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REQUIREMENTS FOR
REFLOW SOLDERING
OF INTEGRATED
CIRCUIT FLATPACKS

BDX-613-187

July, 1971

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PDO 6984374
Final Report

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ABSTRACT

The requirements for producing strong solder connections by reflow soldering are identified and inspection standards are developed. Evaluated for their effects on joint strength are the tin-lead plating thickness on the printed wiring board, bend angle of the lead, tin-lead coating on the lead, and lead-to-path alignment. The application of solder flux to the conductor path, the value of heat sinks for tinning and soldering, the fusing of printed wiring boards, and the feasibility of multilead soldering are also discussed. The methods described and the criteria given apply specifically to the reflow soldering of integrated circuit flatpacks.

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SUMMARY

The material and process requirements for producing high-strength, high-reliability solder joints of integrated circuit flatpacks by reflow soldering were determined. Visual inspection criteria and standards were developed and put into use.

Tinning the flatpack leads before soldering is desirable for good solderability. Tinning also supplies additional solder to the joint providing insurance against inadequate plating on the printed wiring board. Ultrasonic agitation during tinning produces a more uniform coating thickness.

The amount of solder required to make a strong flatpack solder joint increases as the lead bend angle increases. A 60-degree bend angle is the optimum from the standpoint of minimizing both the tin-lead thickness and the space occupied by the flatpack.

The tin-lead plating on the printed wiring board should be at least 1.5 mils thick for strong, reliable solder joints with tinned leads preformed to 60 degrees. The conductor path should be at least 8 mils wider than the flatpack lead to facilitate placement of the lead on the path.

Flatpack solder joints should be pull-tested at the same angle as the lead bend angle. A pull-test angle greater than the lead bend angle will cause premature cracking of the solder fillet and produce unrealistic pull strength results.

Activated rosin fluxes are not required. A thin, nonactivated or mildly activated rosin-in-alcohol soldering flux applied sparingly to the conductor path prior to soldering produces the best results.

Hot oil fusing of the printed wiring board before reflow soldering is not recommended. Although some improvement in joint strength is achieved, the rounded surface of the conductor path produced by fusing makes alignment of the leads difficult.

For optimum joint strength, flatpack leads should be soldered in the center of the conductor path. Leads soldered near the edge or overlapping the edge of the path produce low-strength solder joints.

Joint strength is reduced when connections are made on or next to heat sink areas on the printed wiring board (lands or plated-through holes). Heat sinks draw the molten solder away from the joint, producing solder-starved fillets. Additional heat input will not fully compensate for this effect.

Protection of the integrated circuit from excessive heating during tinning or soldering is not necessary in most cases. An external heat sink is useful, however, in controlling the flow of solder on the leads during tinning.

The feasibility of multiple-lead reflow soldering was investigated. Accurate positioning and consistent soldering of 7 and sometimes 14 leads was found to be impractical.

Both solder preforms and solder paste can be used to supply additional solder needed when making repairs. Solder preforms are preferred. Tinning the flatpack leads after forming produces a heavier solder build-up on the lead and can be used to compensate for insufficient tin-lead plating on the printed wiring board.

There is good correlation between the strength of the joint and the size and shape of the solder fillet formed at the heel of the flatpack lead. Based on this, visual inspection criteria and standards were developed for reflow soldering of flatpacks. Use of these criteria and standards was effective in eliminating low-strength solder joints.

DISCUSSION

SCOPE AND PURPOSE

In parallel gap reflow soldering, flatpack leads are attached to printed wiring boards by passing current between two electrodes. Resistance heating melts the solder on the board allowing it to flow around the lead and form the joint. Some reflow soldering systems use a single probe so that the heat is generated within the electrode itself. In both processes the flatpack leads are normally formed and tinned prior to soldering.

The equipment used in reflow soldering is more sophisticated than that used in more familiar soldering processes since the soldering cycle is programmed and automatic. This reduces the amount of operator skill required to make a good solder joint.

Experience at Bendix Kansas City has shown that the parallel gap soldering process is capable of producing reliable solder joints with pull-strengths in excess of 6 pounds. However, strengths of 2 to 3 pounds were typical in production. A study of the reflow soldering process was undertaken to define the requirements for making high-strength, high-reliability joints and to establish visual inspection criteria. A process development project was funded to satisfy these needs.

The work covered in this report was directed by B. T. Lampe and was performed in the Materials Engineering Laboratory by Robert S. Sanders and Mary J. Bronson. The period of the project was July, 1968, to January, 1970.

In this report the equipment, materials, and soldering schedule used are described. The role of each variable is discussed in turn, the experiments are described, and the results and the conclusions drawn from them are given. Finally, the solder joint requirements and the inspection criteria that were developed as a result of this project are given.

PRIOR WORK

Development of the parallel gap soldering process used at Bendix was done by R. P. Noble of Sandia Laboratory, Albuquerque. His report and several publications dealing with soldering are listed in the Bibliography.

ACTIVITY

Equipment

The soldering equipment used was the same type that has been used in production at Bendix for several years: the VTC Soldering System, Model 3001, manufactured by Development Associates Controls. The equipment (Figure 1) has programmed control of temperature, current, heating rate, and cooling rate. Heat is generated by passing alternating current between two electrodes, one of which contains an iron/constantan thermocouple that signals the controller to stop the heating cycle and to start the cooling cycle when the desired temperature is reached. This feature permits the equipment to maintain a given soldering cycle in spite of varying heat sink properties of the solder joint.

The chisel-tip, 0.040-inch-diameter electrodes used with this equipment are shown in Figure 2. The gap between the electrodes was set and maintained at 0.020 inch. The electrode force was set at 2 pounds. Raising, lowering, and firing the electrodes were controlled by a foot pedal. Periodic checks were made to ensure that the soldering tips were clean and properly aligned.

The specifications of the controller unit are as follows:

Temperature	300 to 1000°F
Time	Rise (heating), 0 to 5 seconds Fall (cooling), 0 to 5 seconds
Current	0 to 5 amp ac
Input	115 volts, 60 cycle, 3 amp
Sensor	Iron/constantan thermocouple Inconel-sheathed

A strip-chart millivolt recorder, connected in parallel with the controller unit, monitored the temperature of the solder joint and the rate of heating and cooling.

The completed joints were pull tested using a 0- to 10-pound pull tester (Unitek Model 6-092-02) at a pull rate of 3.5 inches per minute. With this instrument (shown in Figure 3) pull tests can be performed at angles from 0 to 180 degrees. Inspection of the solder joints was performed with a Zeiss Research Metallograph and a Bausch and Lomb stereo microscope.

Figure 1. VTC Soldering Equipment

Figure 2. Close-Up View of Parallel Electrodes

Figure 3. Unitek Pull Tester

Material

Gold-plated Kovar leads trimmed from Fairchild Type U-31 integrated circuit flatpacks were used in all tests. The leads were 0.004 inch thick, 0.017 inch wide, and 0.5 inch long. Pull tested in straight tension at 3.5 inches per minute, the leads failed at 6.4 (± 0.3) pounds. In most cases, the strength of the lead exceeded the strength of the solder joint.

The leads were ultrasonically cleaned in trichloroethylene, tinned in a solder pot, and preformed to various bend angles. The forming fixture used to bend the leads produced a 0.050-inch flat on one end. The solder joints were made at this end.

Figure 4 shows the typical printed wiring test board and dummy flatpack used. The thickness of the tin-lead electroplating on the conductor path was varied from 0.1 to 4.5 mils. Tin-lead composition was 65 weight percent tin.

All materials were cleaned, air-dried, and stored in clean plastic bags until they were used. The plated test boards were pumice-cleaned by hand to remove oxide and etching smut, ultrasonically rinsed in tap water, rinsed in de-ionized water, and forced-air dried.

A non-activated rosin-base soldering flux (Alpha 100-30) was used in most of the tests. Throughout the investigation, a sample size of 20 solder joints was used. From the pull test data, the average strength and standard deviation were computed.

Development of Soldering Schedule

Solder joints were made on test boards of varying tin-lead plating thickness using several different combinations of heating rate, maximum temperature, and cooling rate. The joints were visually inspected and pull-tested. The schedule shown in Figure 5 was found to produce good joints with plating thicknesses from 0.2 to 2.0 mils. This schedule also has a moderate cooling time permitting adjustments to be made if required. For these reasons the soldering schedule shown in Figure 5 was used in all of the work except where noted otherwise.

Tinning Flatpack Leads

Gold-plated flatpack leads are commonly tinned prior to soldering to improve solderability. This is done by dipping the leads into molten solder. Tinning also provides additional solder to the joint. Therefore, it is desirable to control the amount of solder picked up on the leads during the tinning operation. In this study a tinning process was developed that provided a means of controlling the amount of solder on the leads.

Figure 4. Dummy Flatpack and Printed Wiring Test Board

Figure 5. Standard Soldering Schedule Selected for Evaluation of Reflow Soldering Process

The leads were tinned at various temperatures using different procedures, including ultrasonic tinning. Some of the leads were tinned before and some after they were formed to a 60-degree angle. Various heat sinks were used.

After the leads were tinned, they were cross-sectioned at the points indicated in Figure 6 so that the coating thickness could be measured. As shown in the photomicrograph in Figure 6, the thickness is not uniform across the width of the lead. Therefore, a special measurement technique was used to determine the amount of solder on each lead. This involved taking a photomicrograph at 200X magnification and using a planimeter to measure the cross-sectional area of the solder coating. The coated area was then converted to an equivalent plating thickness on the conductor path of the printed wiring board. The conversion formula is shown in Figure 6. Converting the solder coating on the lead to equivalent plating thickness provided a measure of how much solder the tinned lead was contributing to the joint.

The results of this study are presented in Table 1. As expected, tinning at 540°F produced a thinner coating than tinning at 465°F. The use of a heat sink also reduced the amount of solder. Tinning a preformed lead produced a heavier buildup of solder at the bend or heel of the lead.

Ultrasonic tinning produced a thinner, more uniform solder coating. The most uniform coatings were achieved by ultrasonic tinning at 540°F and using a large Teflon* coated aluminum heat sink. An average equivalent plating thickness of 0.13 mil with a range of 0.03 mil was achieved.

The amount of solder picked up by the flatpack leads during tinning can be controlled to some degree by the tinning procedure used. Ultrasonic tinning produces the best results from a uniformity standpoint and produces the thinnest coatings at a given temperature. However, the effect of the ultrasonic energy on the integrated circuit was not determined and may be cause for concern. Good results were also achieved by tinning straight leads at 540°F using a heat sink. An equivalent plating thickness of 0.20 mil with a range of 0.09 mil was achieved with this procedure.

Tinning the leads after forming produces a nonuniform and heavier solder coating, especially near the heel of the formed lead. Tinning procedure Number 3 (Table 1) provided more than 2 mils of equivalent plating thickness in this area. Tinning the leads after forming is an effective way of supplying additional solder for the joint and provides a safety factor against insufficient tin-lead plating on the board.

* Trademark, E. I. du Pont de Nemours and Co., Inc.

✕ = POINTS WHERE FLATPACK LEADS WERE CROSS-SECTIONED FOR MEASUREMENT OF TIN-LEAD COATING

← CROSS-SECTION OF TINNED FLATPACK LEAD AT 120X MAGNIFICATION

A = AREA OF TIN-LEAD CROSS-SECTION

W = WIDTH OF CONDUCTOR PATH

T = THICKNESS OF TIN-LEAD PLATING OF SAME CROSS-SECTION

THEN:

$$T = \frac{A}{W} \quad \text{(EQUIVALENT PLATING THICKNESS)}$$

Figure 6. Measurement of Solder Coating on Flatpack Leads

Table 1. Flatpack Lead Tinning Study

Tinning Procedure	Temperature (°F)	Flux	Heat Sink	Equivalent Board Tin-Lead Plating Thickness		Lead Angle
				Average (Mils)	Range (Mils)	
1. 1 dip-5 sec.	465	Type R	None	0.60	0.14	Straight
2. 1 dip-5 sec.	465	Type R	Teflon-Al	0.46	0.14	Straight
3. 1 dip-5 sec.	465	Type R	Teflon-Al	0.45 (toe) 2.40 (heel)	0.14 (toe) 0.50 (heel)	Formed Prior to Tinning
4. 1 dip-5 sec.	540	Type R	None	0.20	0.18	Straight
5. 1 dip-5 sec.	540	Type R	Teflon-Al	0.20	0.09	Straight
6. 1 dip-5 sec.	540	Type R	Teflon-Al	0.24 (tip) 1.30 (heel)	0.18 (tip) 0.64 (heel)	Formed Prior to Tinning
Ultrasonic Tinning Procedure						
1. 1 dip-5 sec.	465	None	Teflon-Al	0.26	0.18	Straight
2. 1 dip-5 sec.	465	Type R	None	0.26	0.11	Straight
3. 1 dip-5 sec.	465	Type R	Teflon-Al	0.34	0.09	Straight
4. 1 dip-5 sec.	465	None	None	0.24	0.10	Straight
5. 1 dip-5 sec.	540	None	None	0.17	0.12	Straight
6. 1 dip-5 sec.	540	None	Teflon-Al	0.13	0.03	Straight
7. 1 dip-5 sec.	540	None	None	0.17	0.18	Straight

Tin-Lead Plating on the Printed Wiring Board

The tin-lead plating on the printed wiring board is very important in reflow soldering since it supplies most of the solder to form the joint. The quality of the solder joint is dependent upon the quantity of the tin-lead plating on the board. The purpose of this part of the study was to determine the minimum tin-lead plating thickness that would produce strong, reliable solder joints.

The minimum plating thickness requirement is also a function of the conductor path width for a given lead size. In this study, two different conductor path widths (0.029 and 0.025 inch) were used with the standard 0.017-inch-wide flatpack leads. The leads were tinned using procedure Number 1, Table 1. This produced a solder coating on the leads equivalent to 0.6 mil of plating thickness on the conductor path. After tinning, the leads were formed to a 60-degree angle with a 0.050-inch flat on the end to be soldered. Leads were soldered to test boards varying in tin-lead plating thickness from 0.2 to 3.0 mils. A small amount of flux was applied to the board prior to soldering.

Before the pull test, each solder joint was inspected at 20X magnification for defects such as cracked fillets and poor wetting. After they were inspected, the joints were pull-tested at a 60-degree angle. Leads were soldered to alternate paths on the test boards and, following the pull tests, the boards were cross-sectioned and plating thickness was measured on the unused paths.

Figure 7 is a plot of pull strengths as they relate to thickness of the tin-lead plating on conductor paths 0.029-inch wide. The average pull strength first increases with plating thickness and then levels off at 5 pounds and a plating thickness of approximately 1.35 mils. Similarly, the standard deviations in the pull strength data decrease as plating thickness increases to 1.6 mils. Increasing variations and decreasing pull strengths at thicknesses of 2.6 and 2.8 mils are the result of insufficient heat for such heavy plating. At these thicknesses, the soldering cycle had to be adjusted to provide additional heat in order to raise the average pull strengths to the 5.5-pound level obtained at lesser plating thicknesses. Solder joints made at plating thicknesses less than 0.7 mil were fragile as a result of the small fillets that were formed. Care was taken during pull testing to avoid cracking these small fillets. If the fillet is cracked, the pull strength drops to less than 2 pounds. To produce an average pull strength of 5 pounds with a standard deviation of less than 0.5 pound, the minimum plating thickness required for the 0.029-inch path would be approximately 1.5 mils.

Figure 8 shows that the pull strengths of solder joints made on the 0.025-inch conductor paths are lower at any given plating thickness than the joints made on the 0.029-inch paths. A plating thickness of 1.8 mils or greater was required to produce an average pull strength of 5 pounds on 0.025-inch paths. More than 2.0 mils of tin-lead plating was required to reduce the

Figure 7. Effects of Plating Thickness on Pull Strength
(Conductor Path Width = 0.029 Inch)

Figure 8. Effects of Plating Thickness on Pull Strength (Conductor Path Width = 0.025 Inch)

standard deviation to less than 0.5 pound. The pull strengths on the 0.025-inch paths varied less at the lower plating thicknesses than those on the 0.029-inch paths. Figures 7 and 8 are combined in Figure 9 to illustrate the effect of conductor path width on the average pull strength. Proper alignment of the lead on the conductor path becomes more difficult as the path width decreases. Misaligned leads can produce low strength solder joints. This is discussed in detail in a later section of this report (page 35).

Figure 10 illustrates the results of soldering untinned leads to conductor paths 0.029-inch wide. A plating thickness of 2.0 mils was required to produce an average pull strength of 5 pounds. This value correlates well with the 1.35-mil plating thickness required to produce a 5-pound average pull strength using tinned leads. With tinned leads and a 1.35-mil plating thickness, the total equivalent plating thickness is approximately 1.95 mils (1.35 mils on the board plus 0.6 mil equivalent on the lead).

The number of visual defects was much greater with the untinned leads than with tinned leads. The reflowed solder on the board did not wet the gold-plated Kovar lead as well as it did the tinned leads. As a result, approximately 10 percent of the solder joints made with untinned leads were discarded because of visual defects.

Effect of Lead Bend Angle and Pull Test Angle

Usual practice is to solder flatpacks onto printed wiring boards in such a manner that they stand away from the surface. This minimizes the space the flatpack occupies on the board and facilitates cleaning after soldering. The configuration of the formed lead is illustrated at the top of Figure 6 (page 23).

The lead bend angle has a large influence on fillet formation and a corresponding influence on the strength of the solder joint. The indicated strength of the solder joint is also dependent upon the pull test angle. A solder joint made with a flatpack lead is basically a lap joint which is characteristically strong in shear, but weak in peel. A 180-degree pull test angle places the solder joint in full peel; a 0-degree pull angle places it in shear. An angle between 0 and 180 degrees places the solder joint in a combination of peel and shear.

The effects of the lead bend angle and pull test angle on the strength of the solder joint were determined. Joints were made with leads formed at 30, 45, 60, and 90 degrees and tested at several pull angles. Figures 11 through 13 give the results at three different tin-lead plating thicknesses. All of the curves follow the same trend. The high strength solder joints are obtained with leads formed at 30 degrees and pull tested at 30 degrees. The low strengths are obtained by pull testing 60-degree leads at 90 degrees. Results for the 60/60 condition fall in the middle and have the largest scatter. The

Text continued on page 34.

Figure 9. Effects of Conductor Path Width on Pull Strength

Figure 10. Effects of Plating Thickness on Pull Strength When Leads Are Untinned

Figure 11. Effects of Lead Bend and Pull Test Angles on Pull Strength
(Plating Thickness = 1.08 Mils)

Figure 12. Effects of Lead Bend and Pull Test Angles on Pull Strength
(Plating Thickness = 1.28 Mils)

Figure 13. Effects of Lead Bend and Pull Test Angles on Pull Strength
(Plating Thickness = 1.66 Mils)

least plating thickness that will produce joint strengths in excess of 5 pounds for leads formed and tested at 30 and 45 degrees appears to be under 1.08 mils and considerably less than the 1.35-mil minimum which had been established for 60-degree leads. This is expected since less solder is required to form a large heel fillet on leads formed at smaller angles. As will be discussed later, the size and shape of the fillet at the heel of the formed lead is the primary determining factor for a strong joint.

The minimum plating thickness that will produce joint strengths in excess of 5 pounds for leads formed at 90 degrees appears to be much greater than 1.66 mils. As shown in Figure 13, the average pull strength for the 90-degree leads was only 2.9 pounds at this plating thickness. The plating thickness required to obtain a 5-pound pull strength for 90-degree leads was not determined but probably is in excess of 3 mils and not practicably obtained on printed wiring boards without adding external solder. The size of the fillet required to anchor the lead firmly to the path would be quite large. If leads are used with bend angles in the range of 80 to 90 degrees, some compromise in joint strength must be accepted.

Pull testing flatpack solder joints at angles greater than the lead bend angle causes premature cracking of the heel fillet along the lead-to-solder interface during the initial part of the test yielding unrealistically low strengths. Correspondingly, pull testing at angles less than the lead bend angle gives unrealistically high results. The most meaningful results are obtained when the pull test angle is the same as the formed angle of the lead.

Flux Evaluation

Although many types of solder fluxes are available, rosin-base fluxes are generally used to solder electrical assemblies. The three basic types of rosin-base fluxes are nonactivated (R), mildly activated (RMA), and activated (RA). They can be used in liquid form or in the form of rosin-core wire solder. The liquid flux is basically a solution of rosin in isopropyl alcohol. The activated varieties contain an additive to increase their activity and effectiveness. The purpose of this study was to determine the flux requirements for reflow soldering of flatpacks to tin-lead plated printed wiring boards.

Flux was applied sparingly to the printed wiring board before the leads was soldered. The pull strengths of solder joints made using each type of flux were compared for equal plating thicknesses. There were no significant differences. However, nonactivated and mildly activated fluxes produced more consistent results than did activated flux.

Liquid flux is a good heat sink and draws the heat away from the solder joint. In its as-received condition, the activated (RA) flux is more viscous than the nonactivated and mildly activated fluxes. Because of this, the amount of

activated flux applied to the board could not be controlled as effectively as as could the amount of nonactivated and mildly activated fluxes. This caused a variation in heat sink properties from joint to joint and resulted in a wider variation in the pull strength data. There was no evidence that an activated flux is needed in reflow soldering since the solder-coated lead and the tin-lead plated board have excellent solderability.

A thin, nonactivated or mildly activated rosin-base flux, applied sparingly in controlled amounts, minimizes the variation in heat sink properties from joint to joint resulting in consistent strengths.

Effects of Tin-Lead Fusing

The general practice at Bendix Kansas City is to fuse tin-lead-plated printed wiring boards in a hot oil bath. The purpose of this study was to determine whether fusing would offer advantages in the reflow soldering of flatpacks.

The test boards were fused in peanut oil at 450°F. The thickness of the tin-lead plating on the boards was determined before fusing. The same conditions and materials were used as in the previous tests for minimum plating thickness. Tinned leads formed at a 60-degree angle were used and pull tests were made at a 60-degree pull angle.

The pull strength versus plating thickness curves for unfused and fused boards are shown in Figure 14. The plating thicknesses for the fused boards are the thicknesses before fusing. The results indicate that fused boards produce somewhat stronger and more consistent joints. The 5-pound pull strength level is reached at a plating thickness of approximately 1.1 mils for fused boards as compared to 1.35 mils for unfused. Pull strengths appear to be higher at all plating thicknesses, but the curve for the fused boards starts to fall off earlier as a result of insufficient heat.

Fusing offers some improvement in the strength and consistency of the joints, but there are disadvantages. Fused paths are rounded which causes a problem in placing and aligning the lead with its rounded, tinned surface. The lead tends to slip off the path when the electrodes are brought down against it. This does not happen when soldering unfused boards. Also, during fusing of the board, the solder tends to run and become uneven. The varying amounts of tin-lead from path to path cause variations in fillet size of the solder joints and lead to inconsistent pull strengths.

Effects of Lead Alignment

In production it is not always practicable to solder a flatpack lead in the center of the conductor path. Sometimes it must be soldered along the edge of the path. This study was made to determine the effect of misalignment on joint strength.

Figure 14. Effects of Tin-Lead Fusing on Pull Strength

Leads were soldered on test boards in three positions: centered on the conductor path, on the edge of the path, and overlapping the edge of the path. The plating thickness on the paths was 1.45 mils. Tinned leads formed to a 60-degree angle were used and pull tests were performed at the same angle.

Figure 15 compares the strengths of solder joints made with aligned and misaligned leads. The average pull strength of the solder joints decreased significantly as misalignment increased. The average pull strength for centered leads was 5 pounds. It dropped to about 4.2 pounds for leads soldered on the edge of the path and to less than 4 pounds for leads overlapping the edge. Increasing misalignment caused a corresponding increase in the standard deviation of the pull strength data.

The decrease in joint strength associated with misalignment of the lead on the path is caused by the inadequate solder fillet formed along the side and at the heel of the lead. Figure 16 compares the edge fillets of aligned and misaligned leads. The heel fillets (not shown) are similarly incomplete for the misaligned leads. When the lead overlaps the edge or is aligned along it, only one edge fillet is formed, and the fillet at the heel of the lead is incomplete. Consequently, the solder joints made with the misaligned leads are weaker than those made with leads centered on the conductor path where complete edge and heel fillets are formed.

Effects of Heat Sinks on the Printed Wiring Board

Sometimes it is necessary to solder a flatpack lead near a land or a plated-through hole in the printed wiring board. Lands and plated-through holes are good heat sinks and draw the heat away from the solder joint. This study was made to determine the effect of these heat sinks on the strength of the solder joint.

As discussed previously, a thermocouple in one of the electrodes of the VTC Soldering System measures the joint temperature. The system adjusts for changing heat sink properties of the board so that a constant soldering temperature is maintained. Solder joints were made within 1/16 inch of 0.10-inch and 0.15-inch diameter lands and of 0.02-inch diameter plated-through holes. The pull strengths of these joints were compared to the strengths of joints well removed from large heat sinks on the board. A production-type board was used in these tests.

The effects of soldering near large heat sinks on the printed wiring board are shown in Figure 17. Although the soldering system was able to adjust for these effects and maintain a constant soldering temperature, soldering adjacent to lands and plated-through-holes in the board caused a significant loss in strength. Soldering next to a 0.15-inch diameter land dropped the average pull strength from 6 to below 4 pounds. The scatter in the data also increased. Soldering next to a 0.02-inch diameter plated-through-hole had a similar effect.

Figure 15. Effects of Lead Alignment on Pull Strength

LEAD ON EDGE OF CONDUCTOR PATH

LEAD OVERLAPPING EDGE OF CONDUCTOR PATH

LEAD CENTERED ON CONDUCTOR PATH

Figure 16. Effects of Lead Alignment on Formation of Edge Fillets
(All views at 80X magnification)

Figure 17. Effects of Heat Sink Properties of the Printed Wiring Board on Pull Strength

Adjusting the controller settings to provide additional heat improved the results, but did not fully compensate for the heat sink effects of the board.

Large lands and plated-through-holes in the printed wiring board tend to draw both heat and solder away from solder joints made adjacent to them. The soldering temperature was not affected because the temperature feedback feature of the VTC Soldering System compensated for these effects. However, the cooling rate was increased (decreased fall time) reducing the reflow time of the solder. Also, the molten solder tended to flow toward the heat sink. The decreased reflow time and the tendency for the molten solder to flow away from the solder joint produced solder-starved fillets at the heel of the leads causing a significant loss in joint strength.

Heat Sink Requirements for the Integrated Circuit

Since integrated circuits are temperature-sensitive, heat sinks are often used during welding and soldering operations. Usually flatpacks are not heat-sinked during reflow soldering since the heat is localized at a safe distance from the integrated circuit; however, heat sinks are commonly used during tinning of the leads. The purpose of this study was to determine whether heat sinks should be used during reflow soldering and during the tinning of the leads.

Flatpacks with a metal case (Figure 18) were used to enhance heat conduction to the integrated circuit contained within the case. The top of the flatpack package was removed to expose the chip. The temperature was measured at two points shown in Figure 18 with Tempilaq Temperature Indicating Liquid. Stainless steel tweezers were used to heat sink the flatpack during reflow soldering. The machine settings were varied from low to high heat cycles. The high heat cycles were sufficient to burn the epoxy laminate of the printed wiring board. Machine setting 5454 corresponds to the standard soldering schedule used throughout the investigation. The maximum temperatures recorded during soldering with the various machine settings are given in Table 2. The maximum temperature recorded at the edge of the IC chip was 175°F at the highest heat setting (7756). This temperature is not high enough to damage the integrated circuit; therefore, heat sinking the flatpack during soldering is not needed.

Figure 19 shows the types of heat sinks evaluated for tinning the leads. These range from small stainless steel tweezer to the large Teflon-coated aluminum heat sink currently used in production. The leads were tinned by immersion in molten solder at 470 and 550°F. Temperatures were measured at the two points mentioned previously.

The results of this study are shown in Table 3. Temperatures as high as 225°F were measured at Point 1 when no heat sink was used. The tinning temperature was 550°F. Heat sinking reduced this temperature to 125 to 150°F.

Figure 18. Integrated Circuit Flatpack Used in Study of Heat Sink Requirements

Figure 19. Types of Heat Sinks Used During Tinning

Table 2. Effectiveness of Heat Sinks During Soldering

Point of Measurement (Figure 18)	Machine Setting	Heat Sink	Maximum Recorded Temperature (°F)
1	5452 (600°F)	None	125 to 150
1	5454 (650°F)	Stainless Steel Tweezers	100 to 125
2	7756 (700°F)	None	150 to 175
2	5454 (650°F)	None	125
2	3452 (550°F)	None	100

At Point 2, temperatures as high as 200°F were recorded when leads were tinned at 550°F. Heat sinking reduced this temperature to 100 to 125°F. All of the heat sinks proved effective with the large Teflon-coated aluminum heat sink proving to be the best. The Teflon-coated heat sink is also an effective solder stop-off device during tinning since it prevents the molten solder from reaching the flatpack case.

The study indicates that the temperature rise during tinning is not sufficient to cause damage to most integrated circuits and that simply holding the leads with a pair of small tweezers reduces the temperature rise adequately. Elaborate heat sinks are not needed from a temperature standpoint, but may be desired from the standpoint of controlling or limiting the solder flow on the leads.

Feasibility of Multilead Soldering

All studies during this project were made using single-lead parallel gap soldering. Since most flatpacks have 10 or 14 leads, time and labor are saved if more than one lead is soldered at the same time. Several commercial reflow soldering systems are available with multilead soldering heads that permit attaching 7 and sometimes 14 leads simultaneously. Although the heating electrodes used in multilead soldering are different from those used in single-lead soldering, the techniques are the same. The soldering tip used in multilead soldering is usually of solid construction, and the heat is generated within the tip itself rather than at the electrode-lead interface.

The multilead soldering tip made for the VTC equipment used in this project will solder seven leads simultaneously. It contains a tantalum heating element and a thermocouple. An evaluation of multilead soldering was made using

Table 3. Effectiveness of Heat Sinks During Tinning

Point of Measurement	Solder Pot Temperature (°F)	Sequence	Heat Sink	Maximum Recorded Temperature (°F)
1	470	1 dip 5 sec	None	200 to 225
1	470	1 dip 5 sec	Stainless Steel Tweezers	175
1	470	1 dip 5 sec	Aluminum Tweezers	150
1	470	1 dip 5 sec	Teflon-Aluminum	125
1	550	1 dip 5 sec	None	225
1	550	1 dip 5 sec	Stainless Steel Tweezers	175 to 200
1	550	1 dip 5 sec	Teflon-Aluminum	125 to 150
1	550	3 dips 1 sec	None	175 to 200
1	550	3 dips 1 sec	Stainless Steel Tweezers	125 to 150
1	550	3 dips 1 sec	Beryllium-Copper	100 to 125
2	470	1 dip 5 sec	None	200
2	470	1 dip 5 sec	Stainless Steel Tweezers	125
2	470	1 dip 5 sec	Teflon-Aluminum	100 to 125

Table 3 Continued. Effectiveness of Heat Sinks During Tinning

Point of Measurement	Solder Pot Temperature (°F)	Sequence	Heat Sink	Maximum Recorded Temperature (°F)
2	470	3 dips 1 sec	None	150 to 175
2	470	3 dips 1 sec	Stainless Steel Tweezers	100 to 125
2	550	1 dip 5 sec	None	200
2	550	1 dip 5 sec	Stainless Steel Tweezers	125 to 150
2	550	1 dip 5 sec	Beryllium-Copper	100 to 125
2	550	1 dip 5 sec	Teflon-Aluminum	100 to 125
2	550	3 dips 1 sec	None	200
2	550	3 dips 1 sec	Stainless Steel Tweezers	125 to 150
2	550	3 dips 1 sec	Beryllium-Copper	100 to 125

this tip. Representative production-type printed wiring boards were used with flatpacks typical of those used in production (Fairchild Type U-31).

Positioning the flatpack on the board so that the soldering tip made uniform contact on all seven leads was a major problem. The problem, in part, was that not all of the leads on the flatpack could be formed identically. At least one lead would tend to bow up at the toe and not lay flat against the conductor path. The major contributor to the positioning problem, however, was the mismatch between the spacings of the leads on the flatpack and the conductor path spacings on the boards. Some of the leads had to be twisted and bent into proper alignment with the path.

The conclusion reached from this limited study of multilead reflow soldering of flatpacks is that it is not practical with the printed wiring boards currently used in production. For multilead reflow soldering to be practical on a production basis, the following are needed.

The printed wiring board must be designed for multilead flatpack soldering.

The conductor paths should be at least 0.012 inch wider than the leads to permit easy alignment of the flatpack on the conductor path. Straight conductor paths are needed with uniform heat sink properties.

Better lead forming tools are needed to produce uniform bends in the leads.

A simple rework or touch-up procedure would have to be developed in conjunction with a multilead soldering process since some rework will always be required to meet quality standards.

Methods of Applying Additional Solder

One of the principal advantages offered by soldering over some of the other joining methods is that defective flatpacks can be easily replaced. However, whenever a flatpack is removed from a board, a large amount of solder is removed with it. The remaining solder is usually insufficient to produce a strong joint, and additional solder must be added when the replacement flatpack is soldered to the board. Also, additional solder must be supplied during the soldering process when the tin-lead plating on the printed wiring board is inadequate to produce high-strength joints. Methods of applying additional solder were investigated.

As discussed previously, additional solder can be supplied by increasing the amount of solder on the tinned flatpack lead. For example, leads tinned in the formed condition at 465°F will provide approximately 1 mil of equivalent plating thickness as compared to 0.6 mil provided by leads tinned prior to forming. Photomicrographs of solder joints made on test boards with thin plating (0.51 mil) using leads that were tinned before forming and leads tinned

after forming are shown in Figure 20. The size of the fillet made with the lead tinned after forming is considerably larger. Photomicrographs of the cross-sections of these solder joints illustrate the differences in the characteristic shape of the heel fillets. The solder joints made with leads tinned after forming show a build-up of solder in front of the heel fillet while the others do not. All solder joints made with flatpack leads tinned in this manner show this characteristic which may give the joint some added strength.

Two other methods of adding solder to the board were evaluated: the use of solder preforms and solder paste (a powdered solder-flux mixture). Preforms (63/37 composition) and solder paste were used to build up the solder coating on boards that were very low in plating thickness. One group of test boards had been solder-leveled. The coating thickness on these boards was as little as 0.05 mil. Small solder preforms, 5 mils thick, were placed under the leads before soldering. The resulting solder joints were examined and pull tested. The solder paste was applied in small amounts to the path prior to soldering. Since the paste contained both tin-lead solder and activated rosin flux, no additional flux was required. The leads were formed to 60 degrees and the solder joints were pull tested at 60 degrees. The results from this study are shown in Figure 21.

The solder paste appears to produce stronger joints than the solder preforms although both methods produced pull strengths in excess of 5 pounds. The lowest strengths reported for both methods were from solder joints made on solder-leveled boards having essentially no original tin-lead coating. The joints made with the solder paste did not have the bright, smooth appearance characteristic of good solder joints but were very strong. The solder paste was messy and difficult to apply in controlled amounts. The solder preforms, however, were easy to handle and produced attractive solder joints with better than adequate strength.

Inspection Criteria

An important objective of this project was the development of visual inspection criteria. One advantage that soldering has over some of the other joining methods is that the quality of the completed joint can be determined with a high degree of confidence by visual inspection.

The normal visual inspection criteria used to inspect hand-made solder connections are applicable to the joints made by reflow soldering. Shiny, smooth, and concave solder fillets are desired between path and lead. These characteristics indicate good wetting, but give no indication of the strength of the solder joint.

A solder joint made using a formed flatpack lead obtains most of its strength from the fillet at the heel of the lead. The fillets between the edges of the lead and the path are also important but contribute much less to the overall

CROSS-SECTIONAL VIEW

RESULTING HEEL FILLET WHEN LEAD IS TINNED BEFORE BEND ANGLE IS FORMED

CROSS-SECTIONAL VIEW

RESULTING HEEL FILLET WHEN LEAD IS TINNED AFTER BEND ANGLE IS FORMED

Figure 20. Effects of Lead Tinning Procedure on Fillet Size

Figure 21. Effects of Using Solder Paste and Preforms to Supply Additional Solder

strength of the joint. Representative solder joints retained from the study of plating requirements were used to develop a correlation between the size and shape of the heel fillet and the expected pull strength of the completed solder joint. A visual correlation was also developed between the plating thickness on the board and the resulting size of the heel fillet.

Actual flatpacks were used to develop the visual standards presented in this section in order to make the photographs more realistic. The flatpacks were soldered to test boards of varying plating thicknesses. The leads were tinned prior to forming to give an equivalent tin-lead plating thickness of 0.6 mil. The correlation between size of the heel fillet and plating thickness, together with the expected average strengths for both 60- and 80-degree leads, is illustrated in Figures 22 and 23. The solder joints are shown at 20X magnification.

The correlation between fillet size and plating thickness is better illustrated by Figures 24 and 25 which show cross-sections of solder joints made with various plating thicknesses. The increasing size of the heel fillet with increasing tin-lead plating thickness is evident.

Figure 26 shows the size and shape of the fillets formed at the edge of the flatpack lead with various plating thicknesses. Although the edge fillets are not as indicative of joint strength as the heel fillets, they do provide a valuable inspection criteria.

The visual inspection criteria for high-strength, high-reliability flatpack solder joints made by reflow soldering are summarized in Figure 27. The lead bend angles (60 and 80 degrees) are those commonly used in production. The predicted solder joint strengths are based on a flatpack lead 0.017 inch wide by 0.004 inch thick with a 0.50-inch flat. Pull testing was performed at an angle equal to the lead bend angle.

ACCOMPLISHMENTS

The requirements for producing reliably strong solder joints by the reflow soldering process were determined. These were found to deal with the soldering schedule, the method of tinning flatpack leads, the thickness of the tin-lead plating on the printed wiring board, the angle to which the lead is formed, the alignment of the lead on the conductor path, the nature of the flux, and the heat sinking characteristics of the board. A meaningful pull test of the solder joint and visual criteria for reliable joints were developed.

Text continued on page 57.

0.51 MIL, 3.8 LB, 1.0 LB

0.75 MIL, 4.3 LB, 1.0 LB

1.20 MIL, 4.8 LB, 0.8 LB

1.55 MIL, 5.1 LB, 0.5 LB

2.00 MIL, 5.4 LB, 0.3 LB

3.10 MIL, 5.5 LB, 0.25 LB

Figure 22. Inspection Standards for 60-Degree Leads (The numbers below each photograph represent plating thickness, pull strength, and standard deviation, respectively. All views at 20X magnification.)

0.51 MIL, 1.5 LB, 0.5 LB

0.75 MIL, 2.3 LB, 0.6 LB

1.20 MIL, 3.5 LB, 0.8 LB

1.55 MIL, 4.5 LB, 1.7 LB

2.00 MIL, 5.2 LB, 0.5 LB

3.10 MIL, 5.5 LB, 0.3 LB

Figure 23. Inspection Standards for 80-Degree Leads (The numbers below each photograph represent plating thickness, pull strength, and standard deviation, respectively. All views at 20X magnification.)

0.51 MIL, 3.8 LB, 1.0 LB

0.75 MIL, 4.3 LB, 1.0 LB

1.20 MIL, 4.8 LB, 0.8 LB

1.55 MIL, 5.1 LB, 0.5 LB

2.00 MIL, 5.4 LB, 0.3 LB

3.10 MIL, 5.5 LB, 0.25 LB

Figure 24. Cross-Sections of 60-Degree Leads (The numbers below each photograph represent plating thickness, pull strength, and standard deviation, respectively. All views at 20X magnification.)

0.51 MIL, 1.5 LB, 0.5 LB

0.75 MIL, 2.3 LB, 0.6 LB

1.20 MIL, 3.5 LB, 0.8 LB

1.55 MIL, 4.5 LB, 1.7 LB

2.00 MIL, 5.2 LB, 0.5 LB

3.10 MIL, 5.5 LB, 0.3 LB

Figure 25. Cross-Sections of 80-Degree Leads (The numbers below each photograph represent plating thickness, pull strength, and standard deviation, respectively. All views at 20X magnification.)

PLATING THICKNESS = 0.5 MIL

PLATING THICKNESS = 1.2 MIL

PLATING THICKNESS = 1.8 MIL

Figure 26. Sizes and Shapes of Edge Fillets (All views at 20X magnification.)

Figure 27. Inspection Criteria for 60- and 80-Degree Preformed Leads

FUTURE WORK

The inspection criteria developed during this investigation for high-strength solder joints should be used as a basis for developing visual inspection standards for production.

Additional development work is needed before multilead reflow soldering of flatpacks can be considered as a potential production process.

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