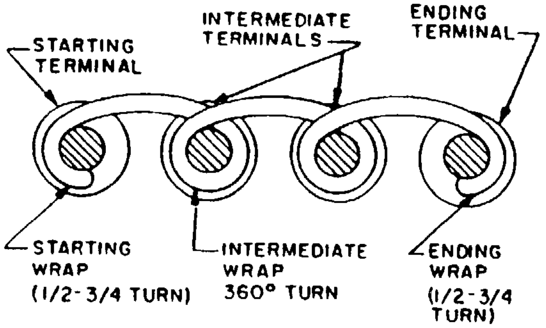
Type Designator	Description	Pictorial	Comments
T	Termination to terminals		
T-1a	Part or wire lead connected to a turret terminal.	 	Permitted by MIL-STD-2000, Task B.
T-1b	Continuous run wrap to turret terminals.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

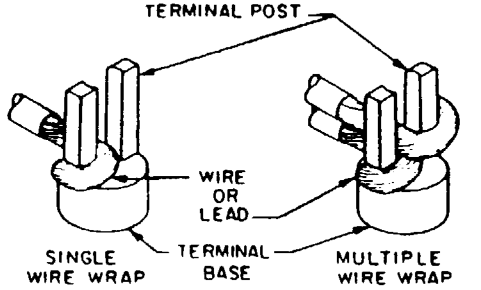
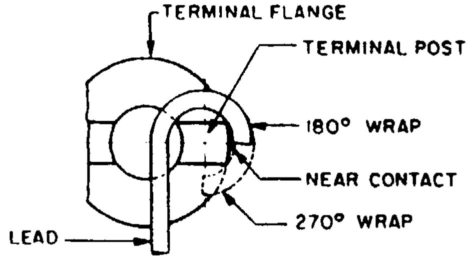
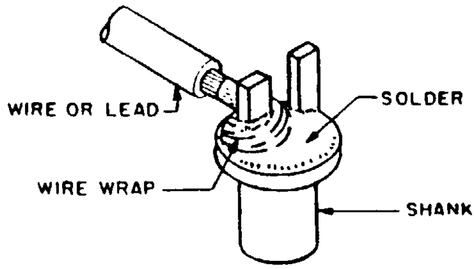
Type Designator	Description	Pictorial	Comments
T-2a	Part or wire lead side mounted to a bifurcated terminal.	  	Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

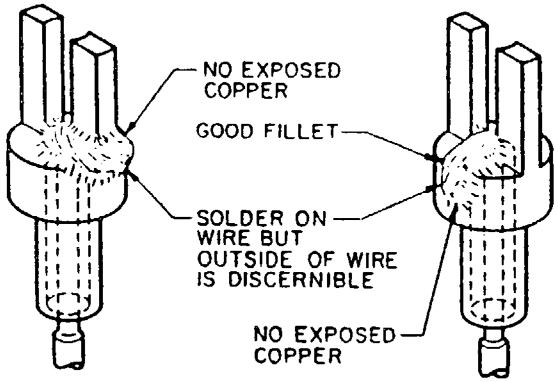
Type Designator	Description	Pictorial	Comments
T-2b	Part or wire lead bottom routed to bifurcated terminal.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

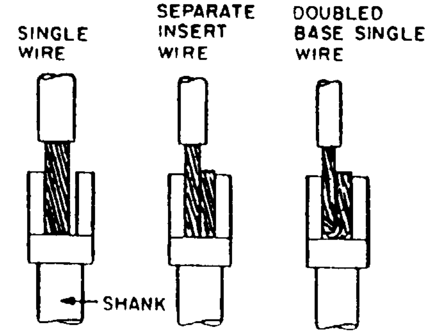
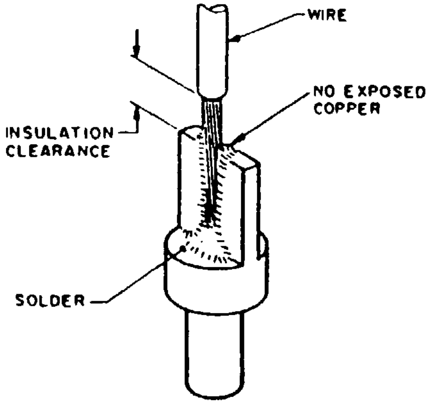
Type Designator	Description	Pictorial	Comments
T-2c	Part or wire lead top routed to a bifurcated terminal.	 	Not permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

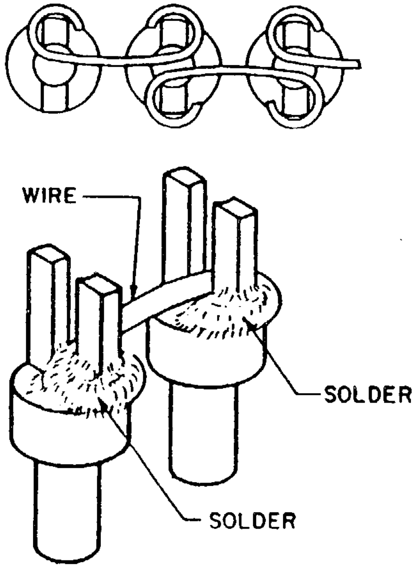
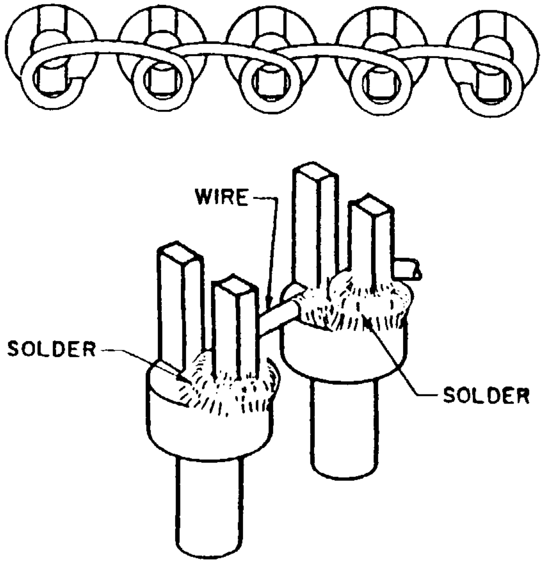
Type Designator	Description	Pictorial	Comments
T-2d	Continuous run wraps to bifurcated terminal.	 	Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

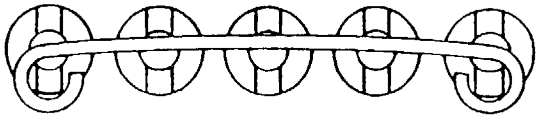
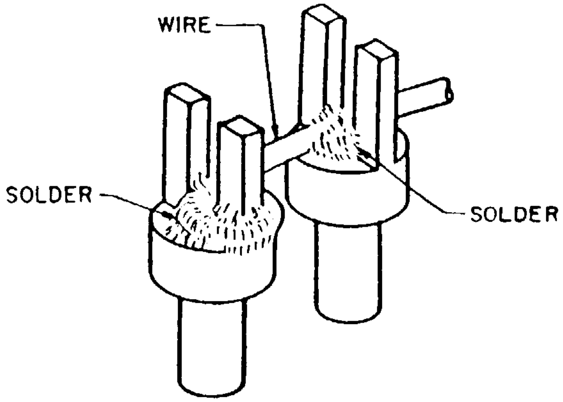
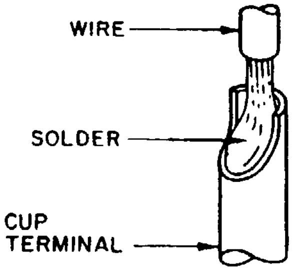
Type Designator	Description	Pictorial	Comments
T-2d (Continued)	Continuous run wrap to bifurcated terminals.	 	Permitted by MIL-STD-2000, Task B.
T-3a	Part or wired lead soldered in a cup terminal.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

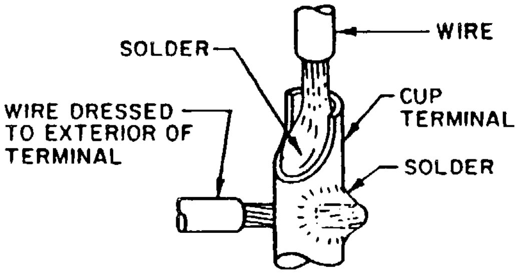
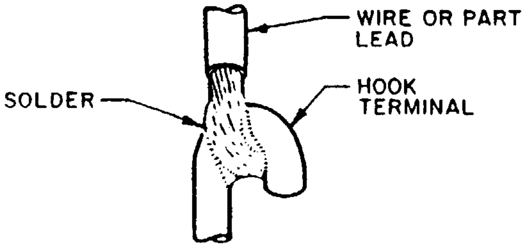
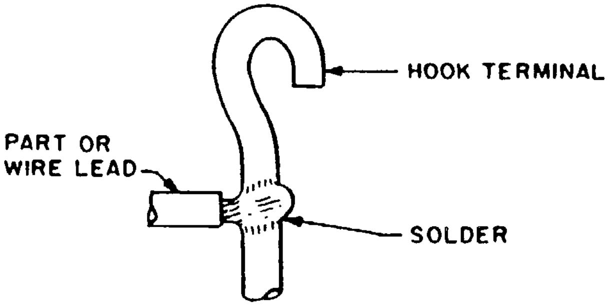
Type Designator	Description	Pictorial	Comments
T-3b	Part or wire lead wrapped to exterior of cup terminal which contains wire in interior of cup.		Not permitted by MIL-STD-2000, Task B.
T-4a	Part or wire lead top-routed to a hook terminal.		Permitted by MIL-STD-2000, Task B.
T-4b	Part or wire lead side-routed to a hook terminal.		Not permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

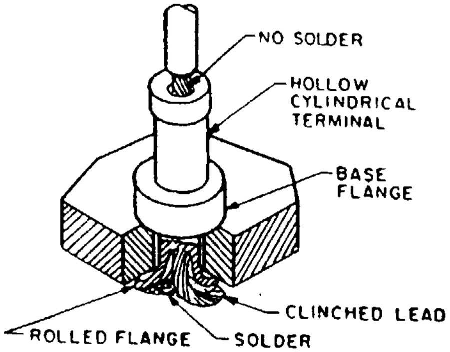
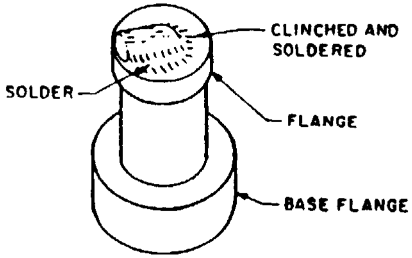
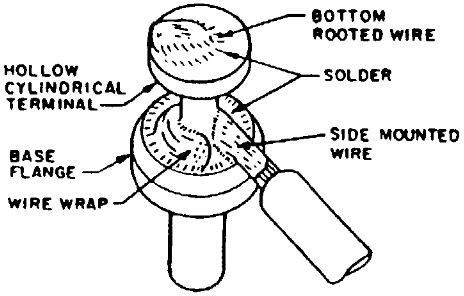
Type Designator	Description	Pictorial	Comments
T-5a	Part or wire lead top routed in a hollow cylindrical terminal.		Permitted by MIL-STD-2000, Task B.
T-5b	Part or wire lead bottom routed in a hollow cylindrical terminal.		Permitted by MIL-STD-2000, Task B.
T-5c	Part or wire lead side-routed to a hollow cylindrical terminal.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

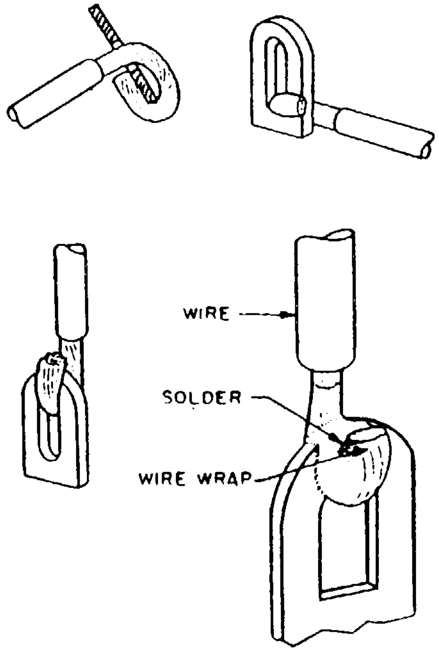
Type Designator	Description	Pictorial	Comments
T-6a	Part or wire lead soldered in a pierced or perforated terminal.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

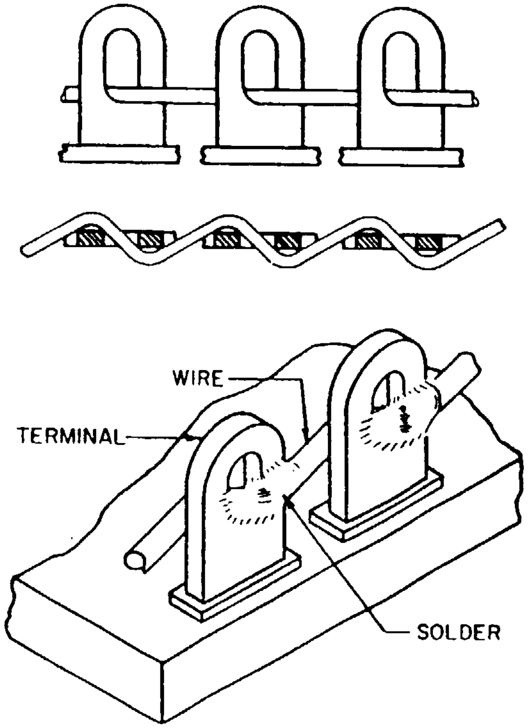
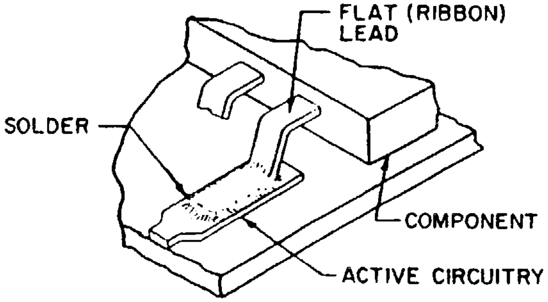
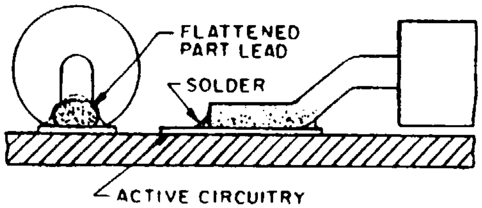
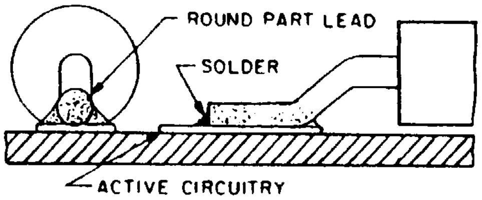
Type Designator	Description	Pictorial	Comments
T-6b	Weaved wire lead in a pierced or perforated terminal.		Permitted by MIL-STD-2000, Task B.

TABLE VI. Type designators for solder connections (continued).

Type Designator	Description	Pictorial	Comments
P	Planar mounted connections		
P-1a	Flat (ribbon) part or wire lead soldered to a surface termination area.		Permitted by MIL-STD-2000, Task B.
P-1b	Flattened part lead soldered to a surface termination area.		Permitted by MIL-STD-2000, Task B.
P-1c	Round part or wire lead soldered to a surface termination area.		Not permitted by MIL-STD-2000, Task B.

8. SOLDERING PROCESSES

8.1 High heat capacity printed wiring assemblies.

8.1.1 Design errors. The best way to avoid the producibility problems associated with high heat capacity printed wiring assemblies is to avoid designing them. Alternative designs should be used wherever possible. Assemblies that utilize heavy copper ground planes and those which utilize greater than three inner layer connections to the plated-through hole are frequently difficult to solder. The heat sinking capacity of the inner layers severely reduces the probability of achieving proper hole fill without processes tailored to this type of design. Many manufacturers have erroneously heat damaged the outer layers of the printed wiring board by leaving the soldering iron on the board too long, allowing the board to stay in the wave too long, or setting their inline wave soldering machine preheaters too high.

8.1.2 General considerations. There are several basic techniques which may solve the producibility problems caused by extraordinary heat-sinking without damaging the boards and assemblies. Before using any of these techniques, manufacturers must verify that the parts mounted on the printed wiring assembly will not be damaged by subsequent heating and soldering processes.

8.1.3 Reflow soldering high heat capacity printed wiring assemblies. One of the most effective techniques for soldering printed wiring with high heat capacities is vapor phase reflow. While vapor phase soldering is more often used in surface mount applications, it may solve several producibility problems in through-hole assemblies. By allowing the printed wiring to dwell in the reflow vapor until complete soldering and wetting has occurred, manufacturers can easily solder without heat damage to surface layers of the printed wiring. Since reflow soldering is not an additive soldering process, the solder must be deposited prior to reflow. Screen printing and syringe solder deposition, combined with proper tinning of through-hole components enables this process to effectively solder through-hole assemblies.

8.1.4 Special preheating processes. For some printed wiring boards, it is possible to sufficiently preheat the assembly so that when additional heat is applied to the plated-through hole (hand soldering) or board (wave soldering), the plated-through hole completely fills.

8.1.4.1 Prebaking. The critical parameter in defining a drying process is the relative humidity of the drying chamber. The relative humidity may be changed by the constituency of the atmosphere (dry nitrogen, etc.), or by raising the temperature of the chamber. Increasing the temperature of the chamber also affects the rate at which the drying occurs. The addition of a vacuum to the ovens may have limited benefit in removing moisture. Vacuums, like dry nitrogen, reduce oxidation. This may be essential in certain situations such as boards with many layers or large ground planes.

8.1.4.1.1 Advantages. Prebaking the printed wiring assembly has been effective in many applications for adding large quantities of heat to the assembly. The baking process, in addition to preheating the assembly, will also drive out water and volatiles from the board. Prebaking is more effective in wave soldering applications than hand soldering applications. The cooling associated with longer duration hand soldering operations and the handling problems associated with soldering hot printed wiring board minimize the effectiveness of this application in hand soldering applications.

8.1.4.1.2 Disadvantages. Prebaking may heat damage the assembly (both the printed wiring or heat sensitive parts). The baking process should slowly raise the temperature of the assembly to avoid heat damaging the outer layers of the printed wiring. The intermetallic layer grows with extensive heating. Also, the baking atmosphere may cause surface oxidation and reduce the solderability of the board and the parts mounted on it. As such, the baking environment should be moisture and contaminant-free. Where possible, nitrogen or other inert atmospheres should be used to minimize any potential solderability degradation. When prebaking prior to wave soldering, either spray or wave fluxing must be used. Hot, prebaked boards will typically collapse the foam of foam fluxers.

8.1.4.2 Hot plate heating. The use of hot plates to heat the printed wiring board during hand soldering operations is another method that is successful in limited applications. This technique is most effective on mother boards (i.e., no parts mounted thereon). The time of contact and the heater operating temperature must be carefully controlled to limit the potential for part or board damage. The assembly contours (i.e., parts mounted on the bottom surface) will affect the heat transfer between the heater plate and the assembly. Hot plate heaters generally work best when there is contact between metal areas of the printed wiring board and the heater to effectively transmit the heat into the inner layers of the assembly. Contact between only the laminate and the heater plate is only minimally effective for heating the inner layers of the board. The combination of prebaking and hot plate heating is a very effective technique for hand soldering printed wiring boards which have many layers.

8.1.4.3 Hot air reflow systems. For the rework of surface mounted assemblies, some equipment suppliers have developed hot air reflow systems for localized heating of assemblies. These systems may be effective in "spot preheating" the assembly. After the region of the assembly is heated, hand soldering operations should be able to be performed adequately. This is a slower, labor intensive process and should be avoided except as a last resort.

8.2 Hand soldering. The soldering iron power rating and tip shape and size must be carefully selected, considering the physical size of the members of the connection. The soldering tip should be checked for proper heat and tinning, and wiped on a clean pad to remove excess solder and oxides. A clean well-tinned tip will promote heat transfer.

8.2.1 Use of liquid flux. For limited applications, a squeeze bottle or syringe is a suitable method for application of the proper amount of flux. Only enough flux to wet the connection elements should be used. If flux cored solder (flux) is used, the (liquid) must be compatible with the flux in the solder core.

8.2.2 Tip selection. The soldering iron tip should be as short and the shape should provide the largest possible heat conduction path as practical for the job. The tip should be of such a shape to provide the largest possible contact patch with the connection (see Soldering irons, paragraph 5.1).

8.2.3 Time on connection. The maximum time required on most connections is 5 seconds. Large terminals and ground planes may require longer. Ideally the connection should be completed in less than 2 to 3 seconds. Proper tip selection keeps the dwell time to a minimum. Problems caused by excessive dwell time include measling, lifted pads and grainy solder.

8.2.4 Tip positioning. The iron tip should be placed in contact with both of the connection elements (i.e., the lead and terminal area) in order for them to heat equally.

8.2.5 Heat conduction path. A good heat conduction path must exist to allow rapid efficient heating of the connection. Initially, the path is provided the liquid flux, then by the molten solder.

8.2.6 Tip maintenance. Between connections the tip should be wiped on a clean moist sponge to remove flux and contaminants. The tip must be kept clean and tinned at all times.

8.2.7 Application of solder. The area to be soldered must first be heated, then the solder applied to the heated connection. Solder should only be flowed onto the solder (not component) side of plated-through holes. Precautions must be taken to preclude movement of the wire or lead during solder solidification. The solder heat bridge must be maintained throughout the solder application process. Wicking of solder under the insulation of stranded wire can be minimized through the use of anti-wicking tools or heat sinks. Figure 17 shows solder application and bridging. Operators must be properly trained to avoid pushing the soldering iron down onto the board. Excessive pressure of the soldering iron will cause board damage. Use of a scale in training is a good technique to teach operators not to force the iron down. Operators should also be trained not to try to solder by forcing a cool tip onto the board. The iron should be balanced so that the tip weight is the basic force onto the board.

8.2.8 Soldering of terminals. The basic steps for soldering and use of a hand soldering iron are as follows (letters correspond to those in Figure 16).

a. Apply the tinned iron tip to the connection at a point near the midpoint of the mechanical wrap, and heat to the flow temperature of the solder.

b. Feed a sufficient amount of solder to form a heat bridge to the other side of the connection.

c. First remove the solder source, then the iron.

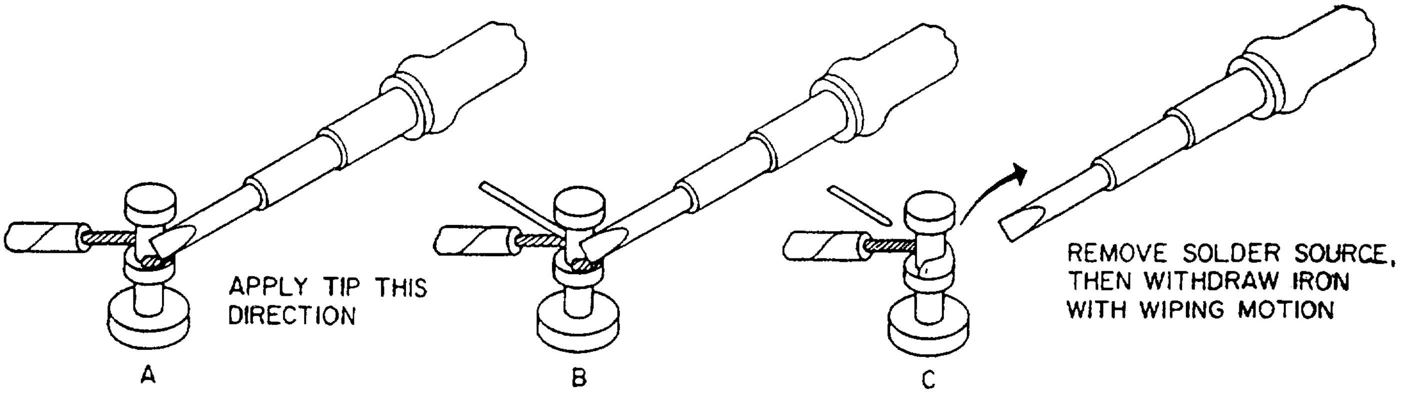


FIGURE 16. Soldering steps (see 8.2.8).

NOTE: The connection must not be moved until the solder has solidified. The connection should complete in the shortest possible time to avoid damage to components and insulation. Allow the joint to cool and remove the flux residue from the connection area with an acceptable solvent.

8.2.9 Soldering of leads in holes. Create a heat bridge between the connection elements and the iron with a small amount of solder. Complete the connection by feeding the proper amount of solder onto cut end of the wire. The tip should always remain in contact with the pad and lead.

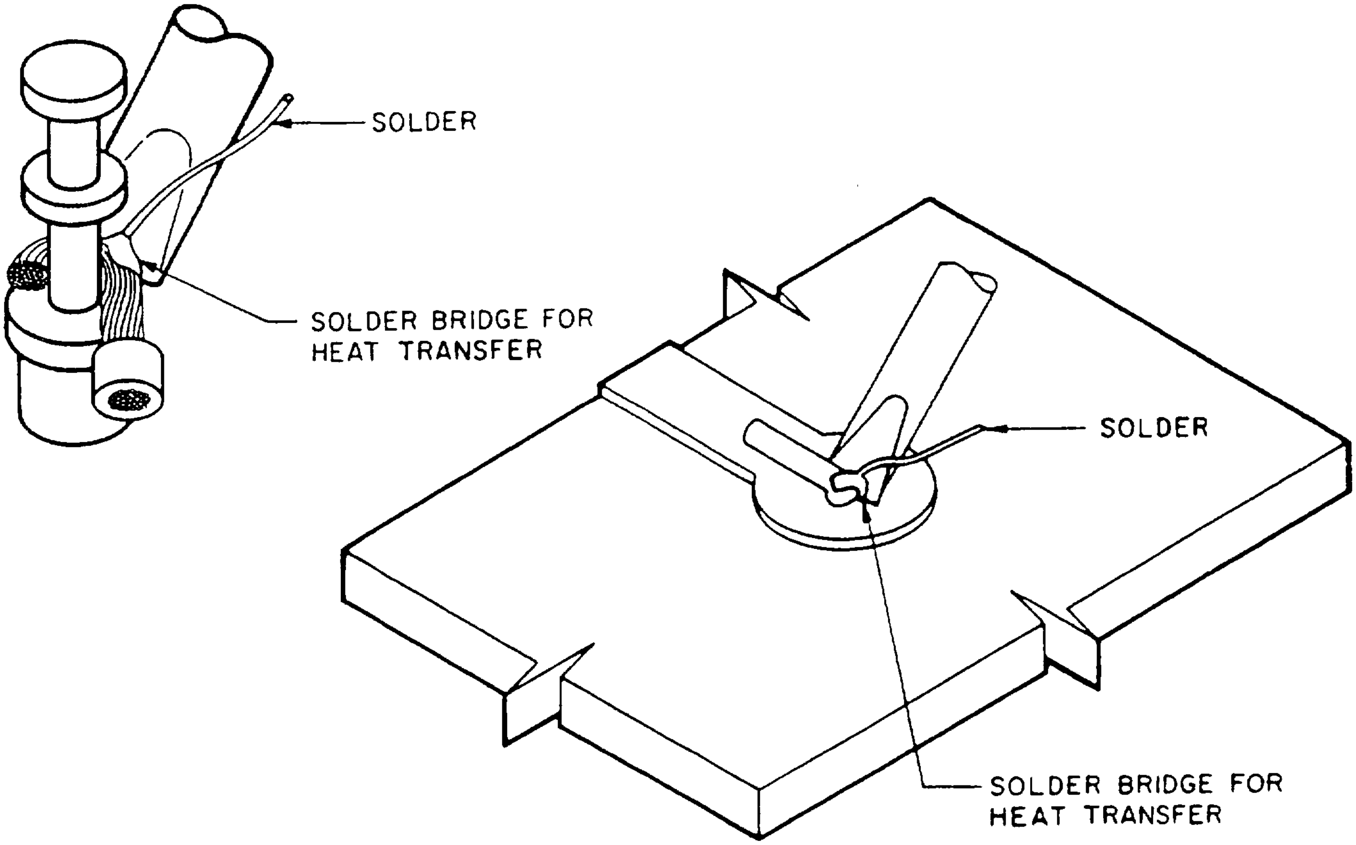
8.2.10 Soldering procedure for cup type terminals. The procedure for inserting and soldering leads in cup type terminals is as follows (see Figures 18 and 19):

a. Place the connector in a holding fixture at an angle of approximately 45 degrees, with the open side of the cup facing the operator.

b. Use the iron to apply heat to the side of the cup until the flow temperature of the solder is reached.

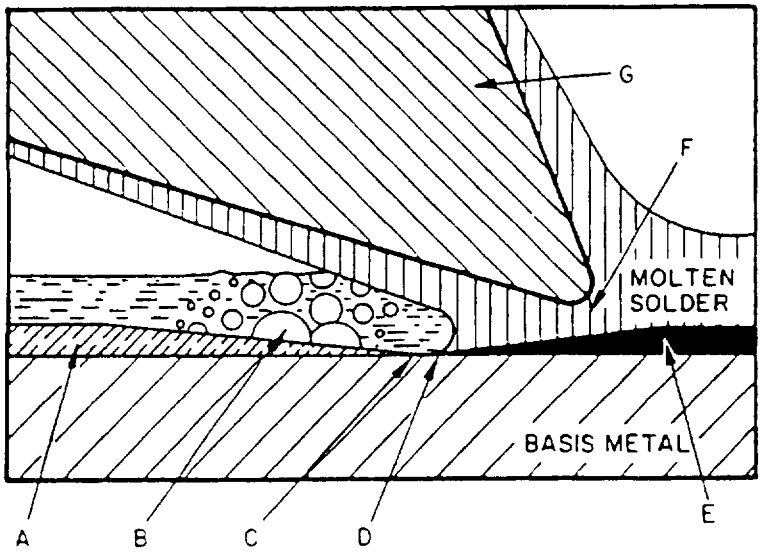
c. Slowly feed the solder into the cup until the required amount is present. Remove the solder before removing the heat. If solder is fed too fast, gas or flux may be entrapped in the cup, making a partially filled cup appear full.

d. If required, place insulation tubing on the wire and slide it back out of the way.



INITIAL BRIDGING BEING FORMED

A



A. OXIDE FILM ON BASIS METAL.

B. BOILING FLUX SOLUTION REMOVING THE FILM OF OXIDE

C. BARE METAL IN CONTACT WITH FUSED FLUX.

D. LIQUID SOLDER REPLACING FUSED FLUX.

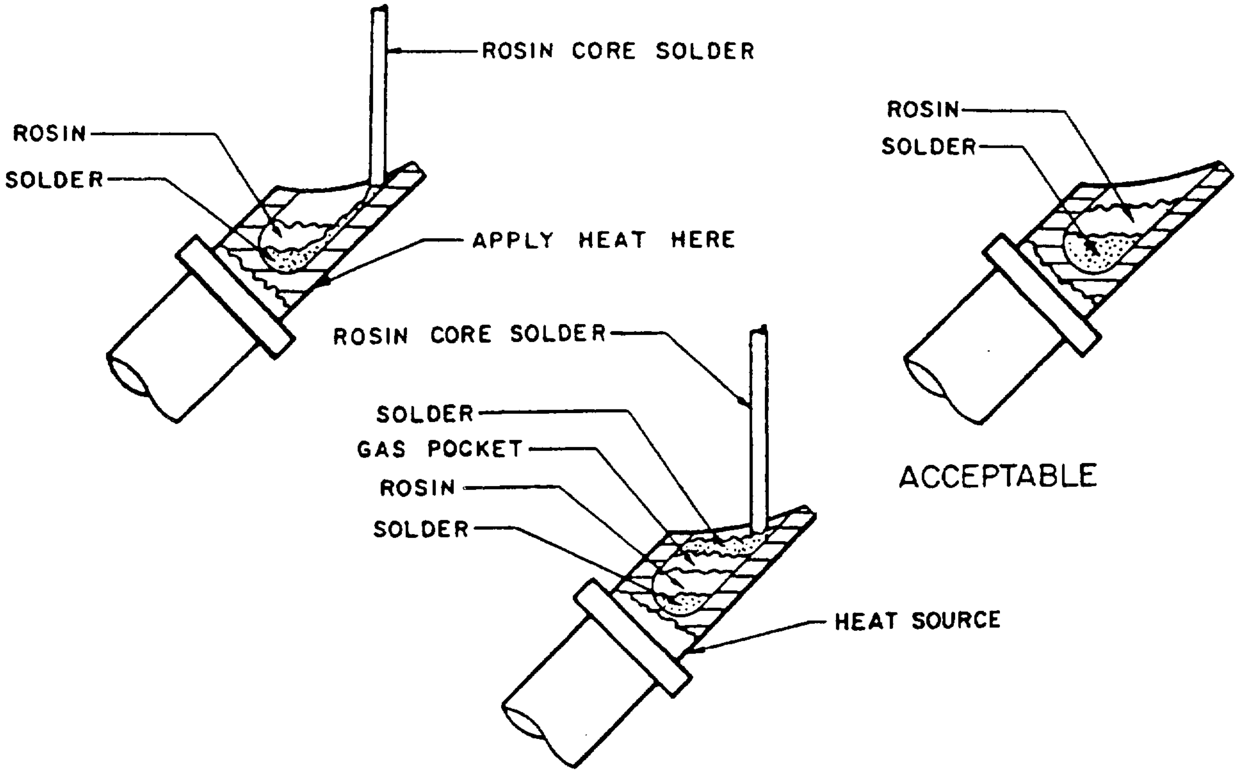
E. TIN REACTING WITH THE BASIS METAL TO FORM A NEW ALLOY.

F. SOLDER BRIDGE FOR HEAT TRANSFER

G. SOLDERING IRON TIP SHOWN NOT TOUCHING BASIS METAL FOR CLARITY.

B

FIGURE 17. Solder application and bridging (see 8.2.7).



ACCEPTABLE

NOT ACCEPTABLE

FIGURE 18. Prefilling hollow cylindrical terminals (see 8.2.10).

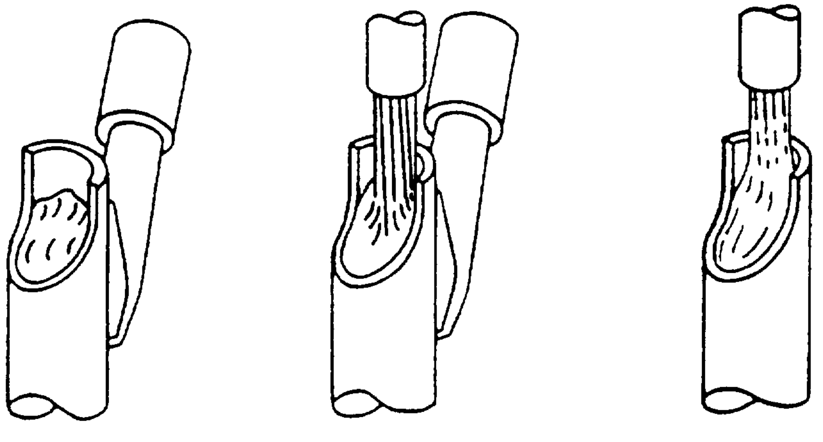


FIGURE 19. Soldering of hollow cylindrical connections (see 8.2.10).

e. Place the iron on the side of the cup near the bottom and heat until the solder is molten. Place the stripped and tinned wire in the cup, bottoming the wire in the cup. Maintain heat until it forms a good fillet to the cup and wire. Do not heat longer than necessary to form an acceptable connection since excessive heat can cause excessive wicking under insulation. Ensure wire does not move while solder is solidifying.

NOTE: Gold plated cups must first be pretinned.

8.2.11 Soldering of flatpacks. The use of a magnifying device will facilitate the attachment of flatpacks. A small tip must be used on the soldering iron. Place the device on the pattern and center the leads on their pads. Put a small amount of liquid flux on the leads to facilitate heat transfer and solder flow. Tack the leads on opposite corners of the device to the board by placing the iron on the leads long enough to reflow the lead tinning and board solder coating. With the device held in place by the tacked leads, solder the leads on alternating sides of the device using a fine solder wire. Alternating sides while soldering will avoid localized overheating, which can result in measling and lifted pads.

8.2.12 Soldering of dual inline packages (DIPs). Use a small soldering tip and small diameter solder. Alternate between the two rows of the device to avoid heat buildup.

8.2.13 Resistance soldering. Resistance soldering is accomplished by heating the workpiece by passing a current through the workpiece itself. The work surface is gripped by a pair of electrodes similar to tweezers, applying power supplied by an intermittently operated power supply. It has the advantages of rapid heating and allowing the electrodes to be positioned while cold, minimizing the danger of heat damaging other areas as can be done with a soldering iron in close spaces. Disadvantages include the possibility of burning surfaces from arcing, fast heating requires quick reactions, current could damage sensitive components and varied surfaces can cause uneven heating. For a cup type terminal, the resistance soldering unit is used as follows:

a. Keep the tweezers clean to ensure good electrical contact. Twist a small diameter solder wire and place it in the cup and cut it off flush with the top of the cup.

b. Grip the workpiece firmly with the electrodes and apply current until the solder melts. Once the flux has bubbled to the surface, the wires may be inserted, bottoming the wires in the cup. Maintain heat until the wire and the cup show good wetting. Release the current switch before releasing the tweezers. (See Figure 19)

8.2.14 Hot plate hand soldering. Some printed wiring designs require additional heat be added to the assembly during hand soldering. One technique for accomplishing this is the soldering of the assembly while it is resting on a heated plate. The use of heated plates, however, interferes with the ability of the operator to work on the assembly. Operators may get burned by the hot surface and the radiant heat from the plate is very uncomfortable. Hot plate hand soldering may be more comfortably accomplished when base cover is fitted over the hot plate and to the board assembly. This concentrates the plate heat into the board and reduces the heat to which the operator is exposed. This also increases the temperatures at which the hot plate may be operated.

8.2.15 Hand soldering under microscopes. The use of microscopes during soldering operations increases the potential that the operator will make the connection correctly the first time. Real time feedback from seeing the connection in detail as it is made enables operators to improve their technique. Good optics reduce fatigue, increase productivity and reduce rework. Optical aids are strongly recommended for operators when soldering connections at 50 mil pitch or less. Selection of magnification powers for operators should be:

Spacing:	Recommended Magnification Range:
>50 mil	0 - 10X
40 - 50 mil	4 - 10X
20 - 40 mil	7 - 15X
<20 mil	10 - 20X

Optics should be protected from flux fumes through the use of small vacuum lines attached near the optics or air ionizers blowing across the optics. This will reduce the cleaning and maintenance associated with the operator's microscopes and will keep the flux fumes out of the operator's face.

8.3 Wave soldering. The wave soldering process consists of three basic steps, fluxing, preheating and soldering. Another step often performed prior to the actual wave soldering is prebaking. The major components of the wave solder machine are the conveyor, holding fixture, fluxer, preheater(s), solder sump and wave, pump, baffles, air knife (on some machines), exhaust and control unit.

8.3.1 Fluxing. Fluxing is the first operation performed by the wave solder machine. The methods most often used for fluxing are foam fluxing, wave fluxing and spray fluxing. The purpose of flux is discussed in paragraph 4.2. The most important parameters to control during the fluxing operation are the flux and purity and the amount of flux applied. Problems associated with improper specific gravity include excessive solder, bridging, icicles, insufficient solder, poor wetting and pinholes due to insufficient vaporization of flux solvents prior to contacting the solder wave. With the exception of pinholes, improper flux quantity will cause the same type of problems as improper density. Table VII gives a listing of wave soldering defects and troubleshooting guide.

8.3.1.1 Foam fluxing. A foam fluxer consists of a porous stone or gas nozzles immersed in a flux tank covered by a chimney to channel the foam to the board. Figure 20 shows a diagram of a foam fluxer.

TABLE VII. Wave solder defects and troubleshooting guide.

Problem	Possible causes	Corrective action
Insufficient solder (solder side)	Conveyor height too high	Lower conveyor
	Uneven solder wave	Clean baffles Level solder pot
	Improperly seated board	Check board seating
	Carrier not properly seated in conveyor chain	Check carrier seating
	Warped or defective carrier	Repair or replace
	Low solder level	Add solder to pot
	Low solder temperature	Adjust temperature
	Solder contaminated	Replace
	Improper flux density	Adjust density
	Insufficient flux	Add flux or increase foam height
	Excessive flux	Lower foam height, check brushes or air knife
	Flux degraded (contaminated)	Change flux
	Wet flux entering wave	Increase preheat Reduce flux volume on board
	Flux bubbles too large	Clean or replace diffusing stone
	Contaminated boards	Degrease boards
	Improper solder mask application	Use properly masked boards
Insufficient solder (component side)	All of the above	
	Defective plated-through hole	Inspect prior to soldering
	Improper lead to hole ratio	Use proper components or hole sizes

TABLE VII. Wave solder defects and troubleshooting guide (continued).

Problem	Possible causes	Corrective action
Depressed fillets	Conveyor speed too slow	Increase speed, verify
	Preheat too high	Check and adjust
	Excess oil in wave	Remove some oil
Excessive solder, bridging, rough solder on traces	Conveyor speed too fast	Reduce speed and verify
	Insufficient oil in wave	Add oil
	Improper lead clinching	Adjust mounting process
	Improper flux density	Adjust density or replace flux
	Improper board immersion depth	Adjust depth
	Low solder temperature	Raise temperature
	Insufficient preheat	Raise preheat temperature or time
	Uneven solder wave	Clean baffles
	Improper conveyor angle	Adjust conveyor angle
	Misaligned or missing solder mask	Insure good boards are used
Peaks or icicles	All of the above	
	Solder temperature too high	Reduce temperature
Blowholes or pinholes	Flux density high	Thin flux
	Too much oil in wave	Reduce oil quantity
	Degraded oil	Replace
	Insufficient board immersion depth	Increase depth
	Conveyor speed too fast	Adjust and verify
	Improper solder temperature	Check and adjust
	Moisture in boards	Pre-bake boards

TABLE VII. Wave solder defects and troubleshooting guide (continued).

Problem	Possible causes	Corrective action
Cracked fillets or grainy solder	Low solder temperature	Increase temperature
	Boards removed too quickly	Allow to cool before removal
	Jerky conveyor motion	Maintain or repair
	Insufficient preheat	Increase preheat
	Contaminated solder	Replace if contaminated
Poor wetting or dewetting	Poor solderability	Use solderable parts, handle properly
	Low wave height	Adjust wave
	Board not fluxed	Check fluxer
	Low flux specific gravity	Adjust specific gravity
	Insufficient preheat	Increase preheat
	Low solder temperature	Increase temperature
	Conveyor too fast	Adjust speed
Measling, crazing, delamination	Moisture in board	Bake boards
	Solder temperature too high	Reduce temperature
	Excessive preheat	Reduce temperature or time
	Slow conveyor speed	Increase speed

8.3.1.1.1 Maintenance of foam fluxer. Several items on the foam fluxer require regular maintenance to ensure consistently good results.

a. The pressurized air must be dry and oil-free. An oil trap and air filter will condition the air for proper operation. The filter and trap should be serviced daily.

b. A clean stone is essential for uniform foam. The element should be soaked in solvent when not in use to prevent clogging of the pores. It should always be covered with liquid flux during use to prevent clogging.

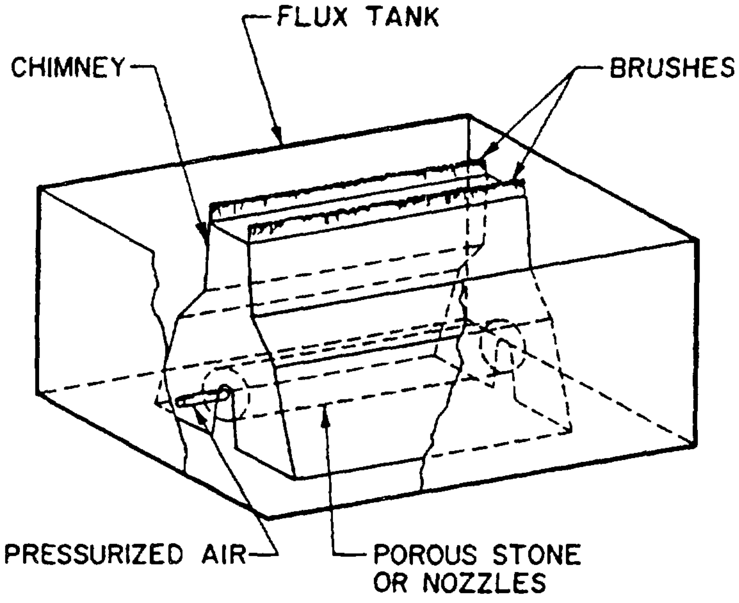


FIGURE 20. Foam fluxer (see 8.3.1.1).

c. Uniform air pressure is required for consistent foam height. The air pressure regulators should be checked occasionally.

d. Specific gravity of the flux should be adjusted at least twice each shift. The foam fluxer should be covered when not in use to prevent thinner evaporation.

8.3.1.2 Wave fluxing. A wave fluxer consists of a trough through which liquid flux is pumped. The boards are transported through the wave by the conveyor.

8.3.1.3 Spray fluxing. A spray fluxer consists of a rotating cylindrical screen partially submerged in liquid flux. An air nozzle blows the flux from the screen to the work. The flux quantity is controlled by the air pressure, screen rotation speed and flux solids content. The overspray from the fluxer is lost and can create problems maintaining machine cleanliness.

8.3.2 Preheat. The preheat step has four functions: activation of the flux, evaporation of the flux solvents, lessening of the thermal shock on the board and components and reduction of time in the solder wave.

8.3.2.1 Flux activation. Rosin flux does not become active until it reaches a temperature of approximately 80°C (175°F). This allows the flux to sit on the board a short time without attacking it, until the preheat step partially activates it just prior to passing through the wave.

8.3.2.2 Solvent evaporation. The evaporation of volatiles off the assembly prior to its passing across the solder wave minimizes the amount of solder spattering as the assembly crosses the wave. Excessive preheating can cause the flux to become too thick or hard due to polymerization, creating wetting problems as the flux resists replacement by the solder and subsequent cleaning problems when trying to remove flux residues.

8.3.2.3 Lessening of thermal shock. A sharp temperature gradient between the top and bottom of the printed wiring board can cause the board to warp. The preheat step using both top and bottom preheats heats the board more slowly than simply running it across the wave, and reduces the temperature difference between the top and the bottom of the board when it contacts the hot solder.

8.3.2.4 Reduction of time in the wave. Preheating brings the temperature of the connections closer to the wetting temperature, reducing the time in the wave before the solder begins wetting the connections.

8.3.2.5 Preheat temperature. The preheat temperature should fall in the range of 72° to 105°C (160° to 220°F). Thin printed wiring assemblies such as flexible circuits and single-sided boards would be preheated in the lower end of the range, while thicker boards, such as double-sided and multilayer boards may require the higher preheat temperatures.

8.3.2.5.1 Measuring preheat temperature. Temperature is measured in a bare area near the center of the board. Devices which may be used to determine preheat temperature include heat sensitive pigment, a temperature sensing stick which melts at a given temperature, a thermocouple, or an Infrared temperature probe. A disadvantage of the thermocouple is that it must be attached to the board to determine the temperature of the board.

8.3.2.6 Preheat equipment. The preheat can be delivered to the board by several means, including top and/or bottom radiation, hot plates, forced hot air, and infrared. Heating units residing below the conveyor will have flux dripping on them and must be maintained or protected to insure cleanliness. Reflectors can be lined with aluminum foil, which is easily replaced, if it is not a safety hazard or violation of manufacturing instructions.

8.3.3 The solder wave. The solder wave completes the operation by providing the additional heat necessary for final activation of the flux and wetting with the molten solder. Solder wave variables which must be controlled include temperature, wave height, stability, parallelism with the board and contact time.

8.3.3.1 Wave shape. The wave shape is defined by the flow pattern and the characteristics by which the wave is discharged from the nozzle. Solder waves can generally be categorized as a parabolic wave, a bidirectional wide wave or an asymmetrical or supported wave.

8.3.3.1.1 Parabolic wave. The prabolic wave has solder flowing in only one direction, opposite that of the board travel, and as the name implies, in the shape of a parabola.

8.3.3.1.2 Bidirectional wide wave. The solder in a bidirectional wide wave flows equally in both directions. The wide wave has a greater contact area which permits faster soldering speeds. This wave shape can be used with either horizontal or inclined conveyors.

8.3.3.1.3 Asymmetrical or supported wave. This wave configuration has more solder flowing against the direction of the board than with it. This provides the greatest contact area with the board and the highest soldering speeds. The zero velocity relative to the board and small volume of solder in the exit direction produces good drainage and peelback, and can minimize bridging defects.

8.3.3.2 Phases in the wave.

8.3.3.2.1 Assembly entering the wave. The first phase of the actual soldering is as the assembly enters the solder wave. During this phase the flux reaches its maximum activation and is washed away by the denser solder as soon as the wave contacts the surface.

8.3.3.2.2 Final heat transfer and wetting. The second phase begins as soon as the flux is flushed away and the solder contacts the metal. The metal in contact with the solder quickly heats to the wetting temperature. As the heat flows through the metal, the solder wets and rises through the plated through hole to the top side, displacing the flux as it goes. The solder rises part way up the plated through hole due to the depth of immersion of the board, with the rest of the rise and the formation of the top side fillet due to the wetting (capillary) forces.

8.3.3.2.3 Wave exit and peel back. The final phase of the solder wave is the exit point, where the assembly leaves the solder and the solder peels back from the board. The forces at this point control the shape of the bottom side fillet. These forces include the solderability of the board and components, the cohesive force of the solder, the thermal mass of the board, wave dynamics, the angle of the conveyor, and the exit speed of the board.

8.3.3.3 Immersion depth. Experience is the best guide for determining the immersion depth of the board in the wave. Flexible and single-sided boards normally require less immersion depth than double-sided, multilayer or boards with large thermal masses. Table VIII gives a general guide for starting points when adjusting the immersion depth.

TABLE VIII. Immersion depth adjustment guide.

Board type	Fraction of board thickness immersion
Flexible	Just touching
Single-sided	Just touching to 1/4
Double-sided	1/3 to 1/2
Multilayer	1/2 to 2/3

8.3.3.4 Wave measurement. A tempered glass guage panel with a grid can be used to determine the width, shape and parallelism of the wave with respect to the surface being soldered. The guage panel is placed in the conveyor in the same manner as a printed wiring board and run through the wave. Exact time in the wave can be determined by timing one of the grid lines from the time it enters the wave until it exits, or by dividing the wave width by conveyor speed. With the conveyor stopped and the guage centered over the wave the width and shape can be observed. The width of the wave should be consistent over its entire length (parallel). The guage must be handled with care after being removed from the wave as it is easily broken during cooling.

8.3.3.5 Dross. Dross is a nonmetallic waste product which forms on the top of molten solder. It consists of oxides and sulfides of the lead and tin, as well as other nonsoluble contaminants such as decomposed flux. Dross appears as a dull film on the top of the solder and may appear gray, brown or blue in color. It is removed by skimming the top of the solder pool with a stainless steel stick. The dry powdery dross removed must be handled with care to prevent health hazards. Agitation of the dross can release enough lead particles into the air to pose an inhalation hazard. Dross should be removed with adequate ventilation and kept in a covered container.

8.3.3.5.1 Dross prevention. Formation of dross can be minimized by mechanical or chemical means, or by isolating the solder from the atmosphere. Dross formation can be reduced mechanically by minimizing the turbulent zone in the wave or by adding glass beads which float on the solder in the sump of the solderfall and keep the dross separate from the solder. The chemical means for inhibiting the formation of dross is the solder blanket, a wax, resin, or oil which isolates the solder reservoir from the atmosphere.

8.3.3.5.1.1 Use of oil. Pumping oil with the solder in the wave creates a thin layer of oil on the wave and the reservoir, creating a barrier between the atmosphere and the solder. The use of oil has benefits other than the inhibition of dross. It lowers the surface tension of the solder, improving wetting and reducing bridging and icicling. The oil also excludes air at the point of exit from the wave, reducing the formation of oxides and improving fillet uniformity. When oil is used in the wave, the cleaning process must be sufficient to remove this oil from the assembly after soldering. If oil is used without adequate controls it can contaminate solder joints.

8.3.4 Hot air knife. The hot air knife is a device used on some wave solder machines to blow excess solder off the board as it leaves the wave. A stream of air hotter than the melting point of solder is directed at an angle at the bottom side of the board as it exits the waves. Solder which did not wet the connections will also be blown off, exposing those areas which had poor solderability.

8.3.5 Wave solder troubleshooting. Table VII provides a checklist to assist in troubleshooting wave soldering problems.

8.4 Vapor phase soldering. The vapor phase soldering machine consists of sump of boiling liquid, the primary and secondary vapor zone, and cooling coils, which contain the vapor zone. A layer of lighter and less expensive vapor is used in batch soldering units above the primary soldering vapor to help contain it. Assemblies are heated in the vapor zone primarily by condensation of the vapor on the assembly, with additional heating by convection of heat from the boiling sump. Advantages of vapor phase soldering are that temperature of the assembly is limited to the boiling temperature of the liquid, and the vapor isolates the assembly from air during heating, preventing oxidation. Some inline vapor phase machines do not require a secondary vapor zone.

8.4.1 System profiles. The time and temperature profiles are critical in vapor phase soldering. Users should avoid excessive dwell time in the reflow vapors. When the reflow time exceeds the needed minimums, intermetallic growth and excessive flux hardening will occur. The system temperature profiles should be defined to avoid thermal shock to the assembly. The preheat rate, the time for reflow, and the cooling rate must be carefully defined to assure proper soldering without damaging parts or the assembly.

8.4.2 Developing systems profiles. An excellent method for developing a temperature profile of the system is attaching thermocouples to the assembly and running the assembly through the vapor phase system. These thermocouples are then attached to a solid state memory unit which moves through the reflow unit with the product. After obtaining the data, the solid state unit may be plugged into a personal computer to download the data. The thermocouples should be positioned on the edges of the assembly and at the center of the board. The assembly will generally begin to heat at the outer edges with the center heating last. The thermocouples should be positioned at the areas suspected to heat the most and least rapidly. The critical elements of the temperature profile are the parts and areas of the board which heat first and those which heat last.

8.4.3 Preheating the assembly. The board should be preheated above the secondary vapor temperature to avoid condensation of the secondary vapor on the board. The condensed vapor may wash flux from the board. A heating rate of 4-5°C (39-41°F) per second to within 100°C (212°F) per second of the reflow temperature is recommended. Where component manufacturers have recommended alternative heating rates, these should be used.

8.4.4 Reflow times. The time for reflow for each assembly will vary depending on the heat absorption characteristics of the board, parts, and the overall assembly configuration. Once the assembly has been heated to the reflow temperature; however, the dwell time should not exceed five seconds.

8.5 Fixturing. Fixturing is critical to ensure boards are not twisted during the cooling cycle. (Most board deflection occurs during cooling rather than the reflow process). This is also a board design and construction issue. Up to 12 layer, 10x20 cm (4x8 inch) boards should be able to be reflowed without fixturing (if designed properly). Reflowing panelized sections may be an alternative to fixturing. This is a high cost area and design solutions should be used wherever possible.

8.6 Rework of solder connections.

8.6.1 Drying. Before reworking printed wiring assemblies, boards should be dried (baked) to eliminate moisture that may have been introduced during processing. This will help avoid measling and lifted lands during rework. Dry nitrogen boxes and holding ovens may be used. This is necessary for both hand and wave rework actions.

8.6.2 Removal of solder. Vacuum devices and solder wick may be used. Minimal pressure should be used when using solder wick to avoid digging into the land, the barrel of the plated-through hole, or the board. When removing and resoldering multileaded devices in a single point (hand soldering) process, every other lead should be processed to avoid excessive heat build-up. Bridging, lifted lands, and measles may result if you don't.

8.6.3 Removal of parts with fine lead pitch. Fine lead pitch parts may be effectively removed by first cutting the leads from the part, removing the part, and then removing the lead. By leaving a maximum lead length, failure analysis of the part is enhanced.

8.6.4 Removal of parts retained by adhesives. Parts epoxied to the board should be removed by twisting (torque) the epoxy rather than prying (tension). When film adhesives are used, heating the assembly has been shown to be effective in facilitating removal. The time and temperature exposure in this process has been, in some cases, critical. This has been especially true when dry film solder masks are used. Special purpose tools, fitted to the part to be removed, should be used to avoid damaging adjacent components.

8.7 Controlled soldering devices.

8.7.1 Description. A controlled soldering device consists of some form of carrier which delivers controlled amounts of solder and flux to an interface where a solder joint is to be made.

8.7.2 Classification. There are two classes of controlled soldering devices, encapsulated and non-encapsulated.

8.7.2.1 Encapsulated controlled soldering devices. Encapsulated devices are those in which the solder and flux are contained within a shaped carrier formed of insulating material. The carrier changes shape during the soldering process and conforms to the contours of the items being soldered together, encapsulating them and providing environmental protection. The degree of environmental protection provided by this type of controlled soldering device depends on several factors in both the controlled soldering device and in the items being soldered. In the controlled soldering device, the carrier material and the presence or absence of sealant materials affect the ability to provide environmental protection. The number of conductors being soldered, their shapes and sizes, and the insulation material all are factors that affect the degree of environment protection obtained. This protection can be as minimal as electrical insulation coupled with mechanical protection and resistance to gross contamination, as is provided by devices not containing sealant. At the other extreme, devices containing sealant and using materials formulated and configured appropriately can provide sealing against altitude immersion, fluid exposure, corrosive gases, and immersion under conditions of pressure. Because the encapsulated types of controlled soldering devices are pre-insulated and self-encapsulating, post-installation cleaning is not required (see MIL-STD-2000).

8.7.2.2 Non-encapsulated controlled soldering devices. These devices are products in which the solder, and in some cases a metal strength member, is attached to a carrier which is removed at some point during the installation process. They are typically used in surface mounting component packages to printed wiring boards or in terminating multiple leads on close center spacing to board terminals. These terminations are subject to the same cleaning requirements as solder joints made by other means on the same type of substrate.

8.7.3 Type designators for controlled soldering devices.

8.7.3.1 Encapsulated devices. Controlled soldering devices in this class can be categorized into general functional types as follows.

8.7.3.1.1 Shield terminators. Shield terminators are used to attach ground leads to the braid of a coaxial or shielded cable. Typical devices of this type are covered by MIL-S-83519 and NAS1745 and are shown in Figure 21.

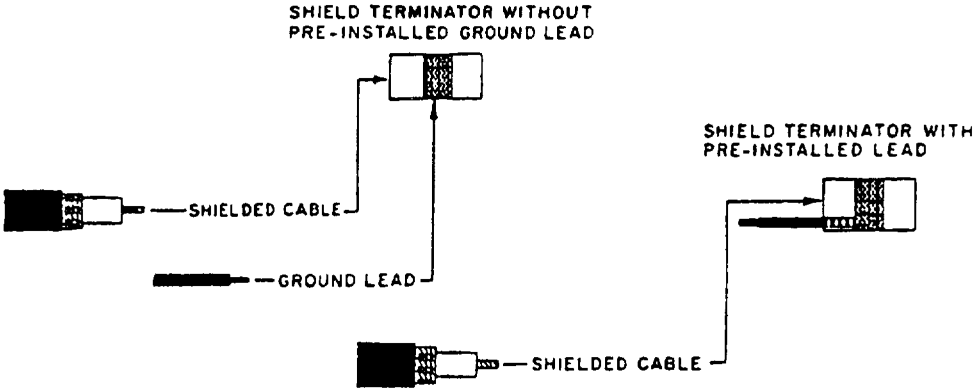


FIGURE 21. Typical solder type shield terminators.

8.7.3.1.2 Conductor splices. Conductor splices are used to join two or more conductive members. Solder type splices are typically used in lieu of crimp type splices in applications where the smaller size and lower weight of the solder splice is necessary. In addition to basic inline wire spacing, solder type conductor splices are also used in coaxial cable termination devices, commonly referred to as coax terminators. Coax terminals are used to attach the two conductors of coaxial cable directly to connector terminals or to a printed wiring board. Some wire splices are shown in Figure 22.

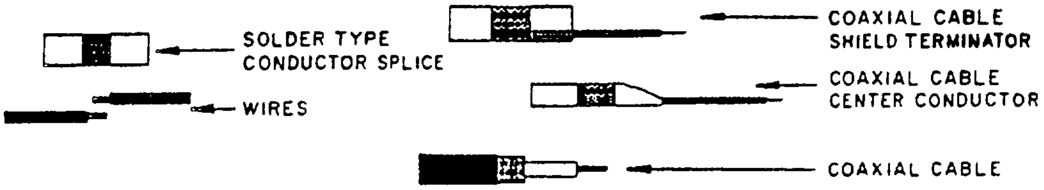


FIGURE 22. Typical solder type wire splices.

8.7.3.1.3 Discrete wire terminators. Discrete wire terminators make it possible to attach one or more wires to the terminals of a connector. One type of discrete wire terminator is installed by resistance heating and is covered by IPC-DW-425/10 and shown in Figure 23.

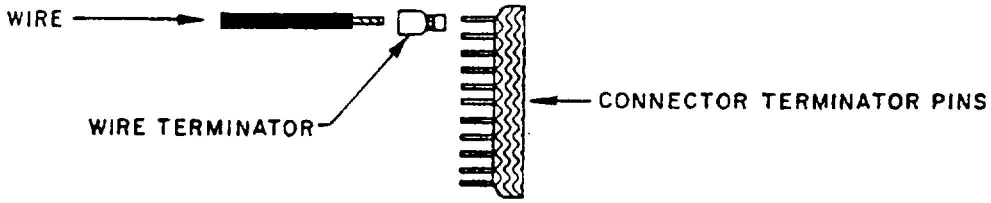


FIGURE 23. Controlled soldering type of discrete wire terminator.

8.7.3.1.4 Shielded cable splices. Shielded cable splices are designed primarily for making soldered repair splices in the shields of shielded cables. They may also be used for fabricating breakouts and taps in shielded cables, and for joining cables of different sizes. Since the installed splices are comparatively rigid, they must be positioned where bending is minimal in the splice area. The primary conductors in cables to be spliced are typically spliced using crimp splices per MIL-S-81824/1. The shielded cable splices and the primary conductor splices are combined in cable splicing kits defined by MIL-S-81824/5 and are shown in Figure 24. The various kits contain components for splicing cables having from one to four primary wires that can range from 26 to 12 gauge.

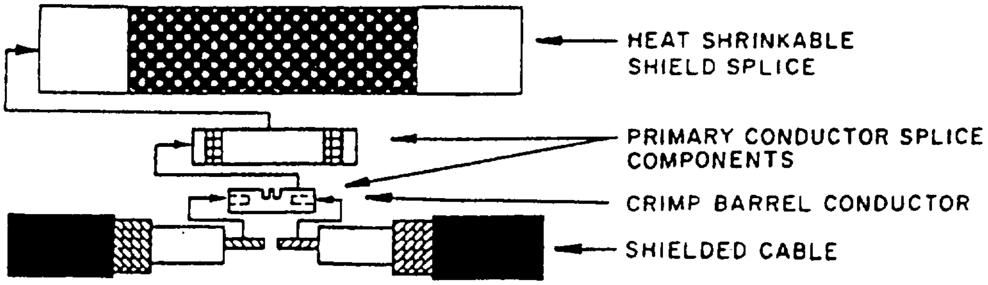


FIGURE 24. Typical shielded cable splice kit showing kit components.

d. Apply heat until the solder melts and flows enough to form a fillet along the soldered interface.

e. Allow the assembly to cool undisturbed until the solder has resolidified.

f. Inspect termination for conformance to the applicable criteria.

8.7.7 Inspection guidelines. Terminations made with controlled soldering devices are no different from those made by hand soldering, and are to be inspected for the same characteristics as well as those applicable to the particular controlled soldering device.

8.7.7.1 Solder device joint criteria.

a. There must be visible solder fillets as specified in the applicable installation instructions or inspection standard.

b. The length of the fillet should be at least 2.5 times the diameter of the smallest item soldered.

c. The soldered items should be in proper alignment. In most applications the smaller member must not extend beyond the edges of the larger, as this could adversely affect the length, and therefore the electro-mechanical quality of the termination.

8.7.7.2 Insulation criteria.

a. The insulation material, where present, must completely cover the solder joint.

b. The material must not be split, charred or otherwise damaged to the extent that its ability to provide insulation and environmental protection is impaired.

c. Sealing rings, if present, must have melted and flowed.

9. CLEANING

9.1 Cleanliness. Cleanliness of parts is necessary both before and after soldering. Poor cleanliness is a common cause of solderability problems. Effective cleaning after soldering is necessary to allow good adhesion of the conformal coating, preventing shorting paths, and avoid corrosion from material left on the board.

9.2 Contaminant types. Board contaminants are generally categorized as polar or non-polar. Polar contaminants are those compounds which have an uneven charge distribution and have a dipole associated with them. They may be ionizable or non-ionizable. Non-polar compounds have no dipole associated with them and will not dissociate into charged particles or carry a current.

9.2.1 Polar contaminants. Ionizable polar contaminants are usually salts introduced to the assembly during the production process. Common sources of these salts include flux activators, salts from skin, and plating salts left over from board fabrication. Ionizable contaminants can cause corrosion, electrical, leakage and measling of the conformal coating. Non-ionizable polar contaminants are normally less corrosive than ionizable contaminants, but can still migrate under the influence of an electric field and result in current leakage.

9.2.2 Non-polar contaminants. Non-polar contaminants include compounds such as rosin, oils and waxes. They are usually insulators. Problems associated with non-polar contaminants include causing open circuits in connectors, failure of conformal coating adhesion, and white residues. Non-polar contaminants may be difficult to detect with standard lab equipment.

9.2.3 Cleaning methods. Cleaning may be done by either batch or inline processing and can be performed using cold cleaning or vapor cleaning. Sample boards should be used to test out the cleaning process prior to the start of production runs. By determining the effectiveness of the cleaning system alternatives prior to production, the most cost-effective method may be realized. During the initial development of manufacturing processes to support surface mount technology manufacturing, parts should be removed from the board after cleaning to verify the effectiveness of the cleaning process. Due to the fine pitch of the part leads (if any), and the small part to board spacings, cleaning systems are often limited in their effectiveness. Closed loop aqueous cleaning systems and solvent recovery systems may be employed to limit the amount of waste material which must be disposed. A significant cost savings may be realized through the use of these systems.

9.2.3.1 Interim cleaning. Interim cleaning with isopropyl alcohol and a brush is a standard technique for temporarily relocating contaminants. Contaminants are not removed by this process (the contaminants must be flowed/washed away). The greatest benefit of interim cleaning with isopropyl alcohol is it limits the ability of rosin flux to polymerize and may be used to delay final cleaning.

9.2.3.2 Vapor degreasing. Items are cleaned in a vapor degreaser by suspending them over a sump of boiling solvent. The cool surfaces of the item being cleaned cause the vapor to condense on it, washing away dirt. The item being cleaned eventually reaches the vapor temperature, at which time the vapor ceases to condense on it. At this point, the dry item can be removed from the degreaser without taking any solvent with it, or cooled for additional vapor cleaning by spraying with or dipping cool solvent. Items cleaned in the vapor only come into contact with clean, distilled solvent. There is also minimal loss of solvent in a vapor degreaser.

9.2.3.2.1 Vapor degreaser. The essential elements of the vapor degreaser are the boiling sump, the vapor zone, the cooling coils and the cold sump. The boiling sump produces a vapor zone above it, the height of which is limited by the cooling coils, which condense the distilled vapor, draining it into the cold sump. Solvent can be drawn from the cold sump for spraying the parts to cool them.

9.2.3.3 Aqueous cleaning. Aqueous cleaning systems typically consist of a washing system that uses a deionized water and saponifier in lieu of solvent cleaning. The equipment used for aqueous cleaning uses a constant flow of fresh water and saponifier (detergent) into the wash system, while monitoring the ionic contamination (resistivity) of the outflow waste water. A sample of known resistivity is used to periodically calibrate the outflow resistivity tester. The saponifier is typically composed of three essential elements: wetting agents, surfactants, and sequestering agents. The wetting agents break down the surface tension of the water and allow it to loosen dried on material. Surfactants react (combine) with surface contaminants and reduce the adhesion characteristics of the contaminants. Sequestering agents react with soluble contaminants to prevent their recontamination of the assembly and aid in "carrying away" the contaminant. The level of the saponifier in an aqueous cleaning system should be monitored. Some systems use batch additions of saponifier instead of a continuous monitoring and addition system. When a batch addition type system is used, the square footage of assembly surface area processed should be tracked. If too much saponifier is added to the system, printed wiring assemblies may be affected (i.e., discoloration, surface texture changes). If there is too little saponifier then there will be a loss of cleaning system effectiveness. Flow rate measurements are the most effective technique for both verifying that the spray nozzles have not become plugged and that the overall system is functioning properly.

9.2.3.4 Ultrasonic cleaning. Ultrasonic cleaning is an effective technique for maximizing cleaning fluid flow or contact with the assembly surfaces. Through the creation of wave fronts (i.e., longitudinal (sonic) waves of higher density solution) and cavitation areas (i.e., low density areas), some ultrasonic systems will create a pumping like action within the cleaning solution. This wave action aids in creating a flow of the cleaning solution between closely spaced items. The primary disadvantage that has been attributed to ultrasonic cleaning systems is the potential to damage parts. This damage potential is not fully understood and is often considered to be more related to poorly controlled systems. It is believed that cavitation and resonance of internal wire bonds in semiconductor devices with the ultrasonic waves is the source of part failures. As such its applications are generally limited to cleaning bare boards or boards incorporating only terminal and connectors without internal electronic elements.

9.3 Cleaning of heat shrinkable solder devices. Heat-shrinkable solder devices generally need not be cleaned. This exception arises, however, because these devices are self-sealing. If there is a poor seal, contaminants may leach out. Since the potential of cleaning the contaminants out of a poorly sealed device is low, the device should be removed. The quality of the seal is a significant issue when using these devices.

9.4 Common problems associated with cleaning.

9.4.1 Removal of part markings. Some trichlorotrifloro-ethane blends which incorporate alcohols and clorothane solvents often remove ink-based markings from parts. To avoid the loss of the marking, clear kapton labels or a clear epoxy covering over the part marking may be effective. Laser cut kapton markings may be added to the part to supplement the initial part marking. Where part suppliers are willing to change the part marking inks, users have been able to obtain parts with markings that withstand these solvents. When part suppliers have been aware of the problem, they have often been willing to adjust their selection of marking inks.

9.4.2 Removing contaminants from underneath parts. The removal of contaminants from underneath parts is dependent on the ability of the cleaning process to flow a sufficient amount of solvent or cleaner under the part. The rate at which contaminants dissolve into the solution will depend on the amount of contaminants present relative to the volume of fluid, the time the assembly is in the cleaning system, and the and the temperature of the cleaning fluid. The volume of fluid which flows beneath the part will be limited by the size of the part, the height of the part from the board, and the lead configuration. It is harder to clean under the center of large surface area parts. As such, as the surface of the part increases in size, the part must be raised off of the board to allow solvent flow under the part. When the part has a large number of fine pitch leads it will be difficult to force the cleaning solution under the part as well. Coaxial connectors are often especially difficult to clean under since they can't be raised high enough to clean under the part (i.e., if the part is too high then the signal fades). Some coaxial connectors incorporate integral standoffs to compensate for this difficulty. Manufacturers need to sensitize their design departments to the design requirements for cleanability.

9.5 Cleanliness test methods.

9.5.1 Insulation resistance testing. Insulation resistance testing is performed by subjecting a printed wiring assembly to high relative humidity (greater than 90%) for several hours or days with a voltage applied to adjacent traces. Current leakage between the traces indicates the presence of contamination which may cause shorting in field use. This test has the advantage of checking the test board under conditions more extreme (higher humidity and voltage) than actual usage.

9.5.2 Resistivity of solvent extract. This test determines the level of ionic contamination by washing the printed wiring assembly with a solution of known resistivity and measuring the change in resistivity of the solvent as a result of solvating ionic contaminants present on the board. The resistivity of solvent extract test is generally considered a cleaning process verification test rather than a true board cleanliness test.

9.5.3 Visual cleanliness inspection. The above test methods only test for ionic contamination and can even miss that if the ions are trapped in hardened flux. Visual inspection under good lighting and magnification can provide additional evaluation of the efficacy of the cleaning by detecting gross amounts of visible nonionic contaminants.

10. INSPECTION

10.1 Purpose of inspection. Inspection is performed to provide data to be fed back for process control and to locate defects which may affect the performance or reliability of the assembly for correction action.

10.2 Facilities necessary for inspection. In order for inspection to be effective, the inspection station must be clean, well-lit, and have effective magnification aids. Magnification aids and lighting which will facilitate effective inspection are described in MIL-STD-2000. For less critical applications, a ring light magnifying lens can be an effective inspection tool. The inspector should be able to meet the visual acuity criteria of MIL-STD-2000.

10.3 Inspection of the solder connection. The ideal solder connection has a smooth, concave fillet which is complete around the connection. Its most important characteristic is good wetting, evidenced by smooth feathering of the fillet onto the connection elements, and the formation of a small angle of contact between the solder fillet and the elements being joined. The connection should be free of the defects described herein.

10.4 Inspection of the printed wiring board and assembly. The assembly should be free of contaminants, mechanical damage, thermal damage, excessive measling, crazing or delamination, lifted pads or traces, blisters or wrinkles in the conductors, warpage, improper component mounting, or any other defect described herein. In addition, leads and wires should be properly cut and exhibit proper stress relief, and components should be properly mounted as described in the applicable specification or assembly drawing. If conformal coating is applied it should be free of pits, voids, bubbles, pinholes, inclusions, mealing, peeling and excessive webbing, and should have a fairly smooth and homogeneous appearance.

10.5 Wetting angle. The most important quality a solder connection has is the degree of wetting. Wetting is the free flow and spreading of solder on a metallic surface to form an adherent bond. Wetting is usually described as being good wetting, partial wetting, or nonwetting, depending on the angle the solder forms with the part being soldered. An angle of less than 30 degrees is considered good wetting, an angle from 30 to 90 degrees is partial wetting, and over 90 degrees is nonwetting. The different wetting angles are depicted in Figure 25.

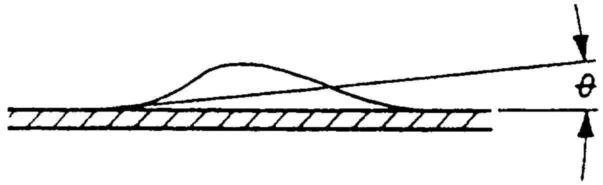
10.6 Typical visual characteristics of defects in solder connections and soldered assemblies.

10.6.1 Nonsoldered connection. The absence of solder between connection elements is a nonsoldered connection.

10.6.2 Bridging. A conductive path, not part of the design, spanning between conductors, caused by the presence of materials such as solder, plating, leads, wires or ionic residue.

10.6.3 Rosin connection. A connection with solidified flux entrapped in the solder or between the connection elements.

10.6.4 Cold solder connection. A cold solder connection is a connection in which the solder has not properly flowed and wetted the surface and the solder does not feather out on the connection elements.



GOOD WETTING $\theta \leq 30°$

PARTIAL WETTING $30° < \theta \leq 90°$

NONWETTING $\theta > 90°$

FIGURE 25. Wetting angles (see 10.5).

10.6.5 Disturbed solder connection. A disturbed solder connection is characterized by stress lines and a localized granular zone which may include minute fractures.

10.6.6 Insufficient solder connection. Connection which has characteristics similar to good solder connection, except that the width of the fillet at the narrowest point is less than the diameter of the wire (undercut).

10.6.7 Excessive solder connection. The solder obscures the outline of the wire or lead, the outline of the terminal, or the outline of the top or milled portion of a solder cup and generally has a convex fillet.

10.6.8 Dewetting. A surface condition wherein no basis metal is exposed, but the solder covering the surface has receded into irregularly shaped mounds surrounded by a thin solder film.

10.6.9 Solder splatter. Solder splatter is unwanted extraneous bits of solder clinging to the surface of the laminates or foil.

10.6.10 Pin hole. A small hole in the surface of a solder connection penetrating to an indeterminate size void within the connection.

10.6.11 Voids and blow holes. Voids and blow holes are a localized absence of solder in the fillet. A blow hole, caused by gas escaping from the plated-through hole, has a crater-like appearance.

10.6.12 Pit. A surface imperfection whose entire inner surface is visible. A pit has sharper edges than a void.

10.6.13 Contaminated connection. Connections that have inclusions (flux residues, cotton fibers, foreign matter, dirt on or embedded in the solder surface), metal oxides, and other matter in the connection are contaminated. They are characterized by discernible matter on or in the solder or dull, gray, or nonmetallic appearing surfaces.

10.6.14 Nonwetting. A surface condition wherein basis metal is exposed. The basis metal has been in contact with molten solder, but due to insufficient heat, contaminants, insufficient flux, or oxidation, the solder has failed to form an intermetallic bond (wet) with the base material.

10.6.15 Solder not smooth. Solder connections which are not smooth but have a dull, grainy and gray appearance.

10.6.16 Solder slivers, points, peaks, protrusions and icicles. Slivers consist of plating overhang or conductive edges partially or completely detached. Solder projections (points, peaks, icicles) consist of protrusions of solder from solidified solder.

10.6.17 Overheated connection. The solder has a chalky, dull or crystalline appearance and may show evidence of coarse grain porosity or pitting.

10.6.18 Excessive wicking. Excessive wicking may be characterized by solder extending to the wire insulation, enlargement of the wire, or a change in wire stiffness beyond the allowed maximum distance from the soldered connection.

10.6.19 Thermal damage. Thermal (heat) damage may be characterized by discoloration, blistering, flowed material and evidence of burned parts or assemblies (charring or scorching). Slight discoloration is not cause for rejection.

10.6.20 Ruptured plating or pattern delaminated. A separation of the conductive pattern or ground planes from the laminate base material or the separation of plating from the foil.

10.6.21 Measling. Discrete white spots or crosses at weave sections of the laminated base material wherein the glass fibers have separated from the resin. Measling is typically caused by thermal or mechanical stresses.

10.6.22 Lifted pad. The separation of a terminal area from the laminate base material. It is usually caused by excessive thermal or mechanical stress on the pad.

10.6.23 Peripheral split. The separation of the barrel of a plated-through hole from the periphery of the associated terminal area or a split along the periphery of a swaged terminal.

10.6.24 Scratched printed circuit pattern. A distinguishable scratch on the surface of a printed wiring pattern that exposes basis metal or damages the board laminate.

10.6.25 Improperly cut wire or lead. Leads or wires that exhibit sharp edges, ridges, points, burrs, nicks, gouges and other surface damage that are improperly cut.

10.7 Visual aids. Line drawings, illustrations and photographs depicted herein (Figures 26-66) and any additional provisions approved by the Government Contracting Officer are provided as aids for determining compliance with the written requirements of the applicable standard and do not take precedence over the written requirements. These illustrations are not to be considered as representative of all conditions.

11. REWORK OF CONFORMAL COATINGS

11.1 Acrylic. Acrylic conformal coatings are the easiest to rework. If the coating is too thin, additional material can be painted on. To remove and replace coated parts, the acrylic can be removed with chlorothane, alcohol, and most other solvents. Once removed, the component may be removed and replace and a new acrylic coating brushed on.

11.2 Urethane. Urethane conformal coatings can be removed by either chemical or thermal (heat) methods. A soldering iron or hot knife may be used. The assembly may be recoated by brushing on a new coat after part replacement.

11.3 Silicone based or RTV. Most silicone-based and room temperature vulcanizing (RTV) conformal coating compounds can be reworked and removed by heat techniques similar to urethane. Manufacturers recommendations should be consulted.

11.4 Parylene. Parylene is very difficult to remove. At this time there are not solvents which will remove it without damaging the parts or the board to which it has been applied. Parylene must be removed abrasively (e.g., using a ground walnut shell blast) and then a different material must be placed over the cleaned area.

12. PROCESS CONTROLS

12.1 Purpose. This section establishes the criteria for implementing a methodology for controlling the processes such that statistical sampling can be used in lieu of 100% inspection in accordance with paragraph 5.4.3 of MIL-STD-2000. An effective process control system focuses on the concept of defect prevention rather than detection, and results in stable process performance and an acceptable level of quality.

12.1.1 Continuous process improvement. There should be continuous improvement of the solder process to reduce defect rates to their lowest possible level. Cost-effective actions should be taken to eliminate all sources of variation, thereby minimizing scrap, rework, repair and, ultimately, the risk of potentially defective products.

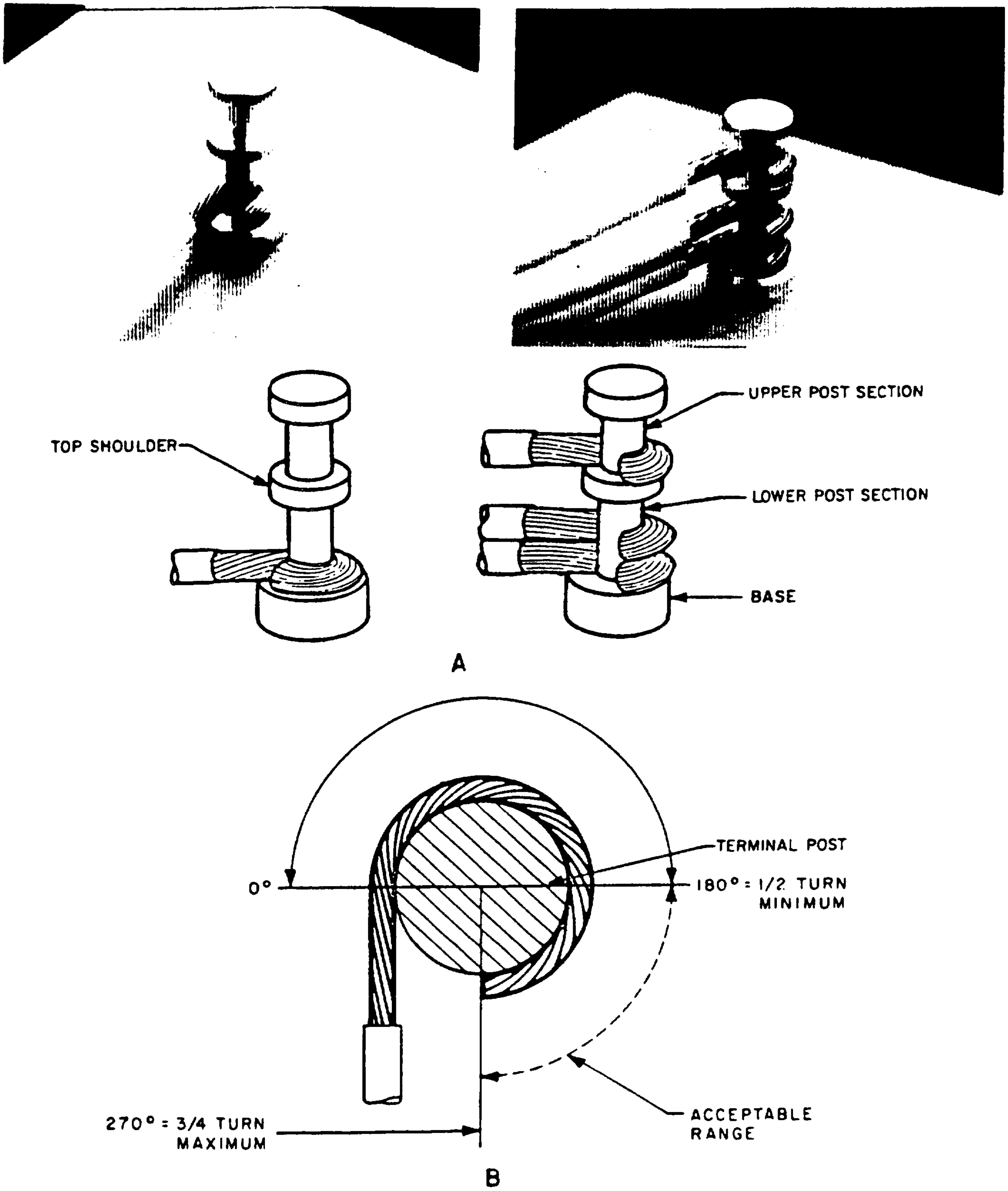


FIGURE 26. Turret terminal wire wrap methods.

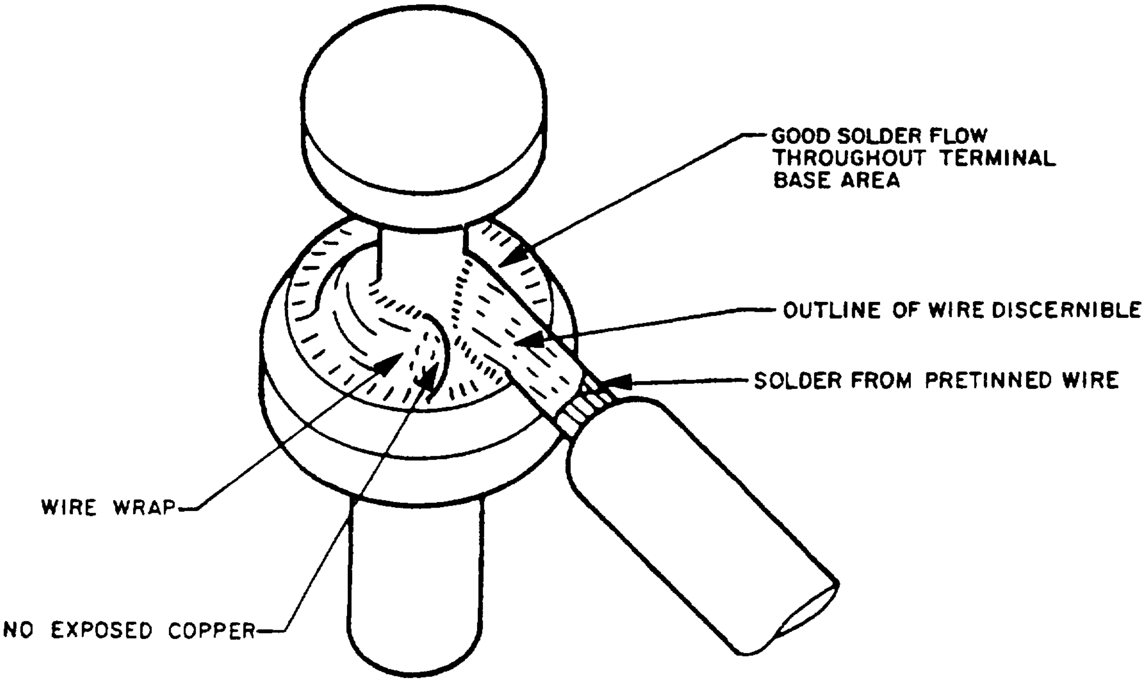
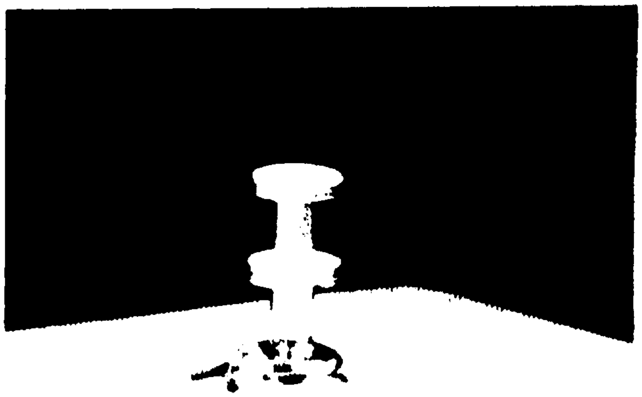


FIGURE 27. Turret terminal solder connection.

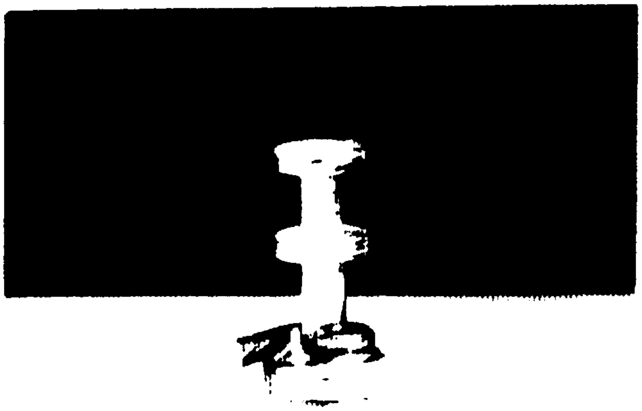
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

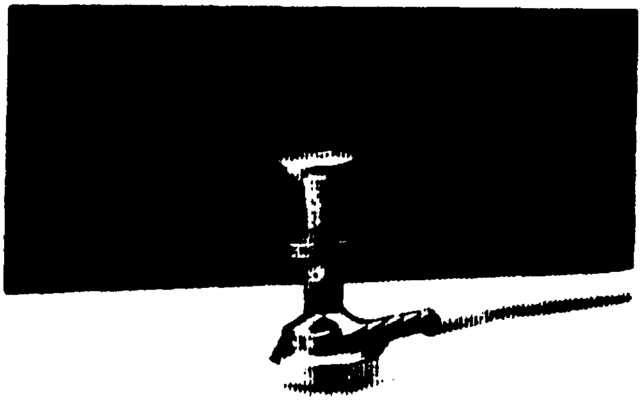
Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

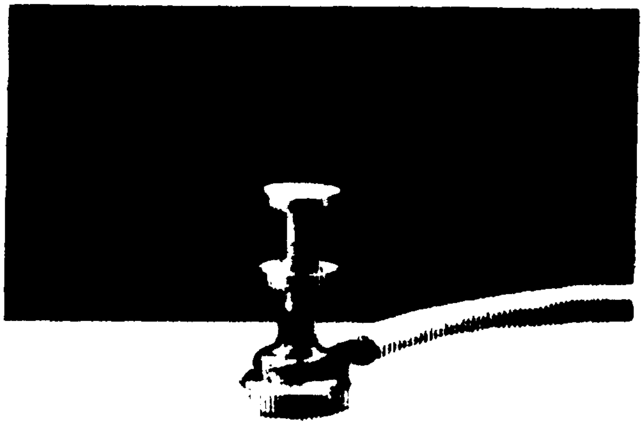
Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 27. Turret terminal solder connection (continued).



MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



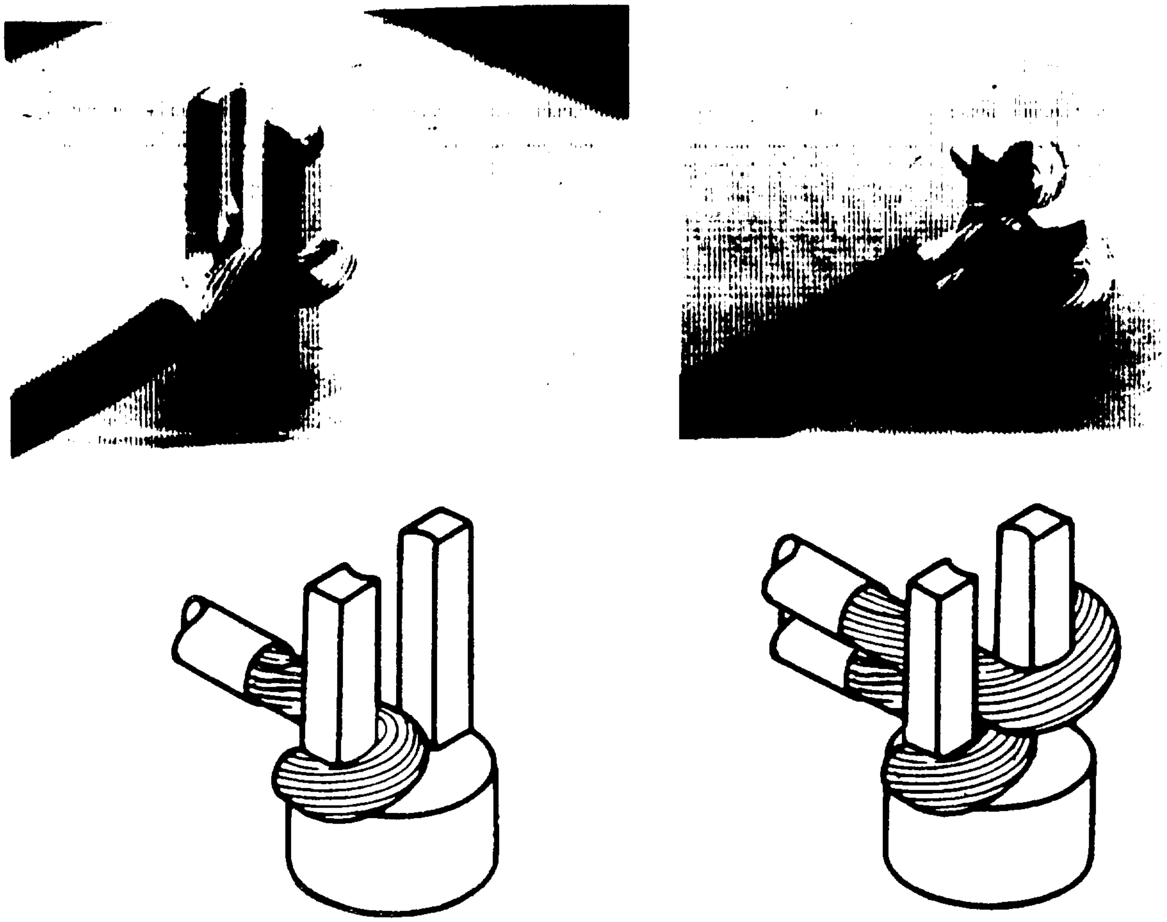
OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.

MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 27. Turret terminal solder connection (continued).



SINGLE WIRE WRAP

MULTIPLE WIRE WRAP

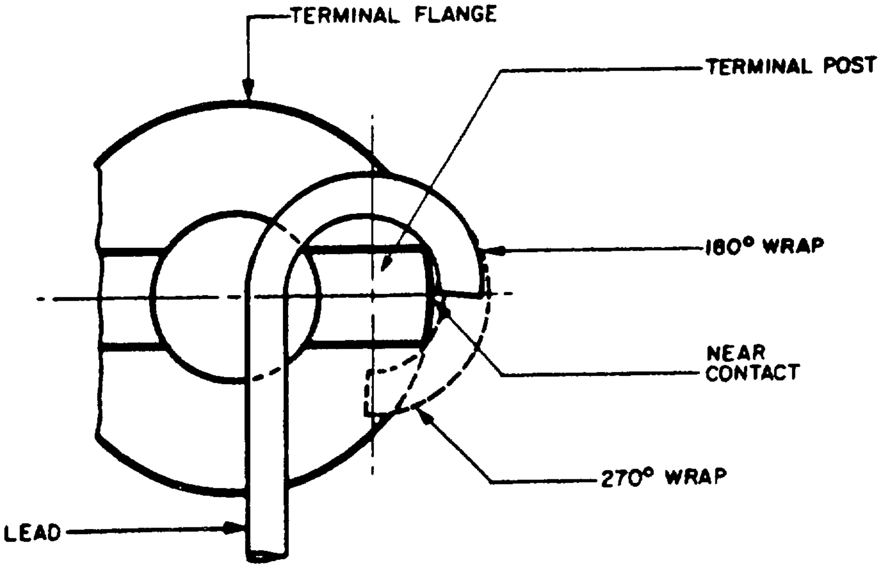


FIGURE 28. Bifurcated terminal, side route and wire wrap.

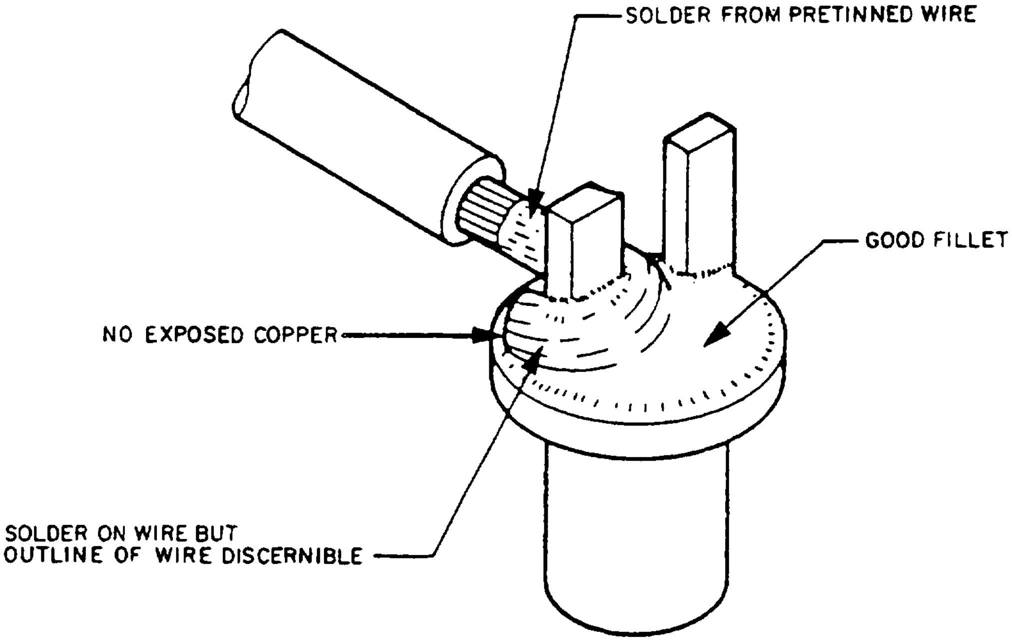
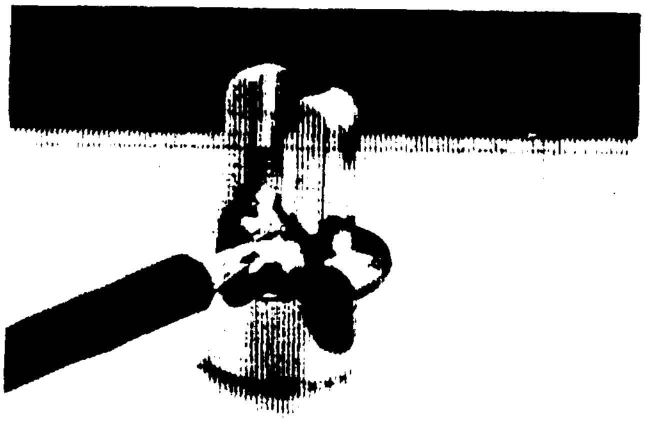
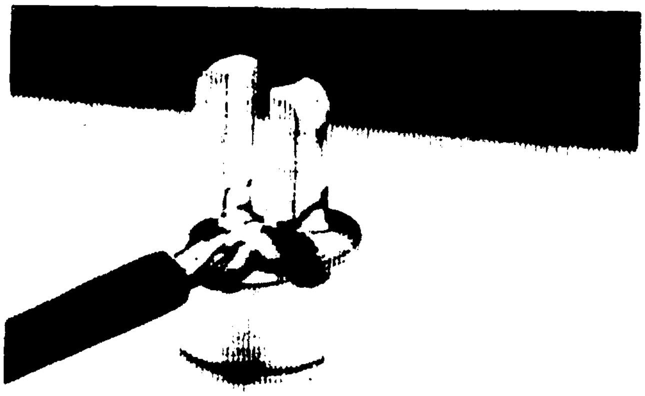


FIGURE 29. Bifurcated terminal, side route solder connection.



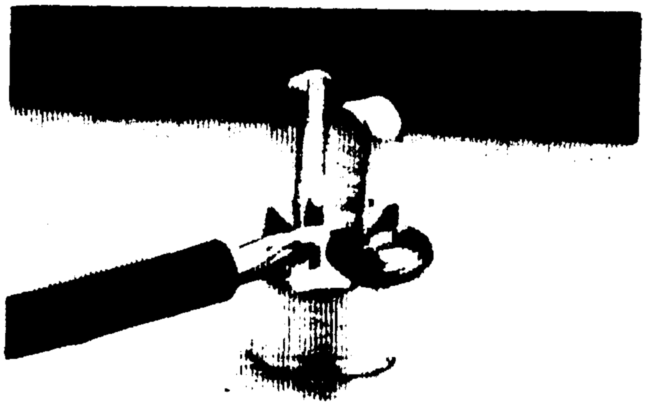
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 29. Bifurcated terminal, side route solder connection (continued).

MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.

OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.

MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 29. Bifurcated terminal, side route solder connection (continued).

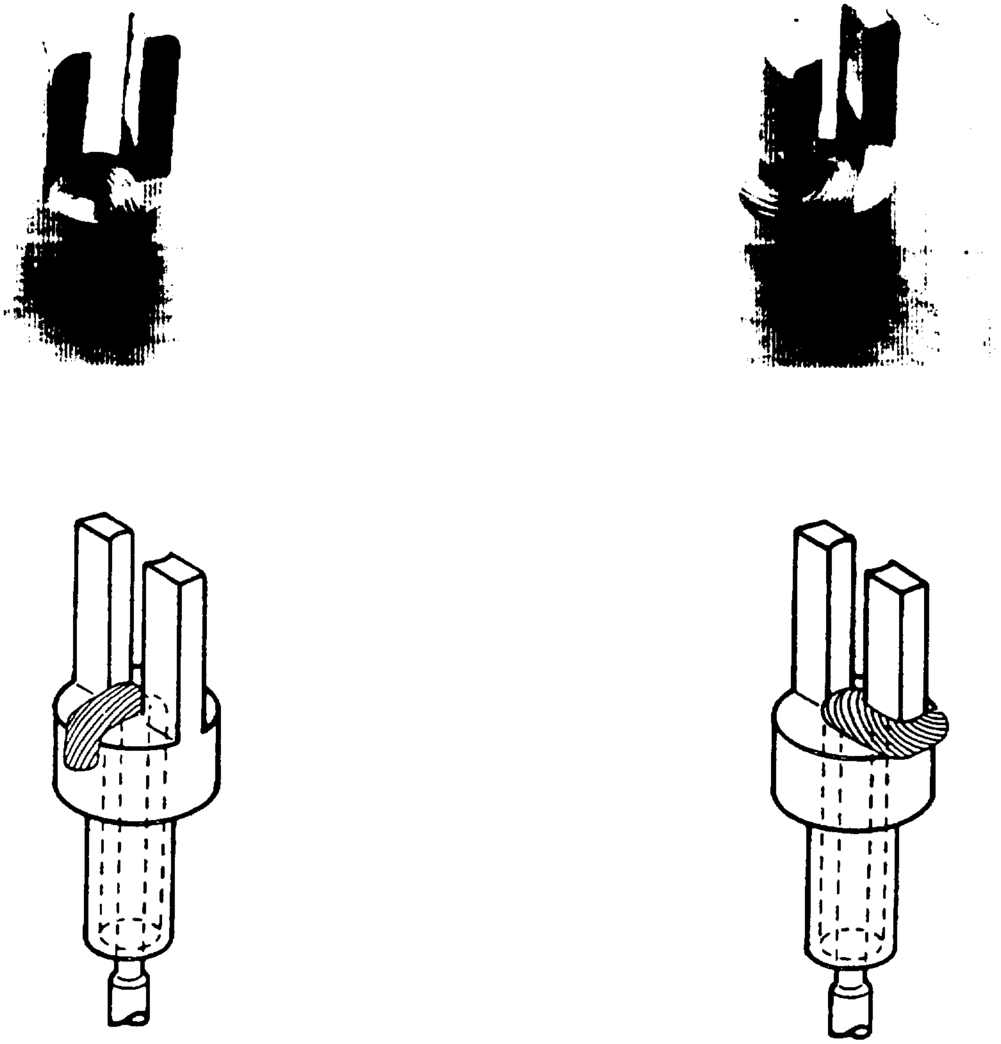


FIGURE 30. Bifurcated terminal, bottom route wire wrap.

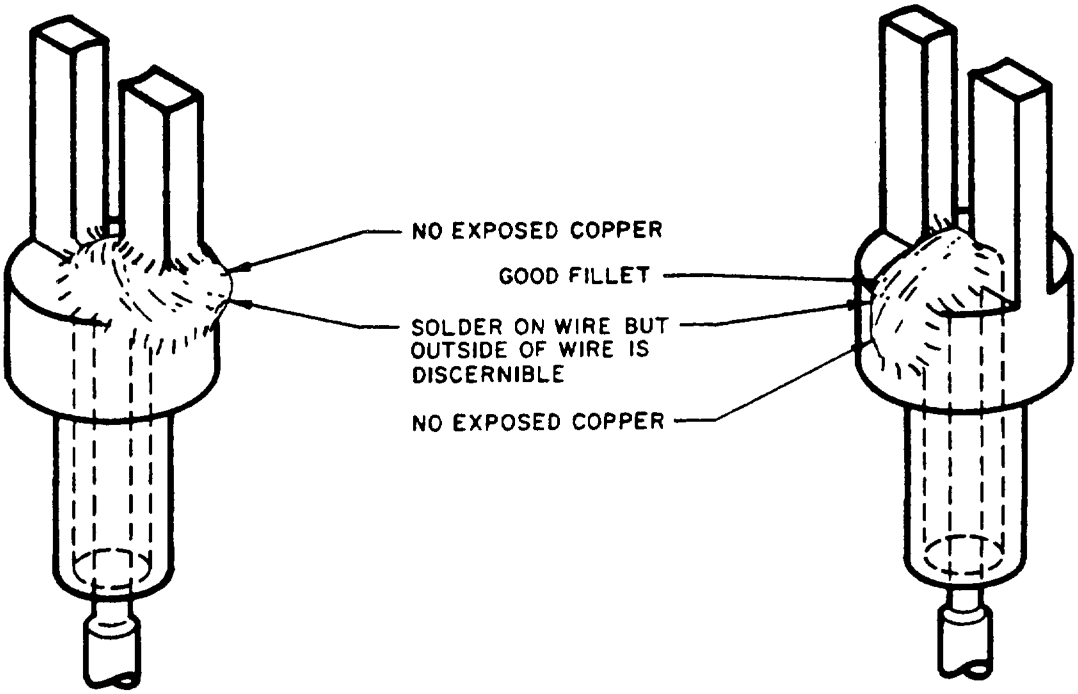


FIGURE 31. Bifurcated terminal, bottom route solder connection.

8.3.2.2 Solvent evaporation. The evaporation of volatiles off the assembly prior to its passing across the solder wave minimizes the amount of solder spattering as the assembly crosses the wave. Excessive preheating can cause the flux to become too thick or hard due to polymerization, creating wetting problems as the flux resists replacement by the solder and subsequent cleaning problems when trying to remove flux residues.

8.3.2.3 Lessening of thermal shock. A sharp temperature gradient between the top and bottom of the printed wiring board can cause the board to warp. The preheat step using both top and bottom preheats heats the board more slowly than simply running it across the wave, and reduces the temperature difference between the top and the bottom of the board when it contacts the hot solder.

8.3.2.4 Reduction of time in the wave. Preheating brings the temperature of the connections closer to the wetting temperature, reducing the time in the wave before the solder begins wetting the connections.

8.3.2.5 Preheat temperature. The preheat temperature should fall in the range of 72° to 105°C (160° to 220°F). Thin printed wiring assemblies such as flexible circuits and single-sided boards would be preheated in the lower end of the range, while thicker boards, such as double-sided and multilayer boards may require the higher preheat temperatures.

8.3.2.5.1 Measuring preheat temperature. Temperature is measured in a bare area near the center of the board. Devices which may be used to determine preheat temperature include heat sensitive pigment, a temperature sensing stick which melts at a given temperature, a thermocouple, or an Infrared temperature probe. A disadvantage of the thermocouple is that it must be attached to the board to determine the temperature of the board.

8.3.2.6 Preheat equipment. The preheat can be delivered to the board by several means, including top and/or bottom radiation, hot plates, forced hot air, and infrared. Heating units residing below the conveyor will have flux dripping on them and must be maintained or protected to insure cleanliness. Reflectors can be lined with aluminum foil, which is easily replaced, if it is not a safety hazard or violation of manufacturing instructions.

8.3.3 The solder wave. The solder wave completes the operation by providing the additional heat necessary for final activation of the flux and wetting with the molten solder. Solder wave variables which must be controlled include temperature, wave height, stability, parallelism with the board and contact time.

8.3.3.1 Wave shape. The wave shape is defined by the flow pattern and the characteristics by which the wave is discharged from the nozzle. Solder waves can generally be categorized as a parabolic wave, a bidirectional wide wave or an asymmetrical or supported wave.

8.3.3.1.1 Parabolic wave. The prabolic wave has solder flowing in only one direction, opposite that of the board travel, and as the name implies, in the shape of a parabola.

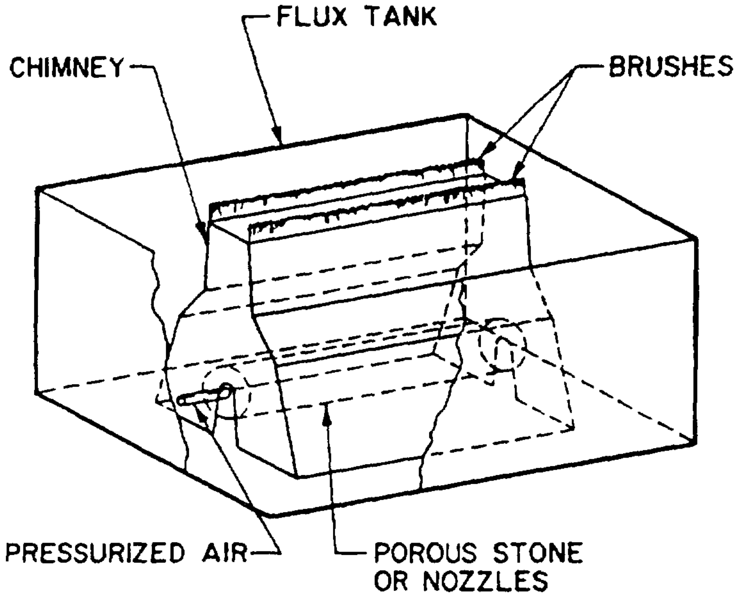


FIGURE 20. Foam fluxer (see 8.3.1.1).

c. Uniform air pressure is required for consistent foam height. The air pressure regulators should be checked occasionally.

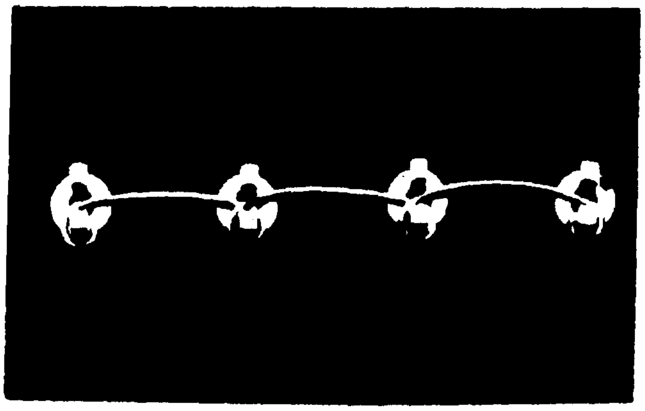
d. Specific gravity of the flux should be adjusted at least twice each shift. The foam fluxer should be covered when not in use to prevent thinner evaporation.

8.3.1.2 Wave fluxing. A wave fluxer consists of a trough through which liquid flux is pumped. The boards are transported through the wave by the conveyor.

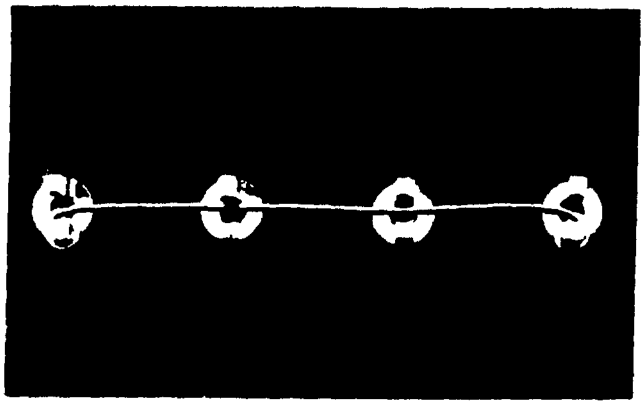
8.3.1.3 Spray fluxing. A spray fluxer consists of a rotating cylindrical screen partially submerged in liquid flux. An air nozzle blows the flux from the screen to the work. The flux quantity is controlled by the air pressure, screen rotation speed and flux solids content. The overspray from the fluxer is lost and can create problems maintaining machine cleanliness.

8.3.2 Preheat. The preheat step has four functions: activation of the flux, evaporation of the flux solvents, lessening of the thermal shock on the board and components and reduction of time in the solder wave.

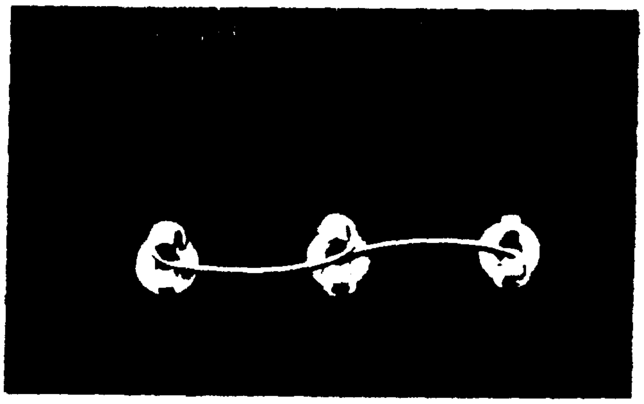
8.3.2.1 Flux activation. Rosin flux does not become active until it reaches a temperature of approximately 80°C (175°F). This allows the flux to sit on the board a short time without attacking it, until the preheat step partially activates it just prior to passing through the wave.



Continuous run wire wrap using solid jumper wire



Alternate method of continuous run wire wrap



Individual wire wrap using solid jumper wires

FIGURE 32. Bifurcated terminal, continuous run wire wrap methods (continued).

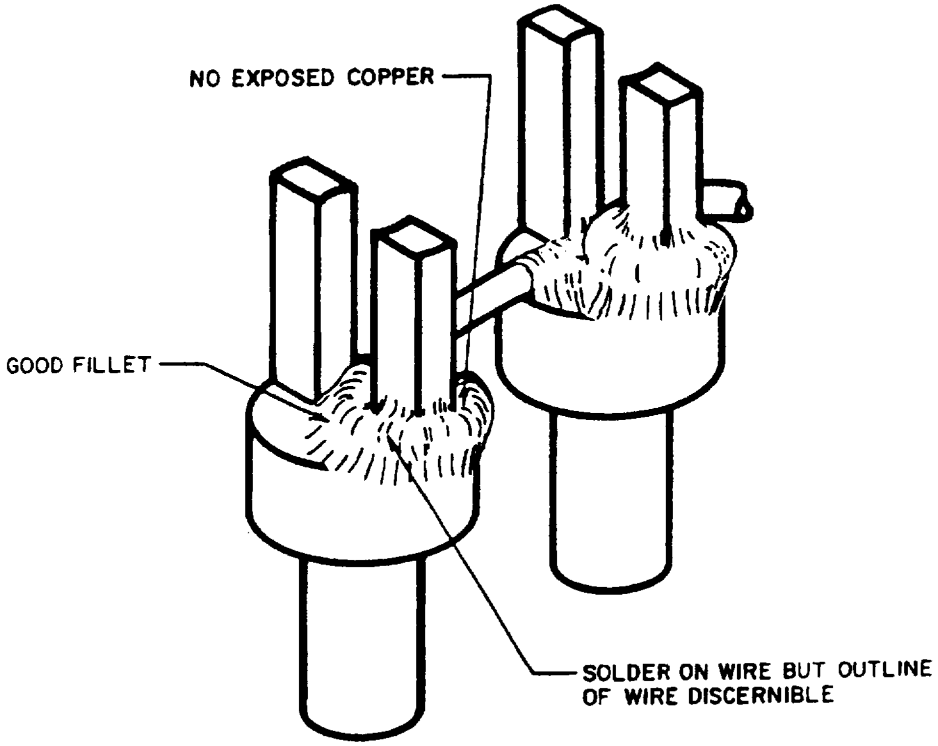
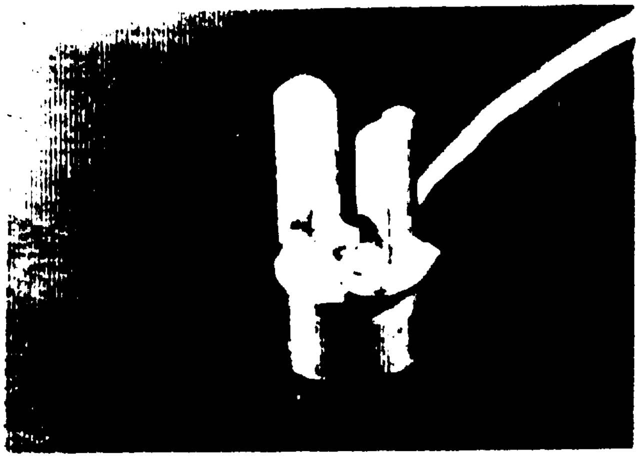
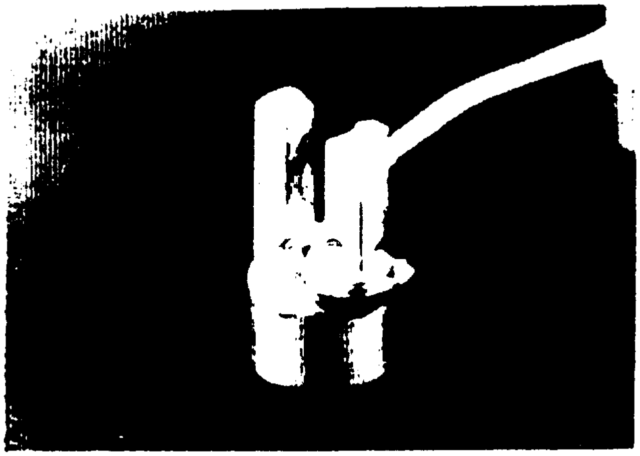


FIGURE 33. Bifurcated terminal, continuous run wire wrap, solder connection.



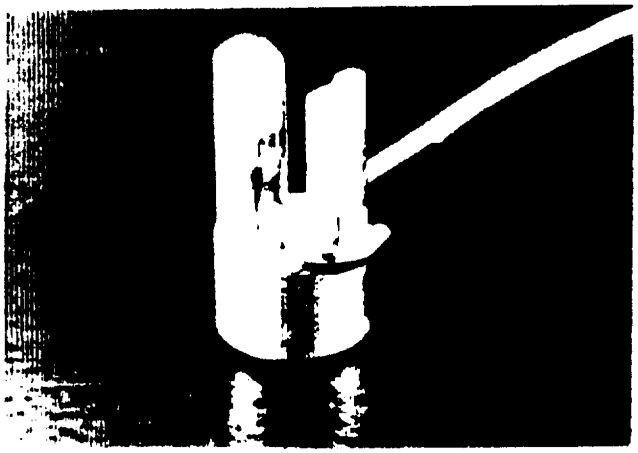
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 33. Bifurcated terminal, continuous run wire wrap, solder connection (continued).

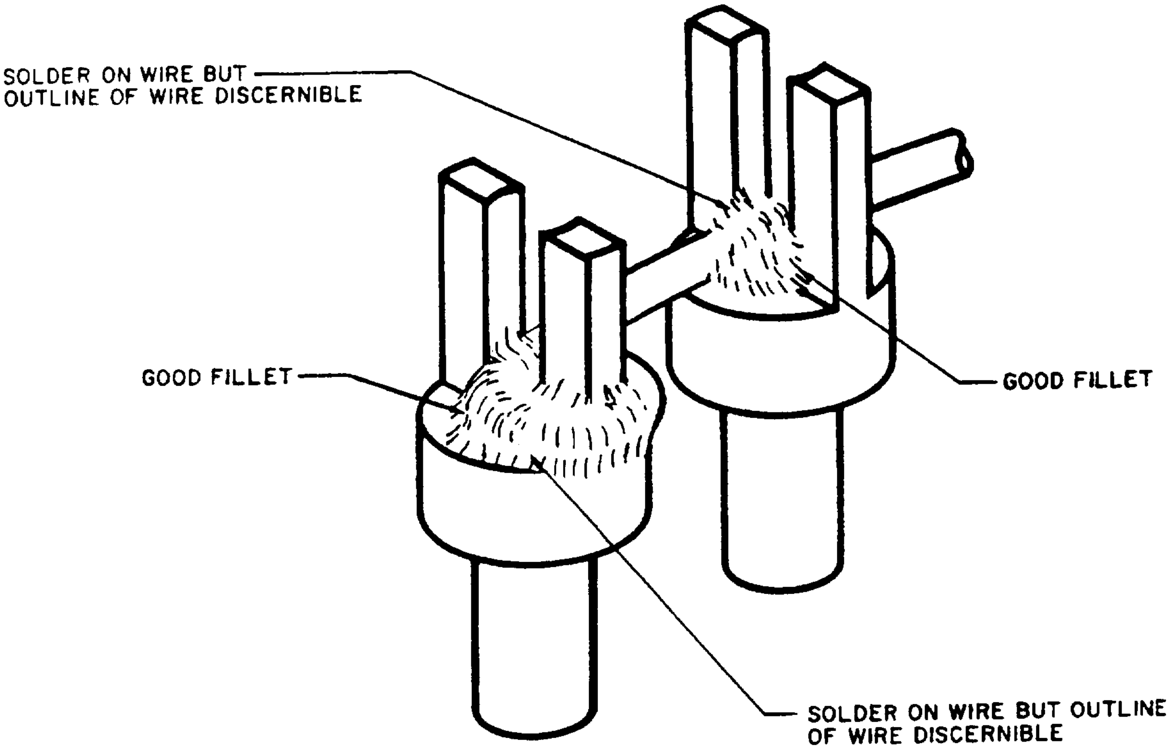
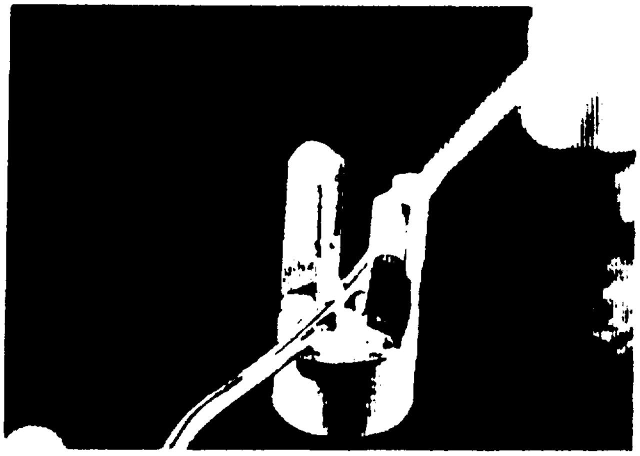
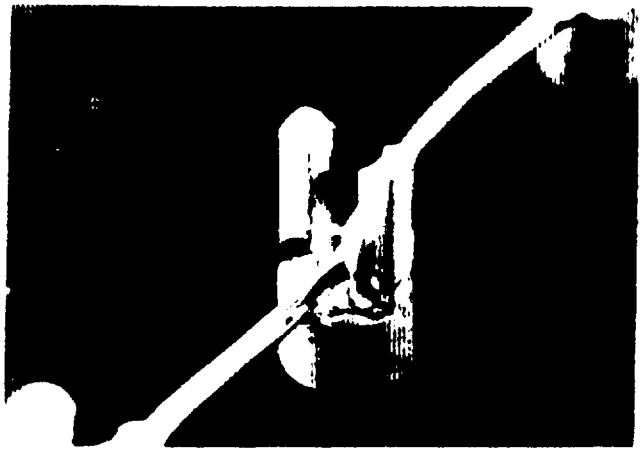


FIGURE 34. Bifurcated terminal, continuous run wire wrap, solder connection, alternate method.



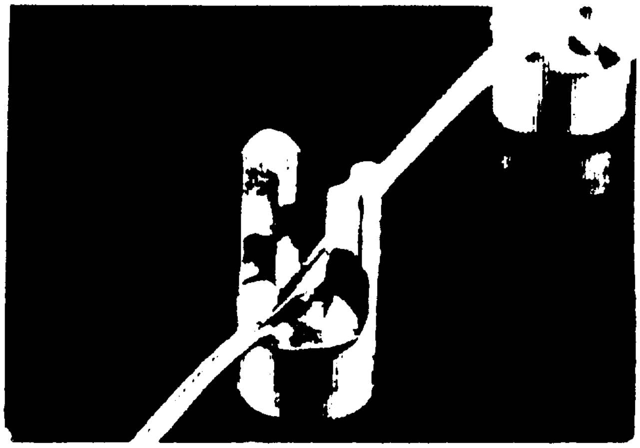
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 34. Bifurcated terminal, continuous run wire wrap, solder connection, alternate method (continued).

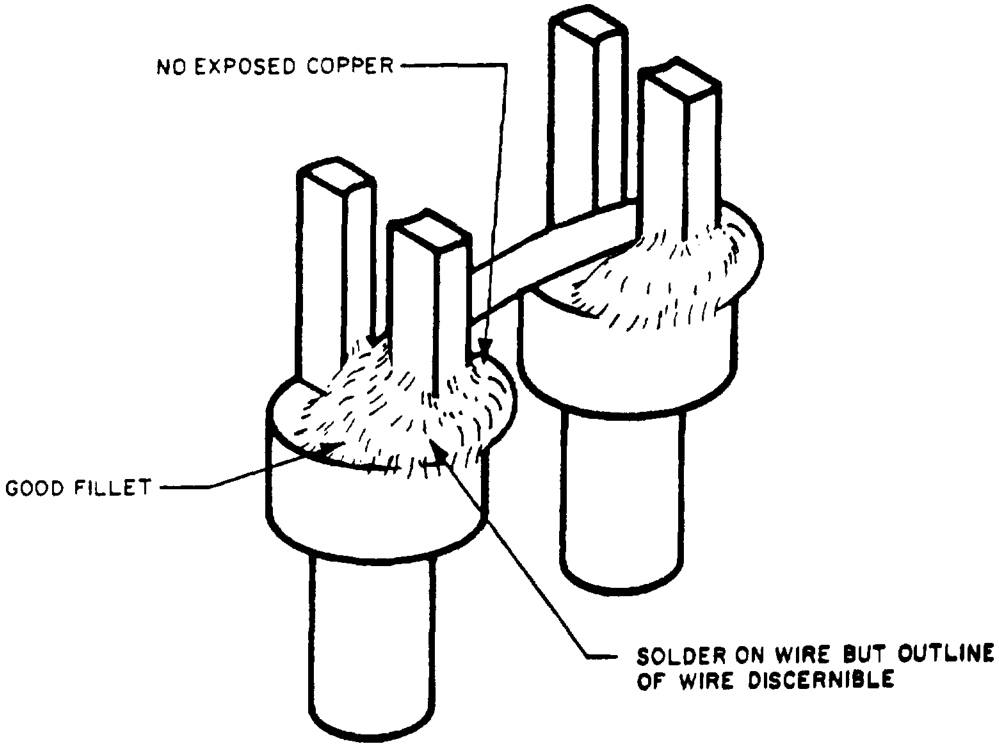
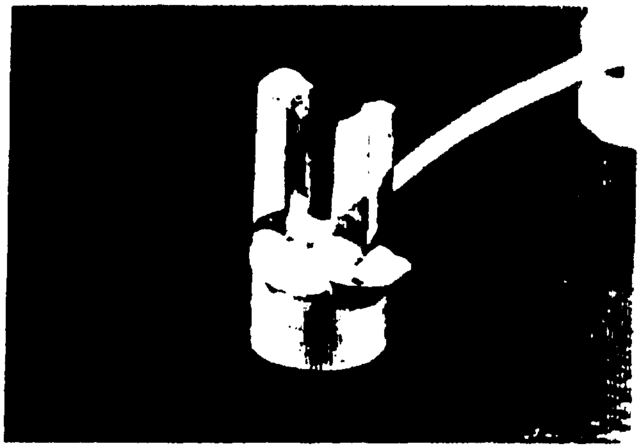
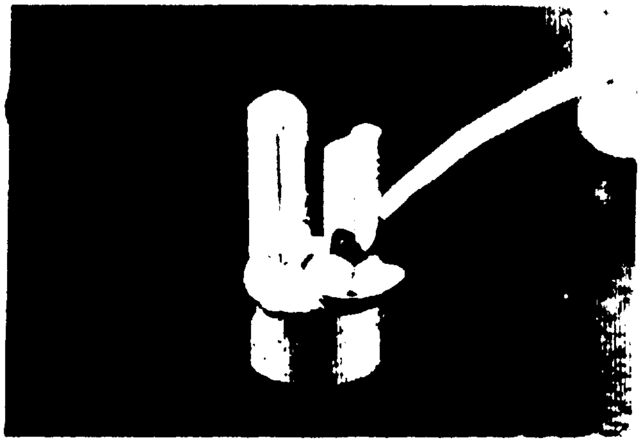


FIGURE 35. Bifurcated terminal, individual run wire wrap, solder connection.



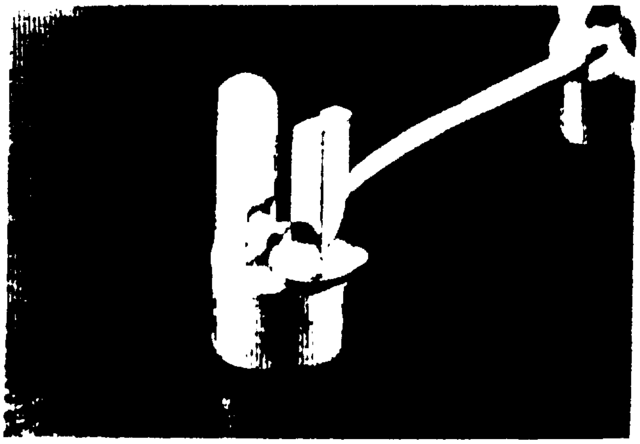
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 35. Bifurcated terminal, individual run wire wrap, solder connection (continued).

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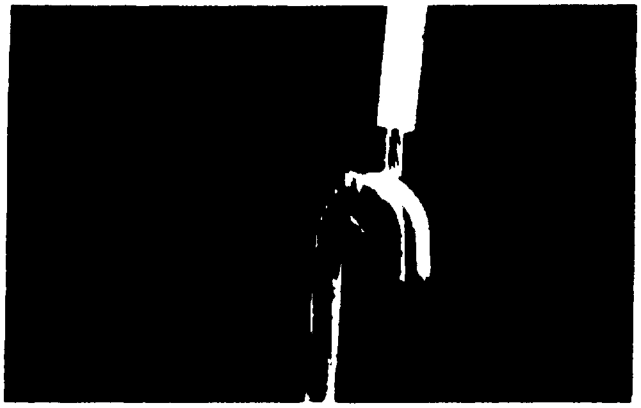
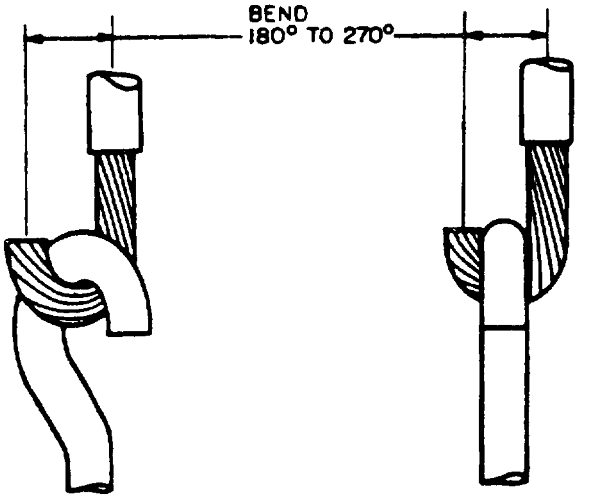
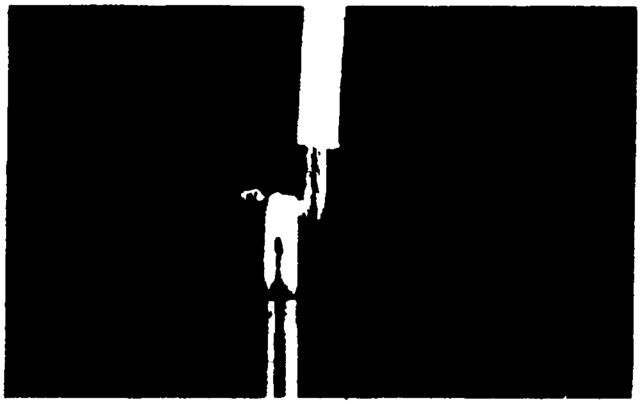


Single wire wrap

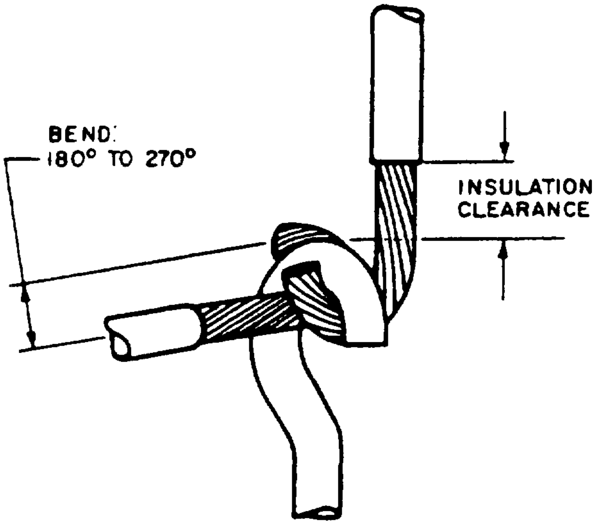


Single wire wrap



Single wire wrap

Double wire wrap



Double wire wrap

FIGURE 36. Hook terminal, wire connection methods.

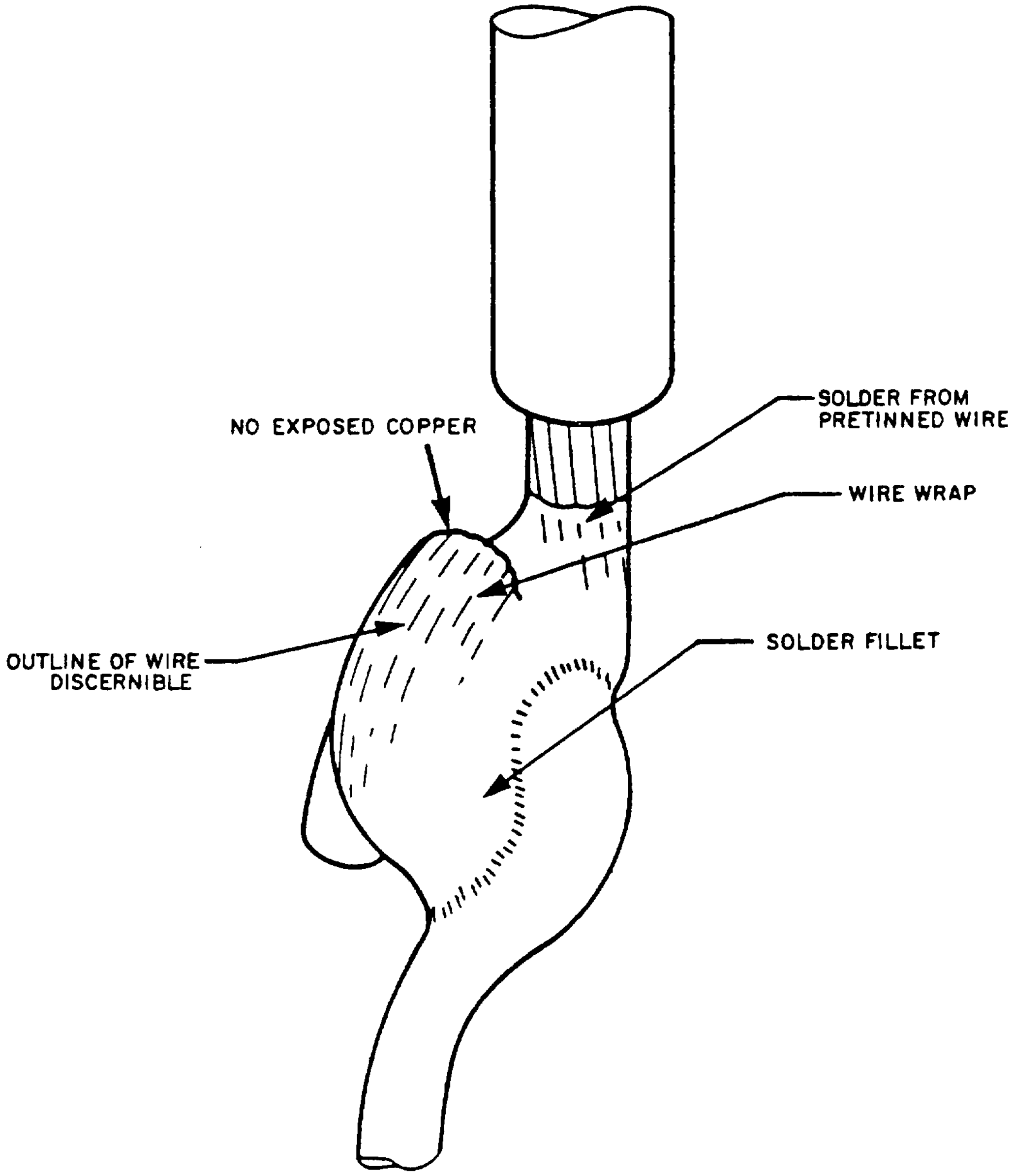
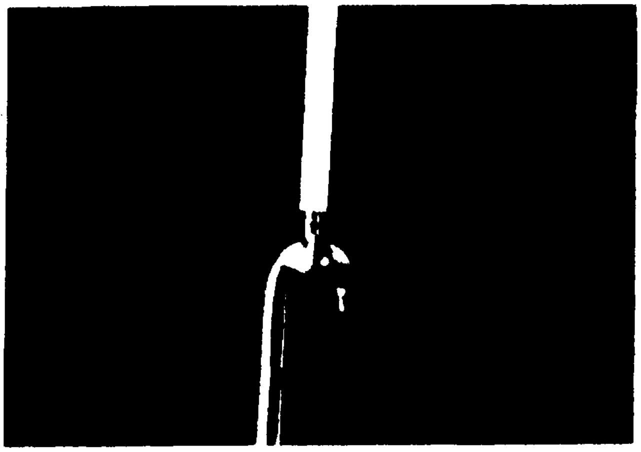
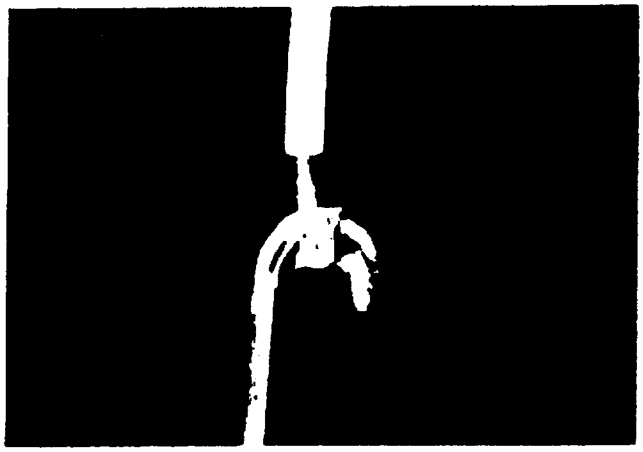


FIGURE 37. Hook terminal, solder connection.



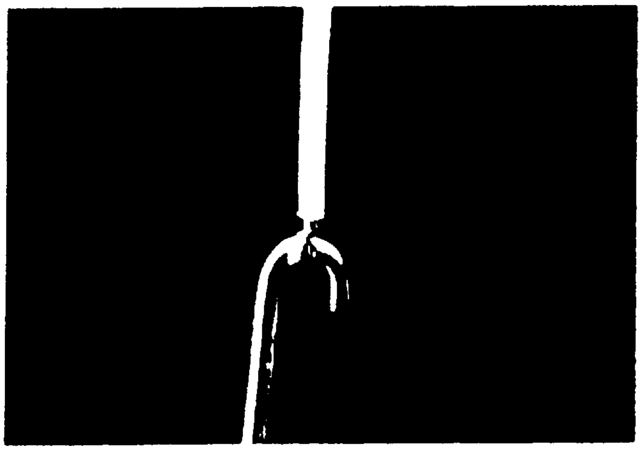
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 37. Hook terminal, solder connection (continued).

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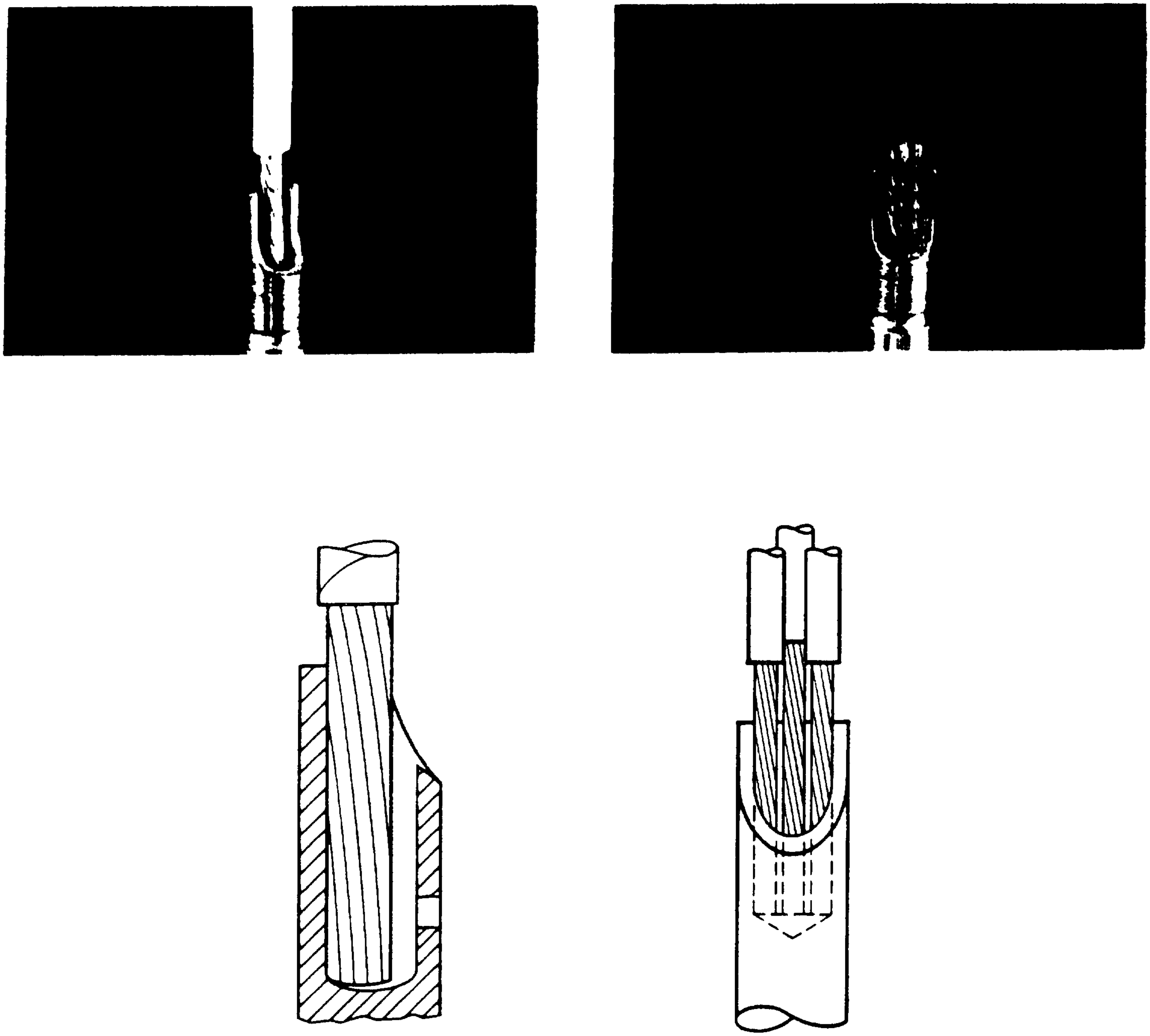


SINGLE WIRE FILL

MULTIPLE WIRE FILL

FIGURE 38. Cup terminal, wire insertion.

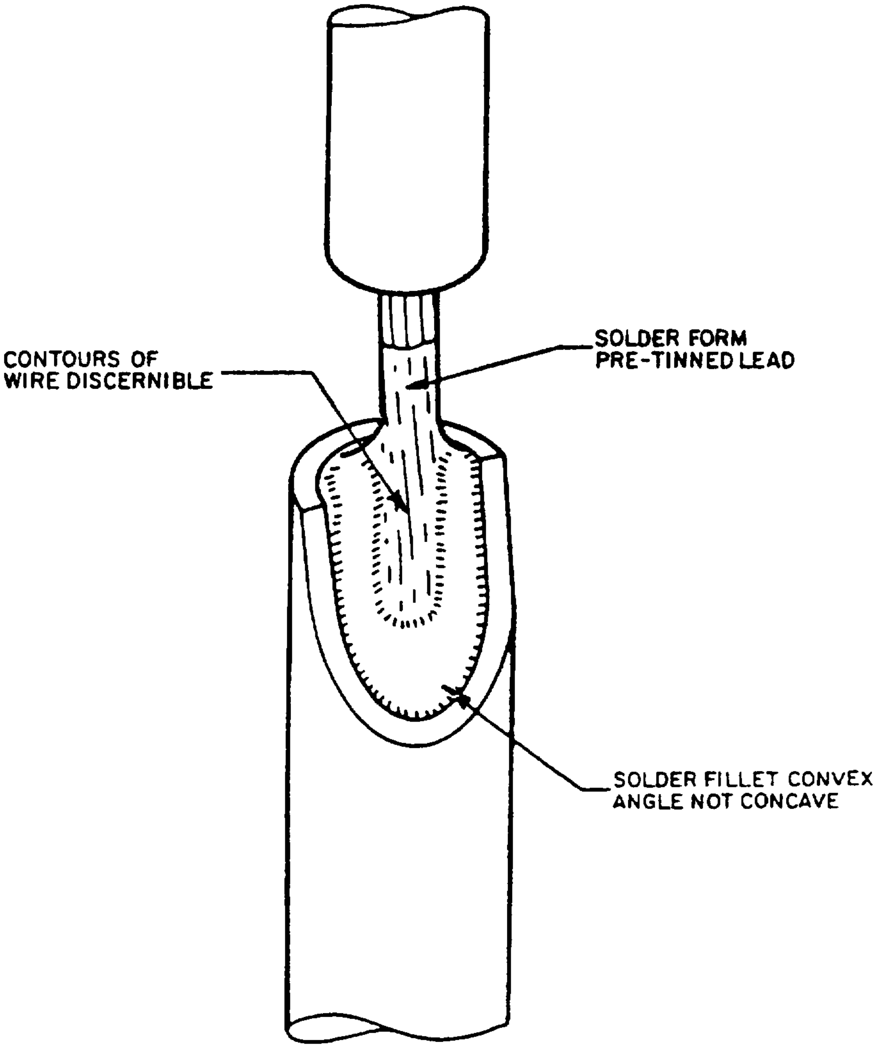
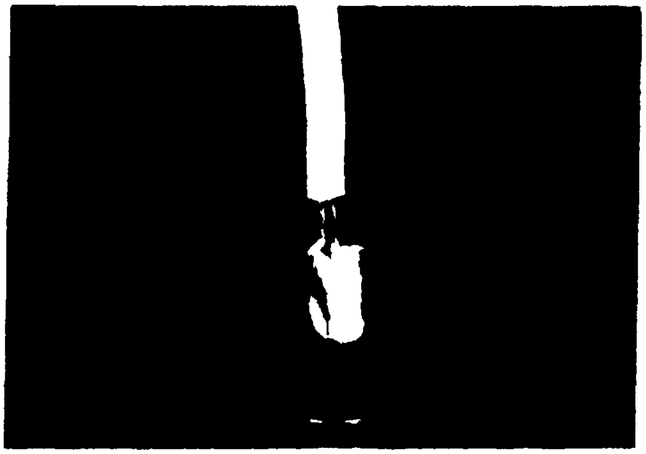
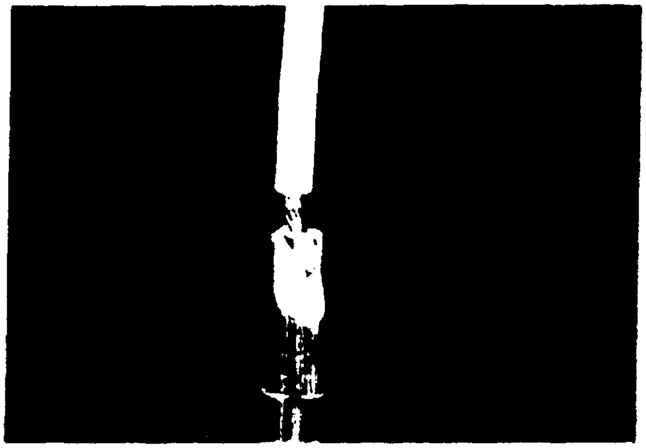


FIGURE 39. Cup terminal, solder connection.



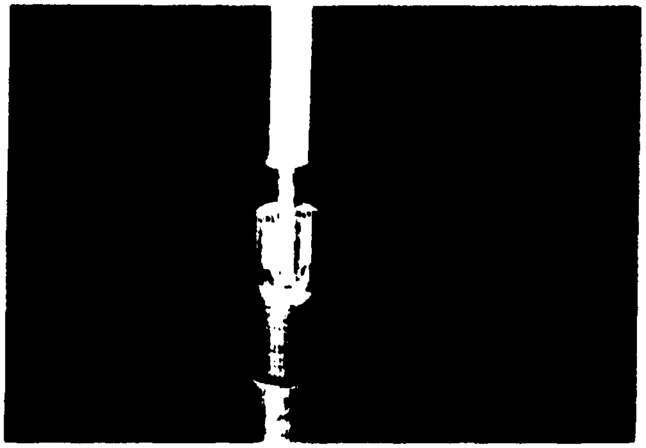
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting. Wire completely obscured by solder, but solder does not extend beyond cup area.



OPTIMUM

Solder is smooth, bright, continuous and flows to front lip of terminal. Slight fillet above top of terminal to wire. No sharp protrusions or evidence of contamination. Contour of wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but minimal fillet extending to front lip of terminal. Solder within cup is level with lower lip.

FIGURE 39. Cup terminal, solder connection (continued).

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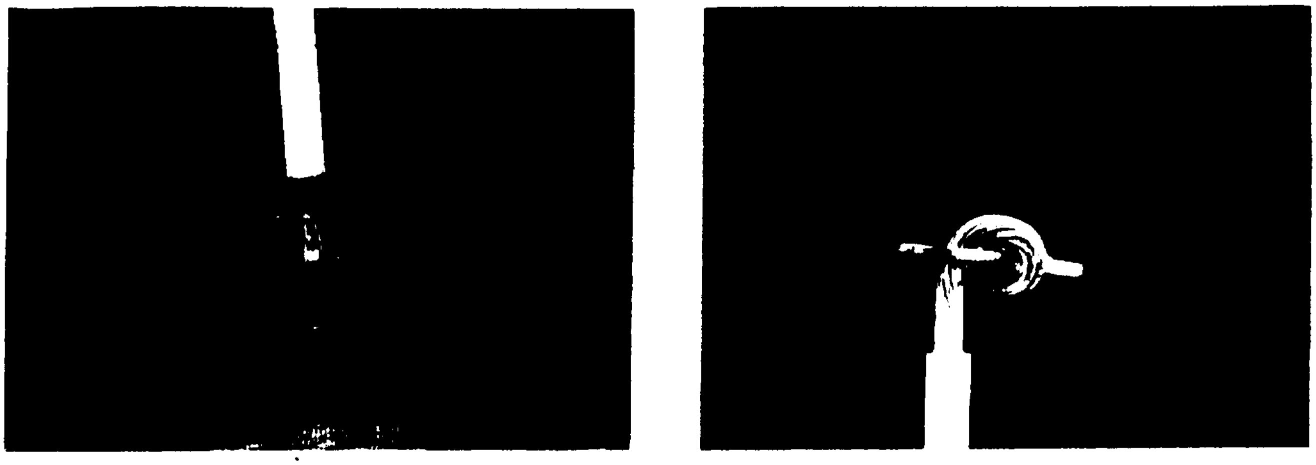


Pierced or perforated terminal
typical wire wrap

Pierced or perforated terminal
acceptable wire wrap
(alternate procedure)

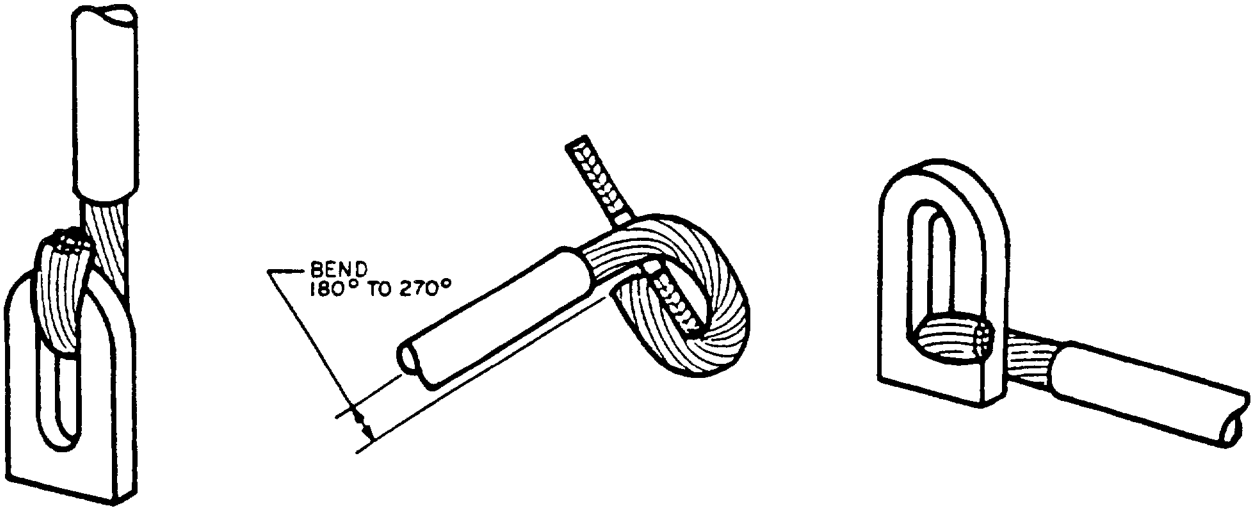


FIGURE 40. Pierced or perforated terminal, wire wrap.

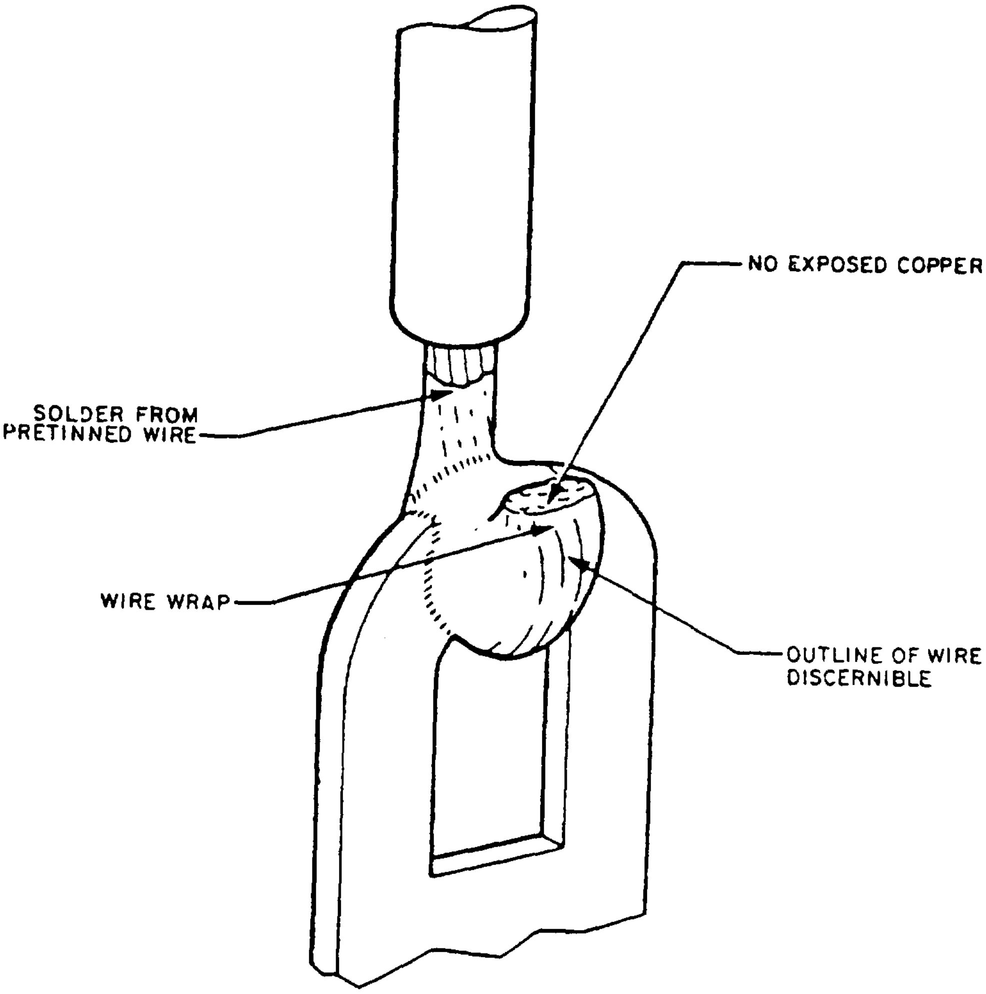
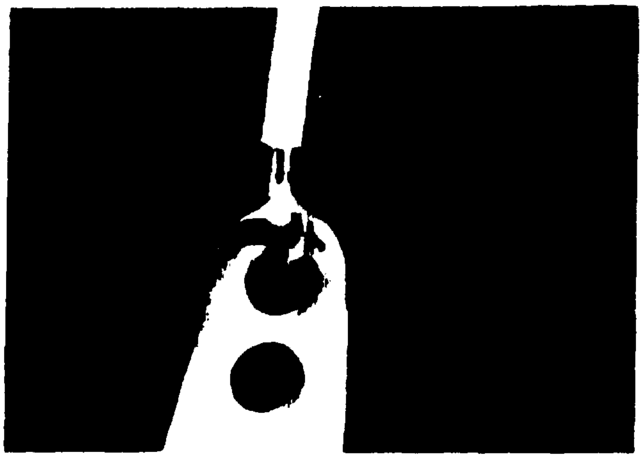
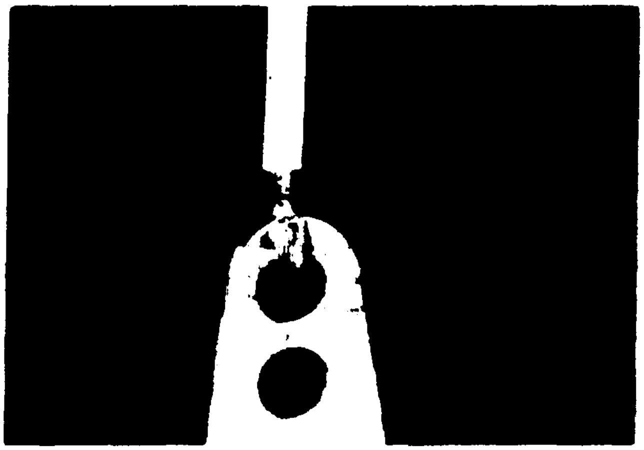


FIGURE 41. Pierced or perforated terminal, solder connection.



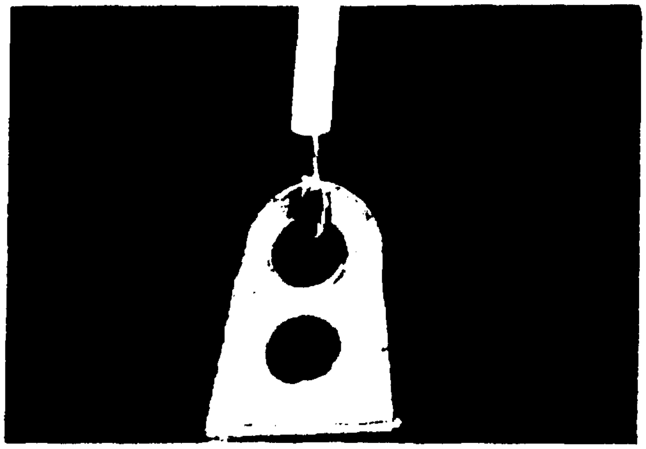
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 41. Pierced or perforated terminal, solder connection (continued).

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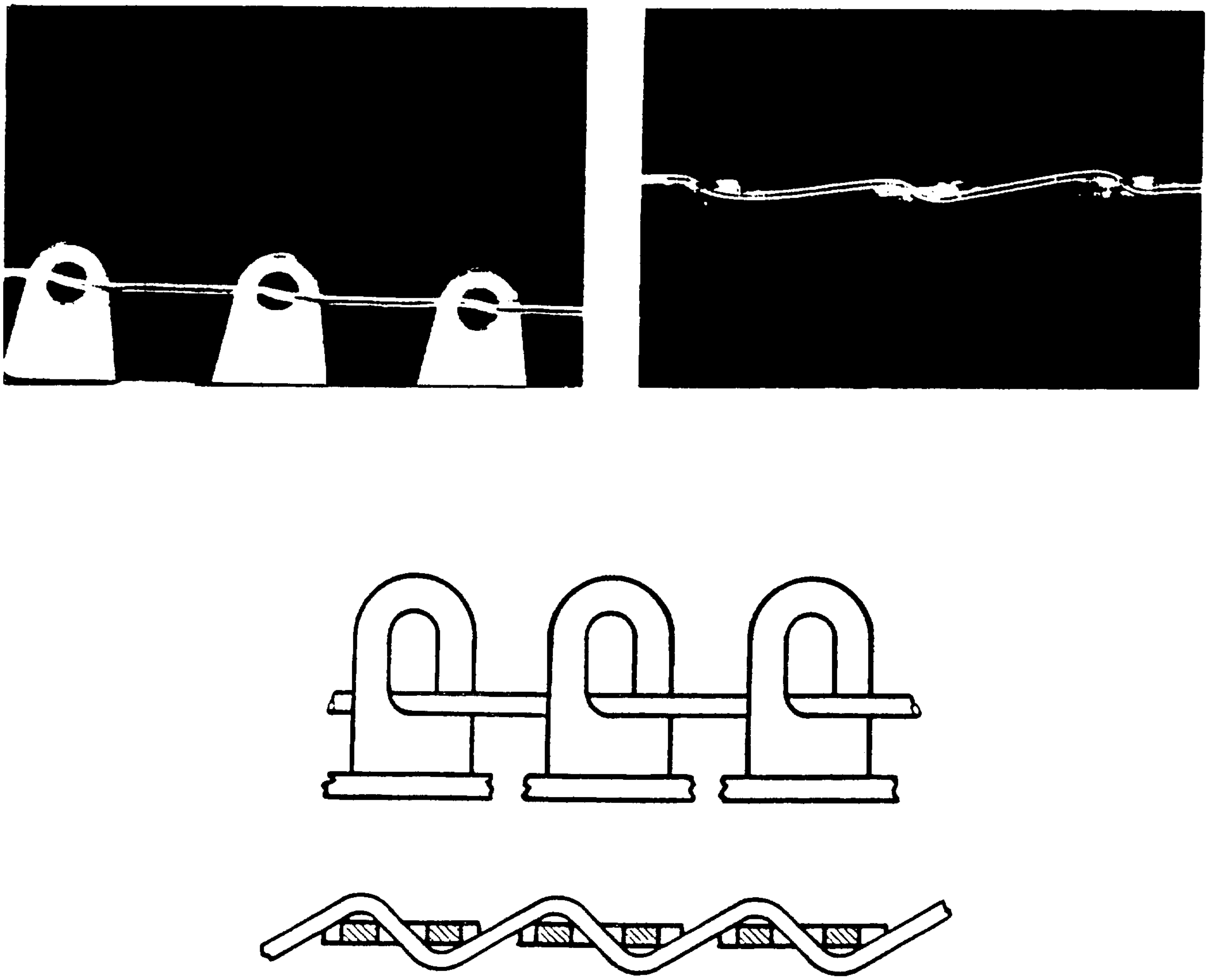


FIGURE 42. Pierced or perforated terminal, continuous run weaving.

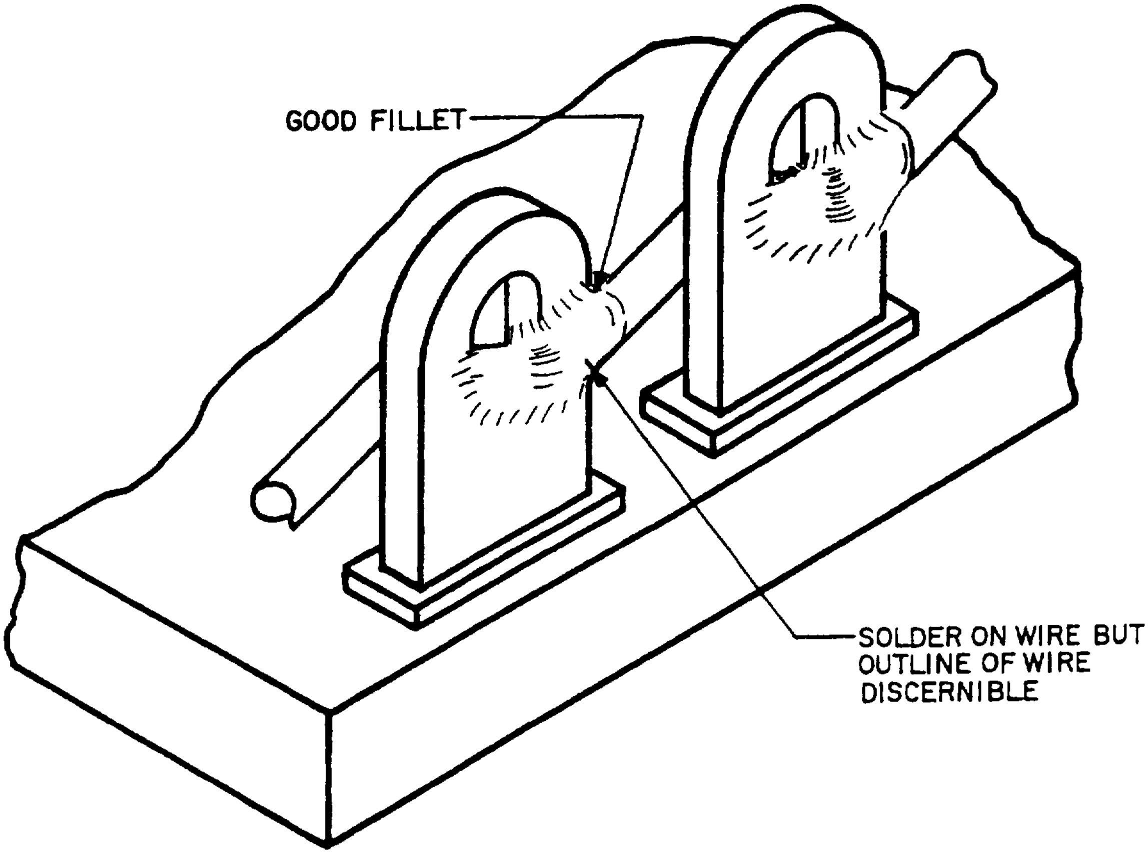
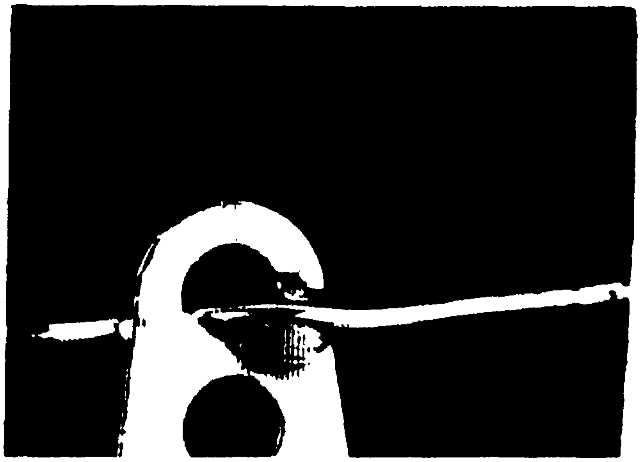
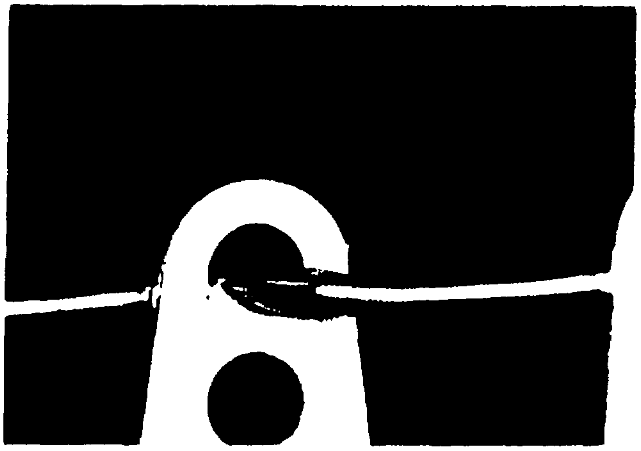


FIGURE 43. Pierced or perforated terminal, continuous run weaving, solder connection.



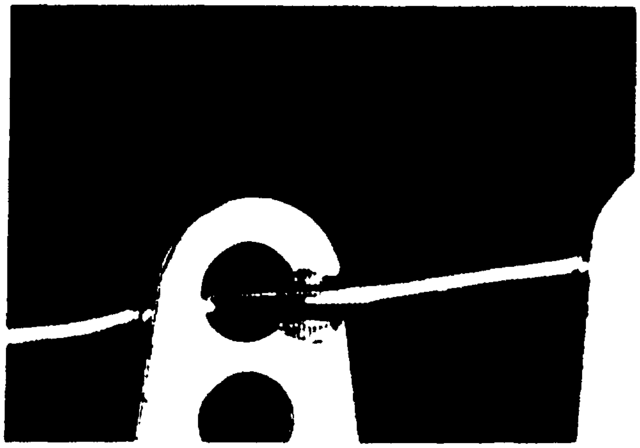
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 43. Pierced or perforated terminal, continuous run weaving, solder connection (continued).

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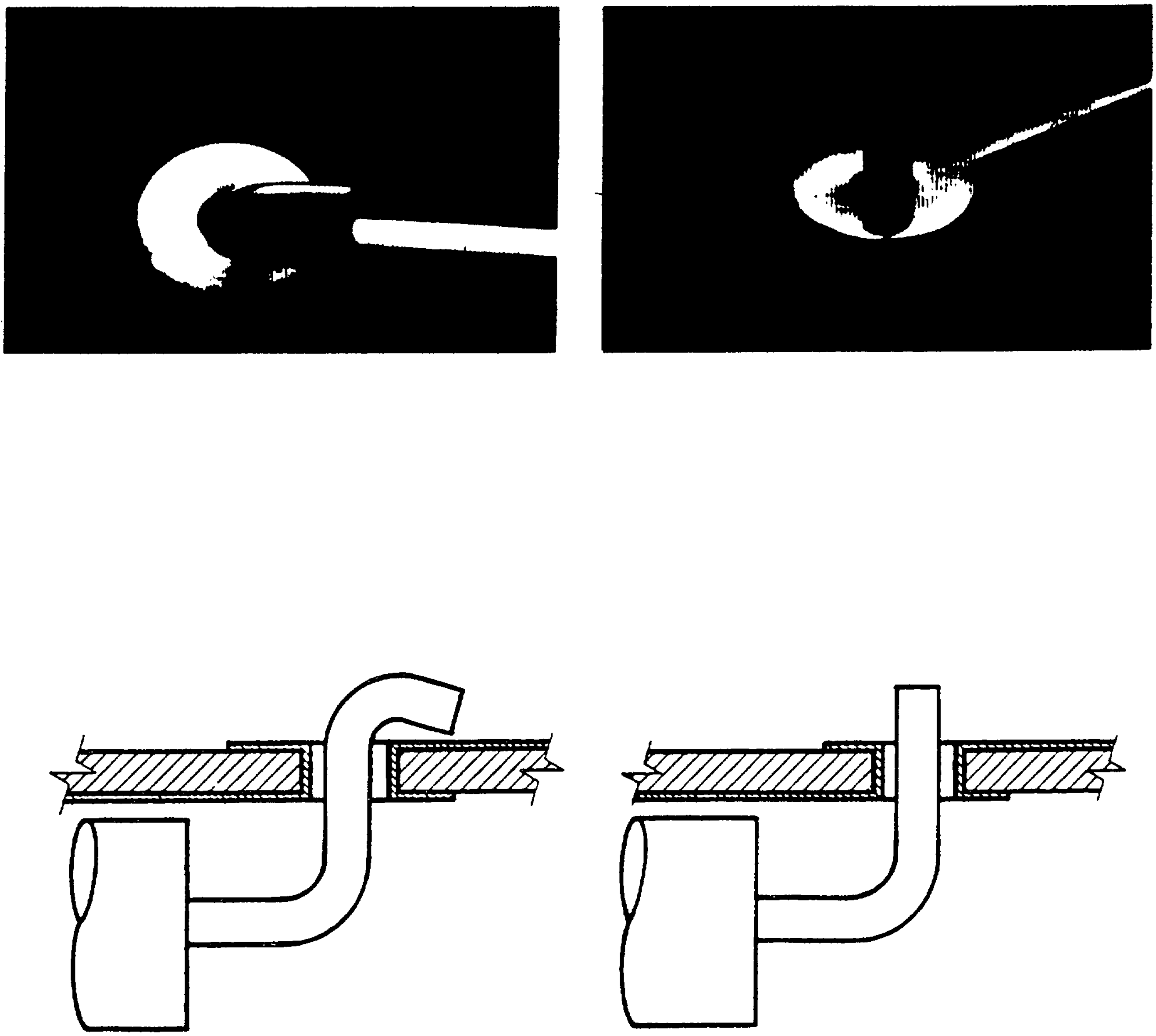


Clinched lead

Unclinched lead

FIGURE 44. Lead termination.

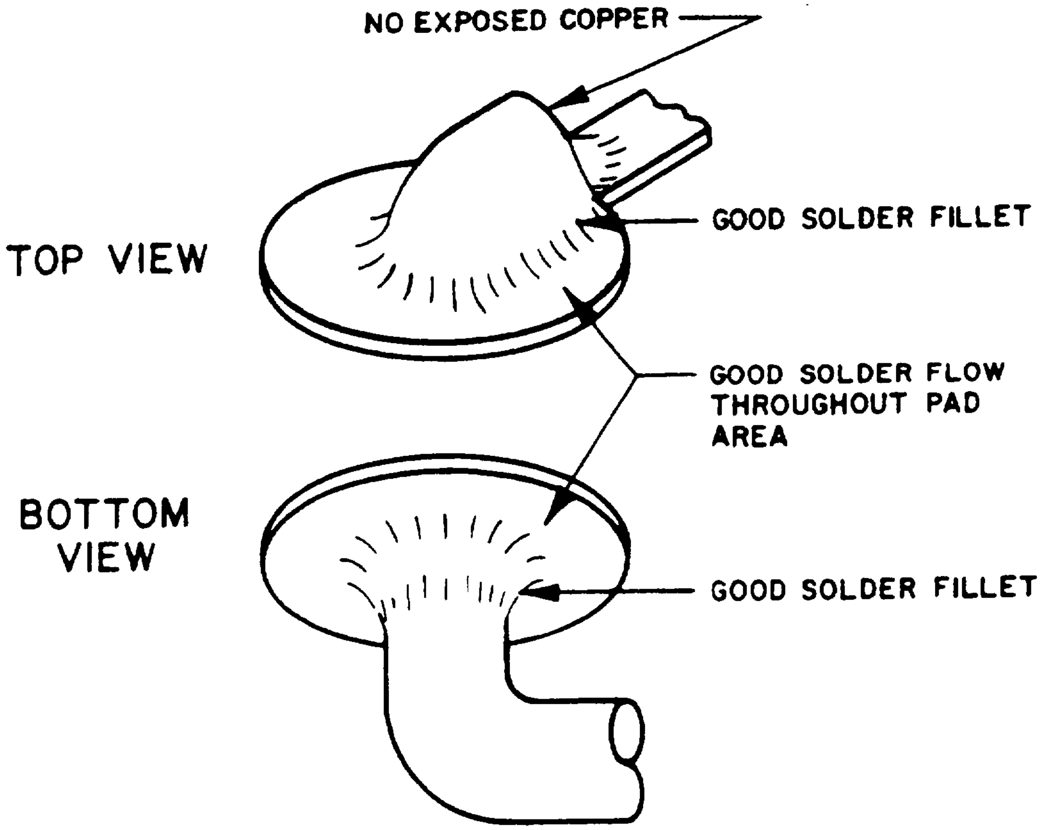


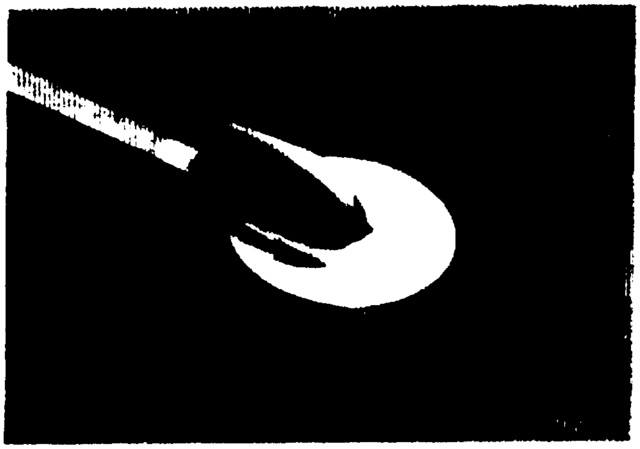
FIGURE 45. Clinched lead termination, solder connection.

MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.

OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 45. Clinched lead termination, solder connection (continued).

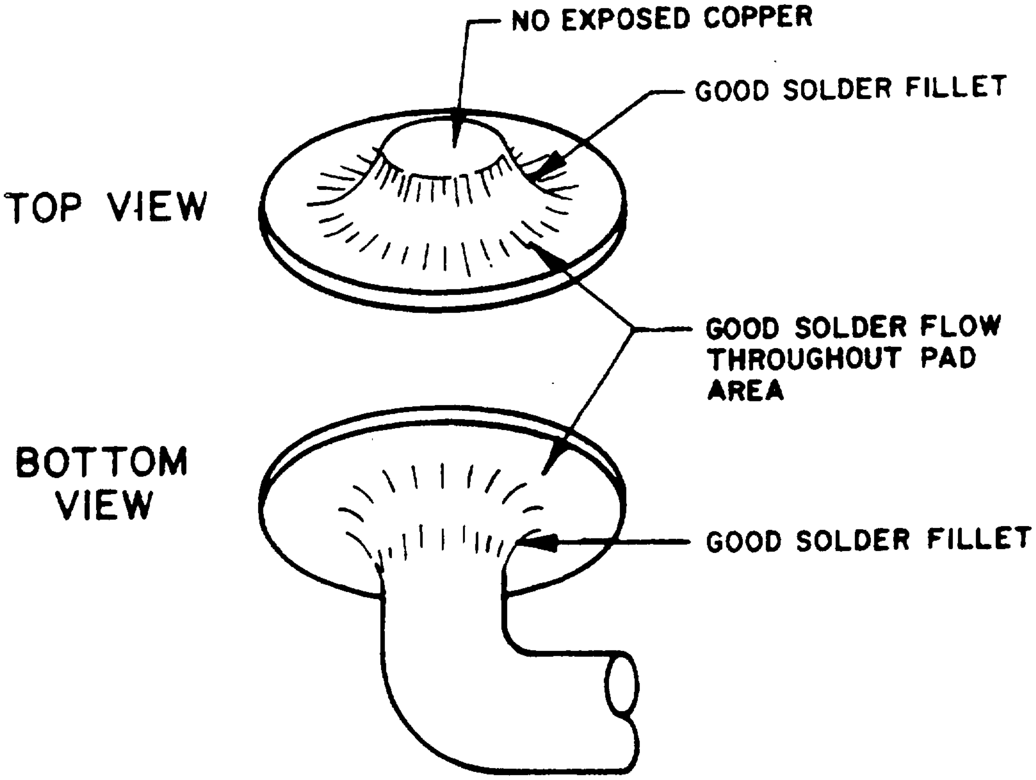
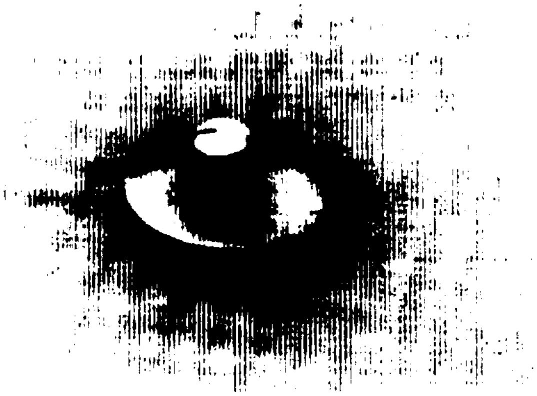
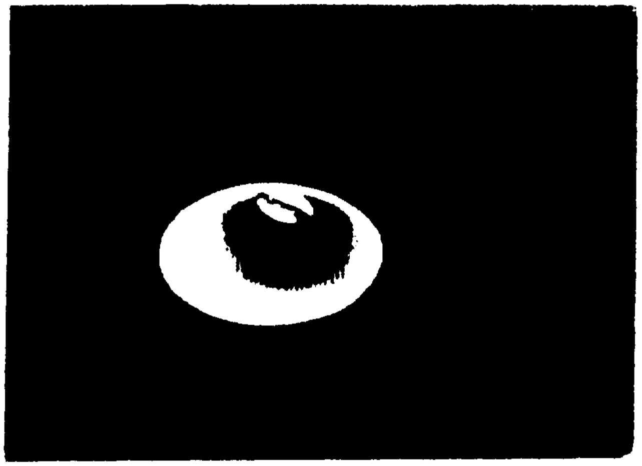


FIGURE 46. Unclinched lead termination, solder connection.



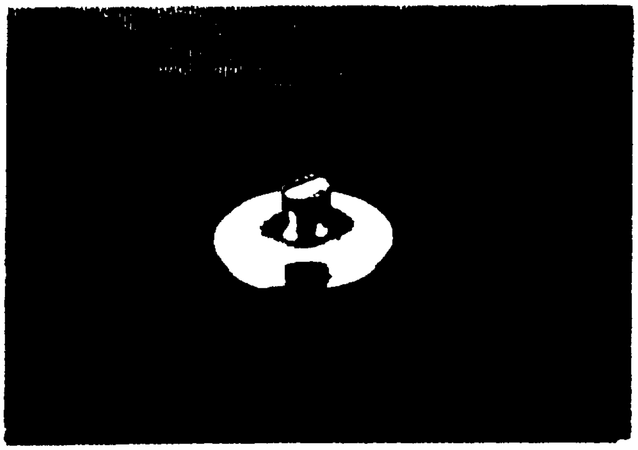
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



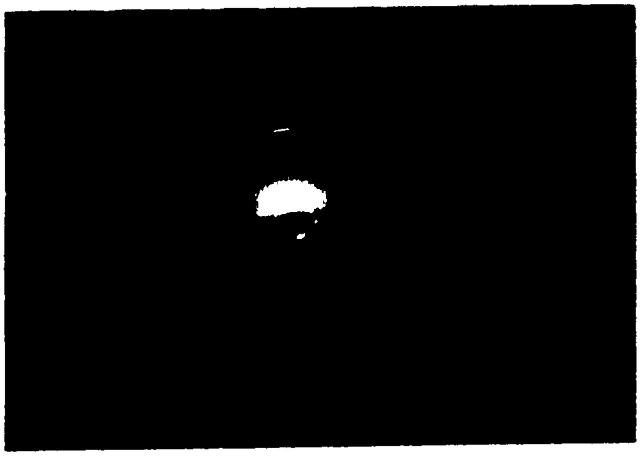
MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 46. Unclinched lead termination, solder connection (continued).

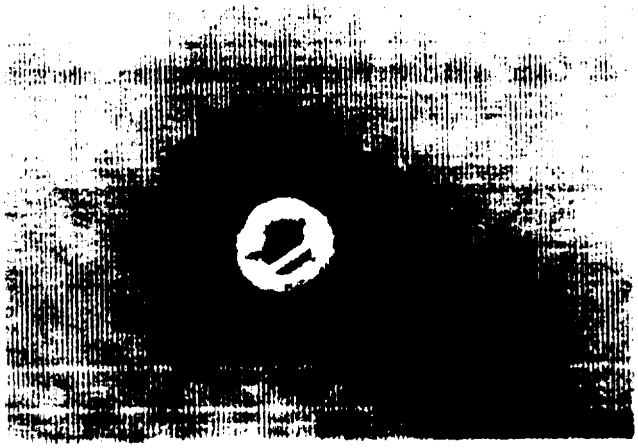
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of wire nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead or wire is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as wire.

FIGURE 46. Unclinched lead termination, solder connection (continued).

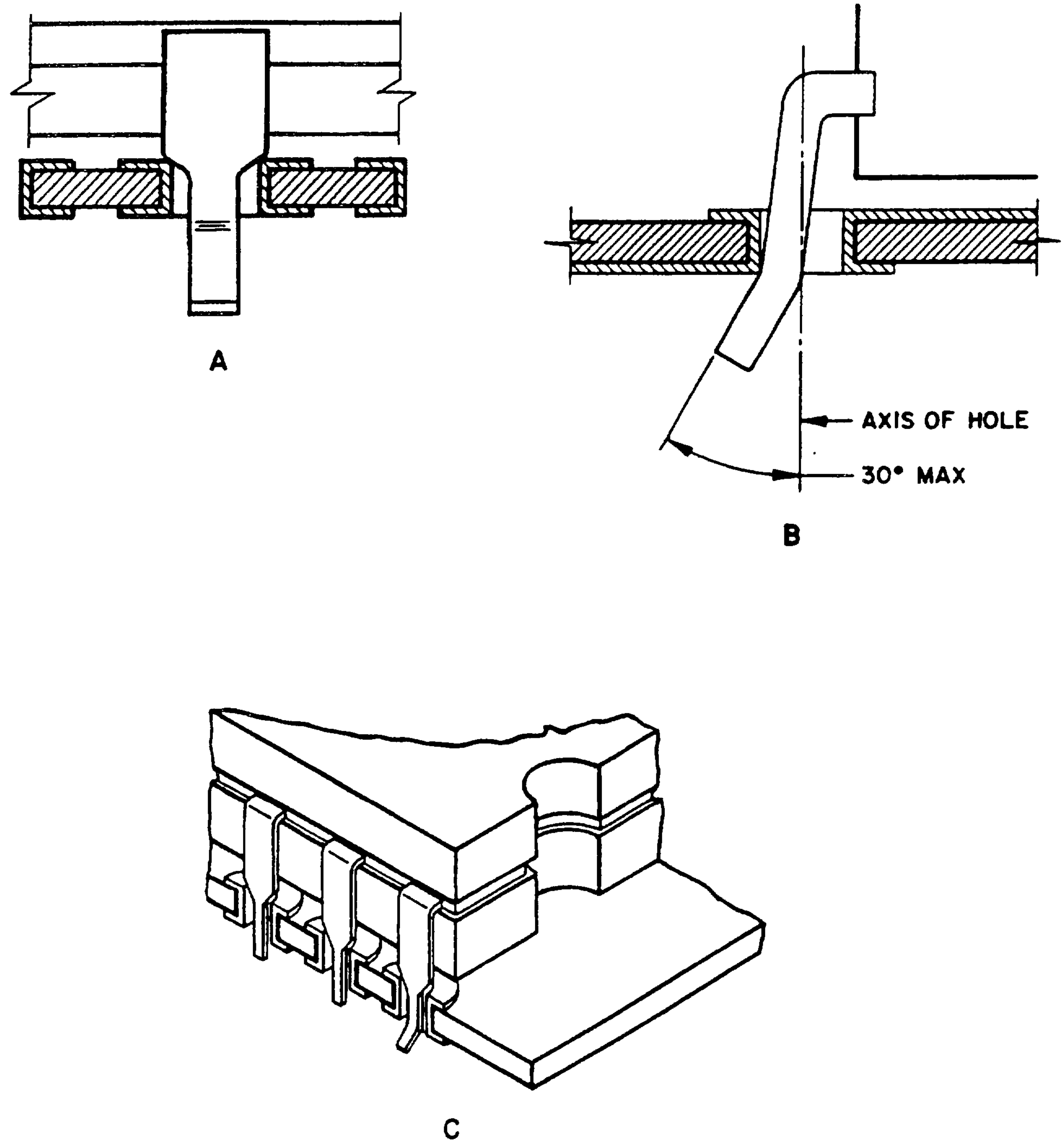


FIGURE 47. Dual-in-line package lead bend limits.

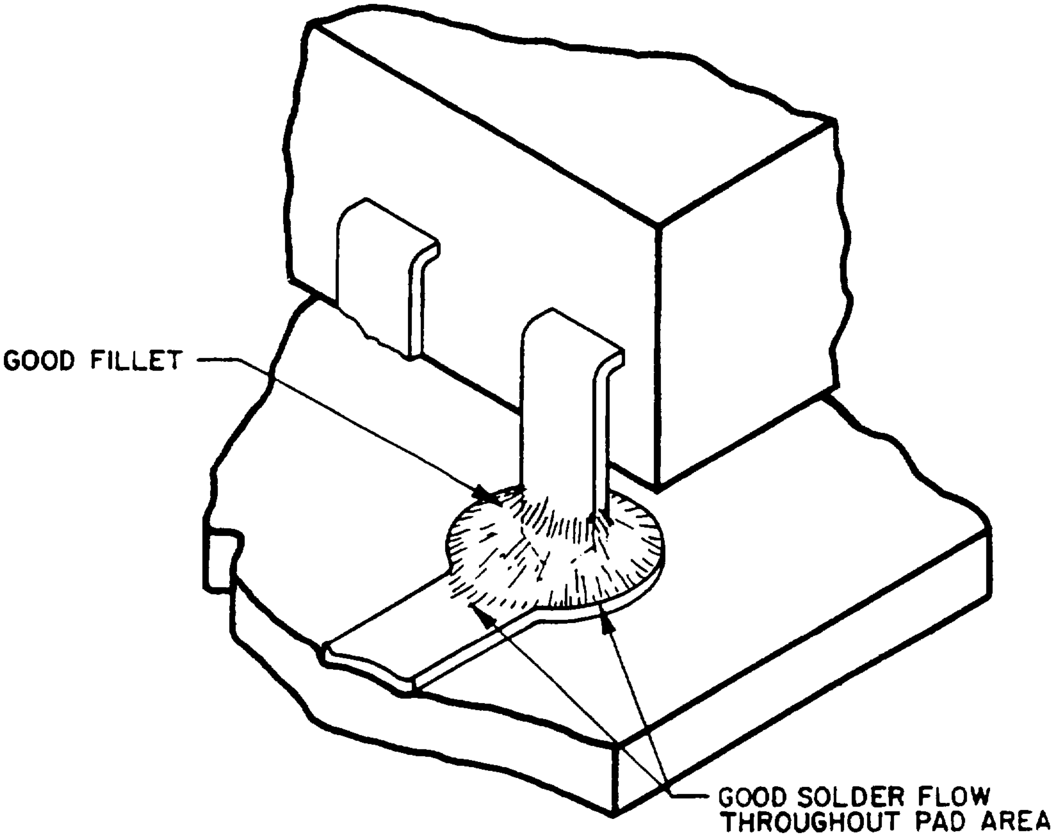
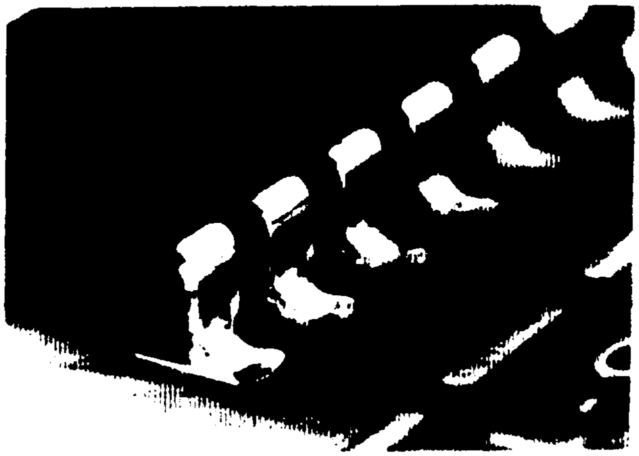


FIGURE 48. Dual-in-line package, solder connection.

MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of lead nearly obscured by solder.



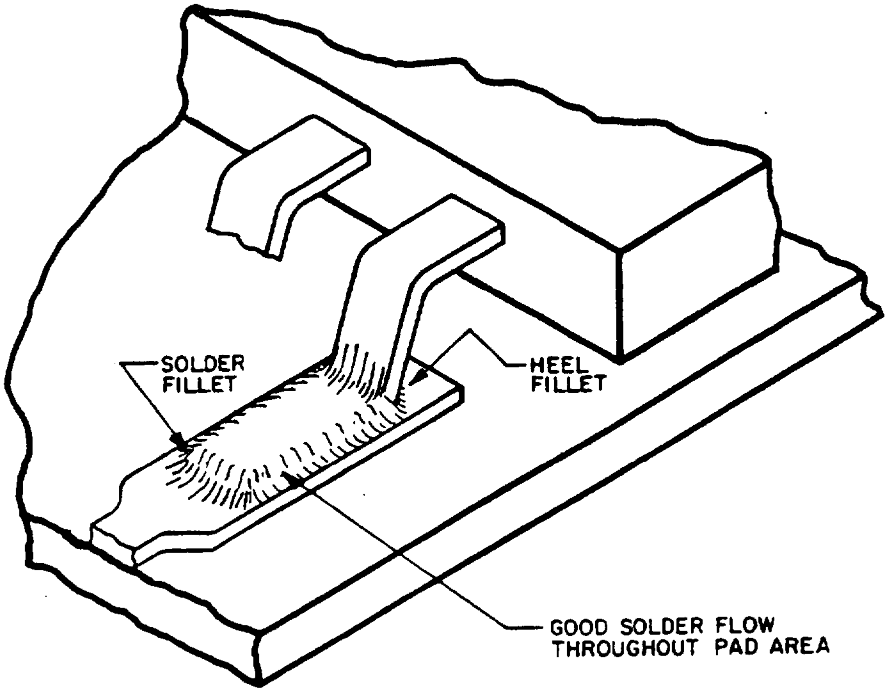
OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead is clearly discernible beneath solder.

MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as lead.

FIGURE 48. Dual-in-line package, solder connection (continued).

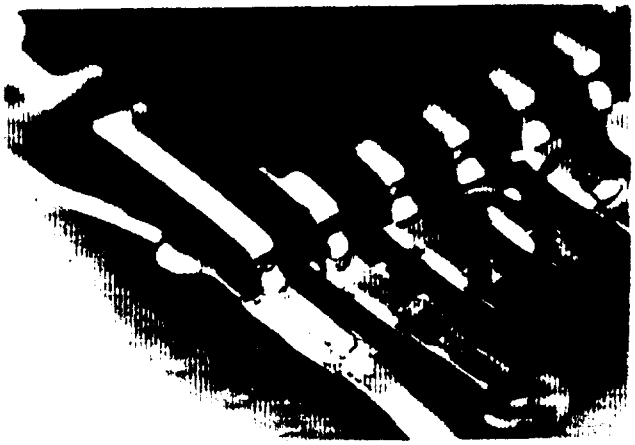


Hold down tool marks shall not be cause for rejection.

FIGURE 49. Flat pack device, solder connection.

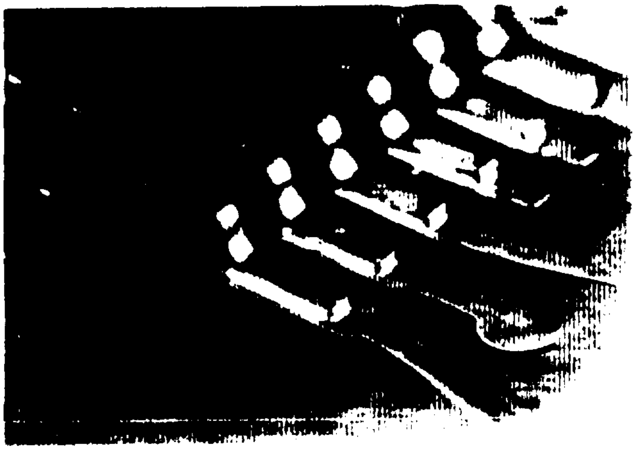
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of lead nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare lead material is exposed and there are no sharp protrusions or evidence of contamination. Contour of lead is clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet only as wide as lead.

FIGURE 49. Flat pack device, solder connection (continued).

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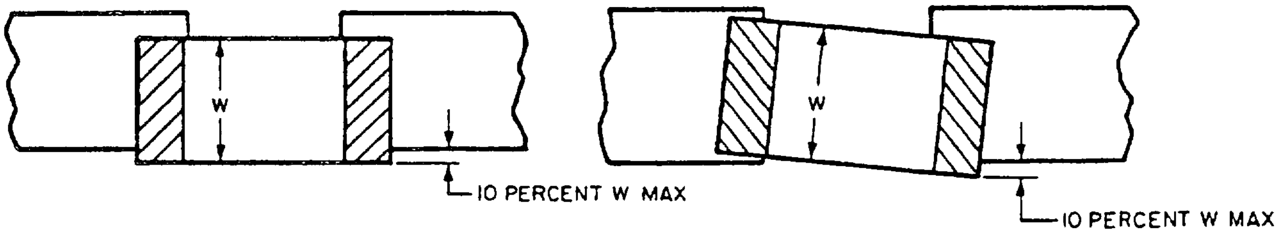
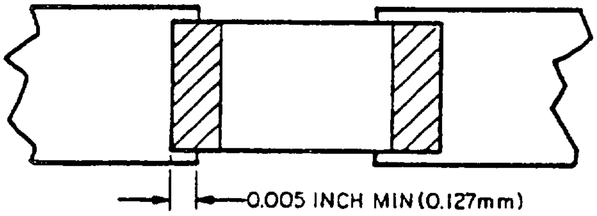
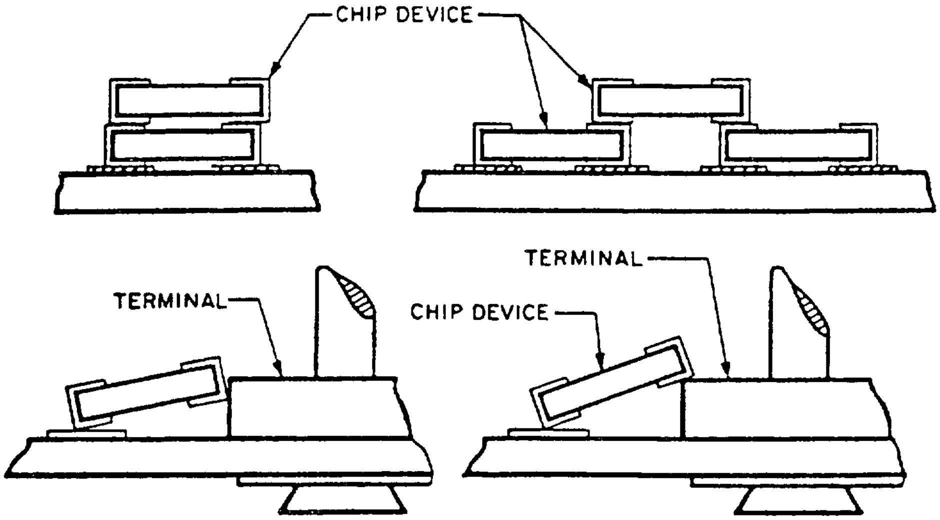


Acceptable chip overhang



Minimum lap of chip on terminal area



Improper mounting of chip devices

FIGURE 50. Chip devices, mounting.

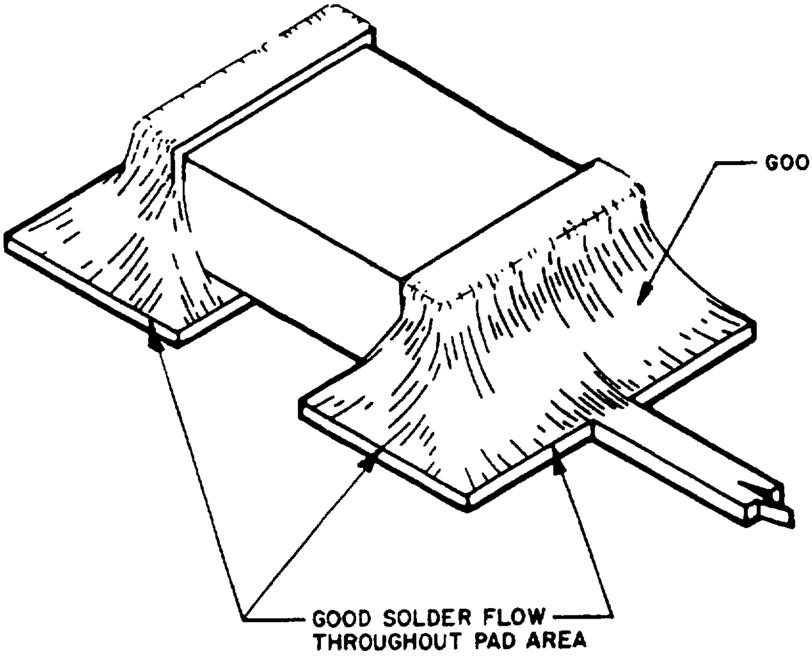
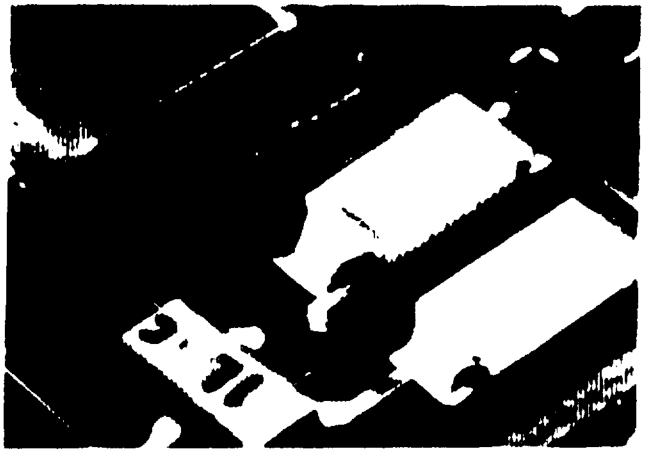
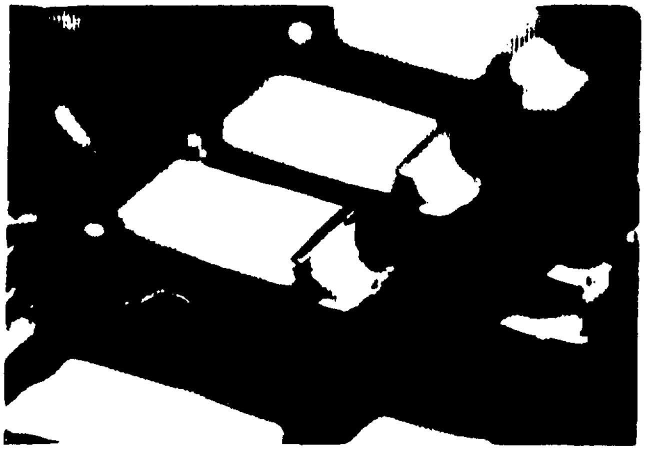


FIGURE 51. Chip devices, solder filleting.



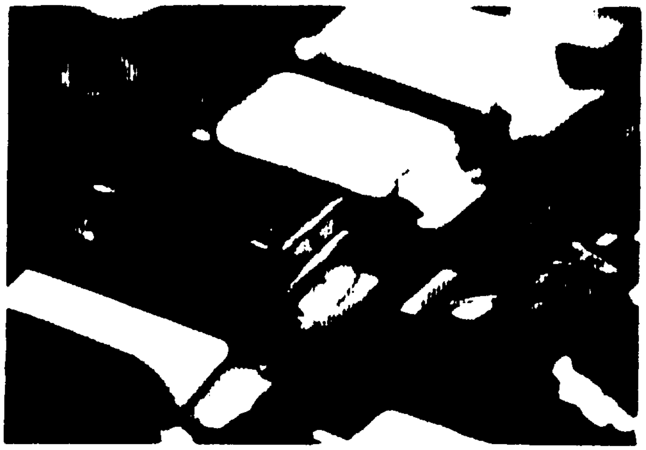
MAXIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but outline of end caps are nearly obscured by solder.



OPTIMUM

Solder is smooth, bright, continuous and feathered out to a thin edge. No bare end cap material is exposed and there are no sharp protrusions or evidence of contamination. Contour of end caps are clearly discernible beneath solder.



MINIMUM ACCEPTABLE SOLDER

Good solder flow and wetting, but solder fillet coverage is only one half the thickness of the component end cap.

FIGURE 51. Chip devices, solder filleting (continued).

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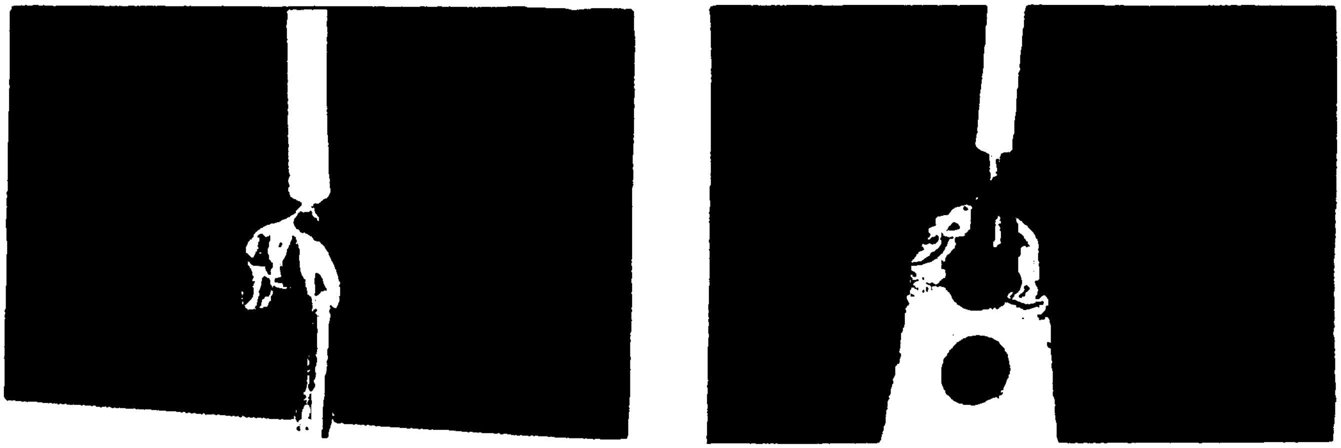
TYPICAL TYPES OF UNACCEPTABLE SOLDER CONNECTIONS AND BOARD CONDITIONS

Series of figures illustrating unacceptable solder connections.

Turret

Bifurcated



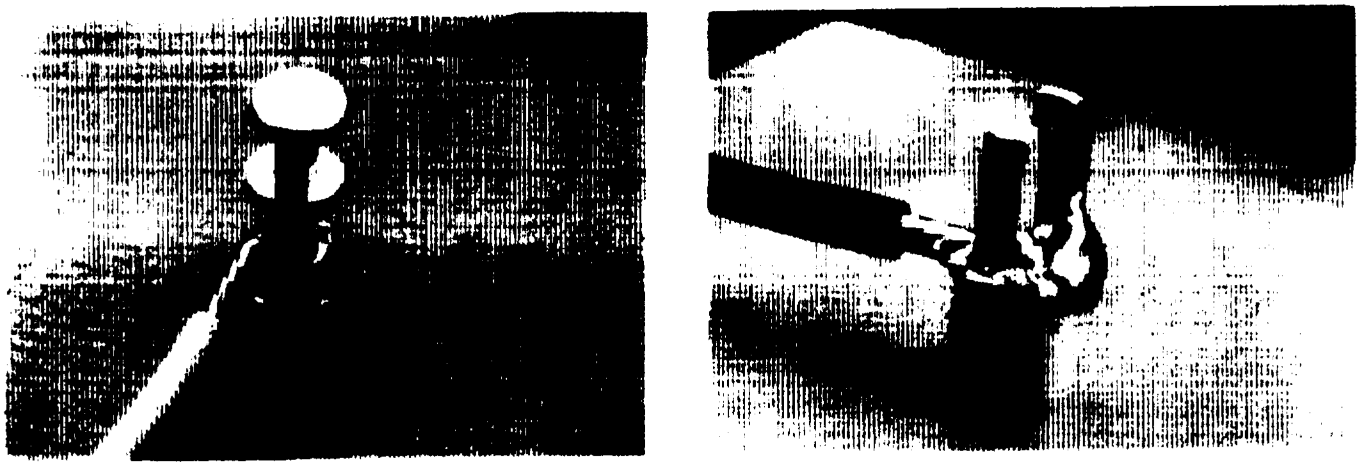
Hook

Pierced

Cup

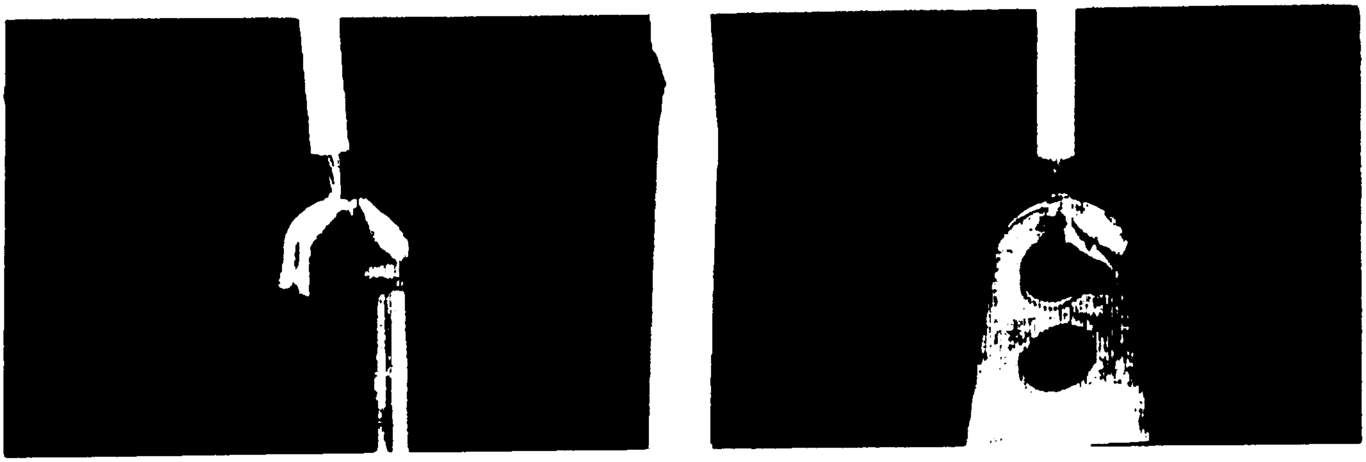
Unclinched lead

FIGURE 52. Rosin connection.



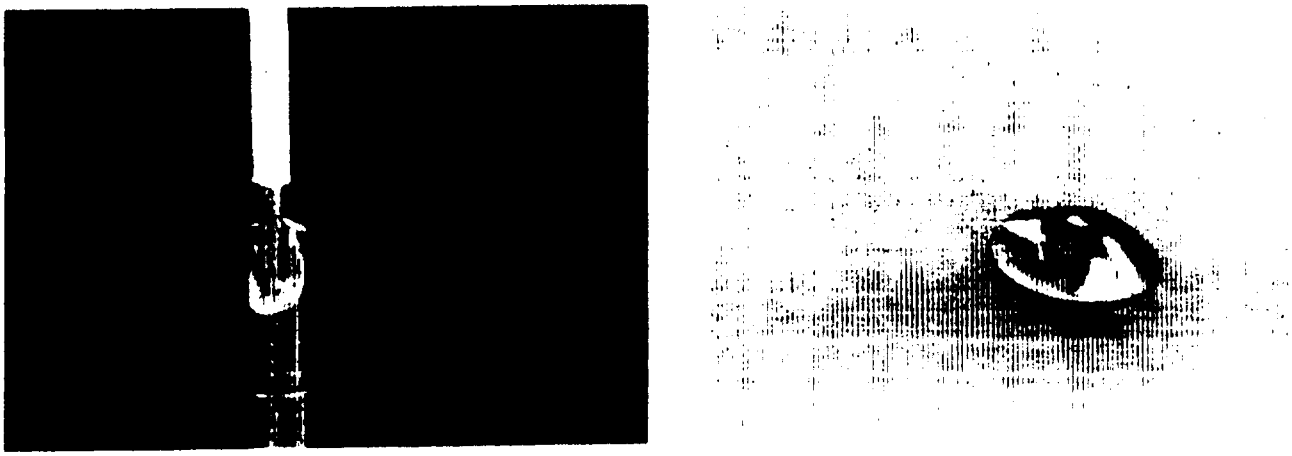
Turret

Bifurcated



Hook

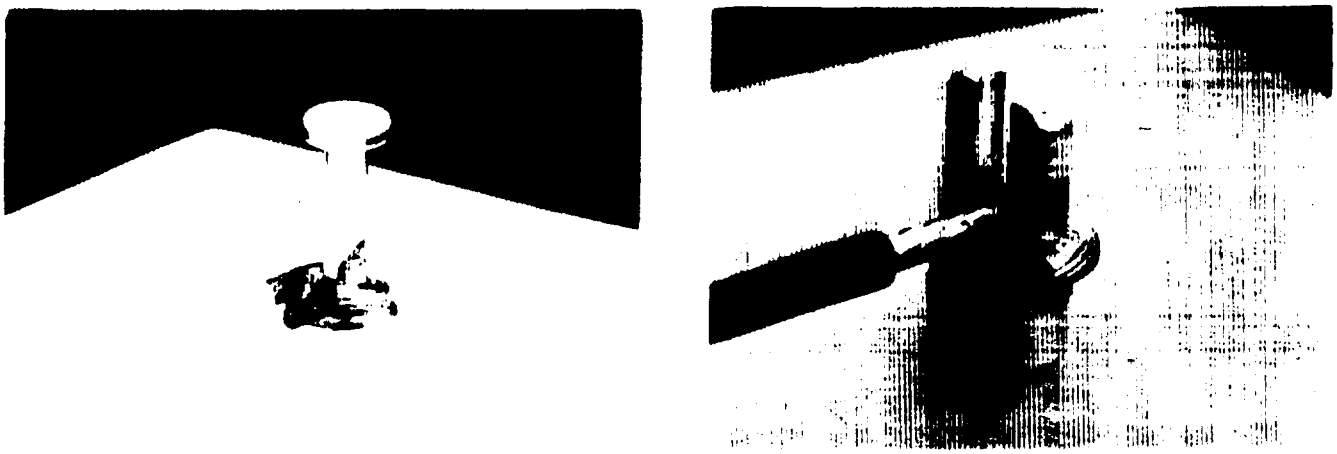
Pierced



Cup

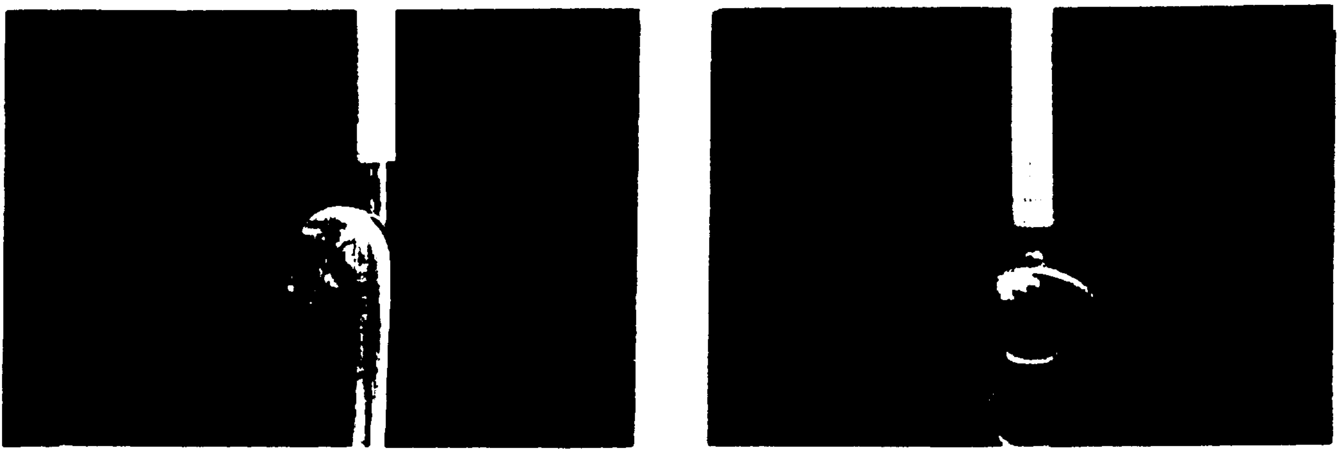
Unclinched lead

FIGURE 53. Cold solder connection.



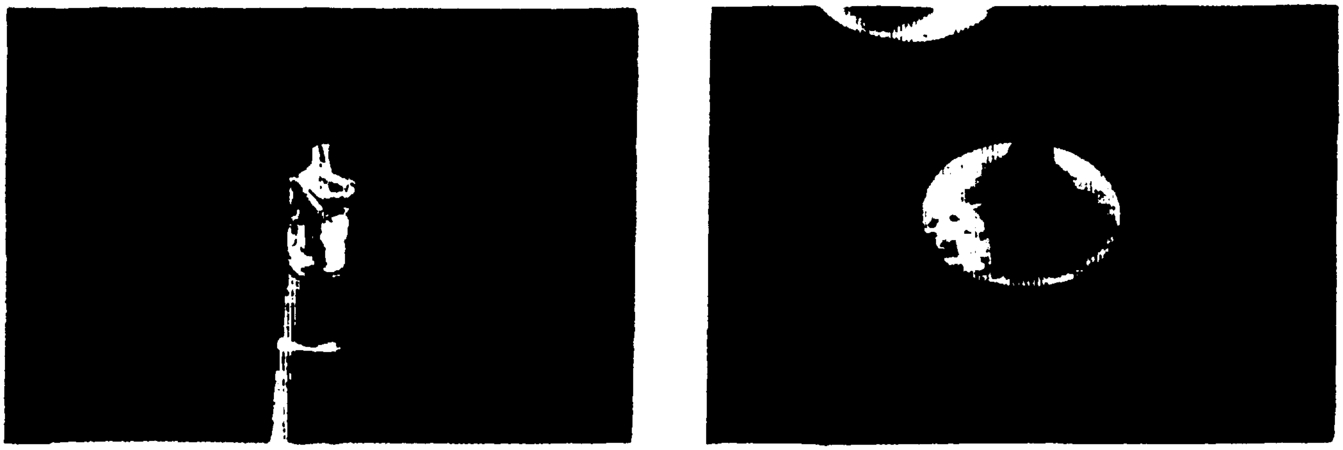
Turret (Disturbed)

Bifurcated (Disturbed)



Hook (Fractured)

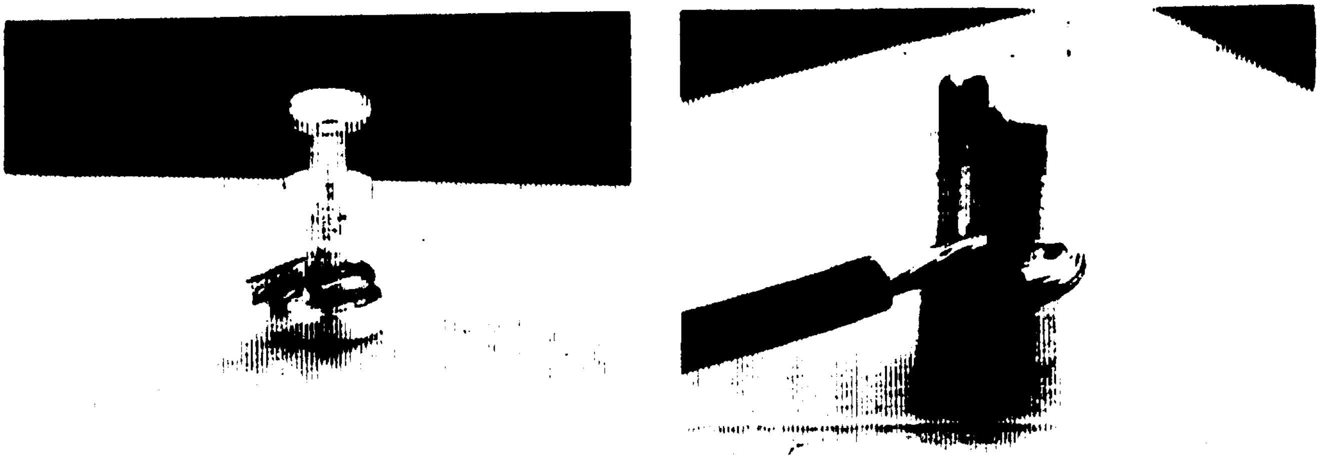
Pierced (Fractured)



Cup (Disturbed)

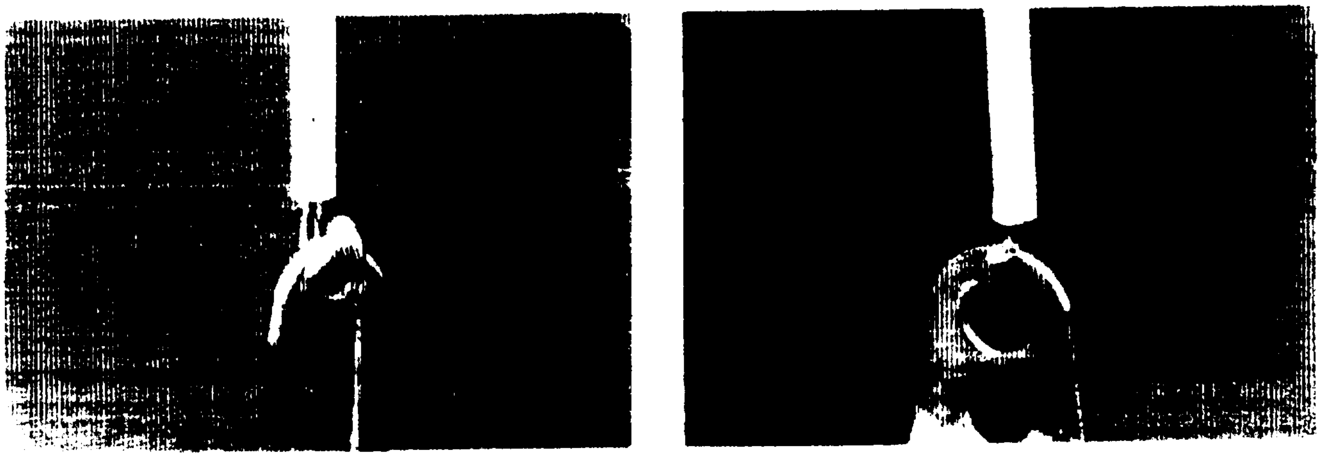
Unclinched lead (Disturbed)

FIGURE 54. Fractured or disturbed, solder connection.



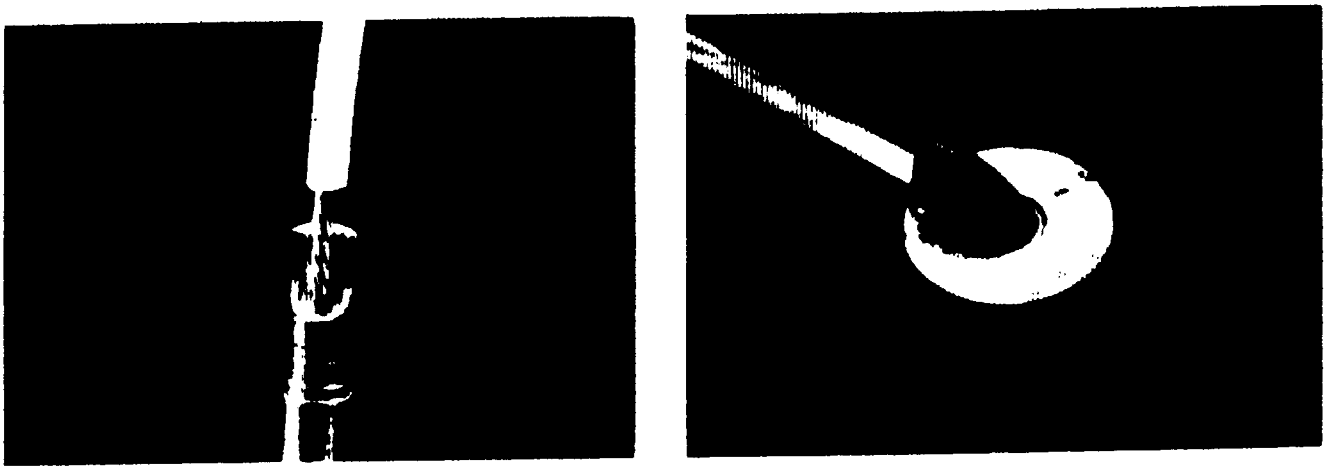
Turret

Bifurcated



Hook

Pierced



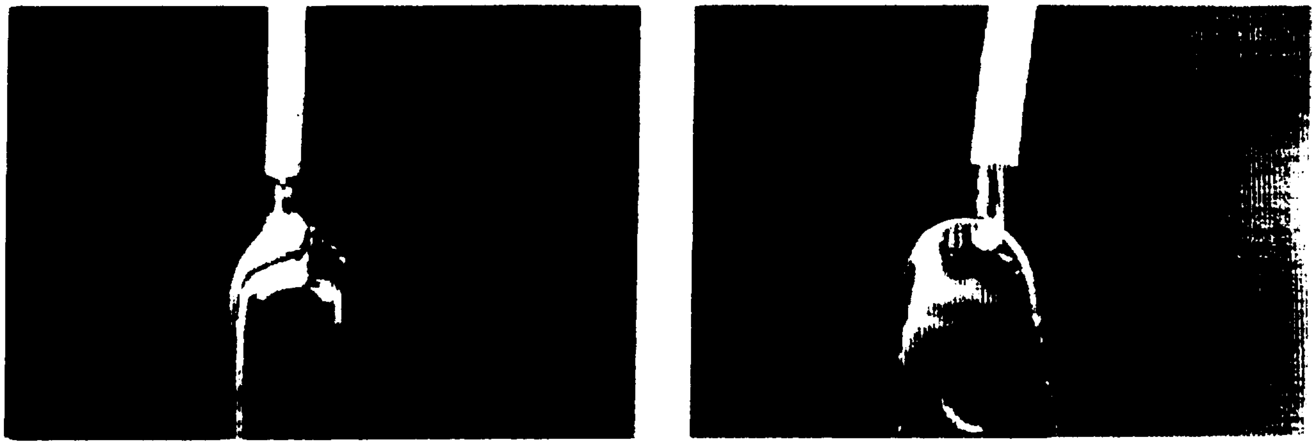
Cup

Clinched lead

FIGURE 55. Insufficient, solder connection.

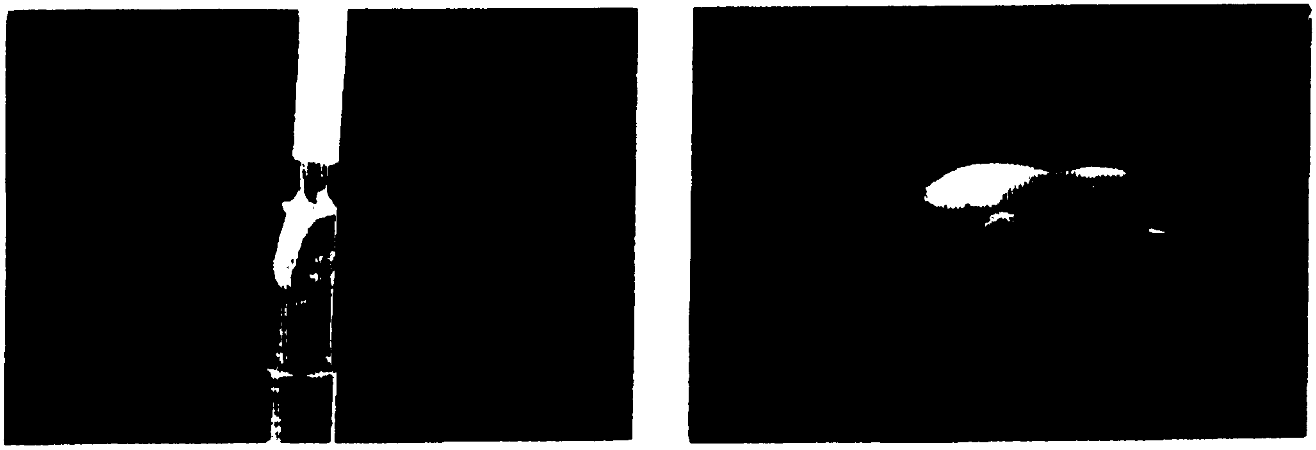
Turret

Bifurcated



Hook

Pierced



Cup

Clinched lead

FIGURE 56. Excessive, solder connection.

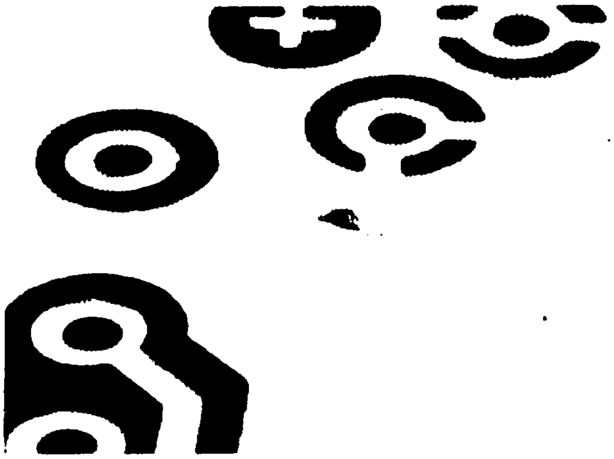


FIGURE 57. Blown plating or pattern delaminated.

FIGURE 58. Dewetting.

FIGURE 59. Nonwetting.

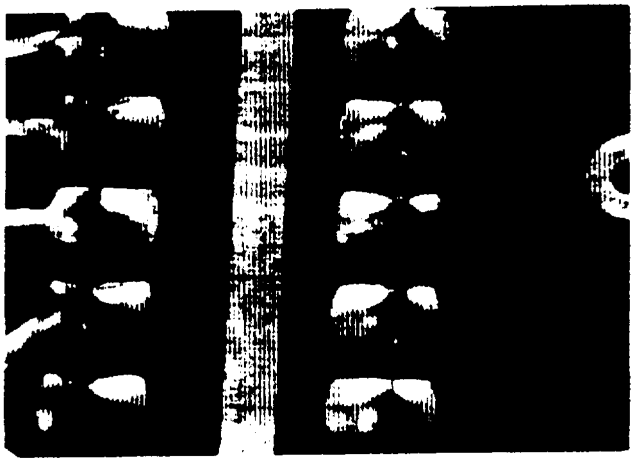


FIGURE 60. Measling.

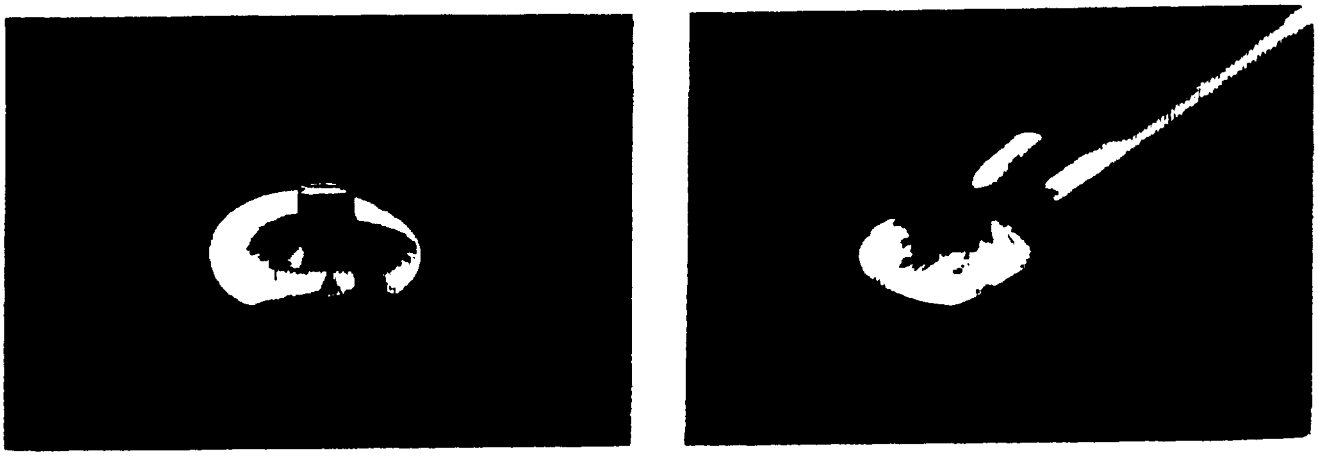


FIGURE 61. Lifted pad.

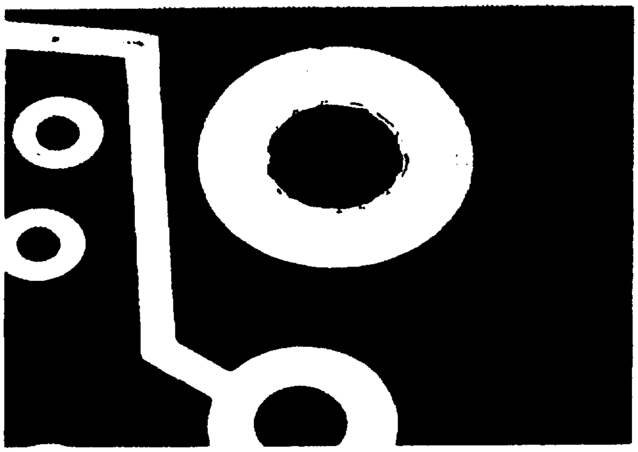


FIGURE 62. Peripheral split.

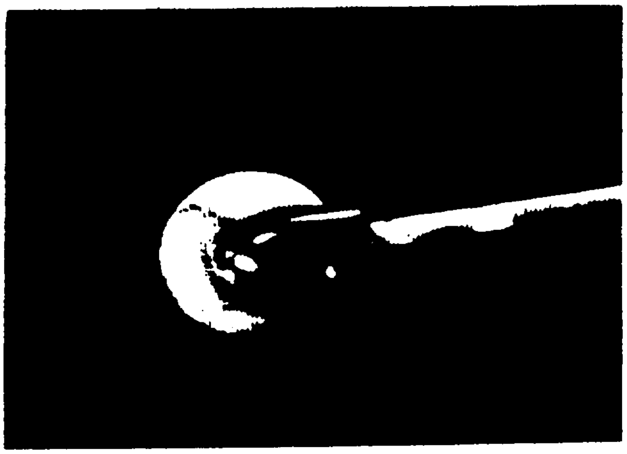


FIGURE 63. Pin hole.

FIGURE 64. Scratched printed circuit pattern.

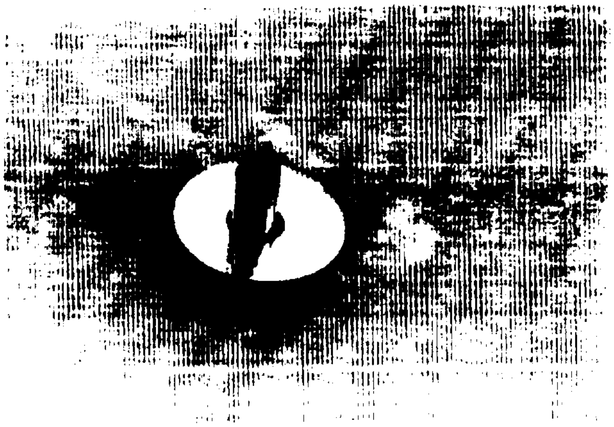


FIGURE 65. Improperly cut wire lead.

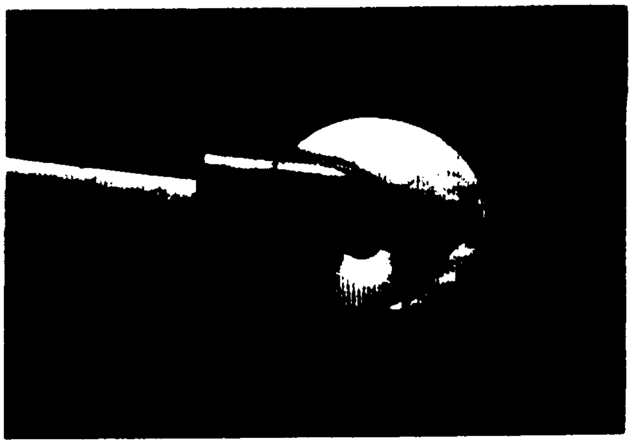


FIGURE 66. Void.

12.1.2 Complete integration of corporate teams. Process control systems need to be comprehensive from a corporate stand-point. The system must include elements in all aspects of the facility, including design, procurement (purchasing), manufacturing and quality. A high level management commitment to process control and improvement is required. Without a high level commitment to making necessary changes, process improvement will not be accomplished.

12.2 Organization. Responsibility for process control should be established at an organizational level that manages process activities, sets measurable goals and maintains effective communications within all organizational levels.

12.3 Documentation. The process control plan should include or reference documentation that contains the following:

a. Organizational responsibilities.

b. Training program.

c. Process flow charts identifying sequence of operations, data gathering points and decision points.

d. Statistical methods to be utilized such as sampling methods, capability studies, control charts, derivation of control limits and design of experiments.

e. Actions taken when control limits are exceeded.

f. Criteria for switching between sampling and 100% inspection.

g. Audits of the process control system.

12.4 Training program. Personnel with assigned responsibilities in development, implementation and utilization of process control and statistical methods should be trained in the techniques they will apply. The training program should establish the types and extent of training for various disciplines and levels of personnel within the organization.

12.5 Process control methodology.

12.5.1 Process control. The following actions should be performed to establish and maintain control of a process:

a. Define process parameters.

b. Select characteristics to be monitored.

c. Establish data gathering points considering process characteristic ranges, product characteristics, volume, etc.

d. Maintain control charts with current data.

e. Evaluate results, perform trend and root cause analysis and incorporate corrective actions or process improvements.

f. Maintain qualified evidence of statistical control and specification conformance.

12.5.2 Process capability. A process is capable when in statistical control and operating within specification limits. If studies indicate that the process is not capable, appropriate adjustments must be made to design, equipment, methods, materials, or other parameters to achieve process capability.

12.5.2.1 Evaluating process capability. Process capability is best determined through combination of experiments and historical data reduction. Through the use of process experiments, critical parameters, control charts (control parameters), the impact of changes to critical parameters, and overall process capability may be established. Once the overall process capability has been estimated from the experimental study, history data (operational parameters and defect data) must be collected. The capability of a system for a specific assembly or product, using a specific process, can then be determined. The process capability may be increased over time depending on the amount of experimentation and effort expended on process improvement. Once process capability has been determined at acceptable limits over a period of time, users should evaluate whether they are ready to cut-back on visual inspection and begin using sample based inspection.

12.5.2.2 Description. In controlling a process, the sources of variability need to be identified. There are two types of variability in the statistical concept of process control: (1) Common causes - faults of the system which are due to chance and can only be reduced through management involvement, and (2) Special causes - changes in process inputs such as design, material, method, machine, or other process parameters which can be adjusted through operator detection. Typically, common causes contribute to 90 percent or more of the process problems which special causes contribute 10 percent or less. Statistical process control separates the special cause variability from the common cause variability. The process is defined by its average (x) and its control limits (LCL, UCL) where the limits are X +3s (s is defined as the standard deviation) as depicted in Figure 67.

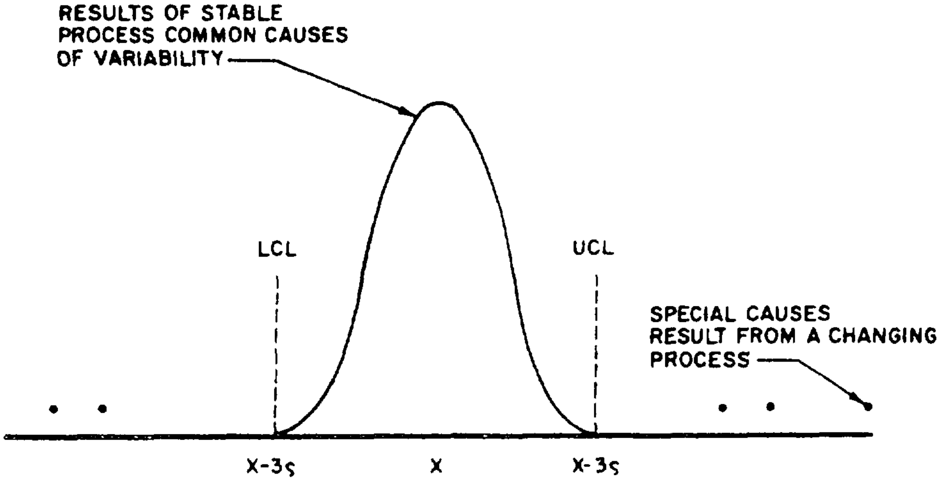


FIGURE 67. Average upper and lower control limits.

Many processes are not capable of meeting the lower and upper specification limits (LSL, USL). This is due to the process spread, as measured by the control limits, often being wider than the specification limits as depicted in Figure 68.

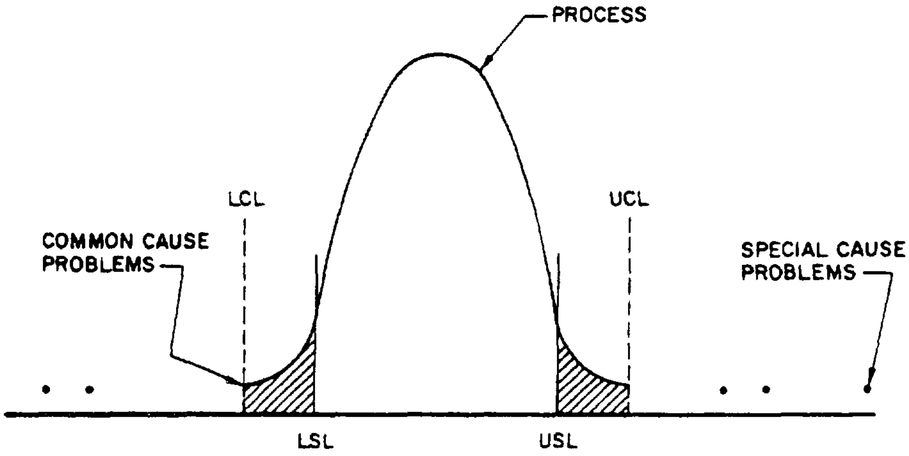


FIGURE 68. Control limits wider than specified.

A process is brought under statistical control by eliminating the special causes of variability as depicted in Figure 69.

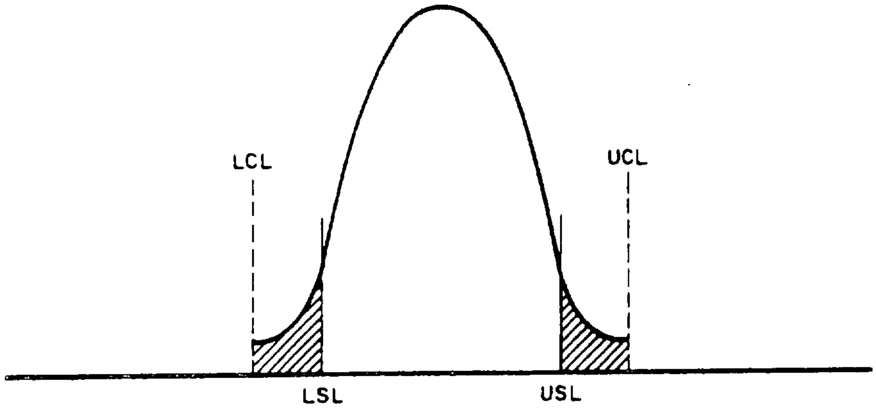


FIGURE 69. Statistical control.

After statistical control is obtained, management action (make a fundamental change to the process, or change the specification limits) will reduce the common causes of variability through process improvement as depicted in Figure 70.

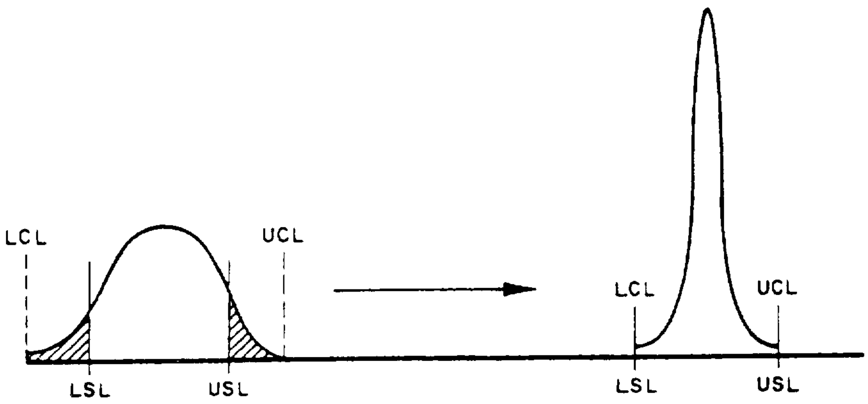


FIGURE 70. Reduction of process variability.

The following is a list of statistical and analytical techniques that can be used in a process control environment:

- Flow Charts
- Pareto Charts
- Cause and Effect Diagrams
- Bar Charts
- Histograms
- Summary Statistics: Location and Variability
- Scatter Diagrams and Correlations
- Special Studies:
  - Designed Experiments - Classical and Taguchi Methods
  - Measurement Capability
  - Process Capability
  - Analysis of Variance (ANOVA)
- Run Charts
- Control Charts: $\bar{X}$, R, S, $\bar{X}$-Moving Range, P, nP, C, U

12.5.2.3 Process capability. A process is capable when in statistical control and operating within specification limits as depicted in Figure 71.

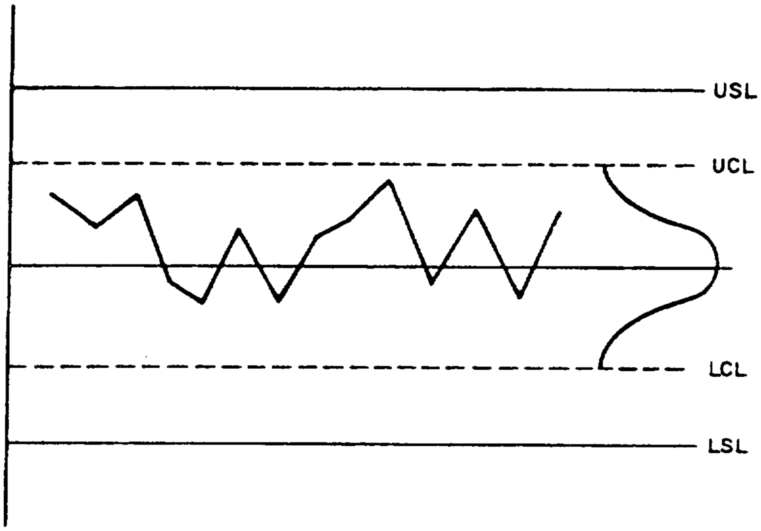


FIGURE 71. Process capability.

Process capability can be measured by indices (Cp, Cpk) which are ratios of the specification limits to the control limits (USL-LSL /UCL-LCL). If studies indicate that the process is not capable, appropriate adjustments must be made to design, equipment, methods, materials or other parameters to achieve process capability (see 12.5.2).

12.5.3 Sampling. When the process has been demonstrated to be capable, sampling may be used in lieu of 100% inspection. Sampling must be statistically based and consistent with data collection requirements for maintaining process control. Guidance on sampling methods may be found in MIL-STD-105, MIL-STD-414, MIL-STD-1235, MIL-HDBK-106 and MIL-HDBK-107.

12.5.4 In-process reviews. Prior to hand, wave, or reflow soldering processes, assemblies should be reviewed to verify proper part selection, part orientation, mounting, etc. After soldering process, a cursory assembly review should be performed to continuously verify the process operation is acceptable. After cleaning, the cleaning process should be verified. These inprocess reviews are part of the overall process control system and enable real-time process correction. Inspection, from a quality assurance standpoint, is typically limited to final product acceptance and may not be timely for preventing defect occurrence.

12.5.5 Material inspection. Material inspection is best performed as part of the contract for the purchase of the material (i.e. by the supplier) with a sample verification by the user manufacturer. Users should require certificates of test which include actual test data and test documentation. Certificates of test, tied to specific production lots, are more effective means for ensuring material verification than certificates of conformance. It is often difficult to determine under what conditions a certificate of conformance was developed and whether conformance is continuously verified. Skip lot inspection of incoming material and supplier source inspection may also be effective alternatives to sample inspection of all incoming lots.

12.6 Defect documentation and tracking systems. The essence of effective process control involves accurate defect identification, data reduction and process control feedback. Many defect documentation systems can be developed, although some will work more easily than others. Defect identification and tracking systems need to be specific enough at the inspection level to provide sufficient data for process improvement. The defect recording and rate tracking process needs to be an integral part of the process through which the cause of the defect is identified.

12.6.1 Traveler sheets. Many manufacturers have found it advantageous to place a series of process documentation sheets in antistatic bags which then move with the work piece through production. Frequently referred to as travelers or traveler sheets, this data package may contain a set of sheets which provide top and bottom side drawings for use during assembly inspection. These assembly drawings are then marked by the inspectors during each inspection operation. When rework and reinspection is required, a second set of drawings may be added to the package.

12.6.2 Data recording and reduction. Once indicated on the inspection records, the data is easily processed through personal computer data base systems. When bar code serialization is used to mark both the assembly and the bag containing the traveler sheets, it is simple for a computer operator to enter the assembly identification. Then using one of the menu driven data base packages commercially available, the defect data may be entered. At the end of the day, routines may then be used to reduce the data to defect rates.

12.7 Process control. Effective process control is characterized by knowledge of the manufacturing process critical steps and parameters, sufficient control authority to set and maintain the critical parameters within acceptable levels, and feedback systems which signal the need to process adjustment.

12.7.1 Identifying critical parameters. Critical process parameters must be identified through operation of the processes. Many equipment manufacturers supply data on the effect of changes of equipment settings on the final product (defect reduction). Often however, similar effects on the final product may be accomplished through several different process adjustments. Also, the combination of multiple units as part of inline systems will cause adjustments in one piece of equipment to flow through downstream equipment. Manufacturers must study their individualized processes to fully understand the effect of process changes.

12.7.2 Preproduction studies. When new equipment is intended to be brought onto the production line, it should be first installed in an offline production assessment laboratory. As an offline operation, the equipment characteristics may be carefully evaluated prior to the production need to obtain full capability. While subsequent online studies will still be required, methodical offline studies will produce data which will significantly reduce the time required to bring the equipment to full operating capability and will reduce the long term overall cost of equipment installation and operation.

12.7.3 Production studies. Once installed into the production facility, the effect of changes on all equipment must be accurately recorded and evaluated. Methodical data collection and reduction on equipment performance is often erroneously considered unnecessary. Operators and manufacturing process engineers will rely on their expertise to make process adjustment. While this may be effective, it is not a good substitute for an effective data base which will survive personnel changes and which is not subject to memory lapses which may damage production hardware. Readily accessible, online computer data bases can be generated with only modest investment. The cost of developing these data bases is generally amortized when only a few assemblies are saved from being scrapped. They are also effective in demonstrating process control to auditing activities.

12.7.4 Feedback systems. Feedback systems are an essential element of effective process control. Both forward and reverse feed process control systems should become a part of the continuous process operations. These systems are only effective if the data transmission almost immediately follows data collection. These systems must be real-time systems if they are to be of value. The longer the data is held at the collection point and not fed to the appropriate process correction point, the less meaningful the data becomes.

12.7.4.1 Forward feed systems. Forward feed (feedforward) systems are characterized by process data taken early in the production process being fed forward to a point in the subsequent processes. If the wave soldering machine operator realizes his preheat level has moved outside the established control limits, this data should be fed forward (through appropriate management personnel) to the appropriate production points. For example, if there was insufficient preheating, the plated-through holes of the assembly may not have filled properly. In a single pass system, this data should be used to warn inspectors to check carefully for this defect. In a solder-cut-solder system, however, this data should be fed forward to the operator for the second soldering operation to ensure adequate hole fill. In this way, minor process changes may correct for upstream out-of-tolerance processes before the hardware is manufactured in a defective manner.

12.7.4.2 Reverse feed systems. Reverse feed (feedback) systems are characterized by the transmission of either process data or final product inspection data to earlier points within the processes. This data is used to adjust the process so that subsequently produced hardware does not contain the same defects. Feedback systems are the most common form a data feed system uses.

12.7.5 Optimizing wave soldering machines. Wave soldering machines may be rapidly optimized using a series of statistical experiments. Using the basic assumptions listed below, a minimum number of experiments will yield data which enables process managers to optimize their system operations.

12.7.5.1 Assumptions used during machine optimization. These assumptions are recommended for initial process optimization experiments.

a. The mathematical functions which model the responses are simple curves at most. As such, only a few increments of the independent variable is required.

b. There are interactions between the independent variables.

c. The experimental error is small with respect to the increment of the response (i.e., it can be neglected).

12.7.5.2 Variables for study. The variables which should be varied to determine the effect on end-items are the solder temperature, the topside printed-wiring board temperature, and the conveyor speed. All other variables, including the flux type, flux density, solder wave height, and conveyor angle should be maintained constant. For the results of these experiments to be meaningful, all variables must be measured in a consistent manner. In addition, the assemblies processed must be as consistent as possible with respect to part and board solderability, lead to hole ratios, solder mask adhesion, etc.

12.7.5.3 Inspection parameters. After soldering, all assemblies must be inspected for all potential defects. Which defects are considered during the experiment will affect the significance of the experimental results. The baseline and process control tasks of MIL-STD-2000 contain different sets of defects. Experiments may be tailored to address either set of defects. As an alternative, however, experimenters may wish to use only a subset of these defects. Prior representative experiments have shown that inspecting for

a. Nonwetting or dewetting of components,

b. Nonwetting or dewetting of printed wiring boards,

c. Peaks, points, and icicles,

d. Voids, pin holes, and blow holes,

e. Adequacy of plated-through hole fill,

f. Insufficient solder in the joint, and

g. Grainy solder.

provides a good basis for initial experiments. Prior experiments have also shown that the frequency of occurrence of voids, pin holes, and blow holes, bridging, nonwetting or dewetting of the printed wiring board, incomplete plated through hole fill, and grainy solder may be too low for statistical significance. See Table VII for guidance in eliminating these occasional defects.

12.7.5.4 Experiment and test design. The order of runs should be randomized to minimize the potential that unknown or uncontrolled sources of bias will arise. A wide variety of experimental methods may be selected. One method, known as the rotatable central composite design, has been shown to rapidly estimate the main effects of the variables (factors), all two factor interactions, and the three factor interaction. Since interactions will exist among two or more factors, each factor will affect both defect rates and the response of the system to changes in the other factors. For example, using the variables of 12.5.7.2, the effect of changes in solder pot temperature in reducing defect rates will be dependent on the actual value of the conveyor speed and the topside preheat board temperature. Changes in the solder pot temperature may have a greater effect on end-item defect rates at lower conveyor speeds than at higher conveyor speeds.

12.7.5.5 Rotatable central composite experiments. A test design known as a rotatable central composite design may be used to estimate the effects of the three variables recommended in 12.7.5.2. "Rotatable" indicates that each factor will be varied over a corresponding range (weight) without regard to its physical nature. "Central" indicates that the effect of changes in each factor will be measured with respect to a center point in the range of each control factor (variable). "Composite" indicates that the interactions of the factors will be studied. A rotatable central composite is formed from a complete factorial design in three factors (variables) at two levels each. This creates an eight point cubic pattern plus six star points and several repeat center points (see Figure 72). The repeat center points provide an estimate of the random variability of the data (i.e., noise). Since the design is rotatable, the model should estimate responses with equal precision for all test points the same distance from the model center. Table IX shows the design points for a rotatable central composite design. Using the variables of 12.7.5.2, and ranges of 246-268°C (480-520°F) for the solder pot temperature, 81-103°C (180-220°F) for the topside board temperature, and 600-1650 mm/min (1.9-5.7 ft/min) for the conveyor speed, a sample table of test values may be generated (see Tables X and XI).

12.5.7.6 Data reduction. Once the data from the experiments has been obtained, it may be analyzed by a variety of statistical data analysis techniques. Considering the assumptions of 12.7.5.1 and the recommended variables 12.7.5.2, contour plots showing defect levels as a function of time and topside board temperature for a constant solder pot temperature should be developed. Two sample contour plots for the test points of 12.7.5.5 are shown in Figure 73.

TABLE IX. Design points for rotatable central composite designs.

Run No.	Factor A	Factor B	Factor C
1	-1	-1	-1
2	-1	-1	1
3	-1	1	-1
4	-1	1	1
5	1	-1	-1
6	1	-1	1
7	1	1	-1
8	1	1	1
9	-1.68	0	0
10	1.68	0	0
11	0	-1.68	0
12	0	1.68	0
13	0	0	-1.68
14	0	0	1.68
15+	0	0	0

TABLE X. Test points for the sample factors (see 12.7.5.2).

Design Point	Solder Pot Temperature	Board Temperature	Conveyor Speed
-1.68	480	180	5.7
-1	488	188	4.0
0	500	200	2.8
1	512	212	2.2
1.68	520	220	1.9

TABLE XI. Sample design points for rotatable central composite design.

Run No.	Solder Pot Temperature	Board Temperature	Conveyor Speed
1	488	188	4.0
2	488	188	2.2
3	488	212	4.0
4	488	212	2.2
5	512	188	4.0
6	512	188	2.2
7	512	212	4.0
8	512	212	2.2
9	480	200	2.8
10	520	200	2.8
11	500	180	2.8
12	500	220	2.8
13	500	200	5.7
14	500	200	1.9
15+	500	200	2.8

Rotatable Central Composite Design

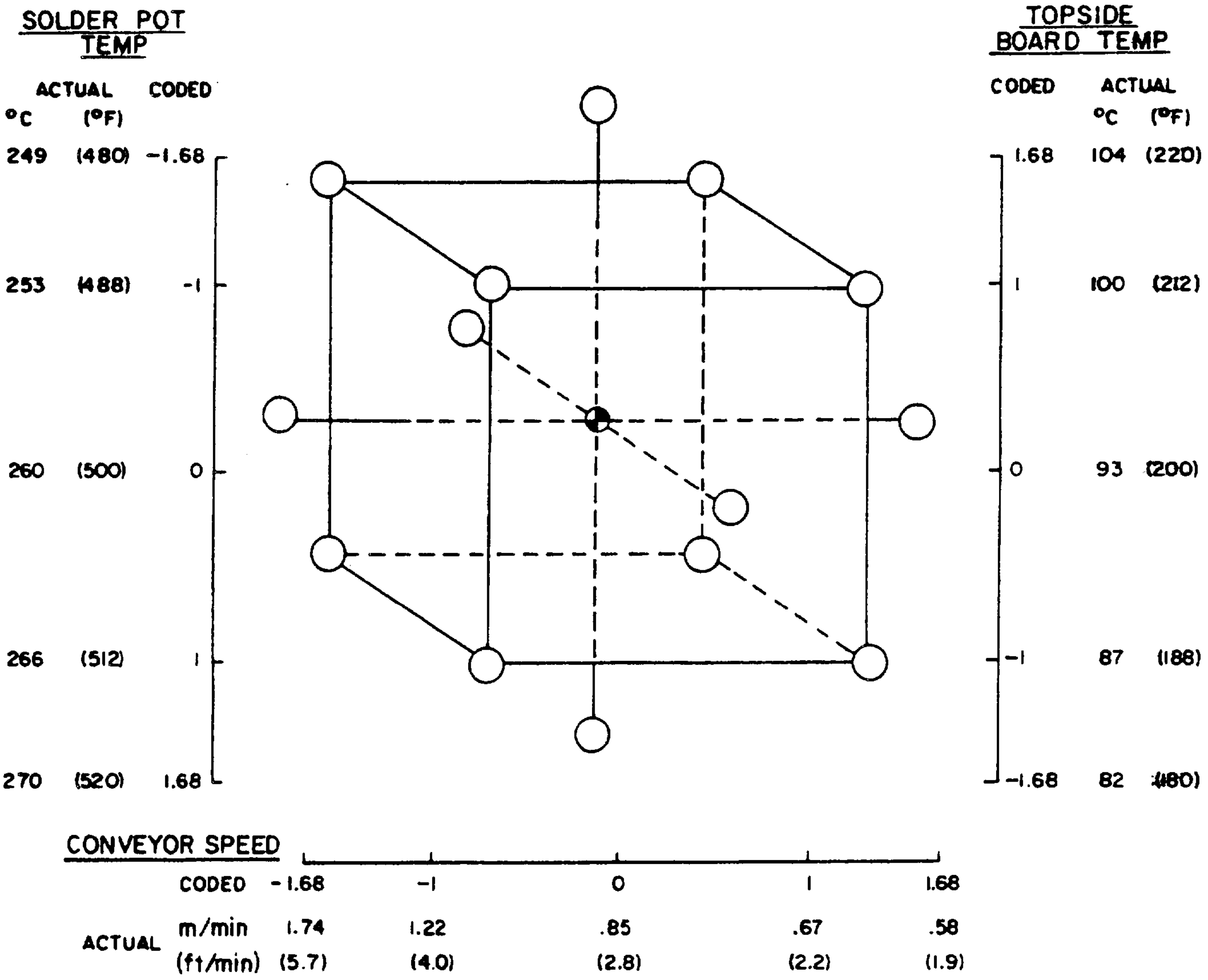
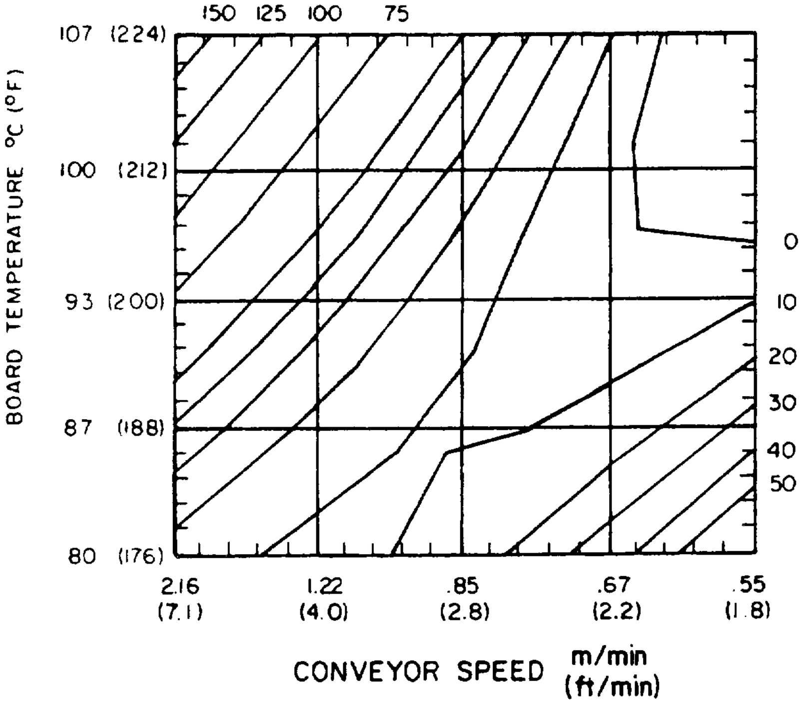
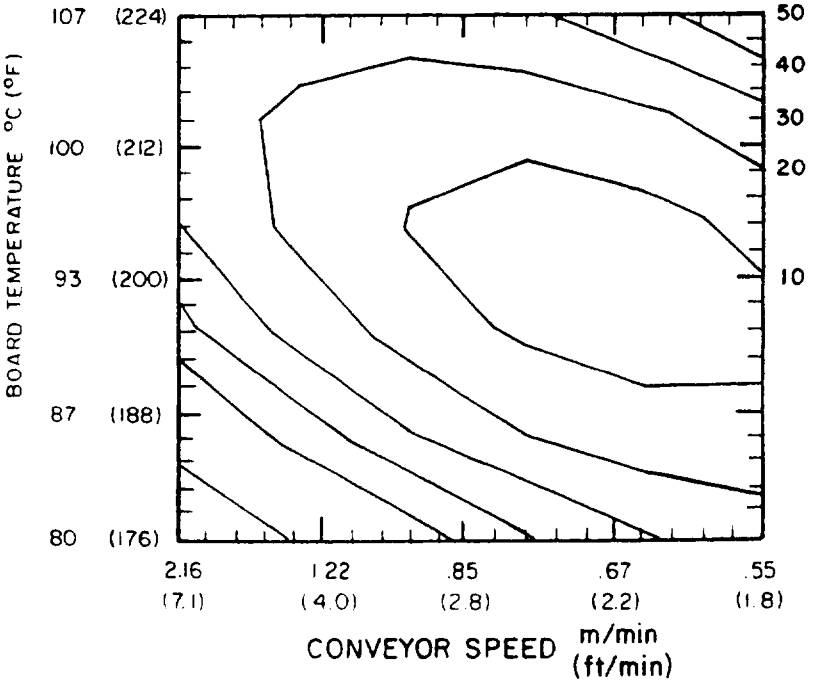


FIGURE 72. Coded factor levels and actual factor levels.



Sample contour plot 1



Sample contour plot 2

FIGURE 73. Sample contour plots - rotatable composite design.

12.7.5.7 Additional sources of information. The topic of statistical data analysis and experimental design is too large for comprehensive treatment in this handbook. Standard texts are available.

12.8 Subcontractor control. Unless otherwise stated in their contracts, prime contractors are responsible for ensuring that all elements of the hardware they deliver meet the requirements of the imposed military specifications and standards.

12.8.1 Flowdown. While the federal acquisition regulations have always required that prime contractors flow their contractual requirements down to their subcontractors, this has been complied with only on a limited basis. Currently, military contracts require greater attention to the flowdown process. To meet this requirement contractors should flow down the specifications and standards imposed on them in their entirety (as opposed to imposing company internal specifications which may not flow down all relevant requirements). Source control drawings and company internal specifications are limited in their effectiveness in ensuring adequate flowdown. Since the requirements which must be flowed down may change between programs, drawings and specification requirements may need to be changed between programs. The documentation related costs of unnecessary source control drawing reviews and updates could be avoided through the flowdown of the basic contractual requirements.

12.8.2 Subcontractor audits. Audits are a necessary means by which contractors can determine that their subcontractors are capable of and are preparing to deliver compliant hardware. Effective subcontractor auditing programs will avoid last minute crisis associated with noncompliant hardware. This will also avoid the potential for last minute waiver requests from the high level contractor/customer. Performing early audits will be a cost-effective investment which will reduce follow-on production costs. Anyone seeking to implement "just-in-time" manufacturing or a similar material dependent process needs to perform audits regularly. All contractors should structure their contracts to have audit authority over their first tier subcontractors. While prime contractors rarely have audit authority over their second tier subcontractors, many first tier subcontractors will allow their customers to unofficially participate in audits of the second tier contractors. This practice is encouraged and should be applied to the lowest practicable tier.

12.8.3 Preferred supplier lists. An effective technique for ensuring that subcontractors are capable of performing is establishing lists of those who have demonstrated acceptable performance. As the tolerance imbedded in the electronics manufacturing process become tighter, the number of capable suppliers is generally reduced. Manufacturers need to establish lists of proven suppliers and should police these lists carefully. Similar to the practices used to control military Qualified Products Lists, manufacturers need to be open to new potential suppliers, allow suppliers with prior unsatisfactory performance to demonstrate improved capability, and should rigorously avoid doing business with suppliers who have proven they cannot supply acceptable products. Purchasing departments should be strongly encouraged to maintain their supplier lists in a manner which assures that acceptable subcontractor products are continuously available.

12.8.4 Use of military and industry documents. The use of specifications and standards prepared by both the military and industry associations is more cost-effective for procuring standard items than company-peculiar documentation. While company prepared "control drawings" are commonly used, military and industry documents which establish widely-used materials, components and subassemblies should enable manufacturers to procure parts at reduced costs. When the military and industry join together in purchasing common items, there will be greater cost competitiveness and reduced overall costs. While special control drawings may specify the same items, the development and tracking of these special procurement documents could be avoided if purchase requests simply specified the appropriate military or industry requirements and any other special provisions. Contractor-prepared drawings should be used only where the terms defined in the existing specifications are not sufficient to fully specify the item in question.

12.9 Process prevention techniques. The first two steps for eliminating defective solder connections:

a. Have the assembly designed correctly, and

b. properly mounted, properly selected components.

The components, boards, wires, and every other element of the assembly to be selected must be solderable, electrically functional, capable of withstanding process temperatures, and not degradable by subsequent processes and material. Parts such as rivets, screws, etc. should be selected only for their ability to perform correctly.

13. NOTES

13.1 Subject term (key word) listing.

Connector
Degreaser
Electronic components assembly
Flux, soldering
Insulation sleeving, electrical
Printed circuit board
Printed wiring, flexible
Printed wiring board
Solder
Soldering iron
Solvent, stoddard's
Wiring harness

INDEX

INDEX (continued)

INDEX (continued)

INDEX (continued)

INDEX (continued)

INDEX (continued)

INDEX (continued)

INDEX (continued)

Custodians:
Air Force - 20
Army - MI
Navy - AS
NSA - NS

Review activities:
Air Force - 11, 15, 17, 19, 84, 99
Army - AR, CR, ER, MR
Navy - EC, OS
DLA - ES, DH
NASA - NA

User activities:
Army - AV
Navy - MC

Preparing activity:
Navy - AS
Project No. SOLD-0003)

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198/290