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Automated radiographic inspection of through-hole electronic circuit board solder defects

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AUTOMATED RADIOGRAPHIC INSPECTION
OF THROUGH-HOLE ELECTRONIC CIRCUIT BOARD SOLDER DEFECTS

by

JAMES ANDREW LEAL

A Thesis Submitted to the Faculty of the

DEPARTMENT OF MATERIALS SCIENCE
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In Partial Fulfillment of the Requirements

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In the Graduate College

THE UNIVERSITY OF ARIZONA

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FIGURE

LIST OF TABLES

TABLES

ABSTRACT

A study has been carried out to investigate the use of "real-time" radiography as a method of automated inspection of through hole electronic circuit board solder joints. By evaluating five major solder defects it has been found that film radiography employing high contrast film results in a definite distinction between a good solder joint and a defective solder joint. The same five defects were also found to be distinguishable from a good solder joint when evaluated by a real-time radiographic inspection unit using digital image processing. Although the type of defect being investigated was not discernible, the ability to distinguish a good solder joint from a defective solder joint is a major step in the implementation of automated solder joint inspection for military electronics.

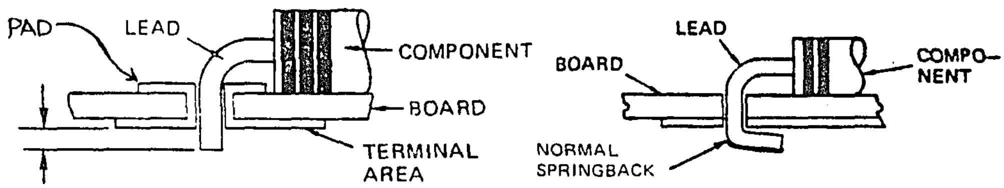
CHAPTER 1

INTRODUCTION

The manufacturing of electronic hardware for the military industry is extremely complex. From the processes involved in manufacturing the bare printed wiring board to assembling, soldering, and inspecting the electronic components, every aspect must be closely monitored. The inspection of the electronic hardware is very important since it is a major step in controlling the quality of the hardware being assembled into the final product. To fully understand the need and criteria involved in the inspection of electronic hardware, the basic manufacturing and assembly operations should be reviewed.

The printed wiring board (PWB), also called a circuit card, is the basis for each piece of electronic hardware. The printed wiring board is used to physically mount the electronic components and to provide conduction paths so that the components can interact and provide a given electronic function. The PWB consist of layers of insulating material, normally epoxy or polyamide glass, with copper printed circuits on each layer. The electrical circuits inside of the PWB are attached by holes that traverse through the various layers allowing the desired circuits to be connected. Table A lists the basic steps involved in manufacturing a circuit card. The holes, which have been copper and tin/lead plated and therefore called plated-through holes, are an extremely important facet of the circuit card. The plated-through holes not only interconnect the circuitry but also mechanically and electrically connect the electronic components to the PWB.

The electronic component leads can be loaded into the plated-through hole by many methods. Both machine insertion and hand insertion are being used to populate circuit cards. Figure A shows axial-leaded components loaded into a circuit card. The pad area shown in Figure A is produced as part of the plated-through hole. The components themselves must meet certain requirements before they can be soldered. The lead bend must have a certain radius limit and be a given distance away from the body of the component. Clinched leads must be clipped to a certain distance from the edge of the pad and straight leads must not extend past a given distance from the bottom of the PWB. Once the PWB has been populated with components and the components have met their quality requirements, the PWB is ready to be soldered. Figure B shows a circuit card populated with electronic components.



Straight Through

Clinched

Figure A. Axial-leaded components loaded into a PWB. One is clinched and the other is straight through.

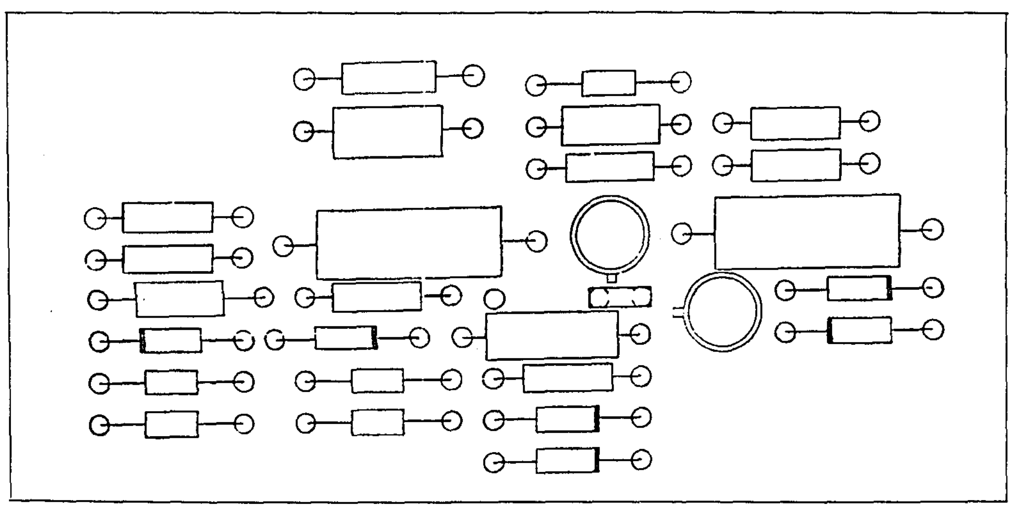


Figure B. Fully populated PWB.

The solder used to mechanically and electrically fasten the electronic components to the circuit board is typically a 63% tin, 37% lead eutectic solder. Tin/lead eutectic solder offers a low melting point and no pasty region which occurs at the eutectic point. The electrical, thermal, and mechanical characteristics of tin/lead solder make it widely used in the electronics industry. One method for applying the solder to the PWB is wave soldering. Wave soldering allows mass soldering of circuit cards in a continuous process. The process employs fluxing, preheatin-g, and a solder wave to apply the correct amount of solder to form a "proper" solder joint. A solder joint is the area of solder that has solidified joining the plated-through hole and component lead. The variables involved in wave soldering are somewhat complex and require tight process control. However, even with good process control, the formation of some "improper" solder joints may occur. These "improper" solder joints are called solder defects. To insure these defective solder joints do not become incorporated into the final product, each solder joint must be visually inspected.

The inspection process insures that each solder joint meets the criteria set by the procuring government agency. The criteria are described in a government specification which defines all of the quality standards. Inspection is performed by qualified inspectors who use optical scopes to evaluate the solder joints at either 10X or 4X magnification. The magnification used is also dictated by the government specification. The list of solder defects is enormous and basically describes the condition of a defect. Five of the most common defects are grainy, dewetted, nonwetted, excessive, and insufficient solder. After defects have been identified on a circuit card it must go to a rework station where the defect is corrected by removing the old solder and making a new solder joint by hand soldering. The method of various operators interpreting the extent of a defect and whether or not it is within specification is extremely subjective. With such a subjective inspection process, many marginal solder joints are being reworked even though they meet the specification. Since the cost of reworking a solder joint is so high, industry is looking for new automated techniques to evaluate the integrity of a solder joint and omit any subjectiveness.

One method presently being investigated is the use of radiography. Radiographic techniques have been used for years as a nondestructive method for evaluating large metal structures and more recently to evaluate electronic components. The technique used to obtain data from defective solder joints using radiography should not be difficult since radiography has been used for many years. However, interpreting the results and insuring that no subtleties are missed will require new digital computer techniques and possible reevaluation of defect criteria. Digital imaging techniques, government acceptance of new defect criteria, and data evaluation will determine whether or not radiography becomes a viable solder joint inspection process.

Table A The steps involved in manufacturing a printed circuit card.

TABLE A

STEP	
A	The first step is to obtain the polyamide insulating layers that have copper clad on both sides.
B	The printed image of the circuits on that layer is put over the copper clad that has a thin layer of photographic polymer.
C	The unit then goes past a UV light source which cures the exposed polymer. The unexposed polymer can then be removed with a developer leaving the unwanted copper exposed and the desired copper traces covered with cured photographic polymer.
D	The exposed unwanted copper is then etched away.
E	Steps B, C and D are done to the copper on each side of the insulating layers with their respective print.

F The layers are then mated together by inserting semi-cured polyamide insulating layers (Prepreg) between the mating faces so that the copper traces will not touch. They are all sandwiched between stainless steel plates and then pressed at 200 to 300 psi at 340 degrees F for one hour. The respective holes are then drilled.

G The PWB then goes through an electroless copper deposition to plate the walls of the holes. This is then followed by copper electroplating.

H The desired circuit pattern for the card faces is then printed on similar to B, C, and D except that the desired copper is left exposed and the undesired is covered with the polymerized polymer.

I The PWB is then tin/lead plated with the tin/lead covering the desired circuit pattern and the copper on the walls of the through hole.

J The polymerized polymer is removed to expose the undesired copper. This copper is then removed with an etchant such as chrome-sulfur. This etchant removes the unwanted copper without disturbing the tin/lead plated copper circuits.

K The board can then go through any additional tin/lead plating steps and hot oil reflow processes to obtain the desired tin/lead finish.

CHAPTER 2

BACKGROUND

2.1 THE WAVE SOLDER PROCESS

Wave soldering is an automated process that applies solder to an entire circuit board in a single step. This process is one of the most important aspects in the assembly of electronic products. Since the wave solder process solders most of the components on the assembly, control of this process is of the utmost importance. A bad wave soldered board will contain defects in nearly every solder joint, requiring touch-up of each joint. The cost of repairing a solder defect can be as high as $2.00/joint, which emphasizes the importance of controlling the process.

The wave solder process contains various interacting parameters. There are four basic aspects to wave soldering: (1) flux, (2) preheat, (3) conveyor speed, and (4) solder. Figure 2.1 shows a typical wave solder machine. The general process involves loading the printed wiring board to be soldered on to the machine's conveyor system. The conveyor is then activated to a desired speed where the board becomes fluxed, preheated to a desired temperature, and then soldered at the solder wave. The following sections discuss the individual parameters in more detail.

2.1.1 FLUX

There are four basic functions of flux which allow it to aid metal wetting:

(1) Removes oxides from metal surface.

(2) Prevents reoxidation of the metal surface during heating.

(3) Assists in heat transfer.

(4) Decreases surface tension.

All four of these functions work together to allow printed circuit boards to be mass soldered with a tin/lead solder when correct fluxes are used. Since fluxes on military hardware must be removed prior to assembly, the solubility of the flux in certain solvents following the wave solder process is important. This leads to the first basic breakdown of the various types of fluxes:

(1) Fluxes soluble in organic liquids (rosin based).

(2) Fluxes soluble in water.

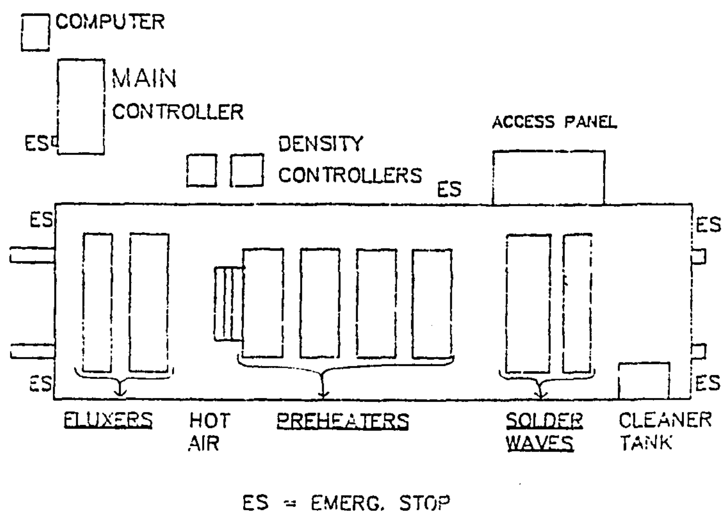


FIGURE 2.1 Wave solder machine.

When military electronic hardware is wave soldered, the fluxes are almost exclusively limited to the rosin based types. These are broken down based upon their relative activity:

(1) Rosin Activated (RA).

(2) Rosin Mildly Activated (RMA).

(3) Rosin (R).

The Rosin Activated flux has the greater activity and therefore performs the four basic functions better. However, the corrosive residue left from the greater activity has put stringent cleaning requirements and cleanliness testing on hardware wave soldered with RA flux. Many new military contracts are limiting contractors to the use of RMA flux due to the less corrosive residues following wave soldering. This has put an additional burden on Wave Solder Engineers due to the increased defects attributed to the lesser activity of the RMA flux.

The basic constituents of rosin fluxes are the rosin, isopropyl alcohol, and various organic salt or acid activators (chlorides, bromides, etc.). The amount and types of acid activators are what classify the flux as RA, RMA, or R type. The rosin itself comes from distilled tree sap which will normally contain 90% rosin acids and 10% filler material. Of the 90% rosin acids, 50% is abietic acid, 40% is primaric acid, and 10% is a combination of 12 different acids (2). The isopropyl alcohol serves as the carrier liquid. The activator of organic salts and organic acids plays an important role in the removal of oxides by the flux. At temperatures involved in wave soldering, the activator will break down and provide chlorides which will remove certain oxide layers. A simplistic reaction example for removal of copper oxide would be as follows (1):

$$Cu_2O + 2HCl = CuCl_2 + Cu + H_2O$$

$$2Cu_2O + N_2H_4 = 4Cu + 2H_2O + N_2$$

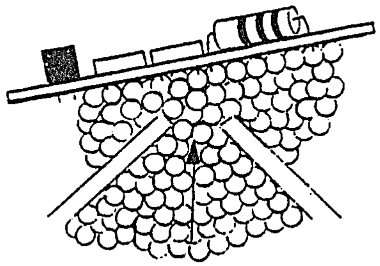
There are many other complex reaction products involved, including the solder bath itself which makes this operation somewhat more complex.

The removal of tin oxides is based upon the Ice Shell Theory (1). This theory states that the oxide layer is relatively thin, allowing the flux to make holes through the oxide and into the underlying tin. When the tin comes into contact with the solder via the holes in the oxide, it melts and the oxide layer breaks away.

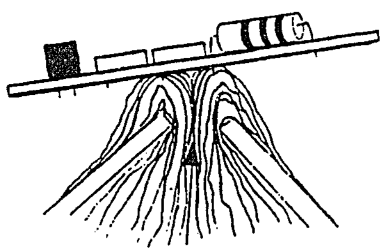
2.1.1.1 FLUX APPLICATION

The two basic methods used to apply flux to a printed circuit card for wave soldering are foam and wave fluxing. Figure 2.2 shows the schematic for each type.

Foam fluxing is produced by forcing air through a porous "stone" to produce fine air bubbles. The bubbles carry the flux up through a chimney and onto the bottom surface of the PWB. The "stone" is usually a ceramic material although some metal "stones" are used. The main



A: FOAM FLUXING



B. WAVE FLUXING

FIGURE 2.2 The two basic methods for flux application, foam fluxing and wave fluxing. (After Schade [2]).

advantage of foam fluxing is the evaporation of the solvent carrier when the bubbles burst upon contacting the PWB. This helps to leave a more uniform solids content throughout the board.

Wave fluxing is produced by an impeller assembly forcing the flux through a baffle and up a chimney onto the bottom of the PWB. Fluxes used in wave fluxing normally have a high solids content to eliminate excess solvent evaporation while moving through the wave. Wave fluxing has a tendency to apply excessive flux to the PWB. However, this aids the capillary action to allow the flux to reach the top side of the plated-through holes. Both fluxing methods have their advantages and disadvantages and one must choose the method that best suits his or her application and machine capability.

2.1.2 PREHEAT

The preheat section of the wave solder machine is one of the most interesting aspects of wave soldering. Evaluating the thermal characteristics of a PWB during preheating is important in assuring and verifying good solderable parameters are obtained. There are three basic reasons for preheating a circuit board:

(1) To evaporate the solvent and activate the flux.

(2) To decrease the thermal shock of the PWB when it enters the solder wave.

(3) To decrease the required immersion time in the solder.

Since it is difficult to obtain measurable temperatures at the solder wave in a production environment, controlling the preheat temperatures is used for process monitoring. If the solder pot wave configuration and temperature are held constant, then insuring that the PWB enters the solder wave at a predetermined temperature will help to insure proper soldering. Board temperatures are normally controlled by their governing specification which limits the maximum topside board temperature to 220 degrees F. Therefore, the workable topside board temperature range is 160 degrees minimum to 220 degrees maximum.

There are various methods available for preheating circuit cards in a wave solder machine. Each method of applying preheat will have its advantages and disadvantages depending upon particular process requirements. There is no single type of preheater that will meet all ideal conditions, but the following are the most widely used:

- Cal-Rod
- Plate
- Hot Air
- Infrared
- Quartz

Cal-Rod

The cal-rod preheat system consists of rod-type elements fitted into a frame. The bottom of the frame is normally lined with foil to collect any flux drippings, as well as to help transmit any infrared energy. The elements operate near red heat and are normally faster in response than the plate preheater (4). Solder machines will normally have two or three cal-rod sections to allow for more uniform heating.

Plate

Plate heaters are metal plates (1/4 inch thick) containing strip heaters bolted to the underside (4). The individual strips will normally have their own activation controls so that certain strips can be turned off. Although this method is the least expensive, it has trouble when preheating circuit cards with many layers. To help control this problem, a tunnel may be installed on the machine to help saturate the air and therefore increase preheat capability (Fig.2.3). Although the response time for plate preheaters is extremely high due to their large thermal mass, they provide very uniform heating.

Hot Air

Hot air preheaters are normally the first preheaters on a solder machine. Although the preheaters following the hot air may be cal-rod or plate, the hot air is directed across the bottom of the PWB to help evaporate any solvents prior to the circuit card reaching the actual preheaters. The heat provided by the hot air does not assist greatly in increasing the temperature of the circuit card, but evaporating the solvent from the board will help to prevent build up of flammable vapors.

Infrared

The use of infrared preheaters is one of the most expensive methods of applying heat to a circuit card. Infrared heaters have an extremely fast response time but there are many inherent problems associated with them. The major disadvantage is that the short wavelength of emissions, 1.5 mm, does not heat the circuit card uniformly. The amount of heat absorbed by the circuit pad will differ from the amount of heat the board or component lead absorbs. This non-uniform heating requires extremely tight control for the heaters and extensive trial runs to insure that the circuit cards are hot enough to provide good solderability but not so excessively hot as to damage components or board material.

QUARTZ

Quartz tube preheaters are the closest to being considered prefect preheaters. Although very expensive and fragile, they have a very fast response time and provide the capability of heating dense multilayer circuit cards.

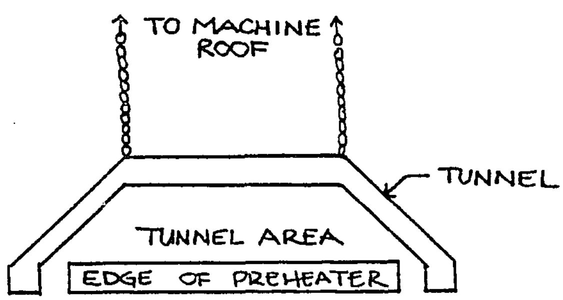


FIGURE 2.3 End view of tunneled preheat section. The PWB travels above the preheaters on a conveyor system that runs through the tunnel area. The inside of the tunnel is often plated with a heat reflective material.

Extreme care must be taken to insure that the preheaters operate within the specified range. Computerization of the wave solder machine has allowed large increases in usage of the quartz preheaters due to the ability to control the fast response times and over-temperature problems.

Verifying the top-side temperature of a printed wiring board after it has passed through the preheat zone and prior to the solder wave can be done by various means. The main method used by wave solder engineers is the use of surface pyrometers. Many fast-response surface probes are ideal for this case. The major disadvantage of this technique is the requirement to have access into the solder machine to obtain the reading. Accessing the interior of the solder machine disrupts the convective heat distribution and introduces a cooling effect which may cause erroneous readings.

A second method for measuring top-side PWB temperature is by the use of I.R. cameras. I.R. cameras mounted in the interior of the machine allows temperatures to be taken without accessing the solder machine interior. However, it is extremely difficult to standardize the use of I.R. cameras if many PWB variations are soldered on the same machine. Since circuit cards are so densely populated with components on the top-side of the board, there is very little board surface area to measure temperature with an I.R. camera. A bottom-side camera can be used if a top-side to bottom-side temperature relationship is to be determined for the various circuit cards.

Once a given circuit card design has been evaluated, a desired top-side board temperature must be arrived at.

2.1.3 Conveyor System

The conveyor system in a wave solder machine integrates the fluxer, preheaters, and solder pot into a feasible machine soldering process. The circuit card is loaded onto the conveyor which travels at a predetermined set speed. The method used to load the circuit card is determined by the type of "fingers" used on the conveyor system. Certain "clip" fingers will allow circuit cards to be run with or without a fixture, whereas, some "slot" fingers only allow fixtured circuit cards to be run. Fixtures allow the solder to be set higher and prevent flooding but they consist of a large thermal mass requiring higher preheat settings to allow the circuit card to reach the desired temperature. Computer-controlled systems allow for tight control of the solder height eliminating the potential flooding problem. The cost of manufacturing and maintaining fixtures is also a major factor in deciding whether or not to use "slot" or "clip" fingers.

The inclination of the conveyor in the solder machine is a very important parameter in wave soldering. Although some machines contain adjustable conveyors to allow the angle to be changed, many machines are manufactured to a specific angle. Conveyor angles will vary from 4.5 degrees to 7.0 degrees. The variance from changing the angle of the conveyor can be seen in Figure 2.4.

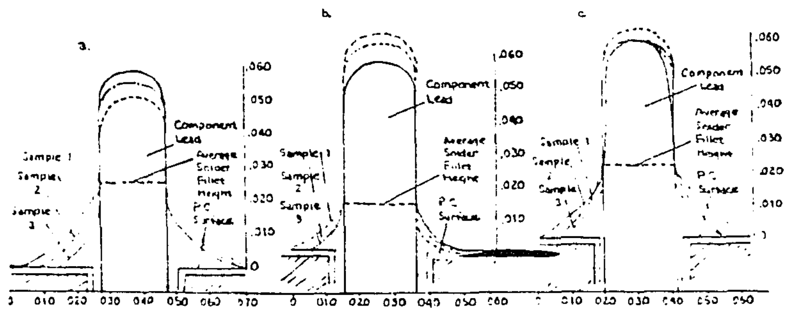


Figure 2.4 Solder profiles for samples wave soldered on a horizontal conveyor (a), on an inclined conveyor without oil intermix (c), and on an inclined conveyor with oil intermix. (After Bernard [3]).

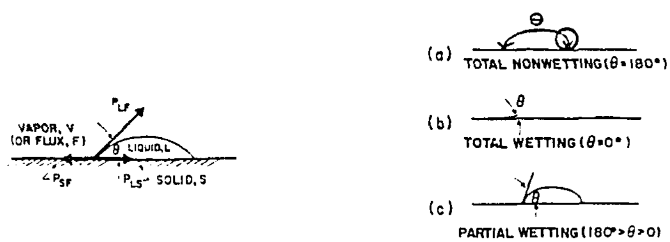
2.1.4 THE SOLDER WAVE

The solder wave is the most important aspect of wave soldering since this is where the solder joint is actually formed. The few seconds that the circuit card is in touch with the solder is the extent of time allowed to form a good electrical and mechanical solder joint. There are various ways of applying the solder to the circuit board with each containing certain advantages. This section will discuss some of the methods used as well as certain aspects of the solder alloy itself.

2.1.4.1 Solder Joint Formation

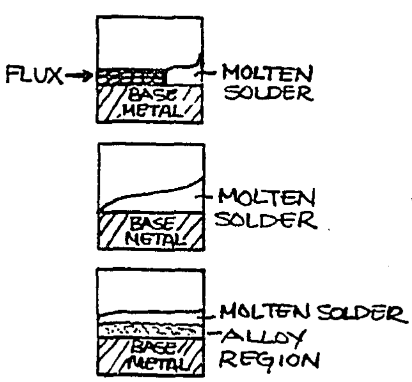
The formation of the solder joint is the joining of metal parts (the circuit card through hole/pad and the component lead) with an alloy of a lower melting temperature (solder). The method of formation of the solder joint is best described by the "bond" formed through the wetting of the solder to the through hole and component lead. Wetting is defined by equation (1), where r_{SV} is the wetting force which spreads the liquid on the solid. Therefore, wetting will occur when the left side of Equation (1) is greater than the right side.

As the solder is wetting, a metallurgical bond is being formed. This bond is formed through the mutual diffusion of the liquid solder and the base metal. When this diffusion occurs, intermetallic Cu/Sn alloys can be formed. Figure 2.6 shows the process sequence.



Equation (1) $r_{sv} = r_{ls} + r_{lv} \cos \theta$

Figure 2.5 Wetting.



A. Molten solder displacing the flux which has removed surface oxides.

B. Molten solder has displaced flux and covers surface.

C. Diffusion between solder and base metal forming alloy region.

Figure 2.6 Schematic showing the various stages that occur during wave soldering.

2.1.4.2 Methods of Application

One method normally used to apply the solder to the circuit card is called the "flowing" solder wave. The solder wave utilizes a large mass of molten solder which is pumped into a chimney producing a wave of solder that the circuit card can be passed through. There are various designs utilized for shaping the molten wave. Figure 2.7 shows the "Lambda Wave" introduced by Electrovert Inc.

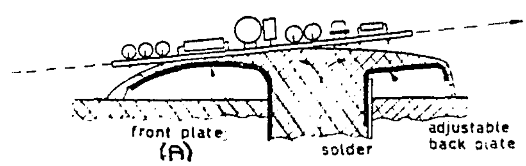


Figure 2.7 Lambda wave. By adjusting the front and back plates, optimum entry and exit conditions can be obtained. (After Wassink [1]).

The design of the wave is extremely important for proper soldering. The front portion of the wave, section A in Figure 2.7, should wash the board as it enters the wave. As the circuit card enters the middle of the wave the solder should be traveling the same speed and in the same direction as the circuit card promoting a "zero velocity zone". The zero velocity zone allows the solder to rise through the hole forming the solder joint. As the board exits the wave, a peel-back situation occurs that is important in providing correct bottom side fillets. The peel-back should pull the excess bottom solder along with the molten wave leaving a smooth solder finish on the bottom of the solder joint. Figure 2.8 shows the circuit card and wave traveling at velocity V as it reaches the end of the wave where peel back is occurring.

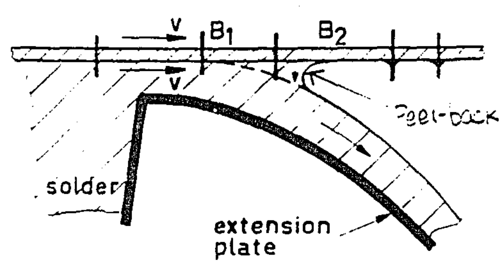


Figure 2.8 Diagram showing a circuit card leaving the "zero velocity zone" and entering the end of the solder wave where peel-back occurs. (After Wassink [1]).

The overall process time for a point on the bottom of the circuit card being washed by the front of the wave, through the "zero velocity zone", and exiting the wave where peel back occurs, can be no greater then five seconds as limited by governmental specification. For well-designed boards with good solderability the five second limitation does not come into effect since a good solder joint can be made in two or three seconds.

2.1.4.3 The Solder Alloy

There are many types of solders used in the electronics industry, each with its own application. For wave soldering military electronic hardware it is common to use a Pb(37)Sn-(63) eutectic solder. Figure 2.9 shows the phase diagram for the tin/lead system. The eutectic is used mostly for its lower melting temperature and non existing pasty range. The actual composition of the tin-lead solder and its impurities are dictated by government specification. Table 2.1 was taken from a military standard to illustrate the types of contaminants that must be monitored and their relative amounts. The tin content within the solder must also be monitored as shown in note 1 of Table 2.1. Table 2.1 is shown only as an example since the contaminants monitored and their amount may change from specification to specification as well as revision to revision.

The solder is maintained at 500 degrees +/- 25 degrees F (depending upon specification). This difference in melting and soldering temperature allows for good melting characteristics without the solder becoming sluggish when flowing. The microstructure of the solidified solder is

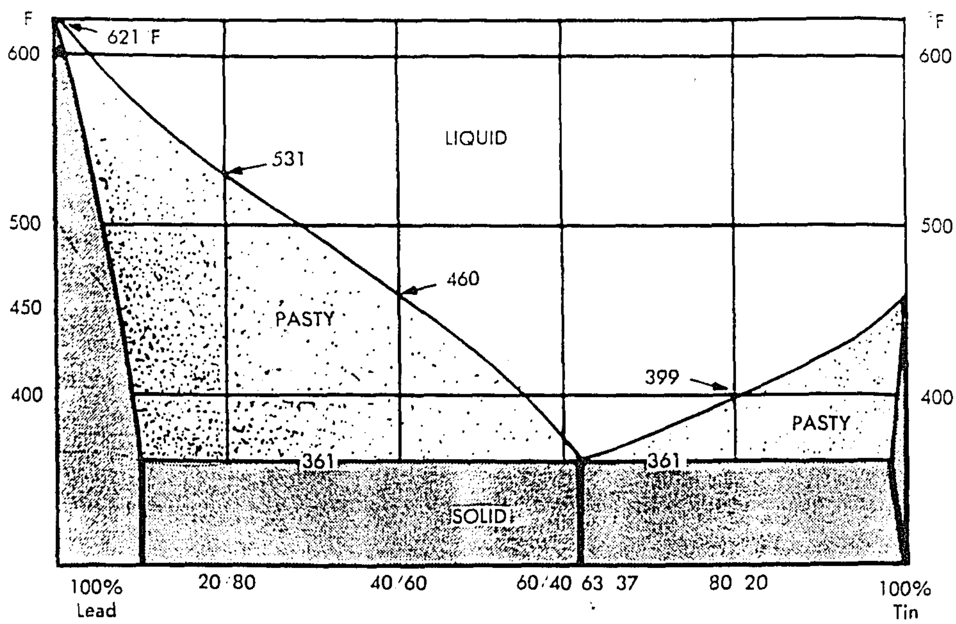


Figure 2.9 Tin-lead phase diagram. (After C.M.G.[5]).

expected to be of a eutectic structure containing lead and tin-rich intermixed phases. Variations of the tin content will alter this structure depending upon whether it is a tin-enriched or depleted solder. Characterization of the solder defects will illustrate the eutectic structure.

Table 2.1

Example of contaminants monitored in a solder pot. (Taken from Military Standard 454 G).

Contaminant1/	Solder Operation: Preconditioning (Lead/wire Tinning)	Solder Operation: Ass'y Soldering2/ (Pot, wave, etc.)	Testing Frequency (8 Hr Operating Days)4/: A	B	C	Solder Joint Characteristic Guidelines (If Solder is Contaminated)3/
Copper	.75	.30	15	30	30	Sluggish solder flow, solder hard and brittle
Gold	.50	.20	15	30	30	Solder grainy and brittle
Cadmium	.01	.005	15	30	60	Porous and brittle solder joint, sluggish solder flow
Zinc	.005	.005	15	30	60	Solder rough and grainy, frosty and porous high dendritic structure
Aluminum	.006	.006	15	30	60	Solder sluggish, frosty and porous
Antimony	.20 → .50	.20 → .50	15	60	120	Not enough: Solder crumbles into white powder after low temperature aging Too much: Solder brittle
Iron	.02	.02	15	60	120	Iron tin compound FeSn2 is not solderable - compound on surface presents resoldering problems
Arsenic	.03	.03	15	60	120	Small blister-like spots
Bismuth	.25	.25	15	60	120	Reduction in working temperature
Silver5/	.75	.10	15	60	120	Dull appearance - retards natural solvent action
Nickel	.025	.01	15	60	120	Blisters, formation of hard insoluble compounds

Notes: 1 The tin content of the solder bath shall be from 59.5% to 61.5% tin and tested at the same frequency as testing for copper/gold contamination. The balance of the bath shall be lead and/or the items listed above.

2.1.4.3.1 Physical Characteristics

Since solders have been used for some time, the physical characteristics have been well researched and are not of a major concern. However, Tables 2.2 and 2.3 show some of the physical characteristics of certain solders. Figure 2.10 shows the types of stresses given in Tables 2.2 and 2.3. Since this thesis is concerned with characterizing and identifying solder defects, it will not cover the physical characteristics important to failure analysis other than the tables provided.

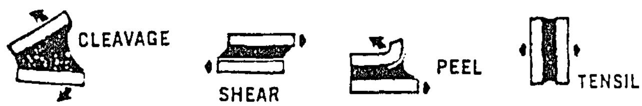


Figure 2.10 Four Basic Stress Types. (After C.M.G.[5]).

Table 2.2 Strength of Soft Solders. (After C.M.G. [5]).

ALLOY %	MELTING BEGINS °FAHR.	COMPLETELY MOLTEN °FAHR.	TENSILE STRENGTH PSI.	SHEAR STRENGTH PSI.
100 TIN	450	450	1800	2560
63/37 Sn, Pb	362	362	6700	6060
62/38 Sn, Pb	362	363	6700	6060
60/40 Sn, Pb	362	375	6400	5700
50/50 Sn, Pb	362	420	6450	5870
45/55 Sn, Pb	362	440	5500	4780
40/60 Sn, Pb	362	460	6320	5680
35/65 Sn, Pb	362	475	6230	5590
30/70 Sn, Pb	362	490	6140	5500
25/75 Sn, Pb	362	514	5770	5310
20/80 Sn, Pb	362	533	5410	4740
15/85 Sn, Pb	437	553	4700	4470
5/95 Sn, Pb	518	596	4190	3000
100 LEAD	621	621	1780	1800

Table 2.3 Strength of Soft Solders at various temperatures. Data is in P.S.I. (After C.M.G. [5]).

ALLOY	ROOM TEMP	200°F	300°F
5/95	4190	2965	1782
10/90	5017	2917	1863
20/80	5410	3043	1518
30/70	6140	3120	1495
40/60	6320	3320	1275
50/50	6450	3090	1150
60/40	6400	3150	1000
95Sn/5Sb	5900	3700	2000
97.5 Pb/1.5 Ag/1Sn	3600	2500	1750

2.1.5 The Profile

The profile of a circuit card can be considered as the information and machine settings that result in optimum soldering of the circuit card during the wave solder process. This requires that the flux, preheaters, conveyor, and solder pot with their individual parameters must be set properly for each circuit card. This section will consolidate Sections 2.1 to 2.1.4 and provide one method of determining proper machine settings. It should be noted that there are many methods for determining a profile, all of which are correct. This method is most suitable for a solder machine that will be soldering many circuit cards of various designs.

Figure 2.11 shows a schematic of the parameters discussed in the previous sections. The following list illustrates the connection between these parameters:

1. The flux of correct density must be applied as a uniform layer onto the bottom of the circuit card.

2. The conveyor speed must be set such that as the board leaves the preheaters it is at 190 degrees F top side circuit board temperature. This temperature will vary depending upon board design but normally will be between 170 degrees to 210 degrees F.

3. For an average solder wave height, the conveyor can normally travel between 3.5 feet/minute to as fast as desired, without breaking the 5 second limit (dwell time) that the circuit card can be in the solder.

4. Therefore, since circuit card thickness and design will vary, the preheaters should be set and held

constant at temperatures that allow the thicker,larger boards to travel at 3.5 feet/minute and reach the desired top side temperature while the thinner circuit cards can be run at much faster speeds.

5. The ultimate factor determining these settings is the quality of the circuit card after it has been soldered.

With these types of problems existing it can be understood why solder defects exist. Now that an explanation as to how the solder joint is formed and why it is so difficult to form a good solder joint, the defects themselves will be reviewed.

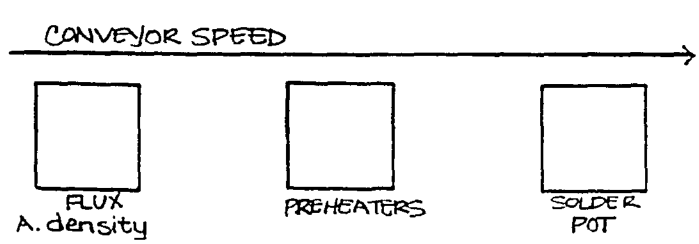


Figure 2.11 Relationship of wave solder parameters.

2.2 SOLDER DEFECTS

There are many solder defects that can be produced when wave soldering a circuit card. Only five of the most prominent defects will be investigated in this study. These will include excessive, insufficient, dewetted, nonwetted, and grainy solder joints. Each defect has its own cause and corrective action with solderability playing a major role in four of the five defects. Since solderability is a major subject of its own, it will suffice to state that solderability is the key to producing wave solder hardware with minimum defects. However, if good solderable materials are used, the machine parameters become the controlling factor.

Tables 2.4 and 2.5 illustrate the equipment and material parameters that should be evaluated for a given defect. This type of table can be used as a guide to reevaluating process parameters if a given defect is constantly appearing.

When evaluating the troubleshooting charts it can be seen that there is some contradiction between nonwetting and dewetting. These should be viewed as two different defects each with their own cause and corrective action. The following definitions can be applied to the five defects being considered:

(1) Nonwetting: This can be viewed as those areas on the circuit pad or lead where the solder has not reached and the solder approaching the nonwetted area has a poor contact angle. See Section 2.1.4.

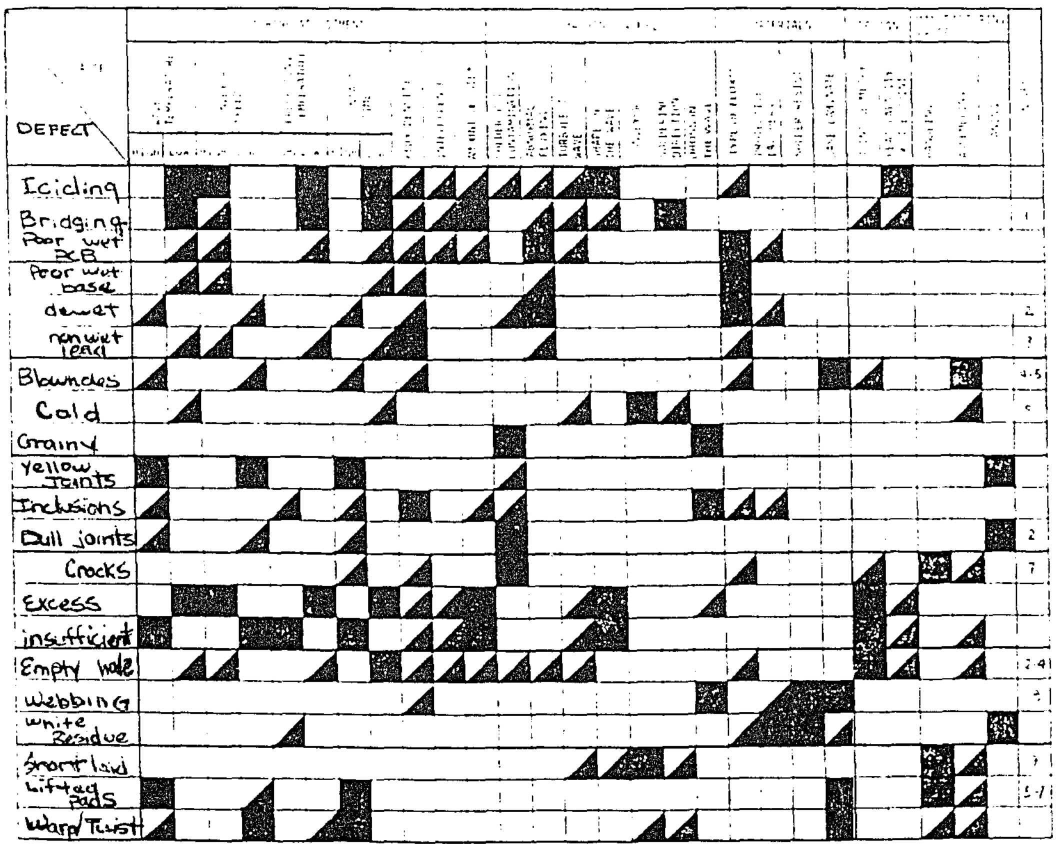
(2) Dewetting: This is similar to nonwetting except the solder did cover all areas but withdrew, balling up and forming a poor contact angle.

(3) Excessive: This is referenced to excessive solder on the component side of the circuit card such that the solder travels up into the stress bend of the component.

(4) Insufficient: This is defined as the lack of solder on the top side of the solder joint.

(5) Grainy: This normally occurs with contaminated or overheated solder joints.

Table 2.4 Wave solder trouble chart. (After Leonida [6]).



(*) Only for wave soldering machines with oil intermix
(**) In connection with the nature of the surfaces to be soldered
(*) Metal onto which the joint is finally made; in the presence of a soluble or fusible coating, it is the metal under it

(1) Also, design of the board.
(2) Also, composition of solder in the pot
(3) Coating to be considered is that of the lead
(4) Also, poor plating of the hole walls
(5) Also, poor hole drilling.
(6) Also, presence of blowholes
(7) Handling is after soldering
(8) Also, uncompleted etching.
(9) Handling is before soldering

<u>LEGEND</u> TABLE 2.4 AND 2.5

● or ■ = highly probable cause
◢ = less probable cause

Table 2.5 Wave solder trouble chart. (After Elliott [7]).

Symptom \ Cause	Solder temp high	Solder temp low	Solder wave height high	Solder wave height low	Solder wave uneven	Solder contaminated	Excessive solder dross	Preheat temp high	Preheat temp low	Flux contaminated	Flux specific gravity low	Flux specific gravity high	Flux no longer active	Flux not making contact	Flux foamhead low	Flux uneven	Flux blow-off excessive	No flux blow-off	Pallet too hot	Conveyor speed high	Conveyor speed low	Conveyor vibration	Conveyor angle high	Conveyor angle low	Early removal of board	Board not seated right
Insufficient solder flow thru	●	●		●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●			●			●
Insufficient solder (solder side)	●			●	●	●		●	●	●	●	●	●	●	●	●	●		●	●			●			●
De-wetting or non-wetting		●		●		●			●	●	●	●	●	●	●	●	●	●	●	●	●					●
Solder voids or outgassing	●	●		●	●				●	●	●	●	●	●	●	●		●	●	●	●		●			●
Excessive solder (solder side)		●			●	●					●	●	●			●		●	●	●	●			●		●
Icicles		●		●	●	●		●	●	●	●		●	●	●	●	●		●	●		●		●	●	●
Bridging		●		●	●	●		●	●	●	●		●	●	●	●	●		●	●	●			●		
Webbing		●				●	●	●		●	●		●	●	●	●	●		●	●	●					
Solder balls and splatter	●		●		●				●	●	●							●		●						
Rough or disturbed solder		●		●	●	●	●													●		●			●	●
Grainy solder		●				●	●		●											●		●			●	
Cold solder joint	●	●				●			●											●	●	●			●	
Discolored solder joint	●					●		●	●	●										●	●					
Flux entrapment									●	●		●						●		●						
Blistering	●							●													●					
Measling	●							●													●					
Components lifted			●		●												●					●	●		●	●
Warpage	●							●	●												●					●

2.3 RADIOGRAPHY

Radiographic techniques have been used for nondestructive evaluation for many years. From the testing of large castings for cracks to the examination of hybrid lead-to-package short circuits, radiography has become a viable method of nondestructive evaluation in the electronics industry. Although radiographic techniques have been applicable to low volume production items or lab-type evaluations, the introduction of "Real-Time Radiography" has made "on-line" radiographic inspection of large volume production items possible.

There are three basic elements in radiography, a radiation source, the test piece being evaluated, and a recording medium. Figure 2.12 shows the relationship between the basic elements. The radiation source generates x-rays that bombard the sample being inspected. X-rays are used since their short wave length allows them to penetrate opaque materials. Figure 2.13 shows an x-ray generating unit or x-ray tube.

X-rays are produced within the tube by the interaction of electrons with a target. The electrons in the tube are produced by heating a tungsten filament to incandescence by the use of an electric current. The electrons are then accelerated at high velocity towards the target by a high electrical potential between the filament (-) and target (+). When the electrons impact the target, continuous x-rays, characteristic x-rays, and heat are generated. The heat generated must be removed by a cooling system to insure the life of the x-ray tube. The continuous x-rays

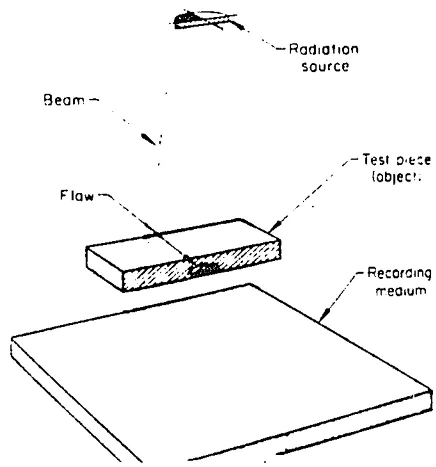


Figure 2.12 Basic elements of a radiographic system. (After Greene [8]).

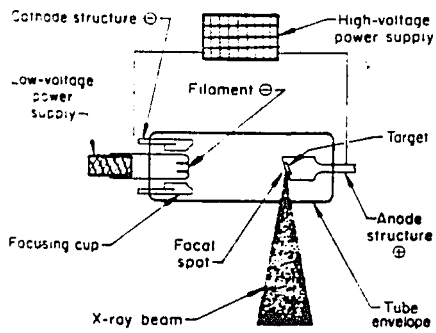


Figure 2.13 X-ray unit. (After Greene [8])

are produced by the deceleration of the impinging electrons which results in x-rays of many wave-lengths.
Characteristic x-rays are produced by the displacement of a target atom electron from its orbit, leaving the atom in an excited state. When an electron in the atom rearranges itself into the empty space, a characteristic x-ray of the rearrangement is emitted. The anode-to-cathode voltage can be considered as the penetrating power of the x-ray beam since it controls the energy of the electrons impinging on the target.

The x-rays generated from the x-ray tube bombard the specimen being investigated. Because of variances in density, thickness, absorption characteristics, and composition within the specimen, the bombarding x-rays will be absorbed differently throughout the specimen. The unabsorbed x-rays passing through the specimen will exhibit the physical variations within the specimen by their varying energy. The unabsorbed x-rays then contact the recording medium.

There are various recording mediums available, each with their own advantages and disadvantages. X-ray film is one of the most popular means of recording a permanent radiographic image. X-ray film is constructed of a thin, transparent plastic support called a film base, which usually is coated on both sides (but occasionally on one side only) with an emulsion consisting mainly of grains of silver salts that are embedded in gelatin (8). A thin coating of gelatin is used on the surface to protect the emulsion. When electromagnetic radiation reacts with the emulsion of the film, a latent image is formed. A visible image is formed from the latent image by chemical processing. The first step of the chemical process employs a developer to chemically convert the exposed silver halide grains in the latent image to black metallic silver. A fixer is then used to convert the unexposed silver halide grains to a water-soluble compound which is then washed off. The type of film being used depends upon the specific radiographic application. Since the characteristics of various x-ray film types are so various, it is important to evaluate the type of radiography being performed.

When using real-time radiography the direct recording medium is a fluorescent screen. Figure 2.14 shows an x-ray image intensifier. The intensifier employs a fluorescent medium inside a vacuum tube envelope so phosphors whose physical properties are unacceptable for use in air can be used. The main objective of the intensifier is to change the x-rays into light photons. When an x-ray strikes a grain of phosphor, a number of light photons will be emitted. Although there are many equations and parameters defining the efficiency of the fluorescent screen in converting x-rays to light, it will suffice to understand that x-rays of higher energy or larger quantity in a given area will produce more light photons resulting in a brighter area. As the x-rays are producing light photons, this information is transferred to the operator by the use of a Low-Light-Level Video Camera. Figure 2.15 illustrates the overall component location in real-time radiography. Once the information is obtained from the video camera, digital image processing techniques can be applied.

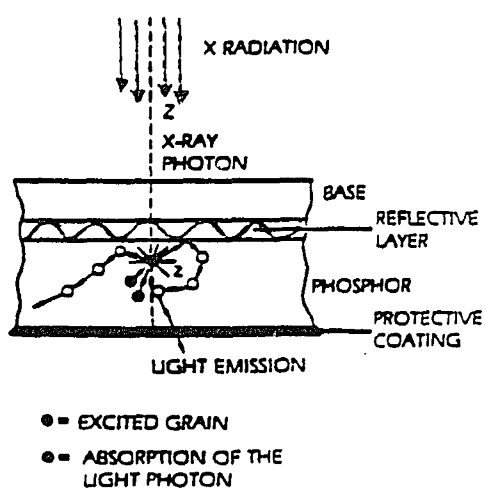


Figure 2.14 X-ray intensifying screen. (After Bossi [9]).

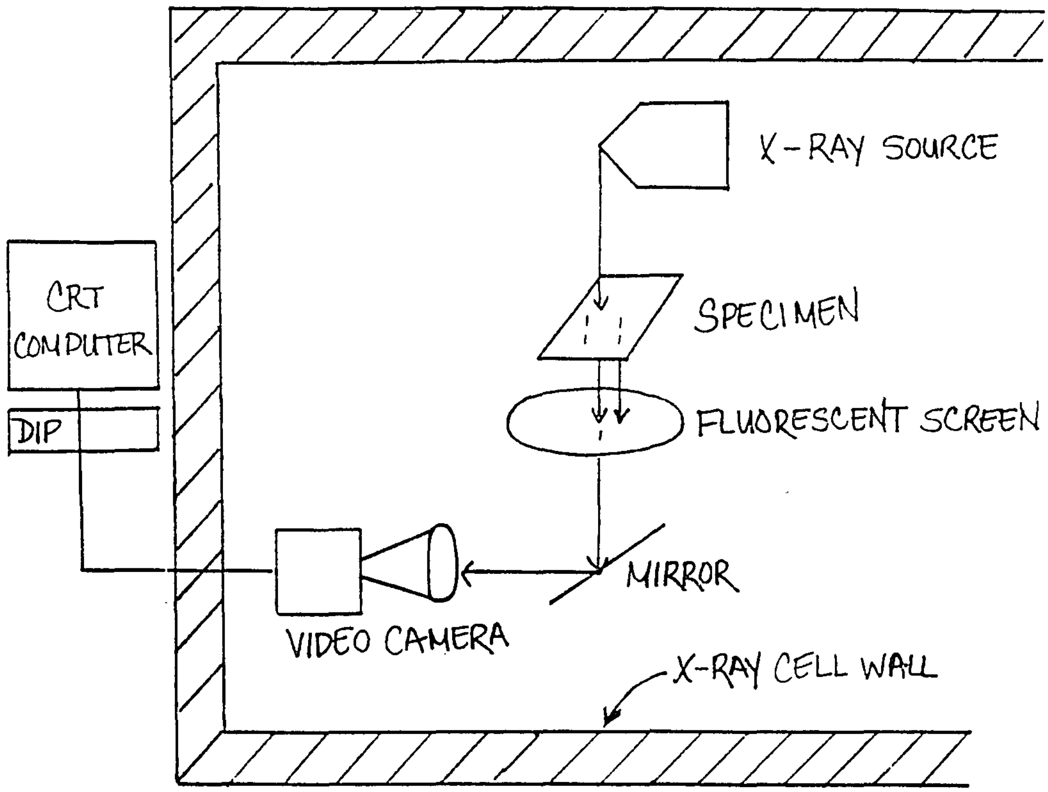


Figure 2.15 Location of elements in a real-time radiographic inspection unit.

The geometrical effects involved in radiography can be summarized as shown in Figure 2.16. Since real-time radiography employs the use of microprocessor units, elements (a) and (c) in Figure 2.16 can be easily monitored and electronically corrected. Element (b) however, is still controlling the magnification of the radiographic image.

The magnification of the sample can easily be determined since Lo and Li are known values.

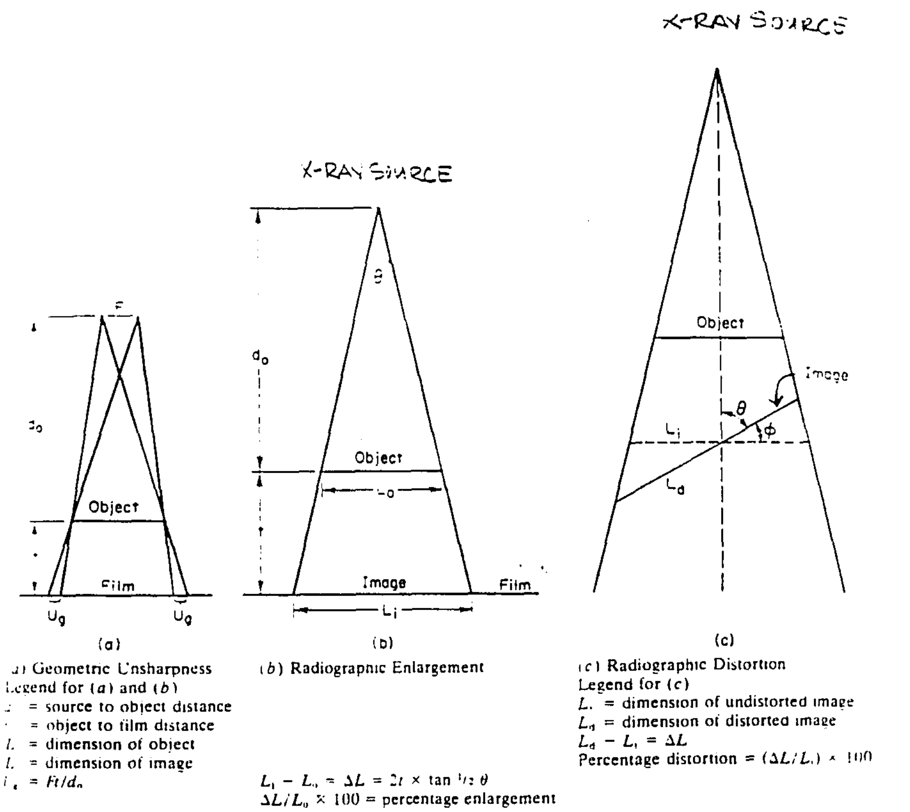


Figure 2.16 Effects of object to screen geometry. (After A.S.T.M. [10]).

2.4 DIGITAL IMAGE PROCESSING

Digital image processing is the analyses of digitized pictorial information. With the availability of dense memory devices, special purpose signal processing components, and inexpensive microprocessors, digital image processing has become a viable analysis technique. Figure 2.17 shows the components used to obtain an image. After the image is detected from the video camera, it goes to an image processor which digitizes the video signals to improve the signal-to-noise ratio and increase specific enhancements. The image processor digitizes the video signal from the low-light-level video camera into 512 x 512 images with 8 bits (256 gray levels) per pixel.

Although digital processing involves many complex mathematical relationships, the basic principles can still

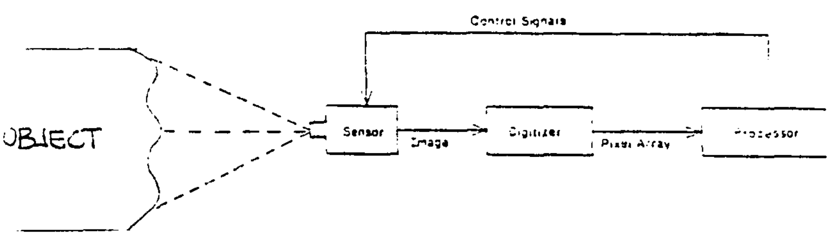


Figure 2.17 Components of processing system. (After Rosenfield [11]).

be discussed. A typical black and white picture is composed of shades of gray spanning from black to white. To convert the picture to a digital image it must be "chopped" into individual points of information. This is referred to as digitizing since samples of brightness at specific locations are being taken. Each sample is given a numeric value based on its brightness, ranging from black through the grays to white. The brightness value is also assigned coordinates describing its location within the image. A sample is often referred to as a picture element, or pixel, because of its representation of a discrete element of the digital image (12).

A square grid of pixels, each with a labeled pair of coordinates, is used for digitizing an image. Figure 2.18 shows the discrete pixel numbering convention. Since each pixel contains a brightness value, it is important that the correct number of pixel samples are taken so that no information is lost. The number of pixels the digital image is divided into is called spatial resolution. The spatial resolution used when digitizing most images is 512x512 since it is compatible with television format. The 8-bit gray scale exhibits 256 gray levels per pixel. Therefore each pixel evaluated in the 512x512 grid can be assigned a digital value between 0 and 255. The location of the digital value is identical to the sample coordinates. When each pixel is evaluated, the result is a digitized image of the picture being evaluated.

Digitizing the original image is only the first step in many digital imaging techniques. There are many enhancement operations including photometric correction operations, dual image processing, spatial filtering operations, and edge detection operations. These digital operations allow the viewer to enhance a specific aspect of the digital image. With these special operations available, a digital image can provide information not possible from a black and white photograph.

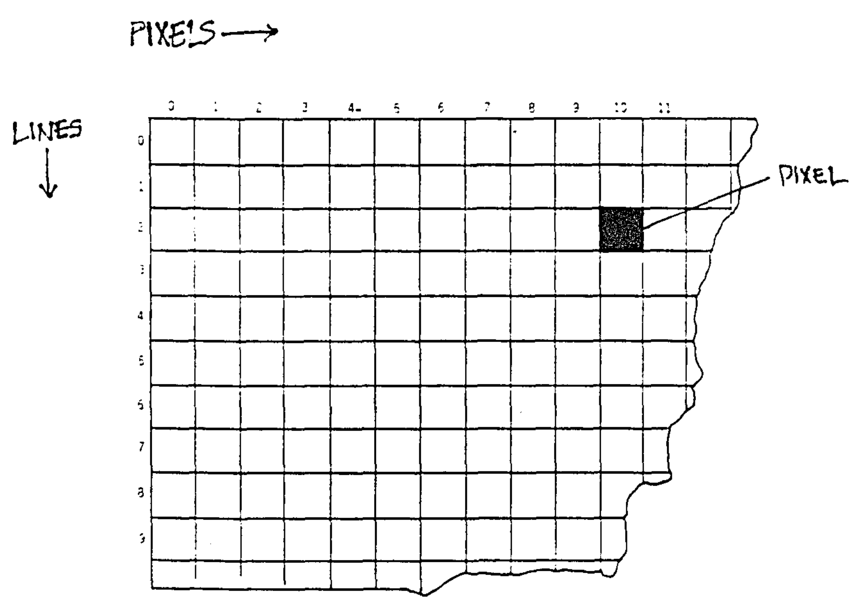


Figure 2.18 Discrete pixel numbering convention. (After Baxes [12]).

CHAPTER 3

OBJECTIVE

The objective of this research was to review the soldering process, discuss five of the major solder defects produced during soldering, and investigate the possibility of using real-time radiography to identify solder defects.

CHAPTER 4

EXPERIMENTAL PROCEDURE

In order to investigate the five major solder defects they must first be produced. This was accomplished by wave soldering printed wiring boards loaded with electronic components with machine parameters set at values that induce the desired defect.

All of the solder joints were of one design containing plated-through holes with clinched leads and soldered with Kester RA flux and Sn63 solder. The printed wiring boards were then inspected with an optical microscope at 10X magnification to locate and identify the desired defects. The five defects being evaluated were insufficient, excessive, dewetted, nonwetted, and grainy solder. Once the defective solder joints were identified, they were removed from the printed wiring board by cutting around the solder joint with a saw.

Once the defects were removed from the printed wiring board they were photographed using a MP-4 Polaroid camera at 10X magnification. The defects were mounted at a slight angle to help increase the contrast of the defect and eliminate shadowing. In order to provide a range of a specific defect, two samples of each defect and two samples of a good solder joint were photographed. The photographs were then enlarged and half-toned to provide an easily copied result.

After the defects had been photographed they were radiographed using a Hewlett Packard Faxitron X-ray Unit. The Faxitron has a maximum focal-spot-to-film distance of 533 mm, a focal spot size of 0.6mm, and employs a tungsten target to generate it's x-rays. Since a high resolution radiograph was desired, the maximum focal-spot-to-film distance was used as well as a minimum object-(solder defect)-to-film distance of 3.1 mm. The radiographic film used was Dupont 35 high resolution, single emulsion film. With the Faxitron settings as stated and Dupont 35 film the total resolution was approximately 85 line pairs per millimeter.

The initial tube voltage used to evaluate the solder defects was the highest possible setting of 110 KV. 110 KV was chosen since it was the most often used and an exposure chart for the Dupont 35 film for various penetrameters at this voltage had been constructed. After evaluating the radiographic results, it was evident that the voltage needed to be lowered to enhance the pad area of the solder defects.

After evaluating a range of tube voltages it was determined that a 70 KV tube voltage for an exposure time of 100 seconds gave the best results. Two samples of every defect including a good solder joint were radiographed at 70 KV at 3 mA and 100 second exposure time at a 0 degree sample tilt and a 30 degree sample tilt. The radiographs were then photographed with a light table and a MP-4 camera at 20X magnification. These photographs were then half-toned for the final image.

The solder defects were then evaluated with an IRT CXI-5210 real-time X-ray inspection unit. The CXI-5210 utilizes a tungsten target providing a microfocus x-ray source with a focal spot size of 0.040 mm. The maximum tube voltage is 160 kv at 32 watts. The focal-spot-to-screen distance is approximately 40 in. with a variable object-(solder defect)-to-screen distance. With a real-time radiographic unit it is important to remember that a fluorescent screen is used instead of film. The CXI utilizes a variable object-to-x-ray source distance to obtain the desired magnification. The x-ray image of the CXI-5210 is obtained with the use of a gadolinium oxysulfide fluorescent screen which changes the x-rays into light photons. The light photons strike a mirror which transmits the photons at 90 degrees to a low-light-level video camera. The camera then processes the information into an analog video signal which is transferred to a digital image processor for digital conversion. It is important to realize that with the combined optics and electronics the CXI-5210 exhibits a total resolution of only approximately 14 line pairs per mm.

The operation of the CXI-5210 for analyses of the solder defects was 155 KV at 0.2 mA. These settings had been experimentally derived for evaluation of solder joints by the IRT corporation. The solder defects were evaluated at 0 and 30 degree specimen tilts. Since the viewed image is digital, digital image processing techniques were applied. This allowed various areas of the solder defects to be analyzed for gray level values. A computer program was then used to print out a scaled gray level plot of every pixel value in the image. The images were then stored on high density floppy disks for future use. Photographs of the digitized images were obtained by accessing the images from the floppy disks onto a CRT screen and photographing the CRT screen. Since the resolution of the images was relatively poor, only one sample of each solder defect was photographed.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Solder Defect Characterization:

Appendix A contains the photographs of a plated-through hole, a good solder joint, and the five solder defects under evaluation. It is important to remember that the classification of a solder defect is a very subjective process itself. An extensive list of various defects is used when identifying solder defects on a printed-circuit-card. However, most defects analyzed can be classified into the five categories of excessive, insufficient, nonwetted, dewetted, and grainy solder. The defects used in this study were identified by four solder experts to insure proper classification.

Figure A.1 shows a plated-through hole before soldering occurs. The pad area and barrel area are illustrated on the photograph. The barrel area is where the electronic component lead is inserted so that it can be soldered to the plated-through hole. The solder that fills the barrel is considered the bulk solder. When soldering occurs the solder should fill the barrel area, extend over the pad with

100% coverage, and flow partially up the component lead. Good solder joints are illustrated in Figures A.2 and A.3. More than one photograph of each type of defect was taken to give a range of each specific type of defect. The magnification of 10X is the highest magnification used when inspecting for solder defects and is normally restricted to 4X magnification. Figures A.2 and A.3 show the good barrel fill, extension of the solder over the pad area, and wetting of the component lead which is characteristic of a good solder joint.

Figures A.4 and A.5 illustrate insufficient solder joints. An insufficient solder joint is characterized by its lack of solder coverage. The solder fills the barrel area but does not extend onto the pad area. Although the solder does wet the component lead, the insufficient coverage of the pad area is enough to classify this solder joint as a defect.

Excessive solder joints are shown in Figure A.6 and A.7. An excessive solder joint has good pad coverage but the solder extends up the component lead and into the lead bend. An excessive solder joint is one of the easiest defects to find and characterize since the defect is normally so extensive. The cracking and chip seen in

Figure A.7 is due to the removal of the solder joint from the printed-wiring-board.

Figures A.8 and A.9 show dewetted solder joints. A dewetted solder joint is one in which the solder was there and then left. Figure A.8 is considered dewetted since it appears the solder covered a portion of the pad area and then withdrew back into the barrel area. Figure A.9 is the more classical case of dewetting where the solder has balled up and only remains together under the component lead. It is important to remember that both of these defects may have been classified into the category of insufficient since they have poor pad coverage. However, with an insufficient solder joint the solder never reaches the pad area of the solder joint.

Nonwetted solder joints are shown in Figures A.10 and A.11. A nonwetted solder joint is characterized by a partial wetting of the pad area. A nonwetted solder joint differs from a dewetted solder joint in that the solder never covers the pad area. The nonwetting of the pad area is illustrated well in both Figures A.10 and A.11. The nonwetted solder joint is very similar to an insufficient solder joint except that a portion of the pad has been wetted verifying that solder was available but did not wet the entire pad area.

Figures A.12 and A.13 illustrate grainy solder joints. A grainy solder joint is one in which a good solder joint appears bumpy. Figure A.12 is the more typical grainy defect and Figure A.13 shows an extensive grainy solder joint. A grainy solder joint is very similar to a dewetted solder joint except a grainy solder joint will normally contain a good barrel fill and good lead wetting making the appearance of a good solder joint.

When evaluating the various defects it is interesting to note that both the nonwetted and dewetted defects require close observation for distinguishing characteristics. The excessive and grainy defects, however, have their own specific characteristics separating them from the other defects. When these defects are evaluated with radiography it will be important to remember the visual characterization of each specific defect. Since there are so many common characteristics between the defects, the first goal when using x-ray inspection will be to differentiate the defects from a good solder joint. Then, if possible, individual identification of the various defects will be attempted. If individual identification is not possible, a new defect breakdown or chart may need to be developed for radiographic inspection.

5.2 Radiographic Inspection:

The first aspect in evaluating solder defects with radiography is to determine if radiography can be used at all, and if it can, which parameters are involved. Appendix B contains the photographs at 40 X magnification of the solder joint radiographs. These results are at 70 KV for 100 seconds and 3 mA at a 0 degree specimen tilt. Appendix C also contains photographs at 40X magnification at the same parameters as Appendix B but the solder joints have been tilted to approximately 30 degrees. Only one example of each type of defect is given in Appendix B since the 30 degree tilt provided better results.

The results shown in Appendix B illustrate some of the characteristics of the solder defects. The radiograph of the good solder joint shown in Figure B.1 has more white (more solder) on the pad area than the dewetted, nonwetted, and grainy solder joints shown in Figures B.4, B.5 and B.6. This is expected since most of the defects have problems occurring on the pad area. The excessive solder joint of Figure B.3. is more white in the pad area due to the large amount of solder coverage on the pad area. Therefore, a definite distinction between a good solder joint in most of the cases is possible. The insufficient solder joint, however, shown in Figure B.2 does not illustrate a difference from the good solder joint even though it has the least amount of solder on the pad area. This does not correlate with the other results since all of the radiographs were obtained at the same parameters. The reason for the inability to distinguish the insufficient solder joint is due to the solder on the bottom side of the plated-through hole. Although none of the bottom sides had defects, the insufficient solder joint had more solder on the bottom than the others allowing a mask effect to occur. Since the ability to identify the defects will rely strongly on relative contrast between the results, a new technique was needed.

To eliminate the mask problem the solder joints were tilted to approximately 30 degrees. The 30 degrees was chosen since it was the maximum tilt available on the real-time x-ray unit. The results, shown in Appendix C, are somewhat confusing at first. The tilt has allowed the top pad to be distinguished from the bottom pad as well as provided a good view of the barrel area. When evaluating the defects at 30 degrees it is easy to distinguish between a good and bad solder joint. It is also now possible to begin classifying each defect by its radiographic results. The good, excessive, nonwetted, and grainy solder joints shown in Figures C.1, C.2, C.5, C.6, C.9, C.10, C.11, and

C.12 each illustrate their specific characteristics. The insufficient and dewetted solder joints shown in Figures C.3, C.4, C.7 and C.8, however, are still very similar to each other. This similarity is somewhat expected since dewetted solder joint is one which wets the pad area and then withdraws back into the barrel area. Therefore, the solder left on the pad area may be too thin to detect with radiography. The information of barrel fill is also very important when evaluating the solder defects. Since the barrel information was not available when inspecting the surface of a defect visually, the classifications relied on the appearance of the surface. Now that the barrel is visible, a new definition of a good solder joint concentrating on the barrel area may be required. This would mean many solder joints presently being classified as a defect are actually very mechanically and electrically functional.

Evaluating the solder joints using high resolution film provided valuable information on the possibility of using radiography for solder joint inspection. Although the film process is much different from real-time radiography, it has verified that x-rays can be used to distinguish and possibly identify solder defects. The next variable is whether or not the hardware involved in real-time radiographic analys can provide the resolution required for solder joint inspection.

5.3 Real-Time Radiography:

Real-time radiography is very different from conventional film radiography. The major difference is the resolution capability between the two methods. The results shown in Section 5.2 illustrate a resolution of approximately 85 line pairs/mm. The IRT CXI-5210 has an ultimate resolution of approximately 14 line pairs/mm. This difference makes film radiography appear much more attractive than real-time. However, real-time radiography employs digital imaging techniques which allow 256 shades of gray to be discerned. The digital technique as well as the on-line results make real-time radiography a possible tool for evaluating solder defects.

Appendix D contains examples of the digital images of the solder defects obtained on the CXI-5210. The images, as expected, do not show much difference between the various solder defects and the good solder joint. This again is due to the poor total resolution of the real-time system. However, the intent of the system is to use digital analysis techniques to evaluate the various solder defects and not a human operator. To illustrate the gray level variance that is not distinguishable to the human eye, samples of the gray level values were taken of the solder defect digital images at 0 and 30 degree tilts. Table 5.1 shows the average gray level value sampled from the various solder joints at 0 degree tilt. The lower gray level value is a darker image (more/thicker solder). The samples of gray level were taken on the pad area of the solder joints. When evaluating Table 5.1 the gray level values do not distinguish the various defects. Good, nonwetted, and insufficient have very close average gray levels. This is due to the mask problem discussed in Section 5.1. The solder joints were then tilted to 30 degrees and the same gray level samples were taken.

The gray level results for solder defects at a 30 degree tilt are shown in Table 5.2. The 1 and 2 are the defects of each specific type evaluated. The gray level from sample to sample of each type of defect showed good correlation. Figure D.1 shows an example of where the gray level samples were taken. The samples were taken over an area and then averaged to obtain the final value. Evaluating the data shows a big difference between a good solder joint and a bad solder joint. This is very desirable since the first step is to separate the good solder joints from the bad ones. The individual

Table 5.1

Gray Level Samples of Solder Joints
at 0 Degree Tilt

Solder Joint	Average Gray Level
Good	125
Nonwetted	128
Dewetted	152
Insufficient	115
Grainy	194
Excessive	62

characterization of the defects, however, is not illustrated with the gray level technique. The insufficient, nonwetted, dewetted, and grainy solder defects all lie between 180 and 200. The excessive is easily detected since it's value is so small compared to the others. Figure 5.1 shows a plot of every gray level of a good solder joint. The gray level scale has been reduced from 0 to 256 to 0 to 10 where 0 is the thickest solder and 10 is the thinnest. This figure is shown only as an example of the many uses of the gray level imaging technique.

Table 5.2

Gray level samples of solder joints at a 30 degree tilt.

Solder Joint	Average Gray Level #1	#2
Good	110	105
Insufficient	185	190
Excessive	37	43
Nonwetted	190	185
Dewetted	195	200
Grainy	180	180

Although the real-time solder joint inspection unit does not provide images that can be evaluated with the human eye, it does provide valuable information discernible with digital techniques. Since the inspection unit is expected to evaluate the digital images within its own computer processors, the average gray level values are important for providing a possible tool for defect analyses.

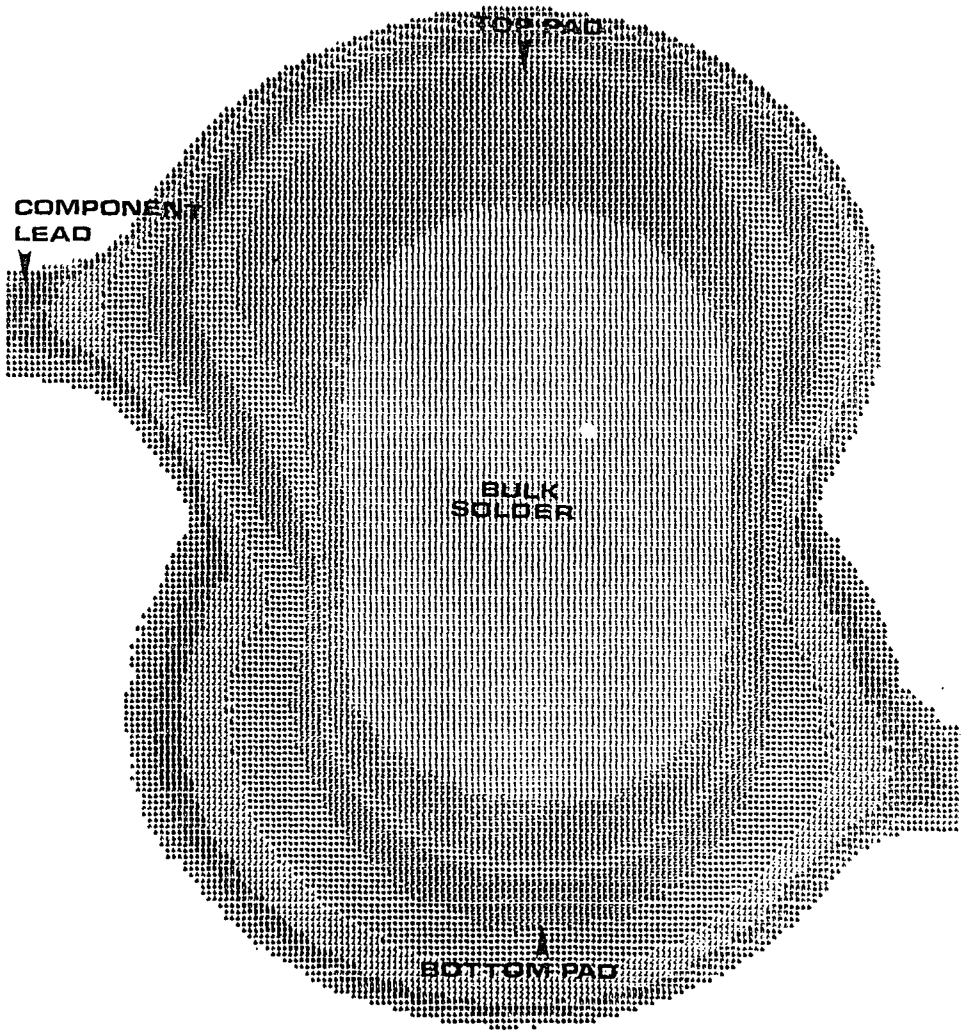


Figure 5.1 Digital image printout of every gray level of a good solder joint.

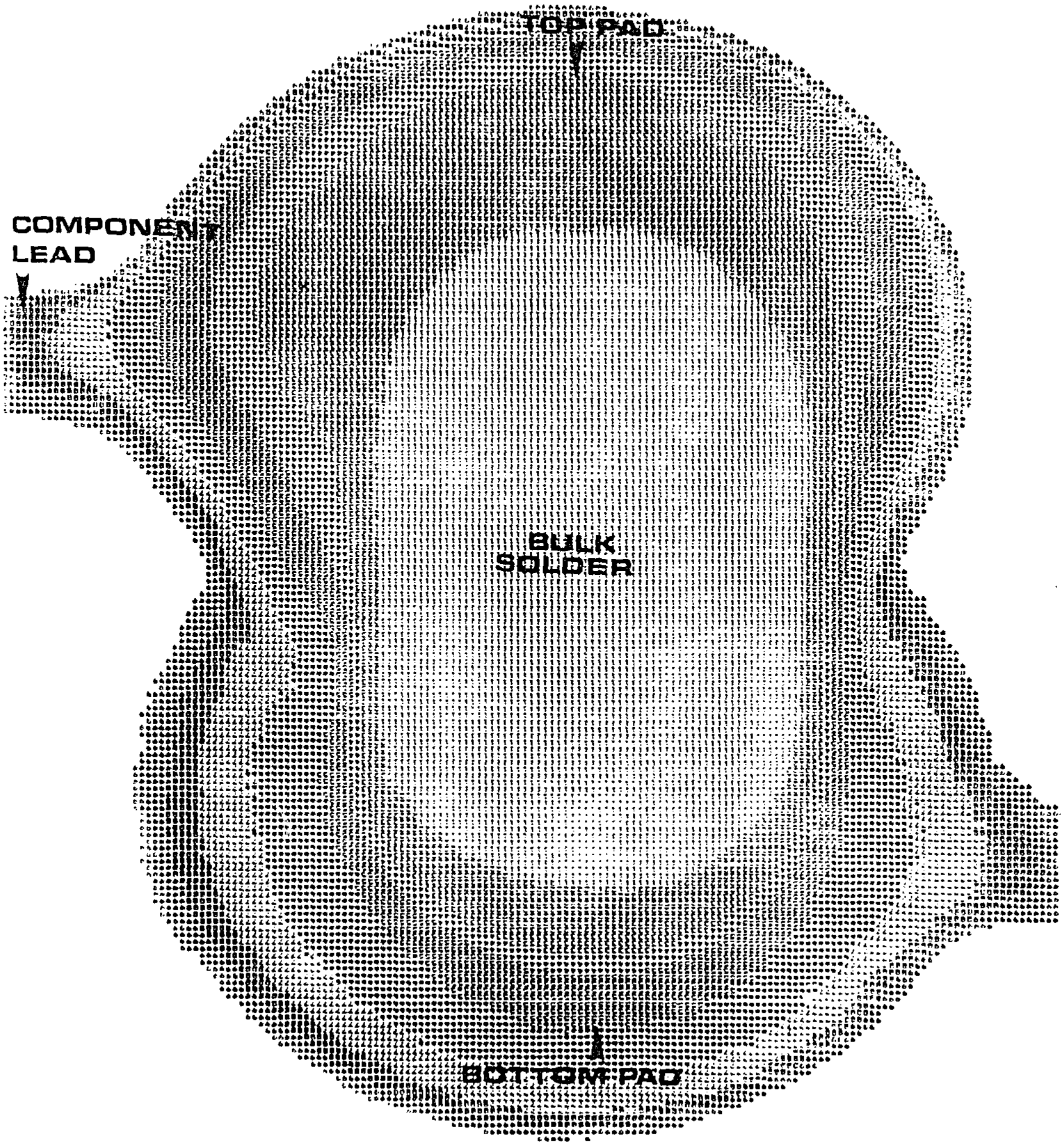


Figure 5.1 Digital image printout of every gray level of a good solder joint.

CHAPTER 6

CONCLUSIONS

(1) The classification of solder defects by visual inspection is very subjective.

(2) Both conventional film radiography and real-time radiography have advantages and disadvantages associated with them. However, only real-time radiography can provide results in a timely manner allowing it to be a possible on-line automatic inspection method.

(3) Radiographic inspection of the solder defects using high resolution film showed that the solder joints should be tilted to approximately 30 degrees to prevent masking from the bottom side of the plated-through hole.

(4) The high resolution film results taken at a solder joint angle of 30 degrees illustrated that the solder defects could be identified using radiography.

(5) The digital images of the solder defects obtained from the CXI-5210 real-time radiographic inspection unit did not provide enough resolution so that defect identification could occur with the human eye.

(6) Digital imaging techniques showed the images obtained from the CXI-5210 did provide a large variance in gray level between a good solder joint and the solder defects under consideration.

(7) The CXI-5210 real-time solder joint inspection unit is capable of distinguishing a good solder joint from a bad one but more work is required before actual defect identification can occur. If actual defect identification is not possible, a new generation of defect classification will need to be formulated. The new classifications may rely more on the internal characteristics of the solder joint versus the external which is the present method.

APPENDIX A

PHOTOGRAPHS OF SOLDER DEFECTS

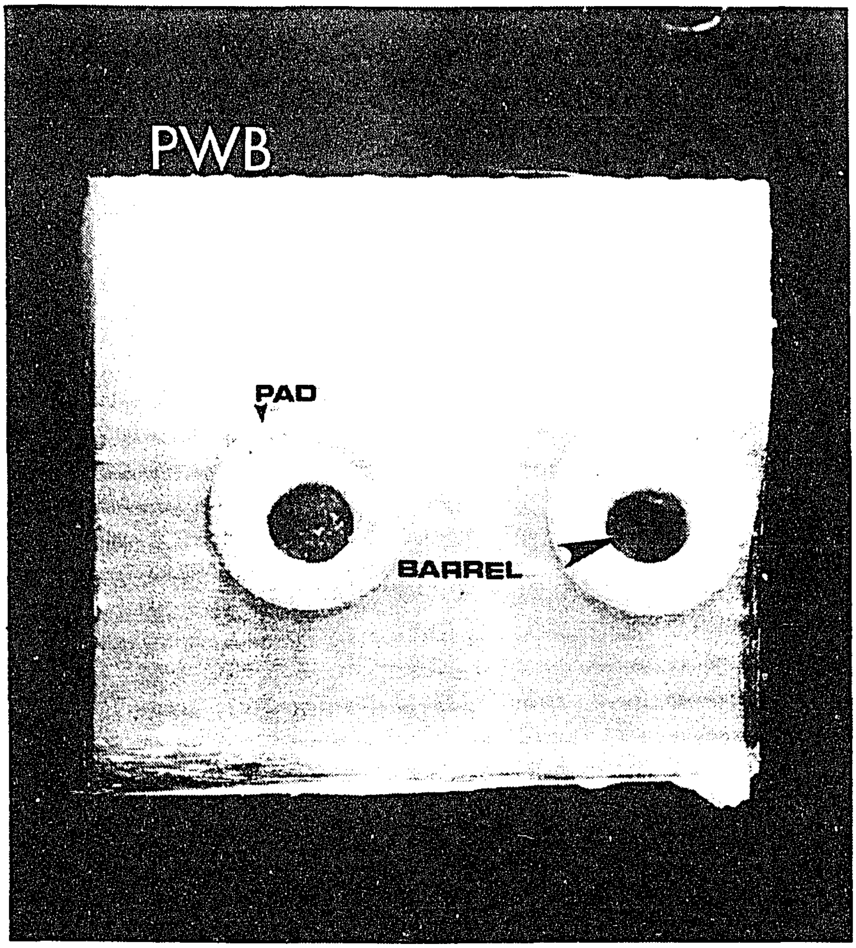


Figure A.1 Photograph of a plated-through-hole before soldering at 10X magnification.

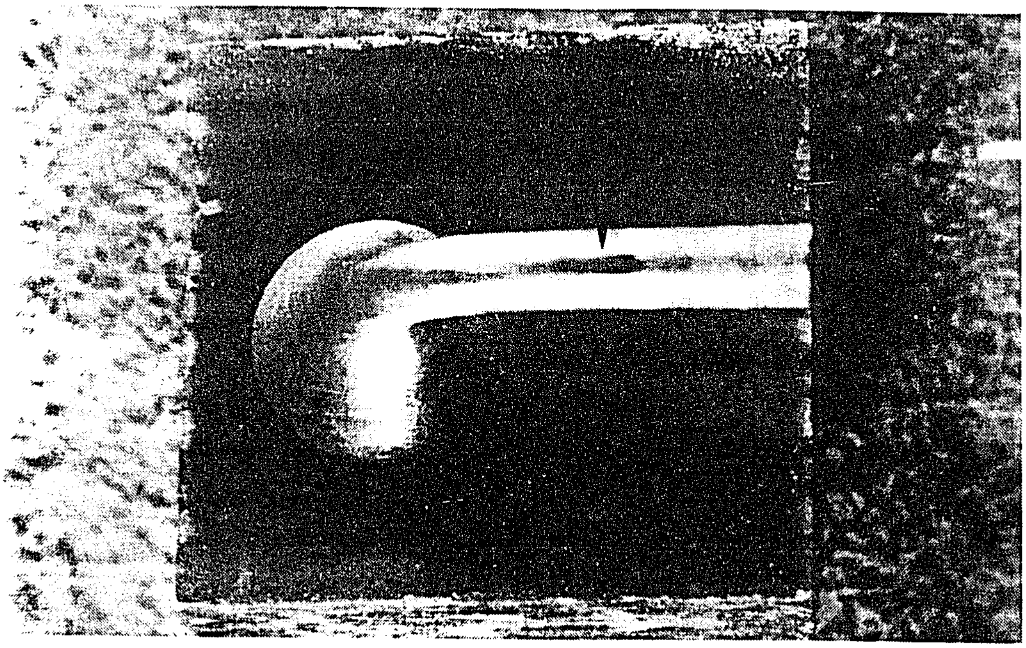


Figure A.2 Photograph of a good solder joint at 10X magnification.

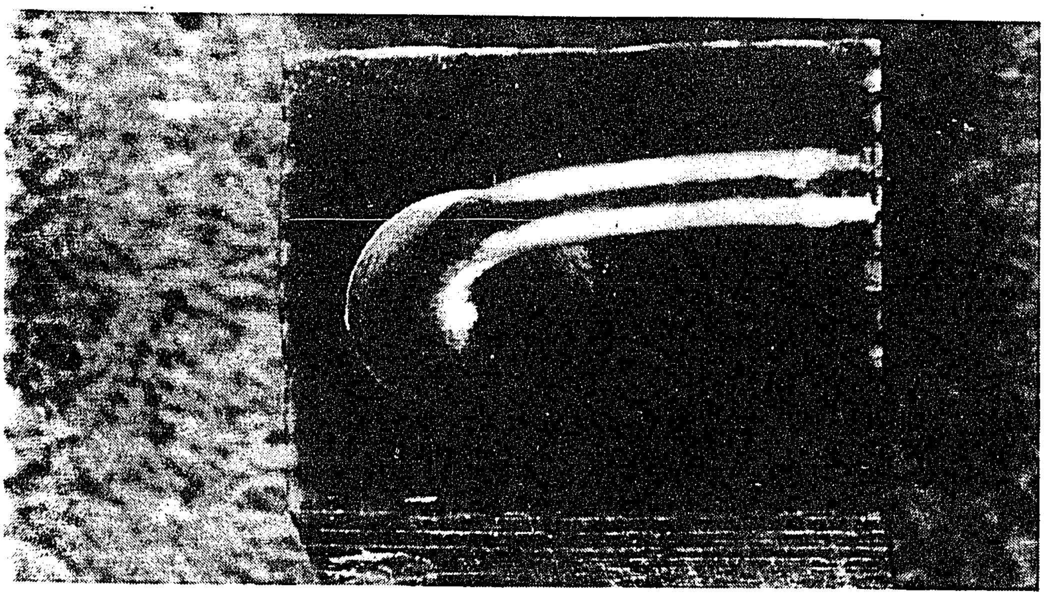


Figure A.3 Photograph of a good solder joint at 10X magnification.

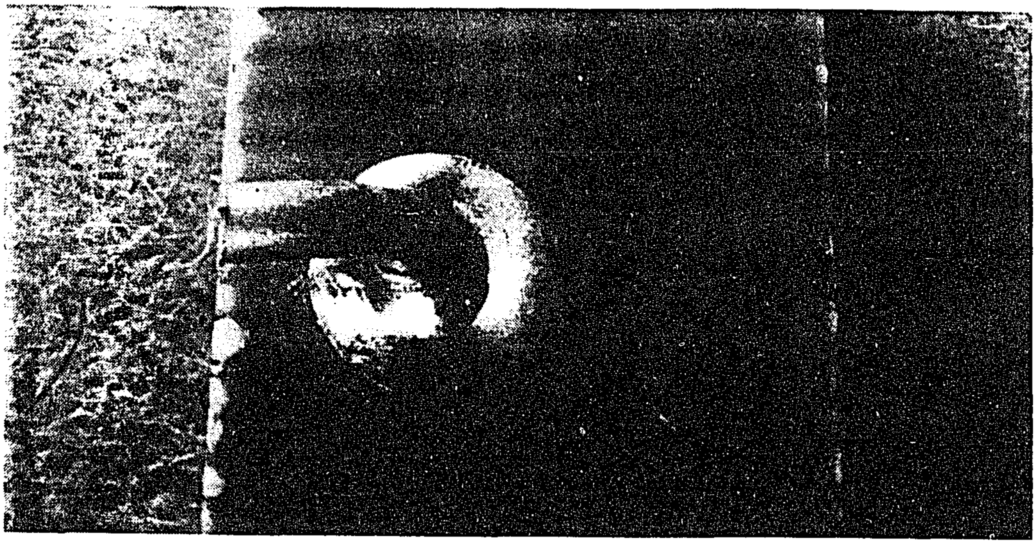


Figure A.4 Photograph of an insufficient solder joint at 10X magnification.

Figure A.5 Photograph of an insufficient solder joint at 10X magnification.

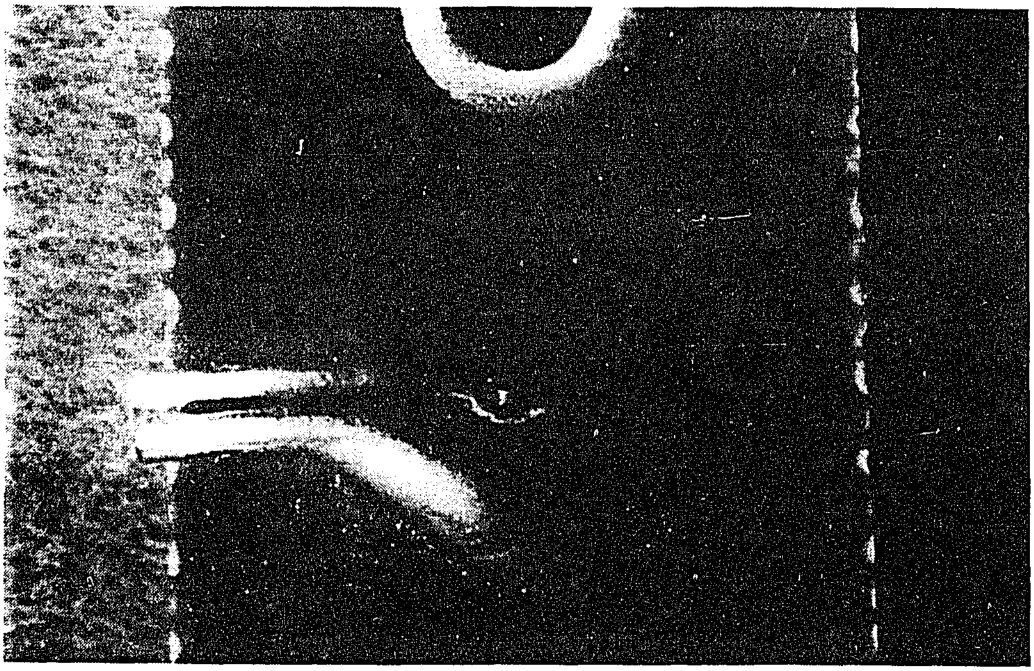


Figure A.6 Photograph of an excessive solder joint at 10X magnification.

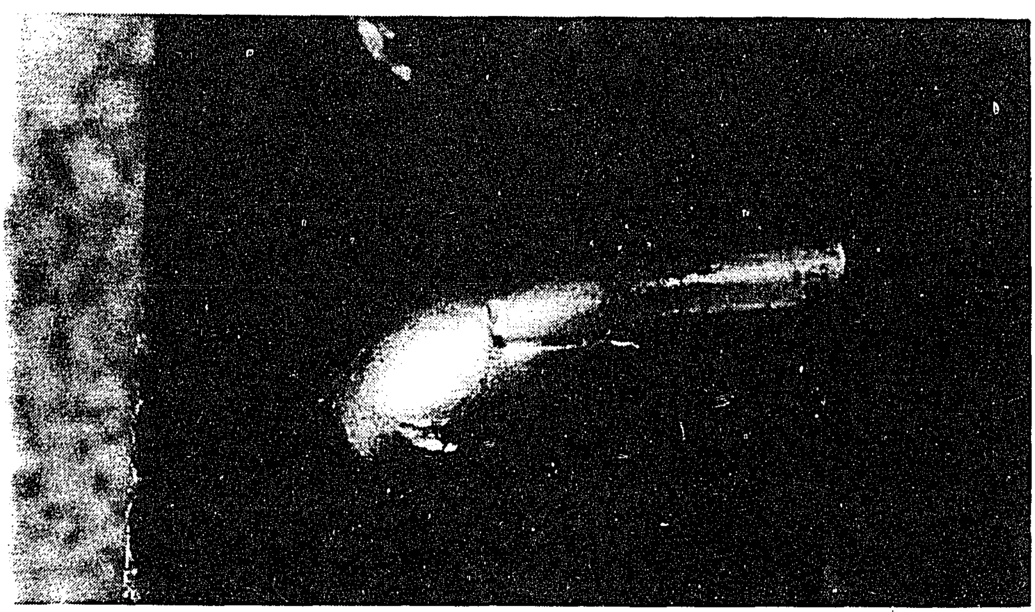


Figure A.7 Photograph of an excessive solder joint at 10X magnification.

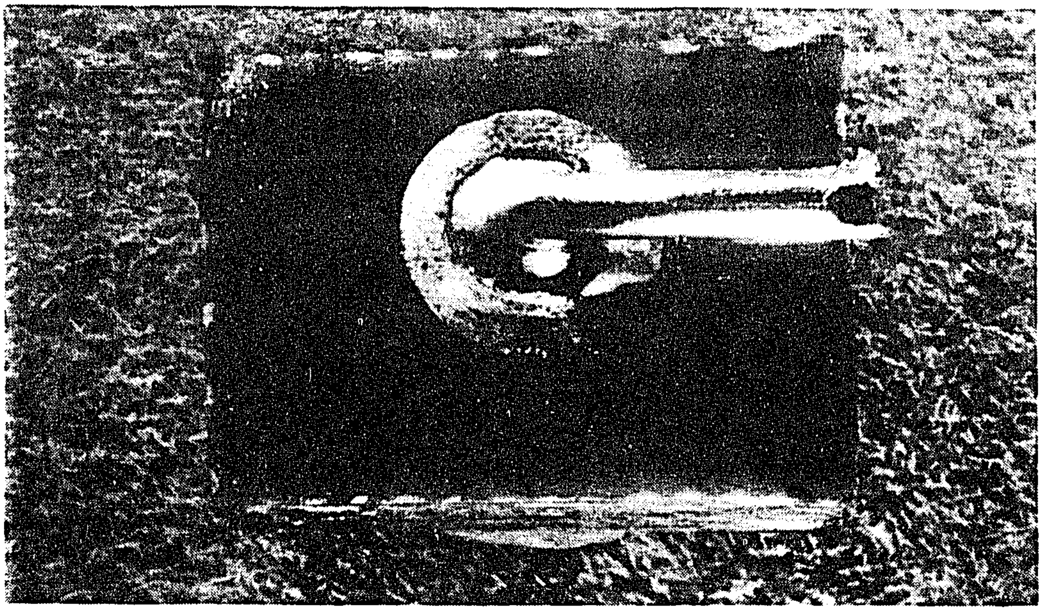


Figure A.8 Photograph of a dewetted solder joint at 10X magnification.

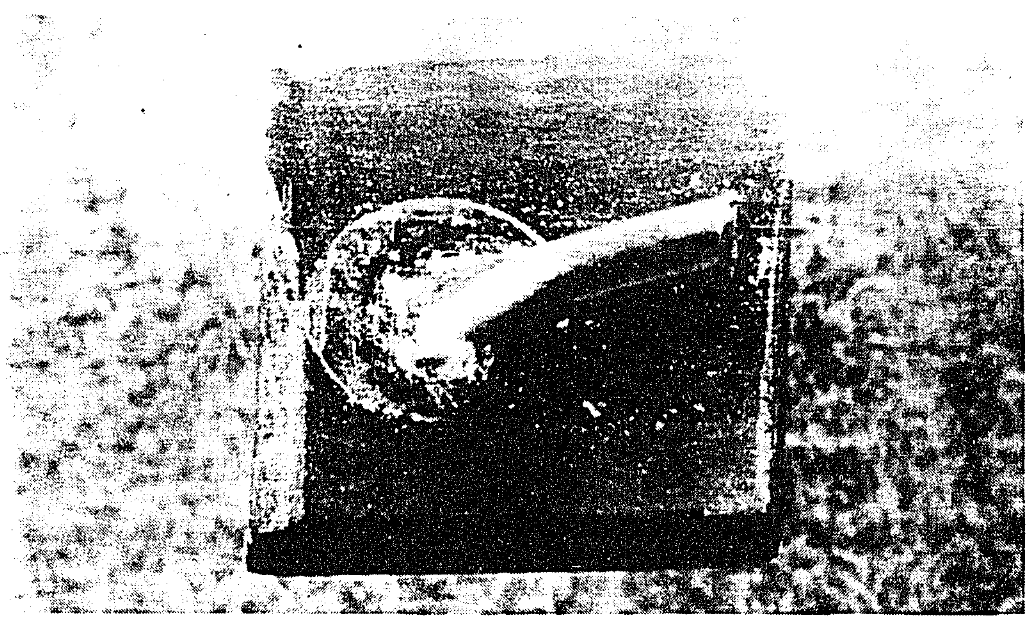


Figure A.9 Photograph of a dewetted solder joint at 10X magnification.

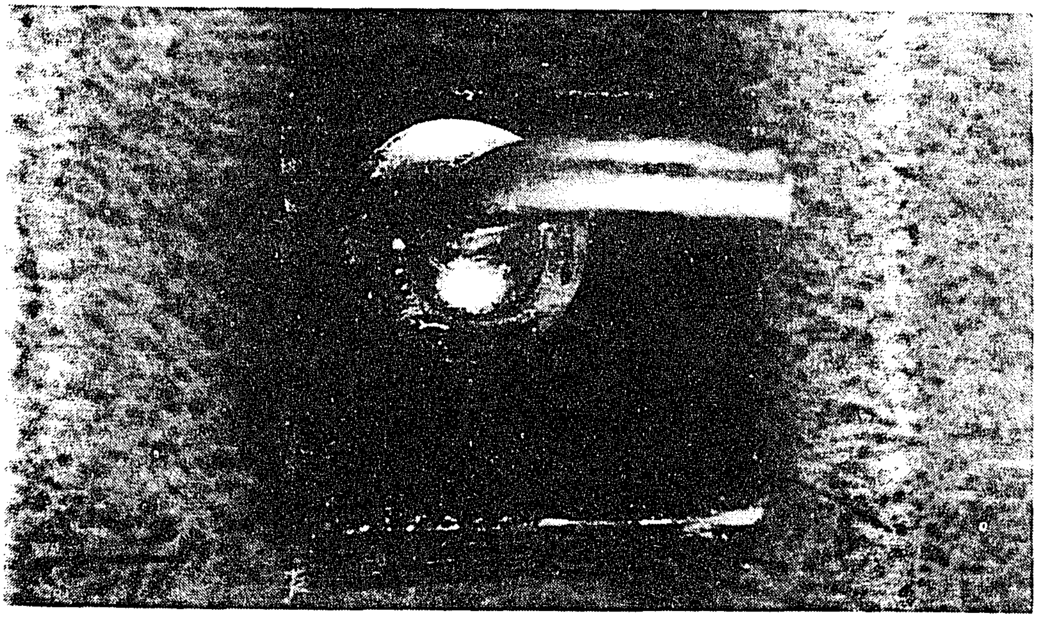


Figure A.10 Photograph of a nonwetted solder joint at 10X magnification.

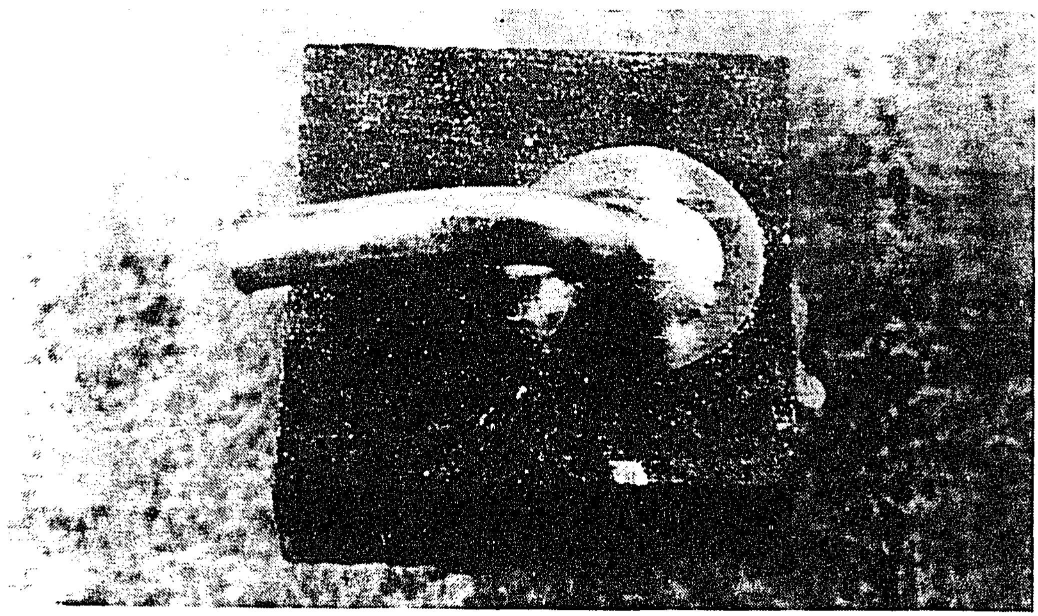


Figure A.11 Photograph of a nonwetted solder joint at 10X magnification.

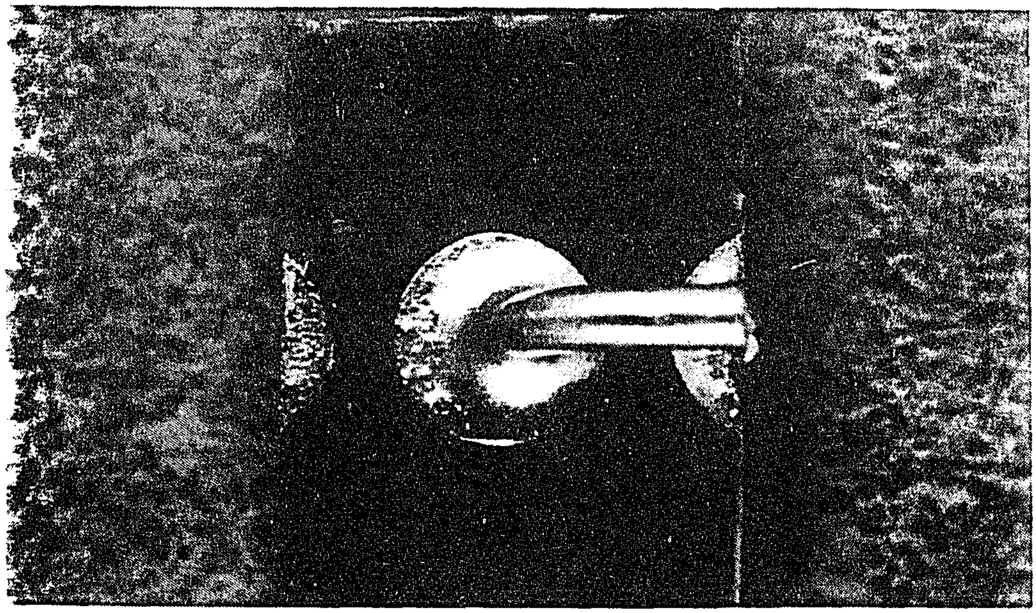


Figure A.12 Photograph of a grainy solder joint at 10X magnification.

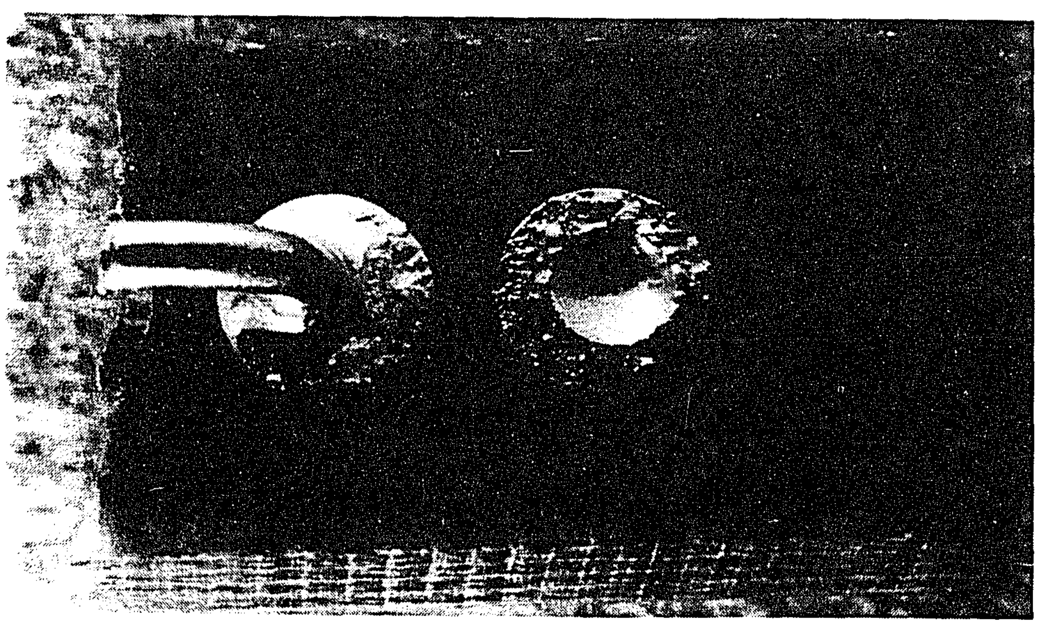


Figure A.13 Photograph of a grainy solder joint at 10X magnification.

APPENDIX B

PHOTOGRAPHS OF RADIOGRAPHS TAKEN WITH HIGH RESOLUTION RADIOGRAPHIC FILM AT A 0 DEGREE SPECIMEN TILT

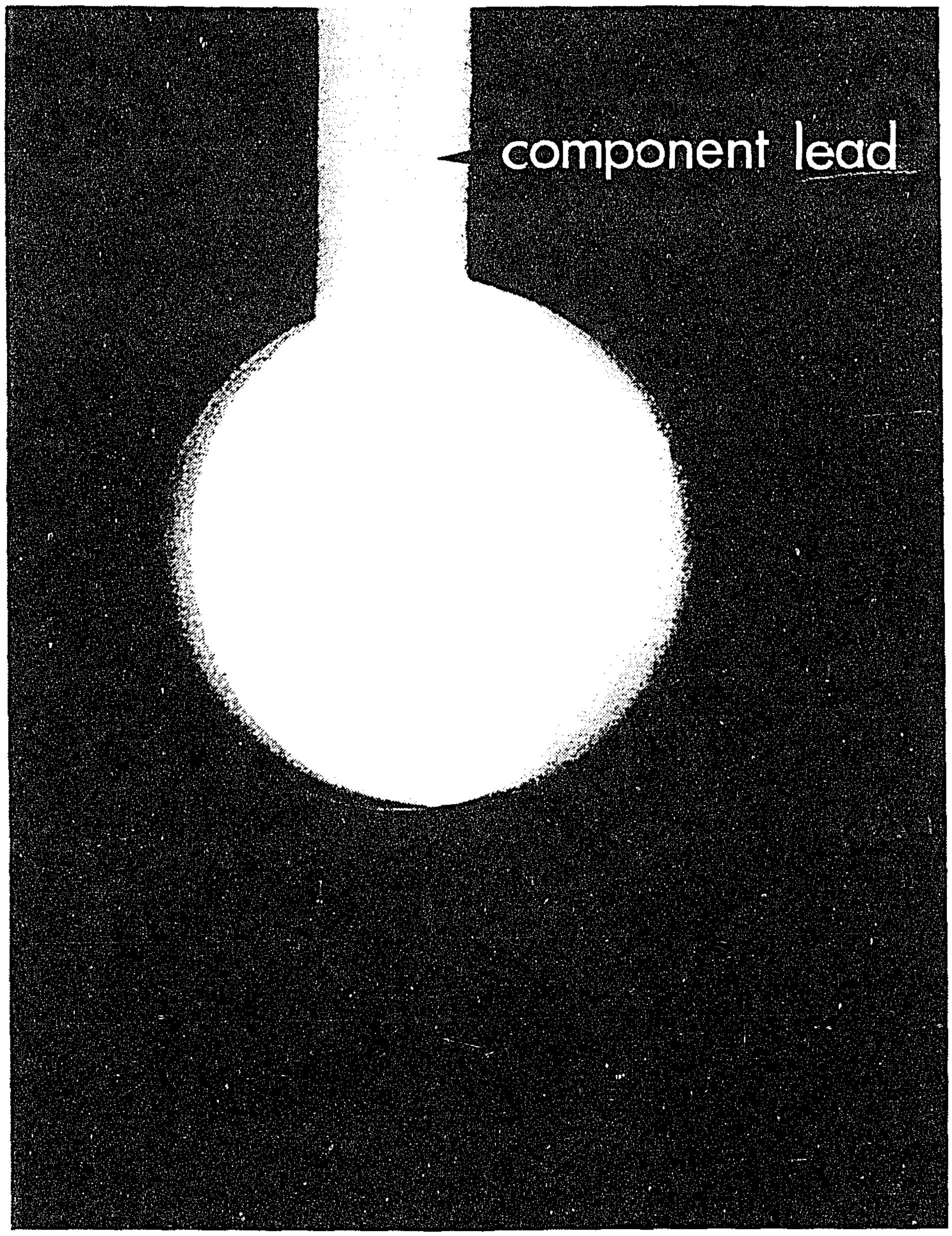


Figure B.1 Photograph at 40X magnification of a radiograph of a good solder joint at a 0 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

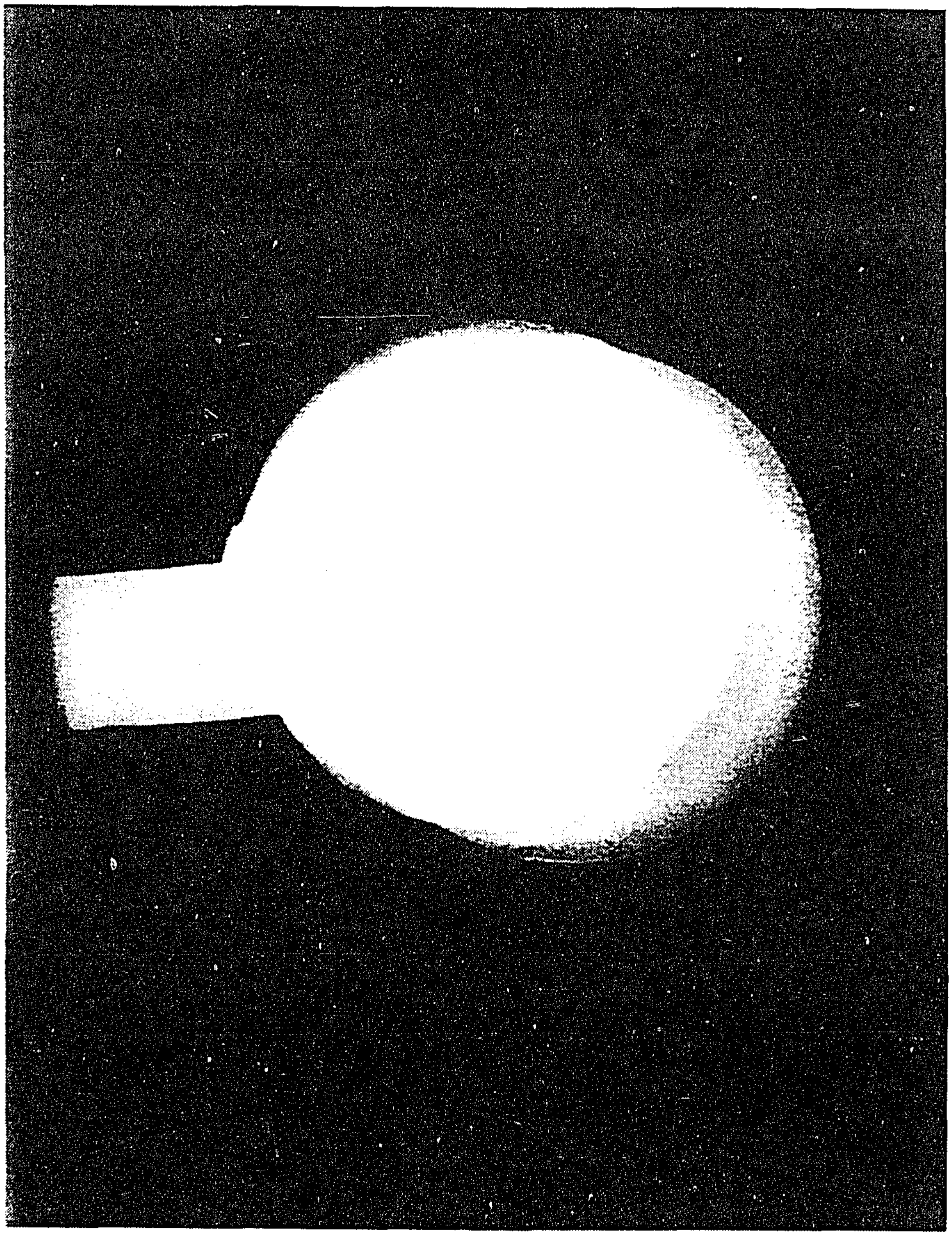


Figure B.2 Photograph at 40X magnification of a radiograph of an insufficient solder joint at a 0 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

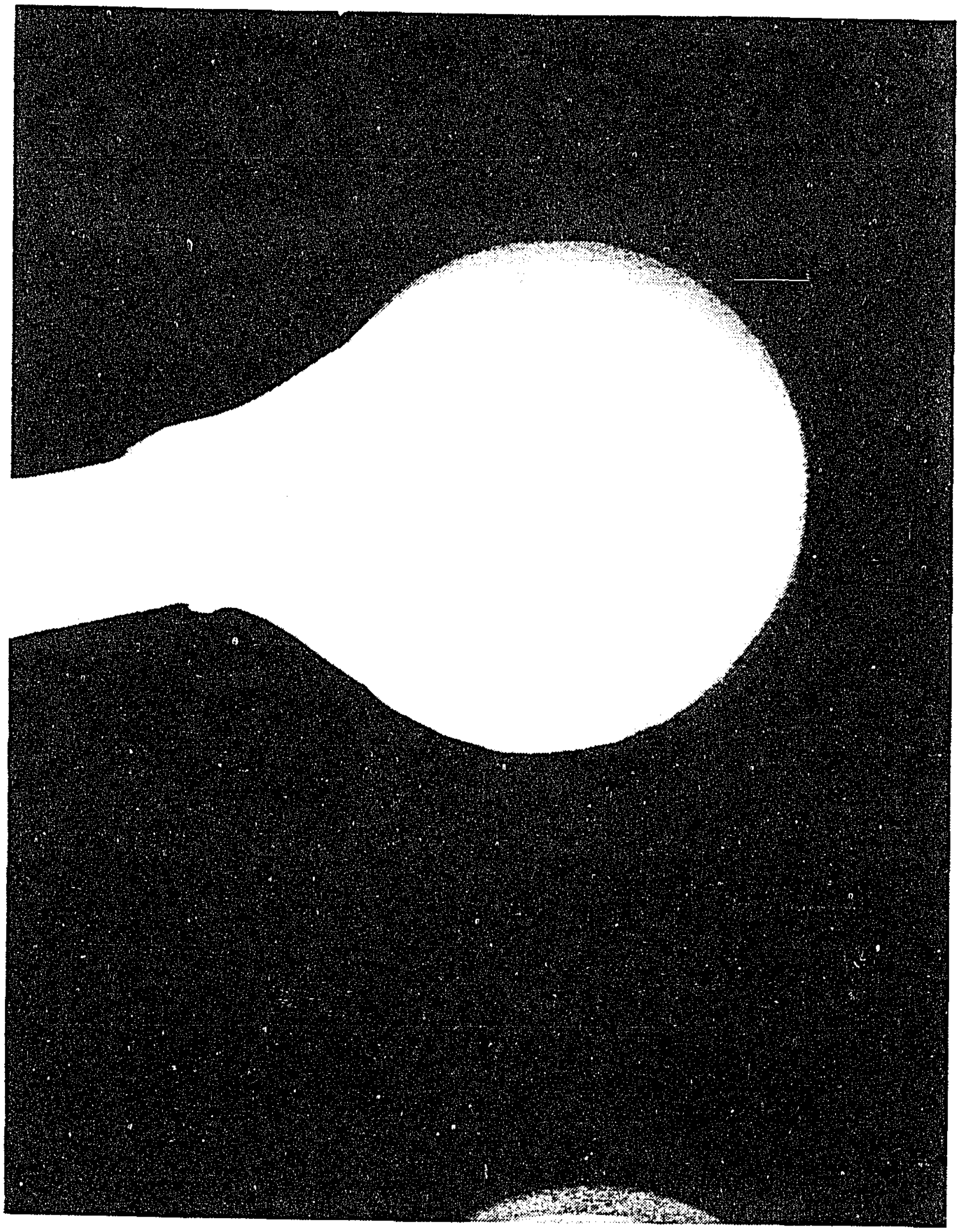


Figure B.3 Photograph at 40X magnification of a radiograph of an excessive solder joint at a 0 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

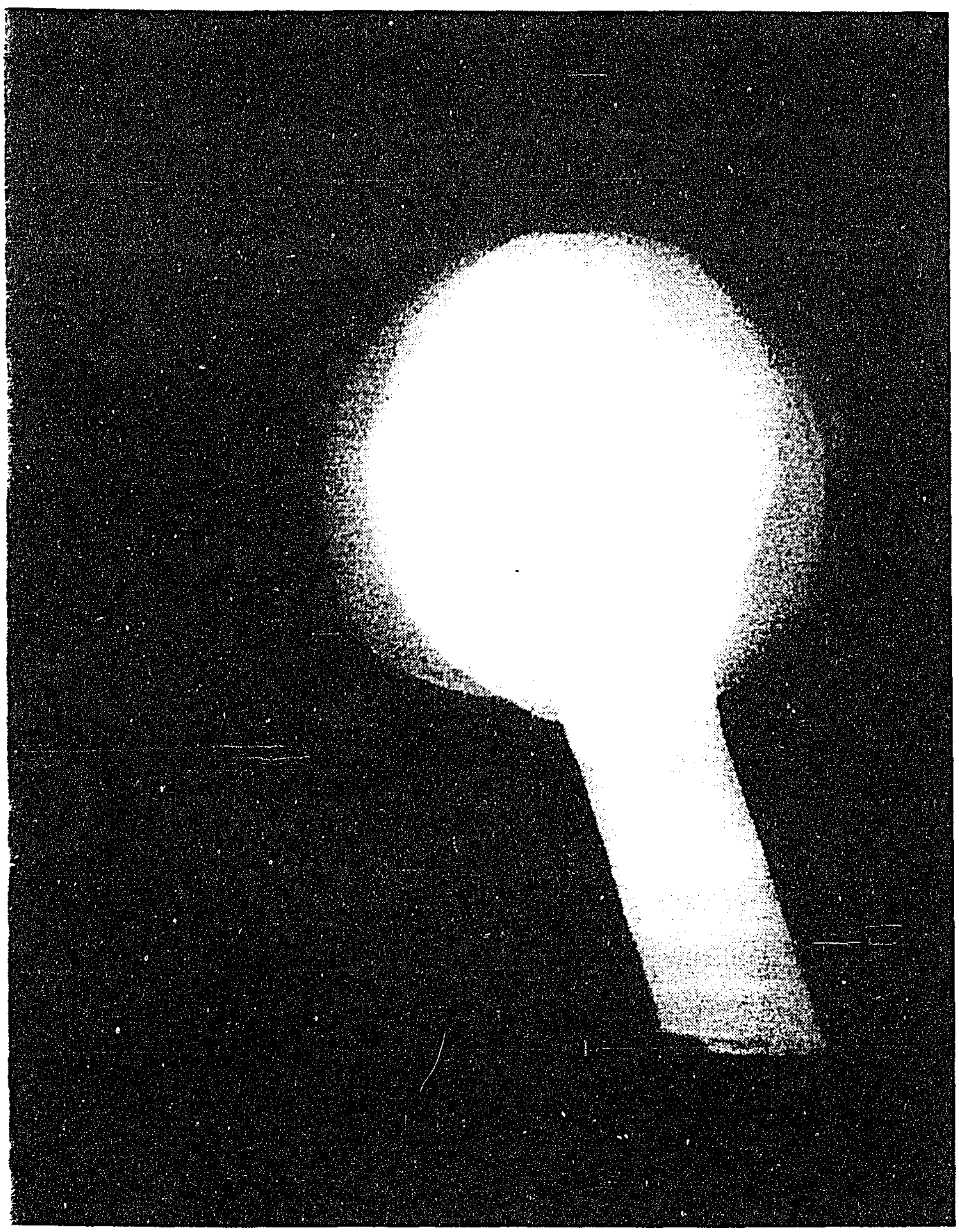


Figure B.4 Photograph at 40X magnification of a radiograph of a dewetted solder joint at a 0 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

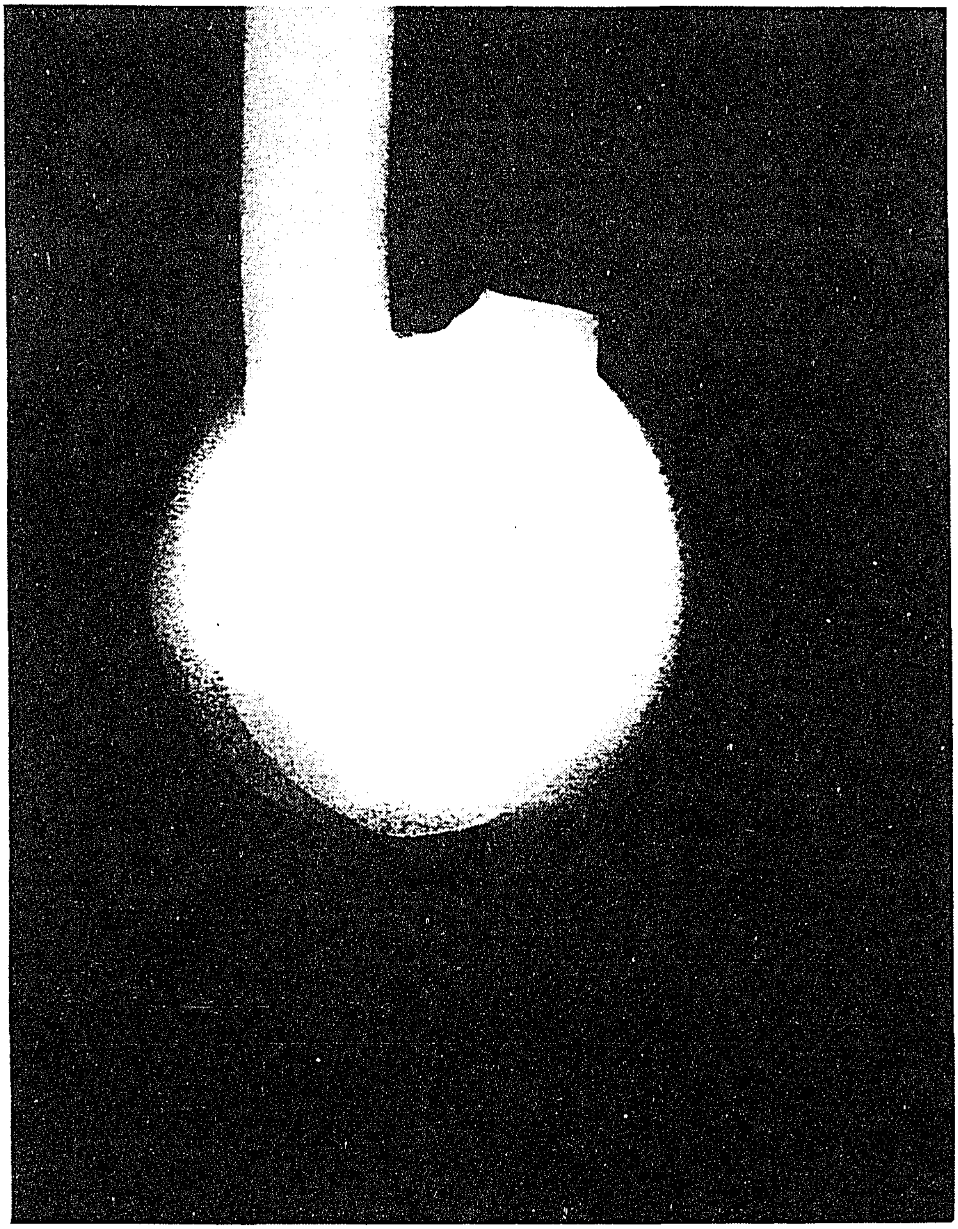


Figure B.5 Photograph at 40X magnification of a radiograph of a nonwetted solder joint at a 0 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

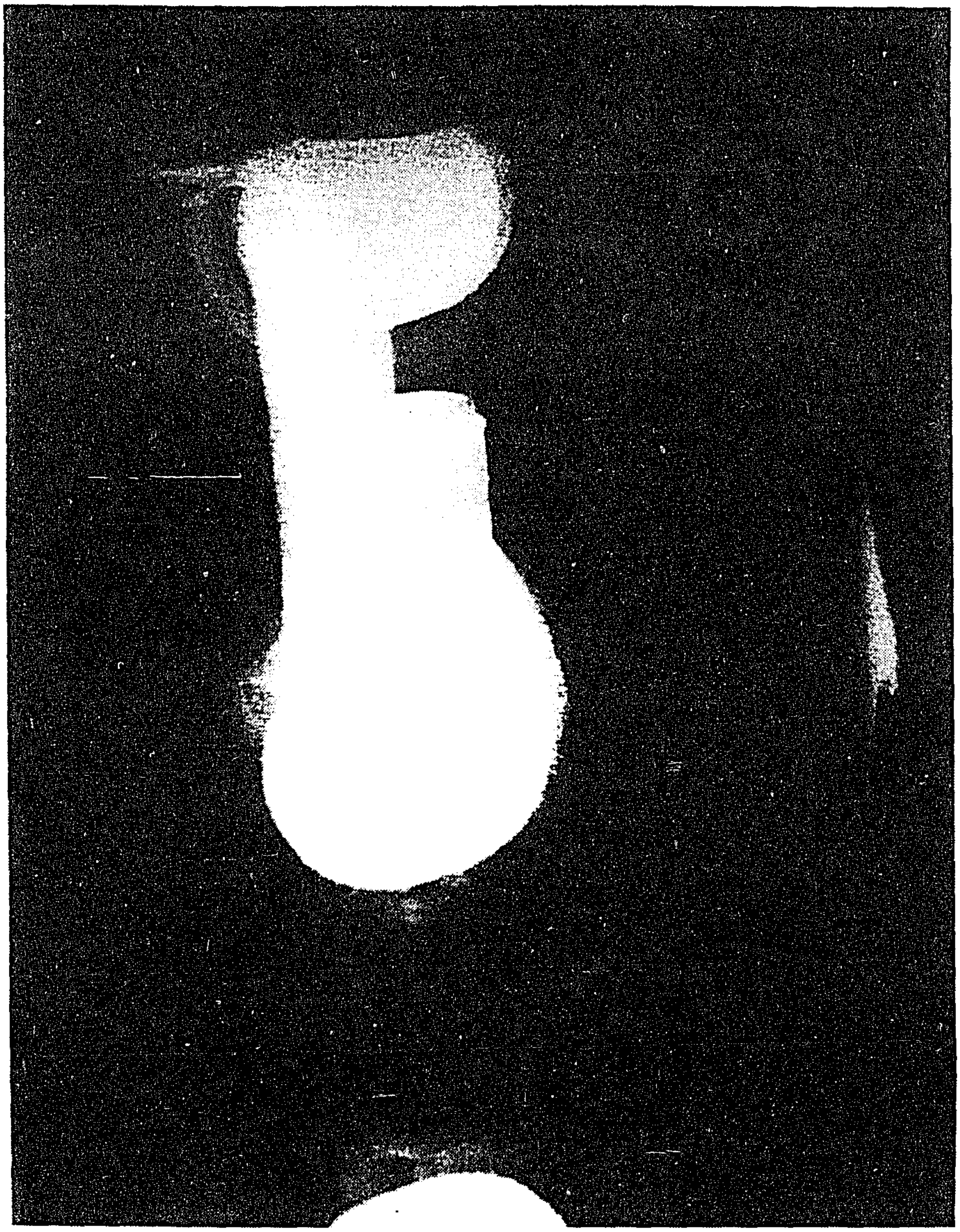


Figure B.6 Photograph at 40X magnification of a radiograph of a grainy solder joint at a 0 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

APPENDIX C

PHOTOGRAPHS OF RADIOGRAPHS TAKEN WITH HIGH RESOLUTION RADIOGRAPHIC FILM AT A 30 DEGREE SPECIMEN TILT

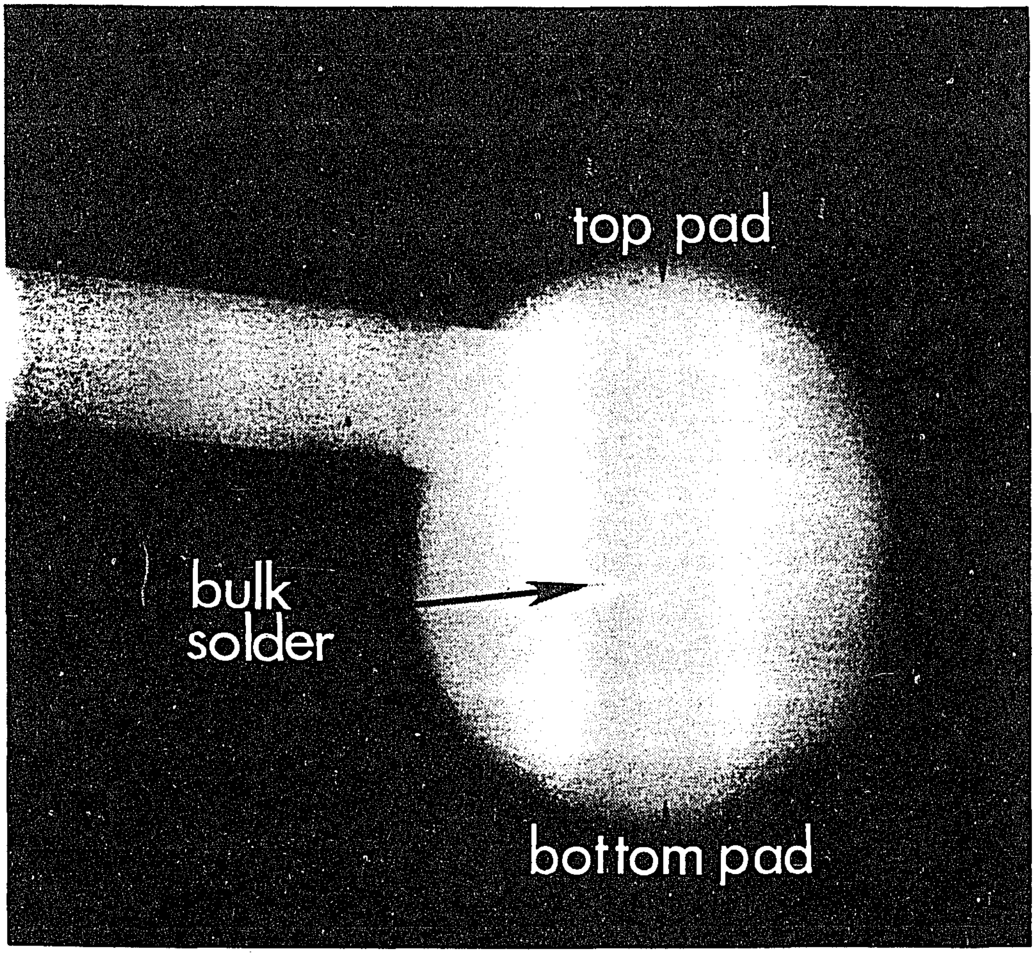


Figure C.1 Photograph at 40X magnification of a radiograph of a good solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

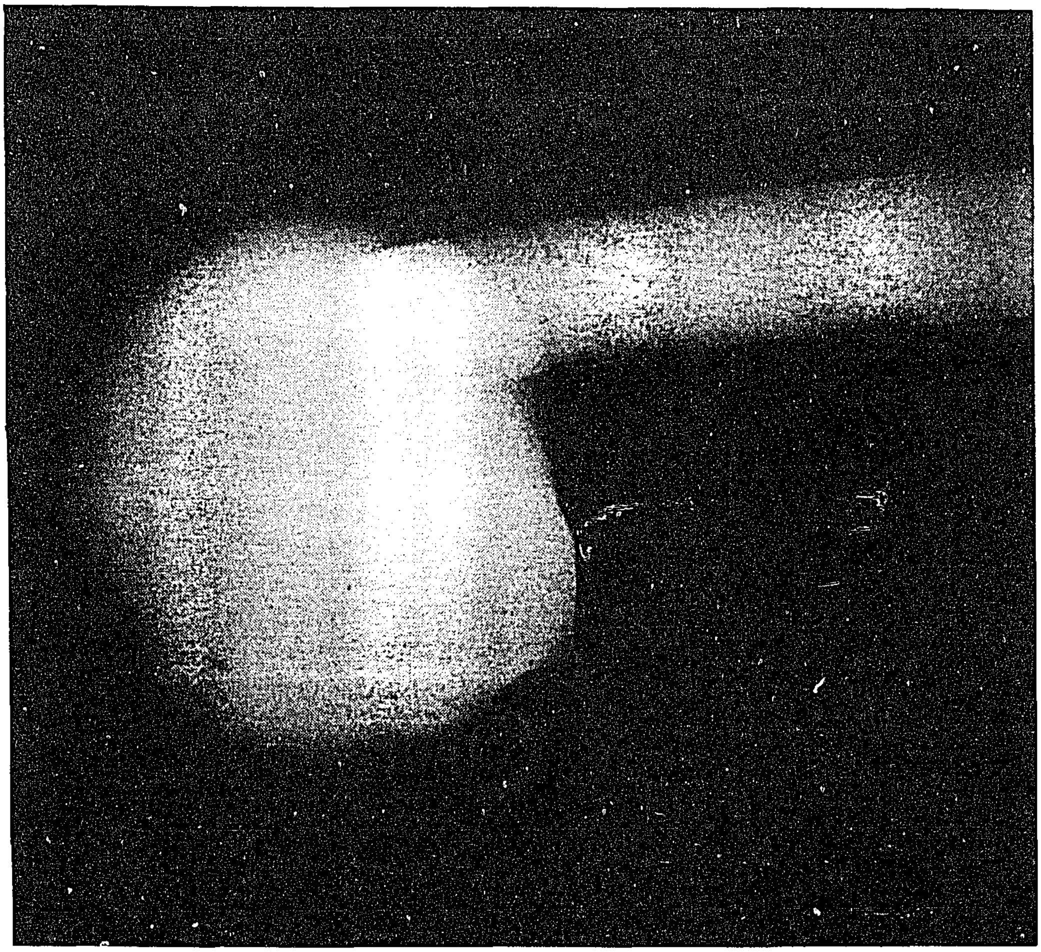


Figure C.2 Photograph at 40X magnification of a radiograph of a good solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

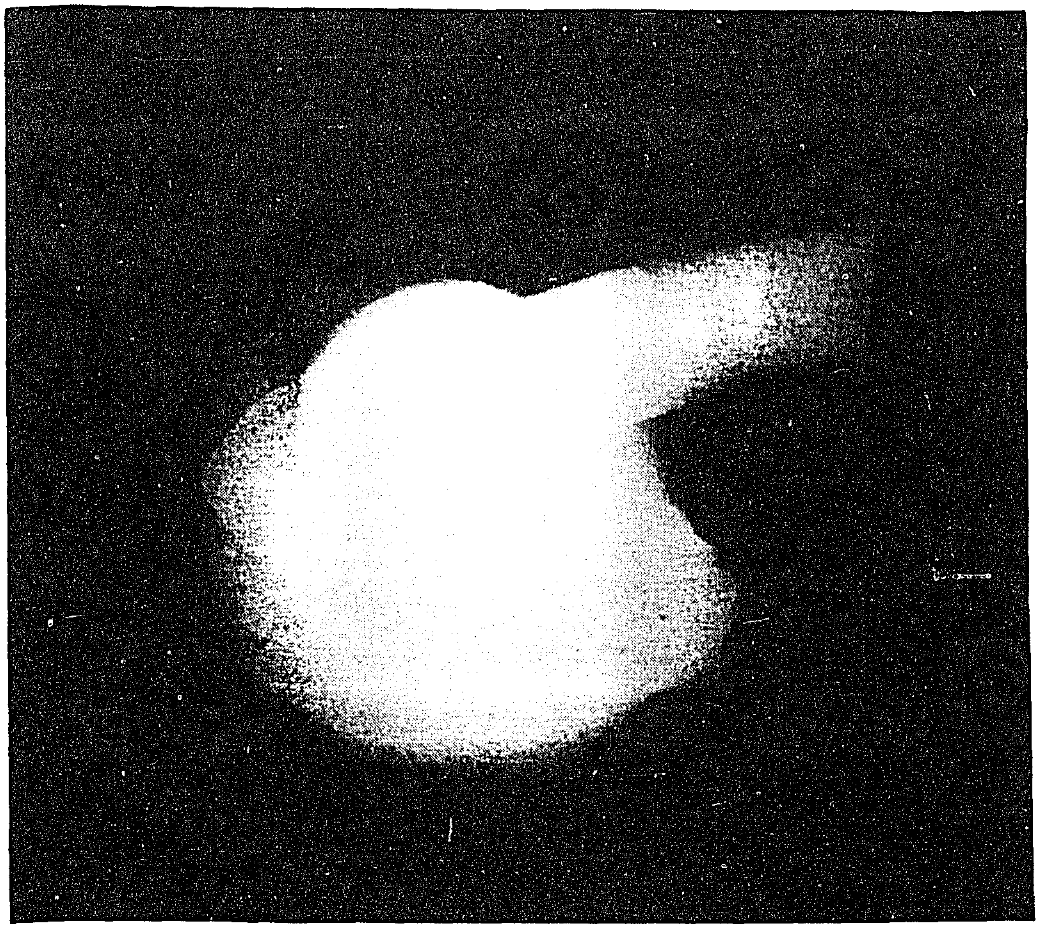


Figure C.3 Photograph at 40X magnification of a radiograph of an insufficient solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

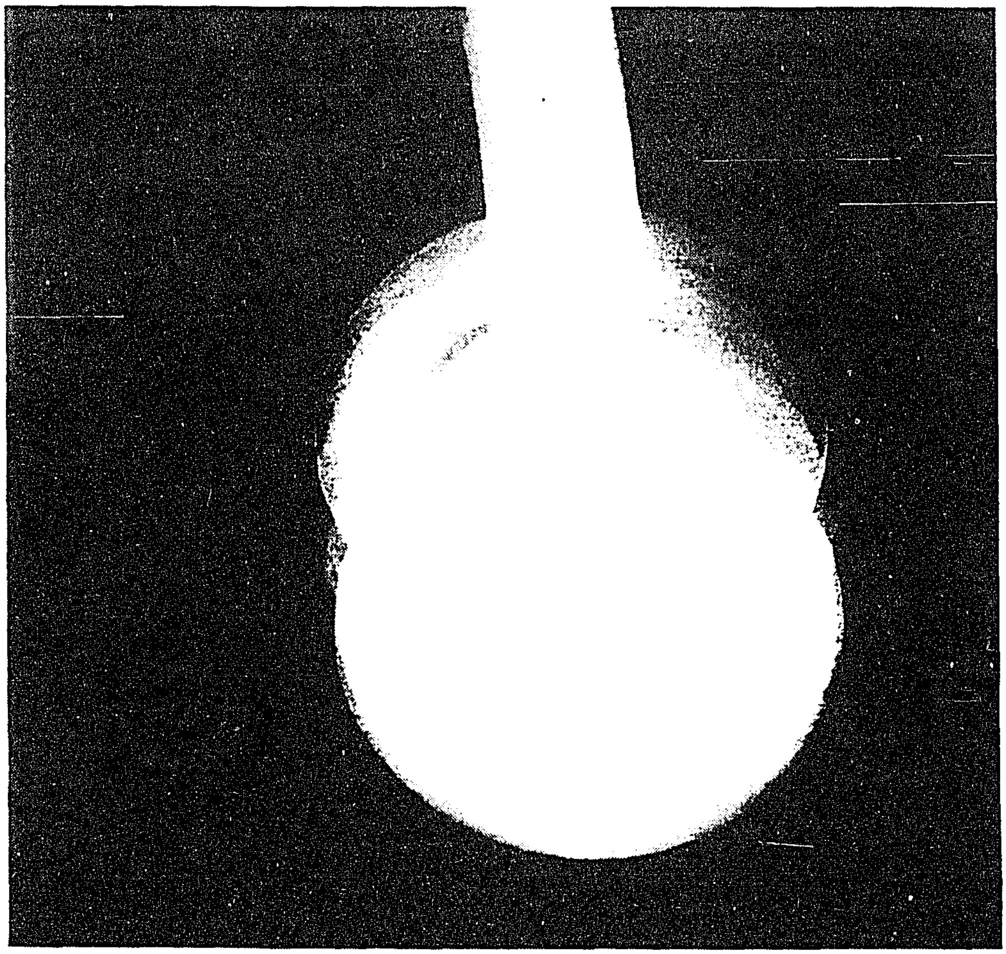


Figure C.4 Photograph at 40X magnification of a radiograph of a insufficient solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

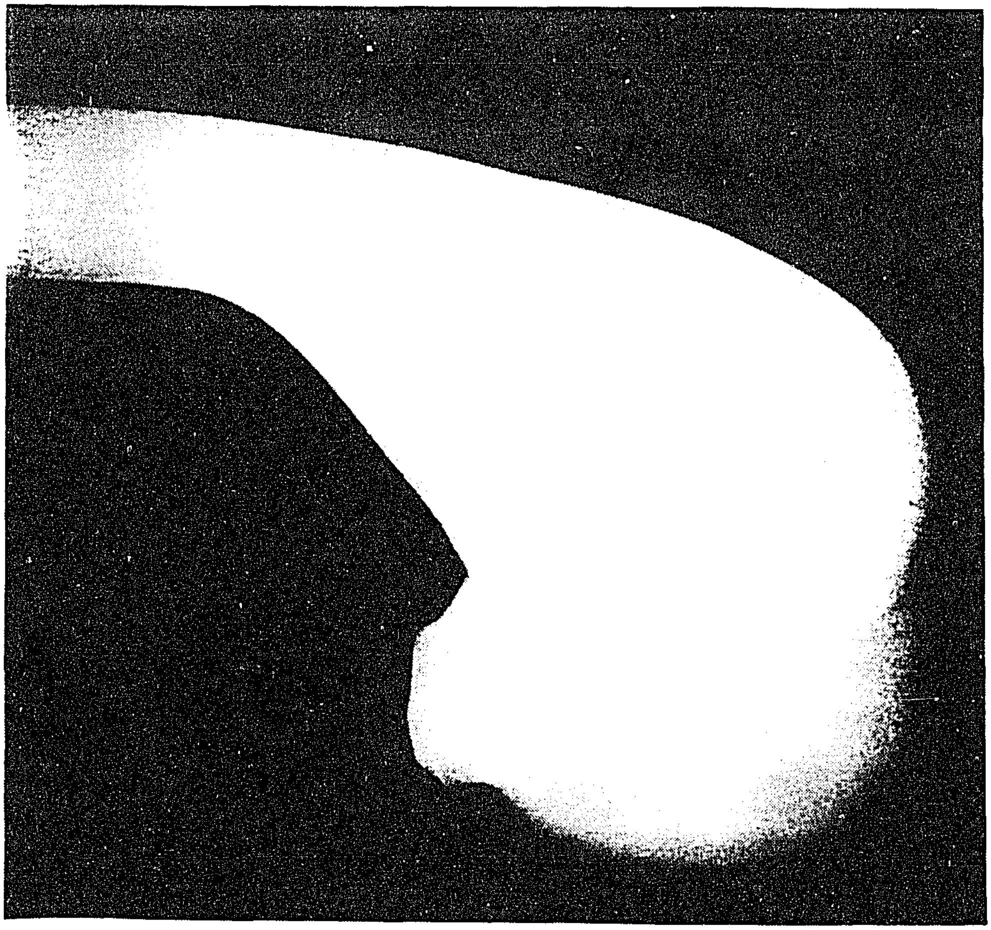


Figure C.5 Photograph at 40X magnification of a radiograph of an excessive solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

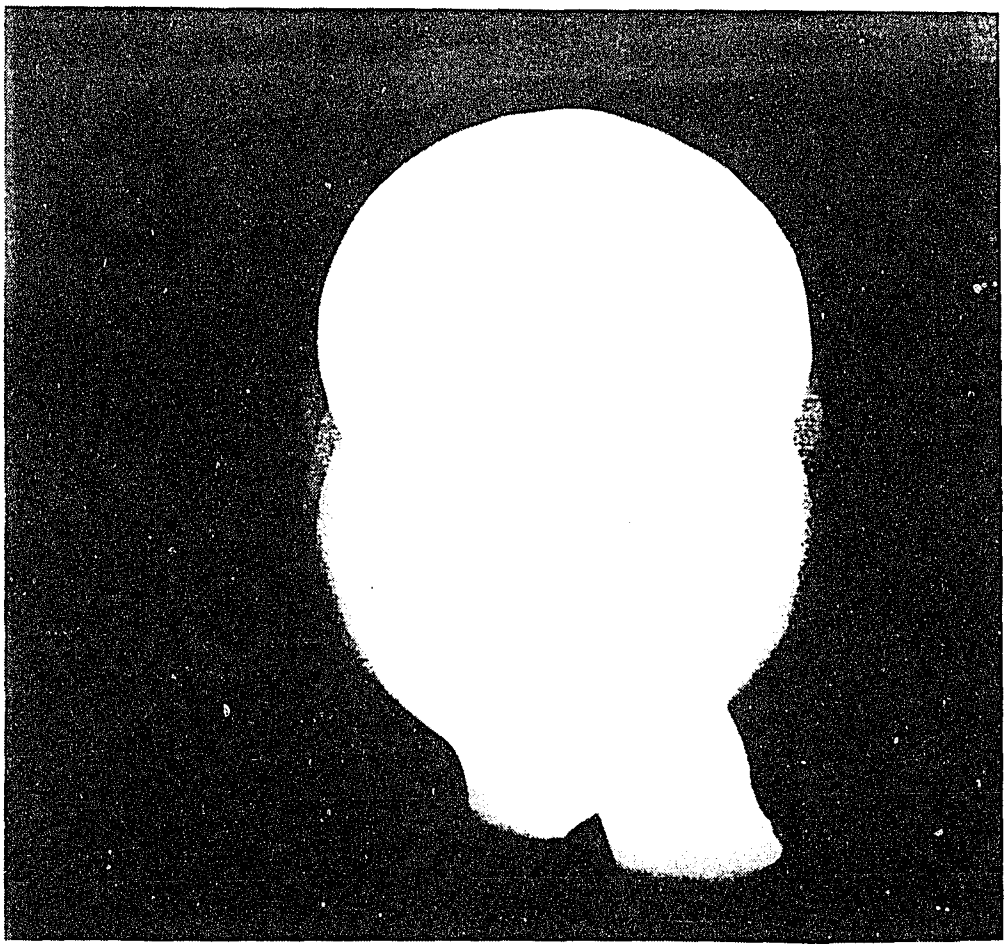


Figure C.6 Photograph at 40X magnification of a radiograph of an excessive solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

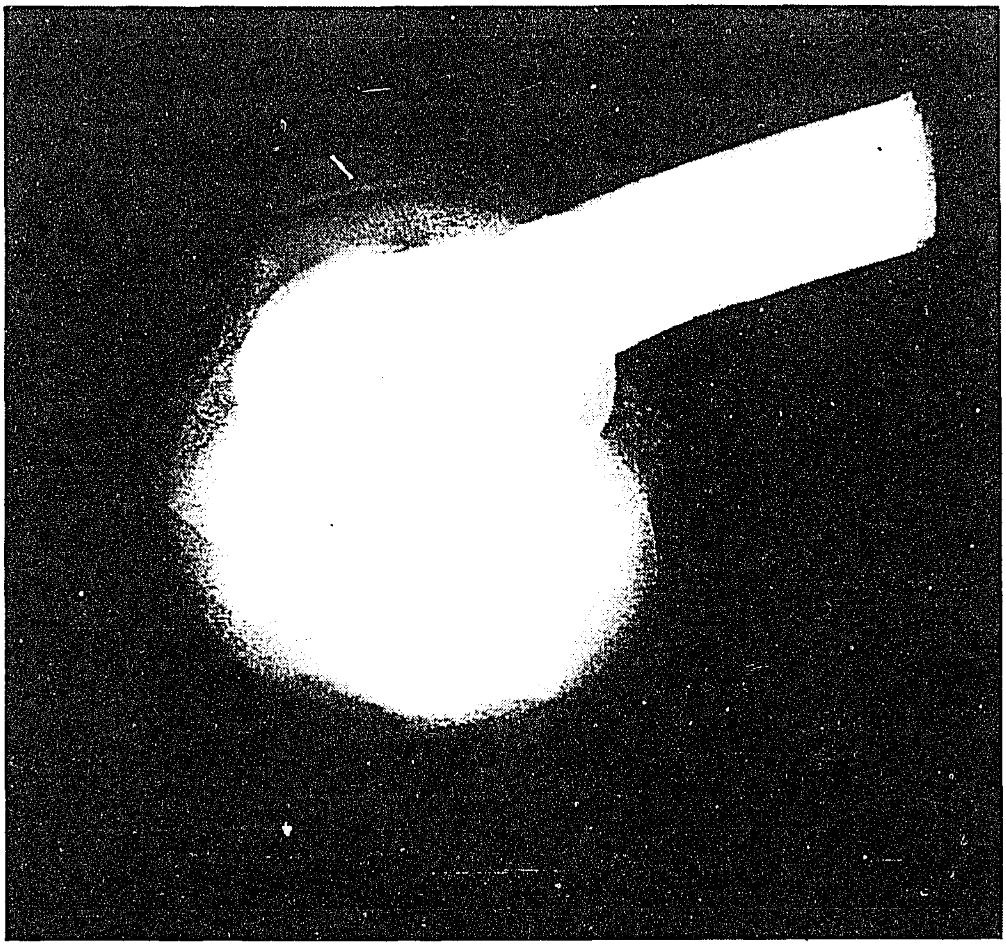


Figure C.7 Photograph at 40X magnification of a radiograph of a dewetted solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

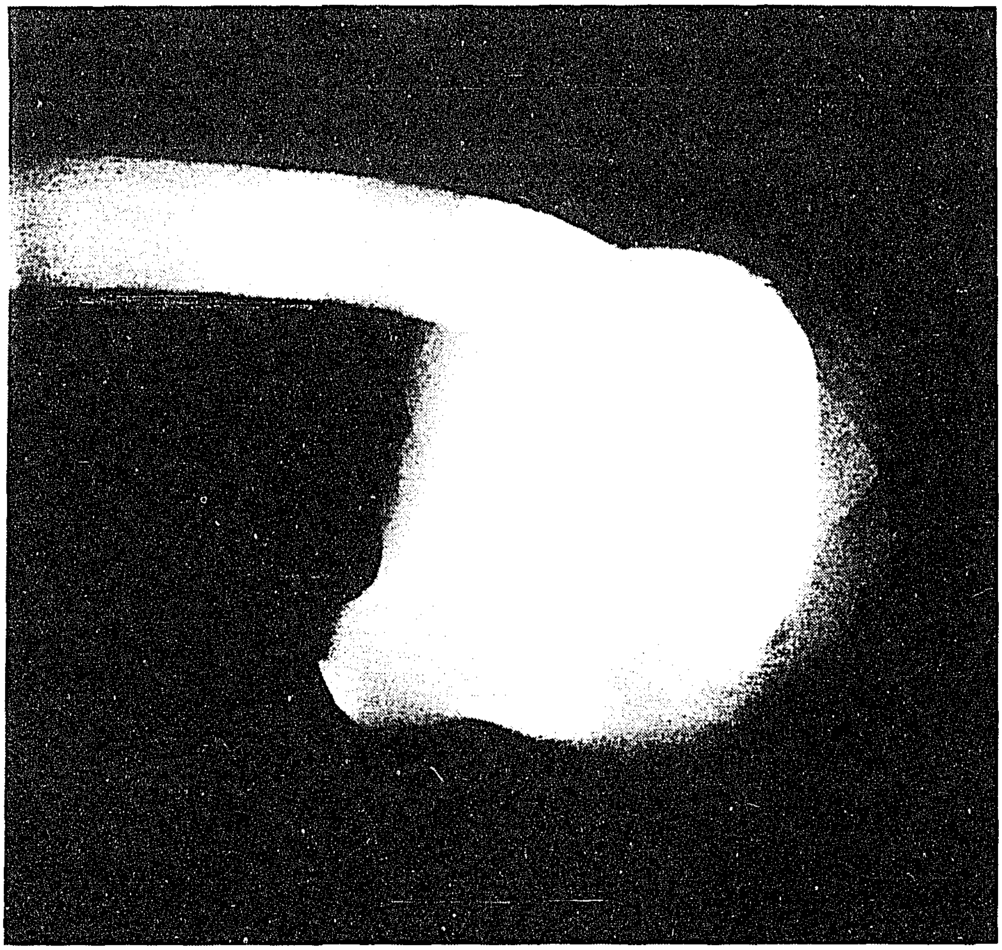


Figure C.8 Photograph at 40X magnification of a radiograph of a dewetted solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

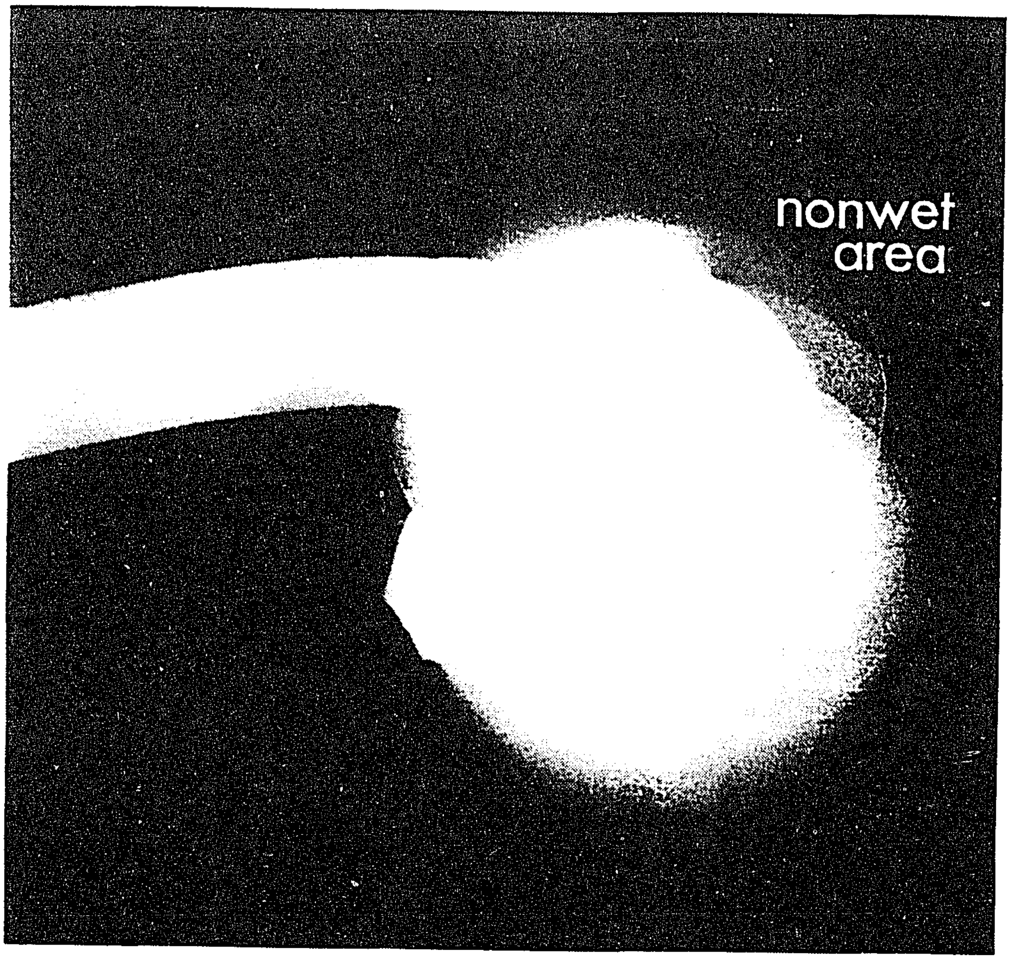


Figure C.9 Photograph at 40X magnification of a radiograph of a nonwetted solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

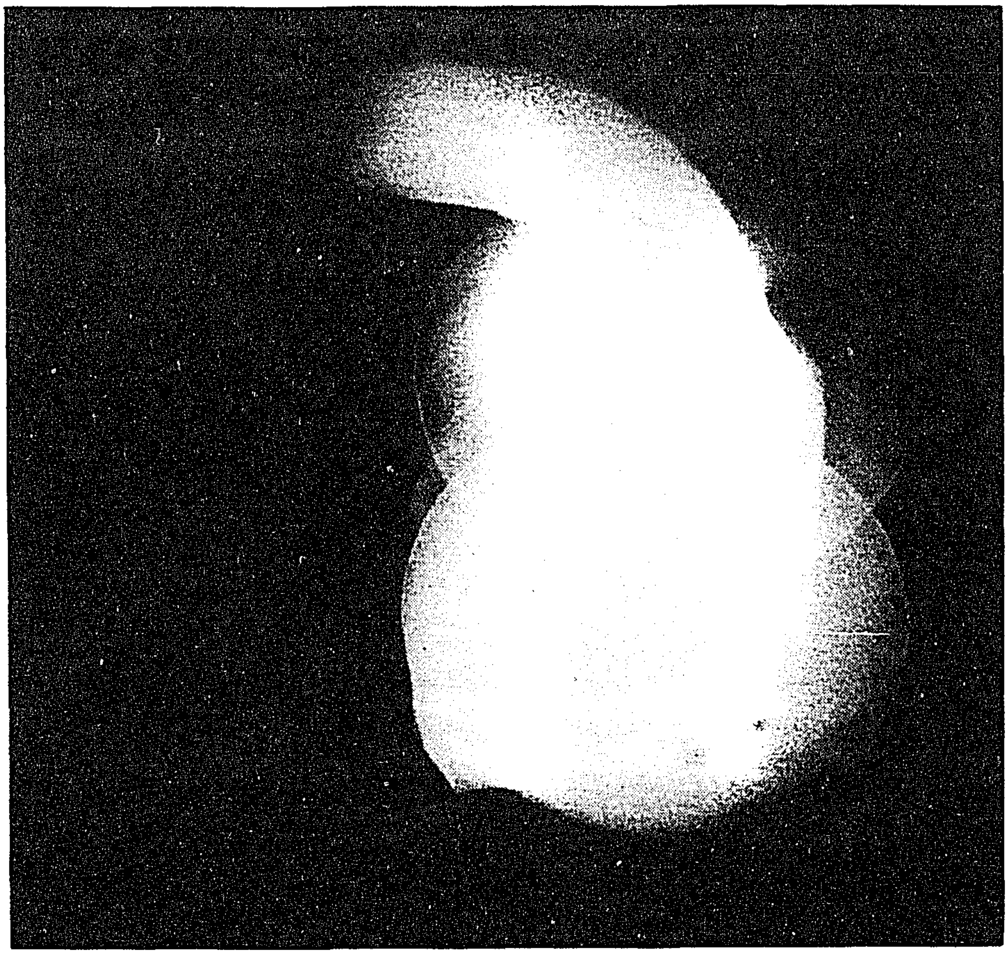


Figure C.10 Photograph at 40X magnification of a radiograph of a nonwetted solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

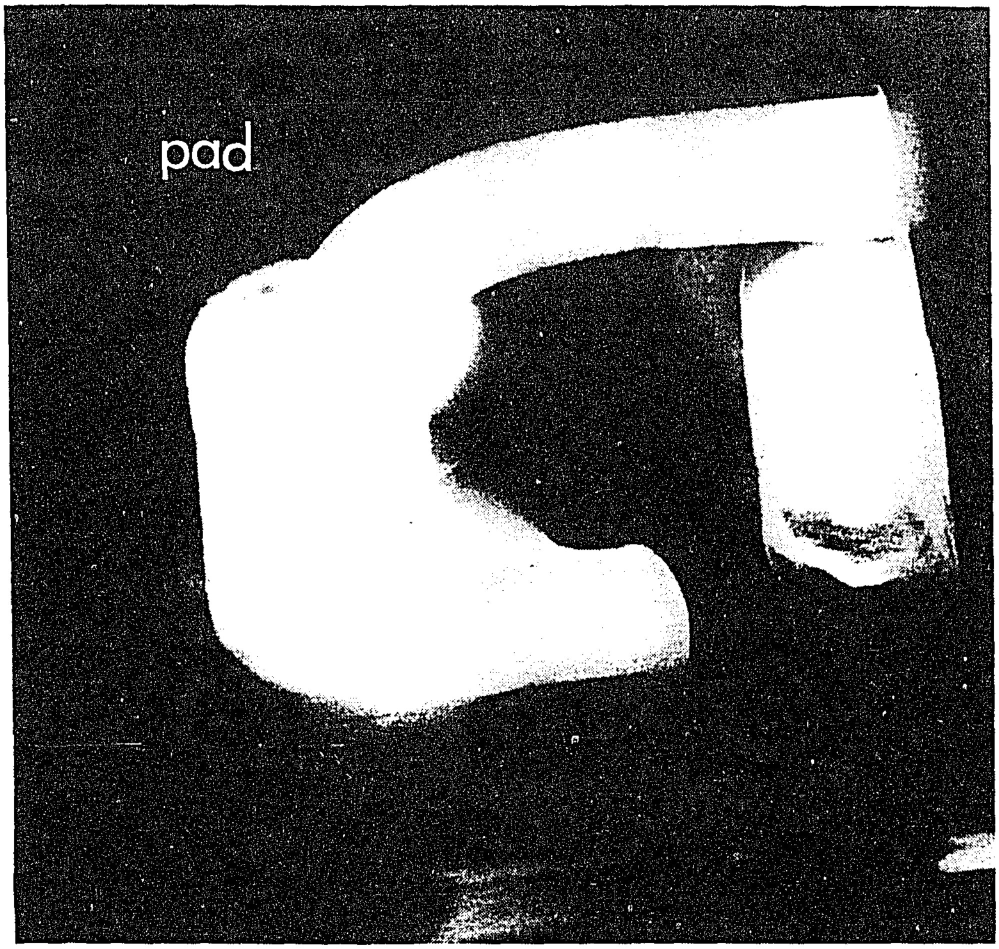


Figure C.11 Photograph at 40X magnification of a radiograph of a grainy solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

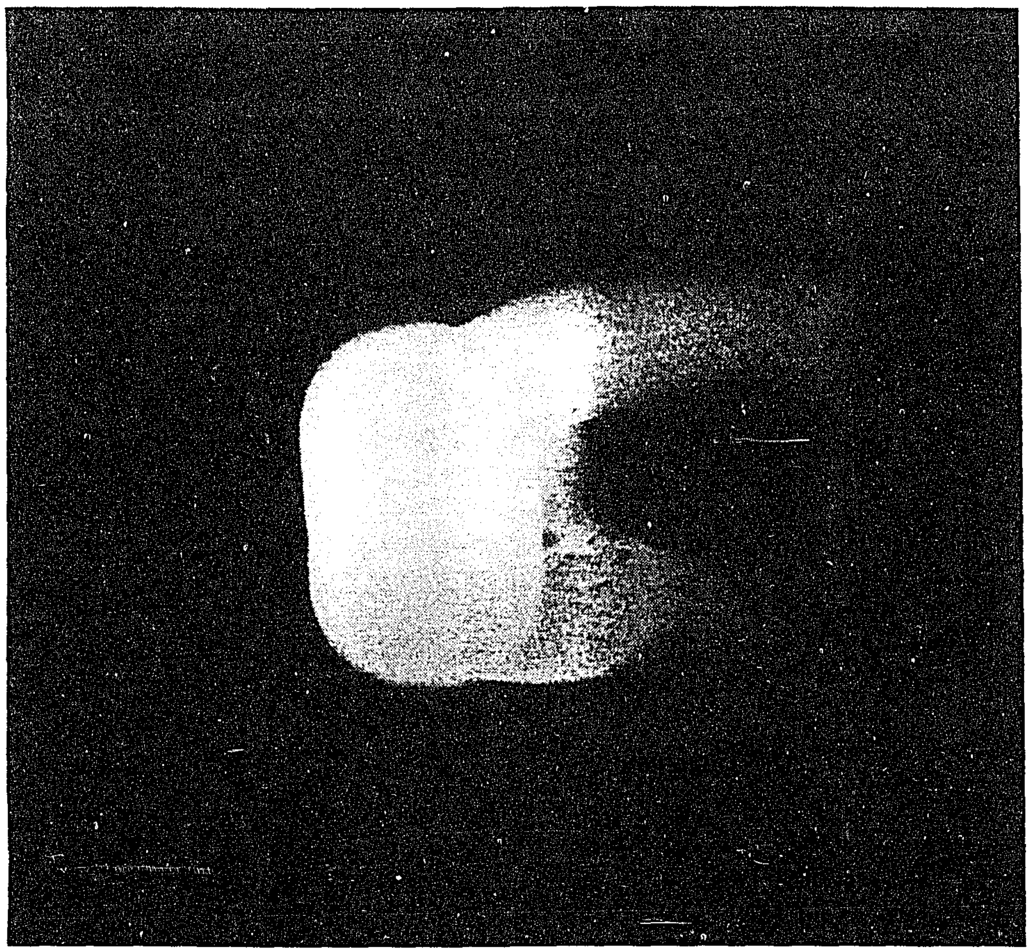


Figure C.12 Photograph at 40X magnification of a radiograph of a grainy solder joint at a 30 degree specimen tilt. Radiograph obtained at 70 kV with an exposure of 300 mA * sec.

APPENDIX D

PHOTOGRAPHS OF DIGITAL IMAGES OF SOLDER DEFECTS VIEWED ON THE CXI-5210 REAL TIME INSPECTION UNIT CRT

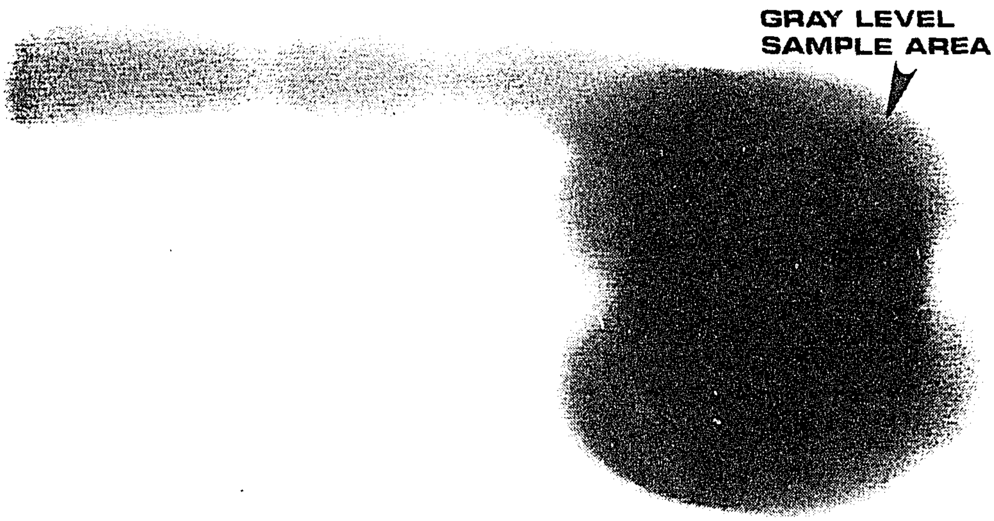


Figure D.1 Photograph of a digitized radiographic image on a CRT screen of a good solder joint obtained at 155 kV and 0.2 mA.

Figure D.2 Photograph of a digitized radiographic image on a CRT screen of an insufficient solder joint obtained at 155 kV and 0.2 mA.

Figure D.3 Photograph of a digitized radiographic image on a CRT screen of an excessive solder joint obtained at 155 kV and 0.2 mA.

Figure D.4 Photograph of a digitized radiographic image on a CRT screen of a dewetted solder joint obtained at 155 kV and 0.2 mA.

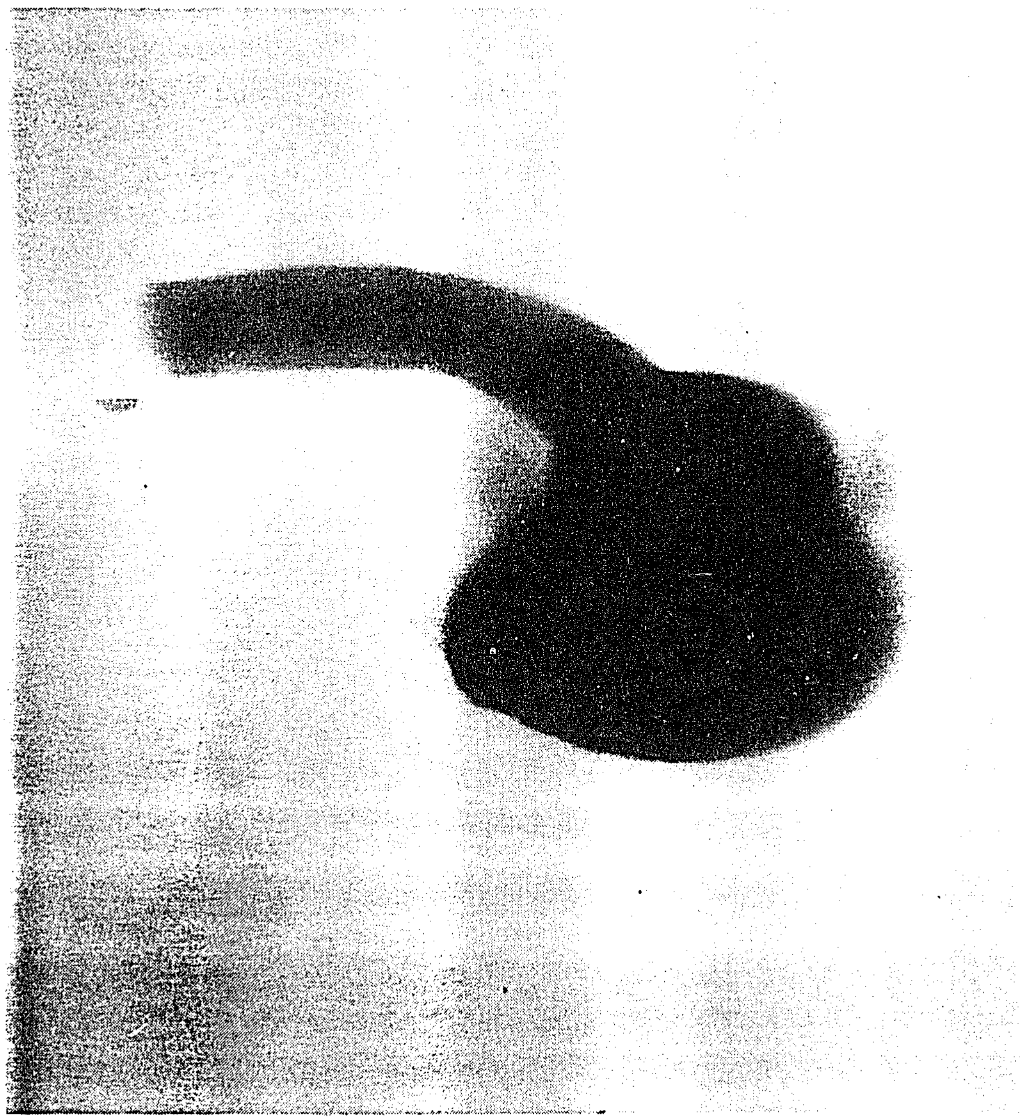


Figure D.5 Photograph of a digitized radiographic image on a CRT screen of a nonwetted solder joint obtained at 155 kV and 0.2 mA.

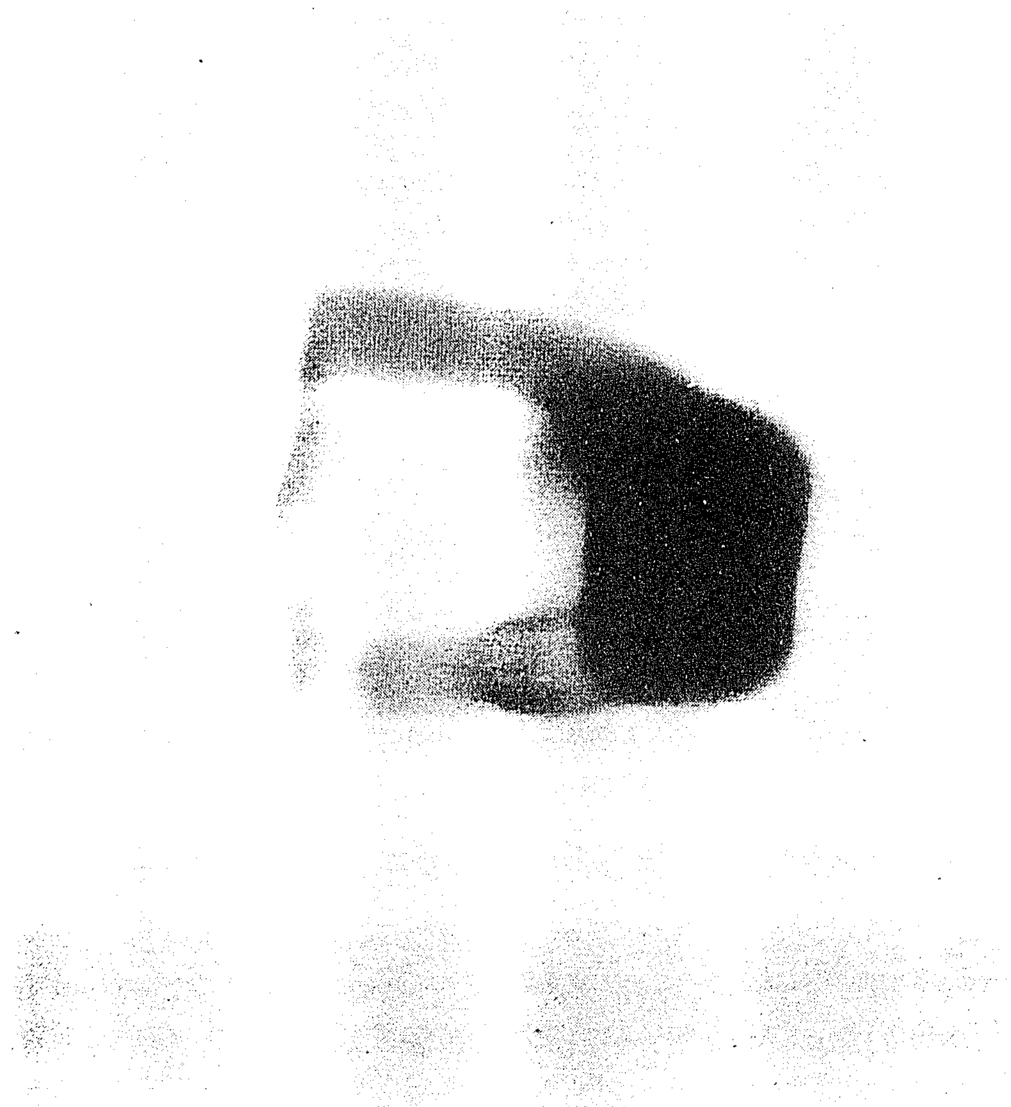


Figure D.6 Photograph of a digitized radiographic image on a CRT screen of a grainy solder joint obtained at 155 kV and 0.2 mA.

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