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ELECTRICAL TERMINATION TECHNIQUES

by

W. E. Oakey

K. R. Schleicher

**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

FINAL REPORT

Contract No. NAS 9-13890

SwRI Project No. 16-3905

Prepared for

**NASA-Lyndon B. Johnson Space Center
Houston, Texas**

January 1976

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Approved:

Handwritten signature of Douglas N. Travers.

Douglas N. Travers

Vice President

Electromagnetics Division

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ABSTRACT

A technical review of high reliability electrical terminations for electronic equipment was made. Seven techniques were selected from this review for further investigation, experimental work, and preliminary testing.

From the preliminary test results, four techniques were selected for final testing and evaluation. These four were: (1) induction soldering, (2) wire wrap, (3) percussive arc welding, and (4) resistance welding. Of these four, induction soldering was selected as the best technique in terms of minimizing operator errors, controlling temperature and time, minimizing joint contamination, and ultimately producing a reliable, uniform, and reusable electrical termination.

I. INTRODUCTION

Purpose and Scope of the Program

The basic purpose of the program was to advance and further develop new electrical termination techniques and to identify new interconnecting materials for use in the manufacture of electrical and electronic devices. These new techniques and materials should improve the reliability, uniformity, repairability, and reusability of the end product.

The scope of the program included the identification of new and advanced techniques for joining, reworking and inspection of various electrical conductors in various configurations. Consideration was to be given to both solid and stranded conductors; various platings such as silver, gold, nickel and tin-lead; and the joining of differing conductor shapes and constructions such as stranded-to-flat, flat-to-round and round-to-round. Although new interconnecting materials were to be investigated, the conductors themselves were to be of standard aerospace and commercial metals, platings and dimensions.

After the investigation of techniques, a selection of electrical termination specimens were to be prepared by methods which would optimize the manufacturing, joining, reworking and inspection operations. Preliminary testing would be conducted to narrow down the types of terminations for final testing, evaluation and selection.

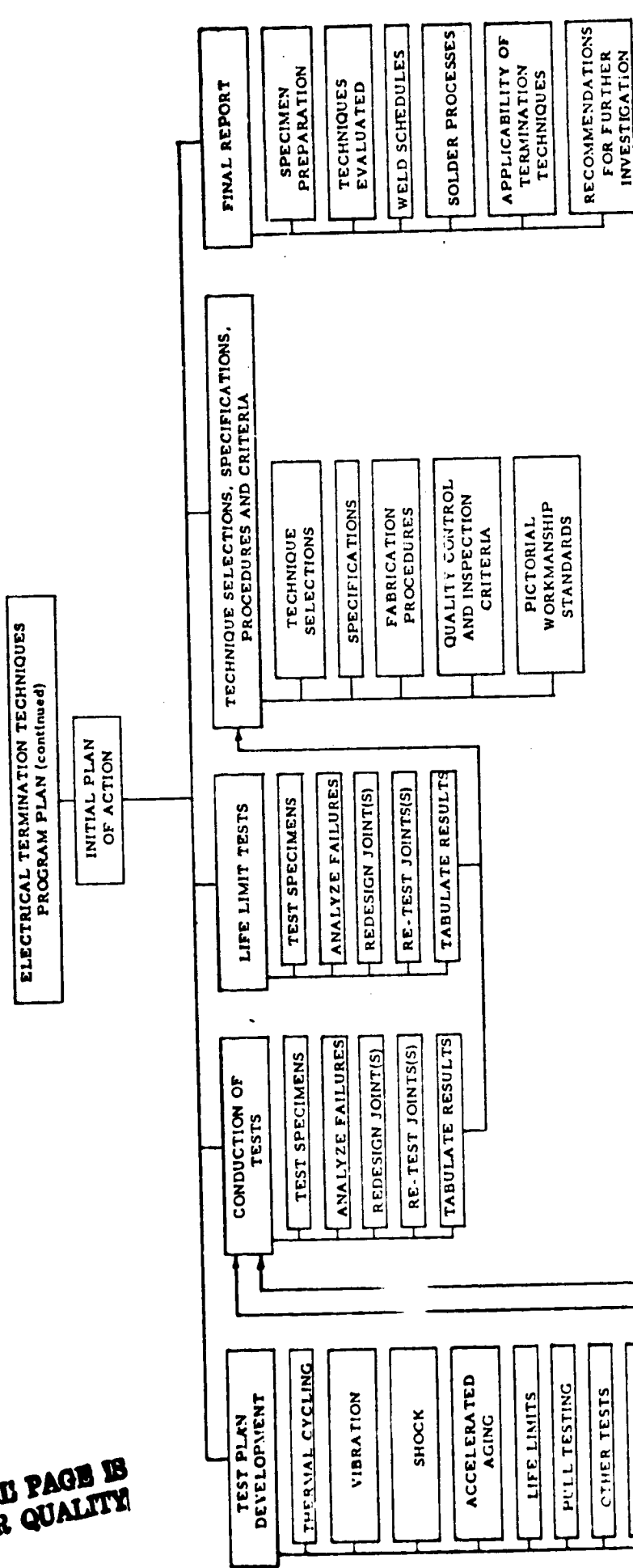
A fabrication and inspection plan for the most promising termination technique was to be the end product of the program. The in-process and quality control criteria were to be in the form of pictorial workmanship standards depicting unacceptable, minimum acceptable, optimum acceptable and maximum acceptable quality limits.

II. PROGRAM PLAN

A program plan was prepared and submitted to NASA to serve as the "Initial Plan of Action." This program plan, in flow sheet form, is shown as Figure 1. Table 1, which is referenced in the flow sheet, lists a number of termination techniques in four categories, which were to be investigated. At this point in the program, the techniques appearing in Table 1 were not necessarily considered all-inclusive.

The program plan served its intended use well. The "Development of Design Concepts" section required a larger portion of the total effort than was anticipated, principally due to the extensive amount of apparently contradictory material uncovered during the state-of-the-art review. This, however, did not affect the organization of the program plan.

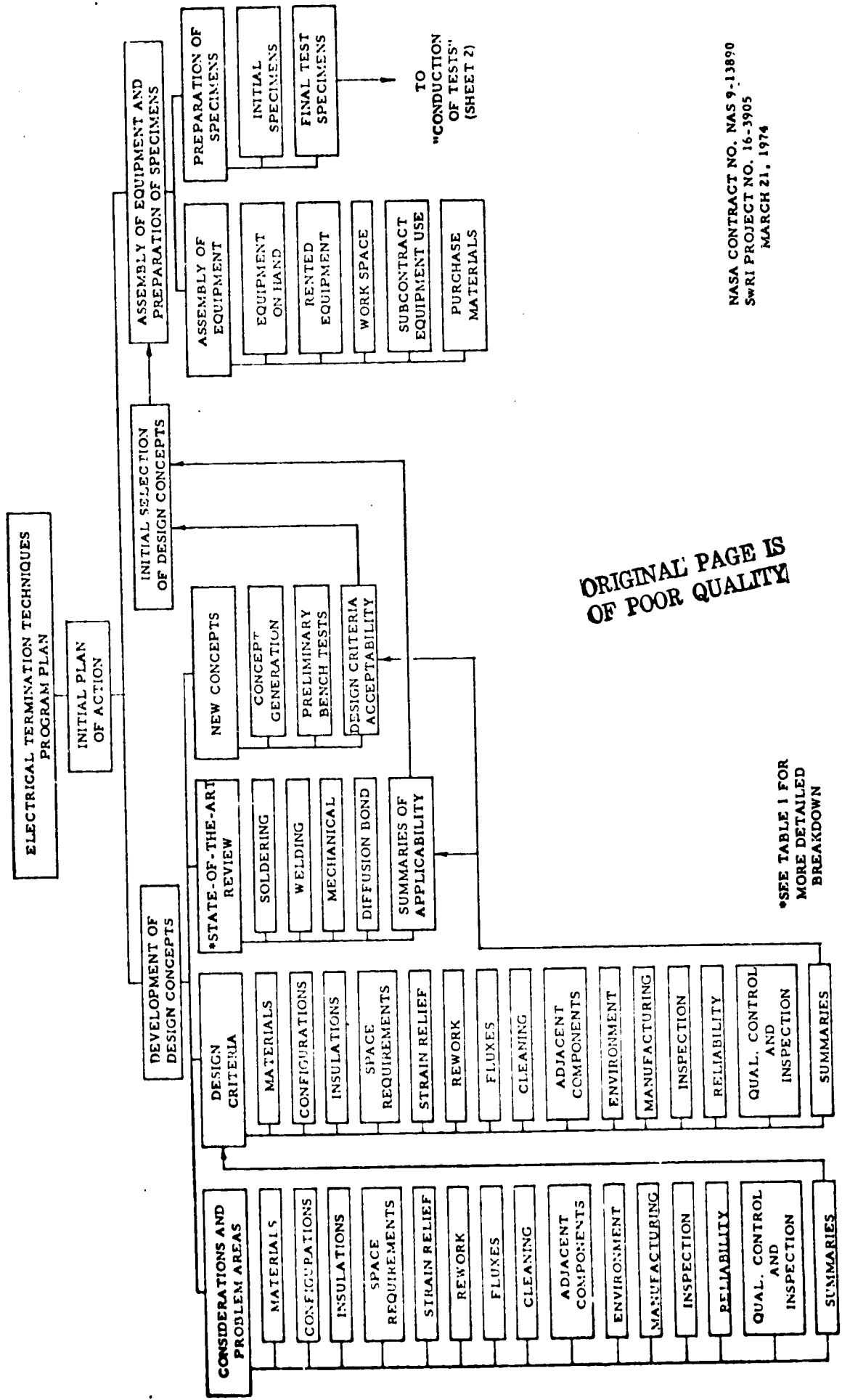
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FIGURE 1 - SHEET 1
 PROGRAM PLAN

FROM "FINAL TEST SPECIMENS" (SHEET 1)



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*SEE TABLE 1 FOR MORE DETAILED BREAKDOWN

FIGURE 1 - SHEET 2
 PROGRAM PLAN

TABLE 1

ELECTRICAL TERMINATION TECHNIQUES

SOLDERING	WELDING	MECHANICAL	DIFFUSION BOND
<p>Hand soldering Dip soldering Wave soldering Reflow soldering Ultrasonic soldering Induction soldering Resistance soldering Infra-red soldering Preform soldering</p>	<p>Cold (pressure welding) Electron-beam Laser Percussive arc Plasma arc Resistance 1. Opposed electrode (crossed-wire) 2. Parallel-gap 3. Pincer 4. Series 5. Series-step</p>	<p>Wire wrap Crimp (swage) Wire-to-clamp Friction 1. Taper pin 2. Tabs Conductive adhesives</p>	<p>Ultrasonic Thermal compression 1. Ball (nailhead) 2. Bird beak 3. Wedge 4. Scissor</p>

III. DEVELOPMENT OF DESIGN CONCEPTS

A. State-of-the-Art Review

1. Introduction

Table 1, presented earlier, groups electrical termination techniques into four categories: soldering, welding, mechanical joining, and diffusion bonding. Under each category heading are listed specific techniques. A state-of-the-art review was initiated to gather available information in these techniques, as well as other techniques which may not have been listed.

It was not expected that all available techniques would be applicable to the requirements of this program. For example, high mass-production techniques such as might be used for commercial television sub-assemblies probably would not apply to the relatively small quantities of high-reliability electronic assemblies considered in this program. However, a complete survey was made in an attempt to extract maximum information on all existing techniques, so that even though a particular technique could not be used in its entirety, perhaps some part of it might be useful when combined with parts of other techniques.

Literature surveys are sometimes difficult because of the scarcity of work previously done, or a lack of published material on the subject. This literature survey did not encounter those problems; if there was a problem, it was that there was such an abundance of material, and that a fair amount of it appeared to be contradictory. Books, articles, reports, specifications, manufacturer's literature, verbal contacts, symposium material, trade associations, and a patent search produced large quantities of information. It became apparent rather early that (1) there was no "universal" termination technique that would satisfy all or even a large segment of the possible applications, and (2) that there are many areas of disagreement about terminations among people who work in the field. In addition, electronics continues to advance at its normal rapid pace, constantly bringing in new techniques along with new problems for terminations. To quote from one source ⁽¹⁾ "There is little agreement among the authorities in the field, as to which method to choose for a particular application. The pros and cons change continually as new materials and methods appear." Another source states, ⁽²⁾ "The optimum joint recommended for an application can depend on who is asked. A literature search can also yield contradictory information."

(1) Fogiel, Microelectronics, Research and Education Assn., New York, 1968.

(2) Harper, Handbook of Wiring, Cabling, and Interconnecting for Electronics, McGraw-Hill Book Co., New York, 1972.

The usual starting point in selecting the best terminations from the vast array available is the specific application, that is, where the termination will be used, and under what conditions it must operate. However, one of the objectives of the program was to select a minimum number of highly reliable terminations with multiple application possibilities. Another problem is that many termination techniques can be made with a high degree of reliability mainly because they can be set up for mass production. With the same termination or group of terminations produced repeatedly, it is possible to spend relatively large amounts of time and money for jigs and fixtures, fine-tuned machinery adjustments, destructive and non-destructive testing of quantities of samples, special training of employees, automatic and semi-automatic operations, etc. Under these rigorously and continuously controlled conditions, reliable terminations can be produced.

The consideration of quantity is one which causes part of the controversy between proponents of different termination techniques. A technique that might be considered unreliable when used for hand-made, small-quantity assemblies may become highly reliable under mass production controls. Information gathered from the literature survey generally covered either: (1) terminations primarily designed for a single application (or perhaps a few applications), or (2) terminations produced by mass production techniques. Therefore more time was spent on the survey than was originally anticipated, in order (1) to identify a larger number of multiple-use terminations from which to make final selections, and (2) to attempt to sort out the apparently contradictory judgements made about certain types of terminations.

2. Basic Techniques

Electrical terminations may be made up by one of four basic techniques: (1) soldering, (2) welding, (3) mechanical joining, or (4) diffusion bonding. They may also be generally classified as (1) permanent joints, in which one or more lead ends must be destroyed to separate them; (2) semi-permanent joints, in which special tools are required to separate the two leads, which may then be rejoined, and (3) quick-disconnect joints, such as plug-in connectors.

Since reusability is one of the criteria by which terminations considered in this program were to be judged, it would appear that so-called "semi-permanent," and "quick-disconnect" joints would be the only types applicable, thus eliminating welded joints. However, some types of welded joints can be repaired. For example, where extra lead length is available, a failed termination can be repaired by clipping off the ends of the leads, and re-welding the new ends. Also, in some types of modular electronic packaging, where welding may have several advantages over soldering, the complete module may be replaced, rather than attempting to repair individual terminations. As far as quick-disconnect joints are concerned, they are in general too large, and require more space for making and breaking than is usually available for the electronic packaging considered in this program.

3. Specific Techniques

a. Soldering Methods

Solder joints made by hand one at a time with a heated soldering iron comprise the most widely known methods used for electrical terminations. However, reliable soldering is a complex process in which consideration must be given to the materials to be soldered, fluxes, solder composition, joint preparation, heating time and temperature, contamination, amount of solder and flux, post cleaning and many other factors. Solder joints of a quality satisfactory for many applications need not consider all these factors in great detail, and unfortunately many people believe that "anybody can make a solder joint."

For mass production operations, techniques such as wave soldering, dip soldering, condensation soldering, reflow techniques, and others have been developed. In these cases, complex processes have been controlled through mechanization to the point where relatively unskilled operators can handle them. In addition, rigid quality control and inspection programs have been designed to complement these mass production operations.

Several specific soldering techniques deserve mention here. Other techniques, as well as additional information on the techniques discussed here, will be found in the Bibliography (Appendix A) of this report.

Manko⁽¹⁾ classifies soldering equipment according to the mode of heat transfer utilized: conduction, convection, radiation, and "special devices." Conduction methods depend upon physical contact of a thermal conductor with the joint to be soldered. The soldering iron and the hot plate fall under this classification. In addition, conduction methods include those in which liquid solder is applied to the joint, such as the solder pot (for dip soldering), wave soldering, cascade soldering, and jet soldering. All of the conduction methods have the disadvantage of direct physical contact of the thermal conductor with the joint, thus increasing the danger of contamination. The soldering iron and the hot plate may carry contaminants on their surfaces, and the liquid solder carries oxides (dross) on its surface, which must be skimmed off or otherwise controlled so as not to contaminate the joints.

Convection-type heating methods used for soldering include flame soldering, furnace soldering, hot-gas-blanket soldering, and the solder reflow methods.

Radiation methods include the use of heat lamps (unfocused radiation) and infra-red heating (focused radiation). These methods are the least susceptible to joint contamination. Special devices include resistance soldering, induction soldering, and ultrasonic soldering.

(1) Howard H. Manko, Solders and Soldering, McGraw-Hill Book Co., 1964, pp. 183ff.

Soldering methods all have one distinct advantage over most other electrical termination methods. This advantage is that re-work is relatively easy. A soldered joint which was incorrectly made the first time, or one which has failed in service, can be "unsoldered" and through proper clean-up and re-work procedures, made into an acceptable termination. The re-work can usually be done without splicing in additional wire or cable. This re-work capability is also useful in retrofit work where circuit design changes have been made.

b. Welding Methods

A complete survey of welding methods was made, including some methods not generally considered usable for small electrical terminations. The purpose of including the latter methods was to investigate the possibility of modifying or adapting them for small electrical terminations. The list of welding methods accumulated is given in Table 2.

c. Mechanical Terminations

Mechanical terminations include wire wraps, crimped connections in many variations, the Termi-point clamp, the taper tab or pin, and spring-loaded mechanical clips.

Most of the mechanical terminations have the disadvantage of requiring more space than other types. This space requirement is due either to physical size of the termination elements, or to space required around the termination for the tools used to make the joint. The wire wrap method, however, has been developed to a point where relatively high packaging density can be achieved.

Crimped terminations generally cannot be repaired or replaced if they are used in a high density package. Even in cases where packaging density is low, time-consuming procedures are required, removal or replacement of adjacent components may be required, and splicing is often necessary.

Taper tabs or pins, and spring-loaded mechanical clips require undue space, and are used more often in electrical rather than electronic assemblies.

d. Diffusion Bonding⁽¹⁾

The principal diffusion bonding methods are thermo-compression bonding and ultrasonic bonding.

The three most commonly used types of thermocompression bonding are ball bonding, wedge bonding and stitch bonding. They all depend on a combination of heat and pressure to attain mechanical bonding. In ball bonding, a fine wire is fed through a small-diameter tube, and the exposed end is melted into a ball by a hydrogen flame. Then the ball is brought down to the area of contact under pressure.

(1) Fogiel, Microelectronics, Research and Education Assn., New York, 1968.

TABLE 2
WELDING METHODS

I. Fusion Welding

A. Arc Welding

1. Inert-Arc Welding
 - a. Gas Metal-Arc Welding (Metal-Inert-Gas Welding)
 - b. Gas Tungsten-Arc Welding (Tungsten-Inert-Gas Welding)
2. Plasma Arc Welding
3. Submerged Arc Welding
4. Shielded Metal-Arc Welding
5. Stud Welding
6. Flux Cored Arc Welding
7. Carbon-Arc Welding
8. Atomic Hydrogen Welding
9. Percussive Arc Welding

B. Electron Beam Welding

C. Electroslag Welding

D. Laser Beam Welding

E. Thermit Welding

F. Induction Welding

G. Gas Welding

1. Oxyacetylene Welding
2. Oxyhydrogen Welding
3. Pressure Gas Welding
4. Air Acetylene Welding

H. Metallizing (flame spraying)

II. Resistance Welding

A. Resistance Spot Welding

1. Opposed Electrode (Crossed-Wire)
2. Parallel-Gap
3. Pincer
4. Series
5. Series-Step

B. Resistance Seam Welding

C. Projection Welding

D. Flash Welding

E. Upset Welding

F. Percussion Welding

G. Butt Welding

III. Solid State Welding

A. Ultrasonic Welding

B. Friction (Inertia) Welding

C. Forge Welding

D. Explosion Welding (Bonding or Joining)

E. Diffusion Welding

F. Cold (Pressure) Welding

G. Thermocompression Welding

Wedge bonding uses a sapphire or silicon carbide wedge, which is brought down on the end of the wire to be bonded. Stitch bonding is similar to ball bonding except that the exposed end of the wire is bent at a 90° angle instead of being balled. Heat and pressure are used as in ball bonding.

Other thermocompression bonding methods, not so commonly used, are resistance-heated thermocompression bonding, and pulse-heated thermocompression bonding.

Ball bonding is accomplished by pressing a lead wire against the surface of the component to be joined by means of a vibrating transducer tip. The bond is formed by the combination of heat, pressure, and scrubbing action. The advantages of the method are: (1) Surface cleaning is not exceptionally difficult; (2) Dissimilar metals and metals of different thicknesses may be joined; (3) Fluxes or adhesives are not required, lessening the chance of contamination. Disadvantages include (1) the requirement for close control of temperature, pressure, and (2) weld schedules are critical.

B. Patent Search

A search was made for existing patents dealing with electrical terminations. Forty-eight patents were found in Class 29: Subclasses 628 and 630, and Class 30: Subclasses 246, 247, 248, 249 and 250.

These patents were reviewed, and no really new methods suitable for use in the program were uncovered. Some of the patents have been reduced to practice, and the techniques are already in use. Others turned out to be useful only for much larger terminations, electrical rather than electronic.

For reference purposes, a list of these patents is included in this report as Appendix B.

C. Considerations and Problem Areas

For the purposes of this program, the selection of a minimum number of termination types with multiple application possibilities was preferable to a large number of highly specialized types due to the quantities of samples required for statistically meaningful testing. Also, for end use purposes, the smaller number of types would require less outlay of equipment, less operator training and fewer inspection and repair techniques, thus improving reliability. This approach required a broad review of known termination techniques, with a selective screening to separate out the very specialized methods.

NASA's intended use of these terminations is for relatively low production quantities as compared to mass-produced electronic consumer items. This consideration eliminated such factory-type termination processes as those which involved: (1) very costly equipment (2) continuous 24 hours/day operation, (3) running numerous termination samples at different machine

settings to obtain optimum operating conditions before starting a production run, (4) long-term training of highly skilled special operators, and (5) high production rates which require mechanized inspection processes.

The capability for re-work was one of the selection criteria for terminations covered by this program. This almost automatically points to soldered terminations, although certain other terminations can be re-worked. Wire-wrap terminations, for example, can be reworked several times, and is usually limited by the repeated stresses on the terminal during the wire-wrapping operations. Some welded joints can be re-worked, if extra lead length is available, or if splicing in a short section of new lead is allowable. However, soldered terminations remain the most adaptable to re-work.

Since contamination is always a problem with electrical terminations, methods which can successfully limit contamination are favored for high-reliability work. A clean working environment can be maintained, but the human operator and his working tools can still introduce contamination. Probably the worst offender is the soldering iron, even when the operator takes all possible precautions to keep it clean. This would indicate that eliminating the soldering iron as the heat source, and replacing it with a remote heat source would be advantageous.

Eliminating judgmental factors in the preparation of a termination is advisable. In any operation which requires heating, some of the factors which must be considered are: (1) minimum and maximum allowable temperatures for optimum metallurgical properties, (2) heating time, (3) possibility of damage to adjacent components or substrate materials by overheating and (4) possibility of melting adjacent terminations by overheating. Other judgmental factors which may be applicable to a particular termination are: (1) correct amount of flux and solder, or other filler materials, and (2) holding termination elements in proper relationship while joining and until molten metal has solidified.

Inspection is another important factor, and in this program, visual inspection methods were specified. Even though there has been criticism of this method as being "cosmetic," an inspector with a good set of pictorial workmanship standards, together with a brief written description of what to look for, can carry out his inspection with a high degree of confidence.

D. New Concepts

Particular effort was devoted to development of new concepts during this program, in addition to the preliminary testing and evaluation of available techniques. The new concepts were not necessarily ones which had never been attempted before, but were in the nature of refined or modified techniques. Several concepts in this category consisted of attempting to adapt successful mass-production techniques to the needs of small-lot production. Summaries of those concepts investigated are given below.

1. Explosive Bonding

A spray-on explosive was used in attempts to bond aluminum, nickel, and copper ribbon to copper-clad circuit boards. When sufficient pressure for bonding was generated, the circuit board substrate was often fractured. Some success was achieved in bonding thin aluminum ribbon to copper-clad fiberglass boards, and in bonding various materials to each other, where a circuit board is not involved. If the explosive were to be formulated in a paste rather than a spray consistency, it should allow the application of more explosive to a joint, which is apparently needed. However, the paste technique was not explored in view of the time required for further refinement, but appears to be worthy of more effort at some future date. A separate report on the experimental explosive bonding techniques carried out in this program is included as Appendix C.

2. Solder Creams and Conductive Epoxies

Samples of solder creams and conductive epoxies were used with various heating and curing methods to make up flat-to-flat conductor terminations, which were then subjected to destructive tensile testing. Some of the solder creams showed better results (in small sample lots) than conventional soldered joints, but the conductive epoxies showed poor results.

3. Focused Infra-red Heating

This method of heating was used to make up soldered terminations. It was used with solder creams and produced good joints at times, but was difficult to focus on the right spot in the work area, and the "spot" where heat was applied was too large in diameter (about 5/16"). With auxiliary visible light beams to target the infra-red beam, and a means of reducing the spot size by proper design of the optics, reliable solder joints could probably be produced.

4. Induction Heating

This means of inducing heat in a solder joint works especially well with magnetic materials such as nickel, but first attempts with a 500-watt machine could not heat non-magnetic materials such as copper sufficiently fast to produce a good soldered joint without unwanted heat flowing into adjacent areas. A larger (5 Kw) generator with "pancake" type work coils resulted in a very workable soldering tool. It soldered rapidly, limiting the heated area to the joint itself, and did not require fixturing of the work pieces. With this method, the work coil does not contact the joint, eliminating one source of contamination, and non-magnetic materials can be soldered in the stronger field produced by the larger generator. Depending on the generator frequency, heat may be generated throughout the joint, or may be conducted inward from the surface, thus producing a stronger bond.

IV. INITIAL SELECTION OF DESIGN CONCEPTS

A. Techniques

The selection of techniques and materials began with the listing of the most promising candidates and constituted a larger group than would be used for final testing. This allowed for a "narrowing down" process, with a more thorough evaluation of these techniques in order to select the final ones. The first listing resulted in these techniques:

- | | | |
|---|---|--|
| <ol style="list-style-type: none"> 1. Soldering by infra-red 2. Soldering by induction heating 3. Soldering by laser 4. Resistance welding 5. Percussive arc welding 6. Laser Welding 7. Wire wrap | } | using solder cream or
preplaced solder and flux |
|---|---|--|

B. Materials

The following materials constituted the initial listing:

1. 7 strand tinned copper (hook-up wire), 22 ga.
2. Tinned copper (buss wire, component leads, co-ax center conductor), solid, 22 ga.
3. Tinned kovar (.018" round for transistors; .018" round and .010" x .018" rectangular for integrated circuits), solid.
4. Gold-plated kovar (.018" round for transistors; .018" round and .010" x .018" rectangular for integrated circuits), solid.
5. Tinned dumet (diodes), solid, .020"
6. 12 strand over 7 strand core, tinned copper (hook-up wire), 22 ga.

C. Comparison of Initial Techniques

Considering the time required for the testing program and consequent specification and inspection documents, it was determined that four types of terminations could be tested with sufficient samples to be statistically

meaningful. Further, at least one of the methods should be a soldering technique, because of its wide-spread use and its adaptability for re-work. Table 3 lists the major advantages and disadvantages of the seven types of terminations comprising the initial selection. The next step was to select the best four of these seven types.

D. Selection of Techniques for Final Testing

It is sometimes possible to set up a very formal evaluation method for selection of the best item for a particular application from a group of items. This can be done when simple, clear-cut, non-overlapping evaluation factors can be set up and agreed upon among those who have input to the selection. Factors can be appropriately weighed and a numerical tally can be made, resulting in the selection of that item having the highest score.

In this program, a formal numerical evaluation could not be made because it was not possible to identify the exact design criteria and end-use application for any particular termination technique.

Therefore, the final test termination selection was based on judgment of the advantages and disadvantages of each technique together with which end-use applications were most important according to the program work statement. After discussions with NASA personnel, the four techniques selected for final testing were:

1. Induction soldering with solder creams or preforms
2. Resistance welding
3. Percussive arc welding
4. Wire wrap

TABLE 3

COMPARISON OF INITIALLY SELECTED TECHNIQUES

Termination Technique	Advantages	Disadvantages
Infra-red soldering with solder creams or preforms	(1) Suitable for copper, silver, gold, or other metals plated with these materials.	(1) Solder joints are not suitable for unplated kovar and dumet.
	(2) Since heater does not touch work, flux is not spread to other areas.	(2) Some solder joints may form intermetallic compounds causing porosity and brittleness.
	(3) Solder creams may be pre-applied by screen, roller, stencil, etc. for form a dry, non-tacky, non-flaking coating. Soldering may be done at a later time.	(3) Solder joints lose mechanical strength at temperatures above 200°F.
	(4) Preforms (containing flux) allow the use of a pre-measured quantity of solder in shapes to match the termination requirements.	
	(5) Solder joints are readily repairable (by hand methods if in field).	
	(6) With machine setup and pre-measured solder and flux, high degree of operator skill not required.	
	(7) Inspectability better than hand-soldered joints because of pre-measured solder and flux.	
Induction soldering with solder creams or preforms	(1) through (7) same as for infra-red method.	(1), (2), (3) same as for infra-red method
	(8) Heat may be induced throughout joint rather than being conducted inward from surface. This allows rapid heating of joint with minimum heating of electronic components.	
(9) Allows precise control of heat and time of heat application.		

TABLE 3 (Cont)

Termination Technique	Advantages	Disadvantages
Laser Soldering	<p>(1) through (7) same as for infrared method.</p> <p>(8) Permits rapid, very concentrated heating.</p> <p>(9) Allows precise control of heat and time of heat application.</p>	<p>(1), (2), (3) same as for infra-red method.</p>
Resistance welding	<p>(1) Can weld ribbons and wires to plated film as thin as one mil.</p> <p>(2) Heat is localized in joining process, therefore, unlikely to damage adjacent components.</p> <p>(3) Can weld without stripping insulation first when properly set up.</p> <p>(4) No flux required in welding processes.</p> <p>(5) High mechanical joint strength compared to soldered joints.</p> <p>(6) No "third material" required in welding processes.</p> <p>(7) Generally faster and less expensive than soldering.</p> <p>(8) Weldable materials include copper, nickel, domet, korar, silver, gold, and aluminum.</p> <p>(9) High weld forces can be obtained.</p> <p>(10) Equipment relatively low in cost.</p> <p>(11) Equipment easy to set up and maintain.</p> <p>(12) Relatively easy visual inspection (mainly centered electrode impression, percentage of filleting, and set down). Also, destructive tests of samples before final welding determines correct weld schedule.</p>	<p>(1) In some cases, space for welding electrodes may be a problem.</p> <p>(2) Interconnections must be accessible from opposite sides.</p>

TABLE 3 (Cont)

Termination Technique	Advantages	Disadvantages
Percussive arc welding	<ul style="list-style-type: none"> (1) Requires only low pressure, therefore can weld small conductors to each other and small conductors to large surfaces. (2) Heat is restricted to weld interface and lasts only a fraction of a millisecond. (3) Process is relatively insensitive to gap setting and capacitance. (4) Tensile strength of joints normally exceeds that of parent metal. (5) Dissimilar metals, including aluminum, refractory metals, and odd alloys can be welded by this method. 	<ul style="list-style-type: none"> (1) Requires relatively sophisticated equipment and some fixturing.
Laser Welding	<ul style="list-style-type: none"> (1) Focusing to very small diameters is done with simple optical systems. (2) Welds dissimilar metals readily. (3) Welds small leads to large leads. (4) Welds through insulation. (5) Forms true fusion welds. (6) Uses low cost fixturing. (7) Direct contact with work piece not necessary. (8) Surface contaminants make very little difference in weld quality. (9) Welds in inaccessible places. 	<ul style="list-style-type: none"> (1) Need careful control to prevent putting excess energy into area around joint. (2) With some materials, up to 90% of laser energy may be reflected. (3) Cost of equipment. (4) Shallow heat penetration (usually less than .020").

TABLE 3 (Cont)

Termination Technique	Advantages	Disadvantages
Wire Wrap	<ol style="list-style-type: none"> (1) Manual or automatic application. (2) Low cost. (3) Mechanically and electrically stable termination. (4) Readily repairable or modified (terminal can be re-wrapped up to 25 times). (5) Withstands shock and vibration. (6) Avoids failures due to heating. (7) Readily taught to inexperienced operators. (8) Capable of high-density point-to-point wiring. (9) Production process tests are simple. 	<ol style="list-style-type: none"> (1) Must use solid conductor. (2) Some limitation on reusability (wire end cannot be reused). (3) Probing may distort or destroy integrity of termination. (4) Tooling and quality control of wire and terminals is critical.

V. TEST PLAN DEVELOPMENT

The test plan to be used for the four selected termination types was designed especially for this program. It was necessary to develop this special plan because the tests were to be conducted on terminations alone, rather than on electronic systems or components containing terminations. Military Standards and other existing government documents did not include test plans specifically for terminations. However, the special test plan developed for this program did adapt some procedures from existing government specifications. Those specifications reviewed included MIL-STD-810, MIL-STD-202, MIL-STD-883, MIL-E-16400, MIL-STD-167, MIL-T-5422, MIL-E-5400, and MIL-STD-750B.

Two test series were developed. Series I - Cumulative Test Plan - consisted of different types of tests run consecutively in the same specimens. The tests, in the order run, were: fatigue, torque, thermal shock, thermal cycle, vibration, and pull-to-failure. Series II - Life Limit Test Plan - consisted of environmental tests wherein each type of termination was subjected to only one type of test, considered critical for that termination. The purpose of this test series was to attempt to establish the useful life limits of each type of termination under a particular environmental condition. These were: (1) Wire wrap-humidity test, (2) Soldered-thermal cycling test, (3) Percussive arc and resistance welded - thermal shock test.

Configurations of the test specimens, as well as materials used and mounting for test were discussed and agreed on between SwRI and NASA program personnel. The cumulative test specimens were designated groups 1 through 10, and the life limit test specimens were designated groups 11 through 15. A description of each of these groups may be found in Appendix D, "Electrical Termination Test Plan," which covers the complete test setups, procedures, and reporting of results, as well as identification of test specimens.

VI. ASSEMBLY OF EQUIPMENT AND PREPARATION OF SPECIMENS

A. Equipment

1. Equipment for Specimen Preparation

(a) Induction Soldering (Groups 1, 2, 11)

To supply the heat for induction soldering, a 5 Kw Taylor-Winfield Mk-II induction heating generator was used. A 1/8" diameter copper tube work coil was used, so part of the cooling water (normally supplied at a flow rate capable of cooling larger tubing) was by-passed. Also, a specially-fabricated timer was added to the control circuit, so that heating time could be set at 1/4 second intervals in the 1 to 2 second total time range. Figures 2 and 3 illustrate this equipment.

(b) Percussive Arc Welding (Groups 7, 8, 14)

The equipment used for percussive arc welding was rented from The Superior Welder Mfg. Corp., New Bedford, Mass. It consisted of a Model 720 High Speed Bench Fixture, a Model 527A Power Supply, and a #OS-2522 Wireholder.

(c) Wire Wrap (Groups 9, 10, 15)

For wire-wrapping, a Gardner-Denver Model 14R2 wire-wrap tool was used. Sleeve No. 500350-413, and Bit No. 519936-433-30G were used with the basic wire-wrap tool.

(d) Resistance Welding (Groups 5, 6, 13)

The resistance welding was accomplished with a Hughes Resistance Welder, Model VTW-30C-MB Power Supply, and a Model VTA-64 Welding Head.

2. Test Equipment

The test equipment used is listed below.

- (a) Tenney Environmental Test Chamber, Model TR-40-100240
- (b) Tenney Jr. Temperature Chamber (No model number available)
- (c) Unholtz-Dickie Corp. Model 454 Vibration Test System
- (d) Hunter Spring Co. Model 7JH Pull Tester with Model D-20-TC Force Gauge
- (e) Shallcross Model No. 673-D Milliohmeter.

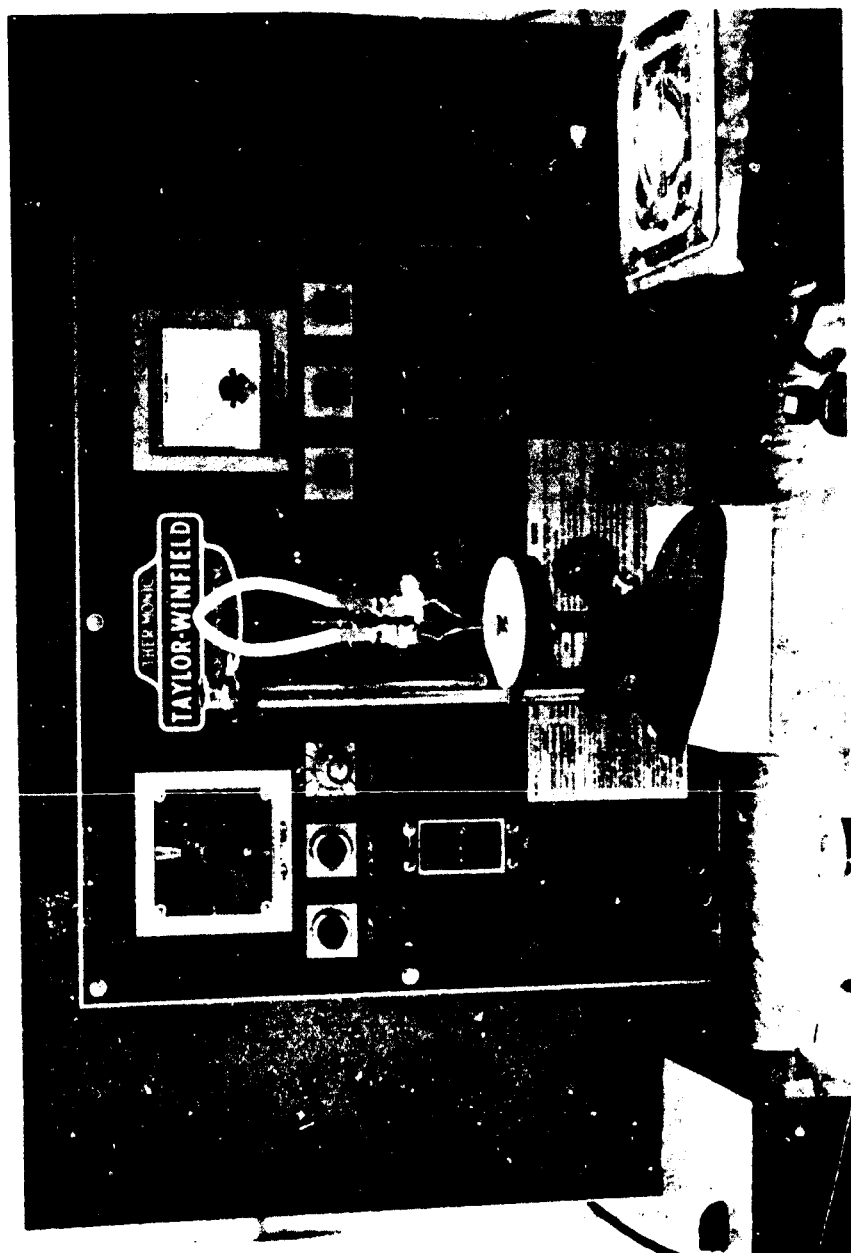


FIGURE 2
INDUCTION HEATING SET-UP, WITH PANCAKE COIL
IN PLACE OVER WORK TABLE

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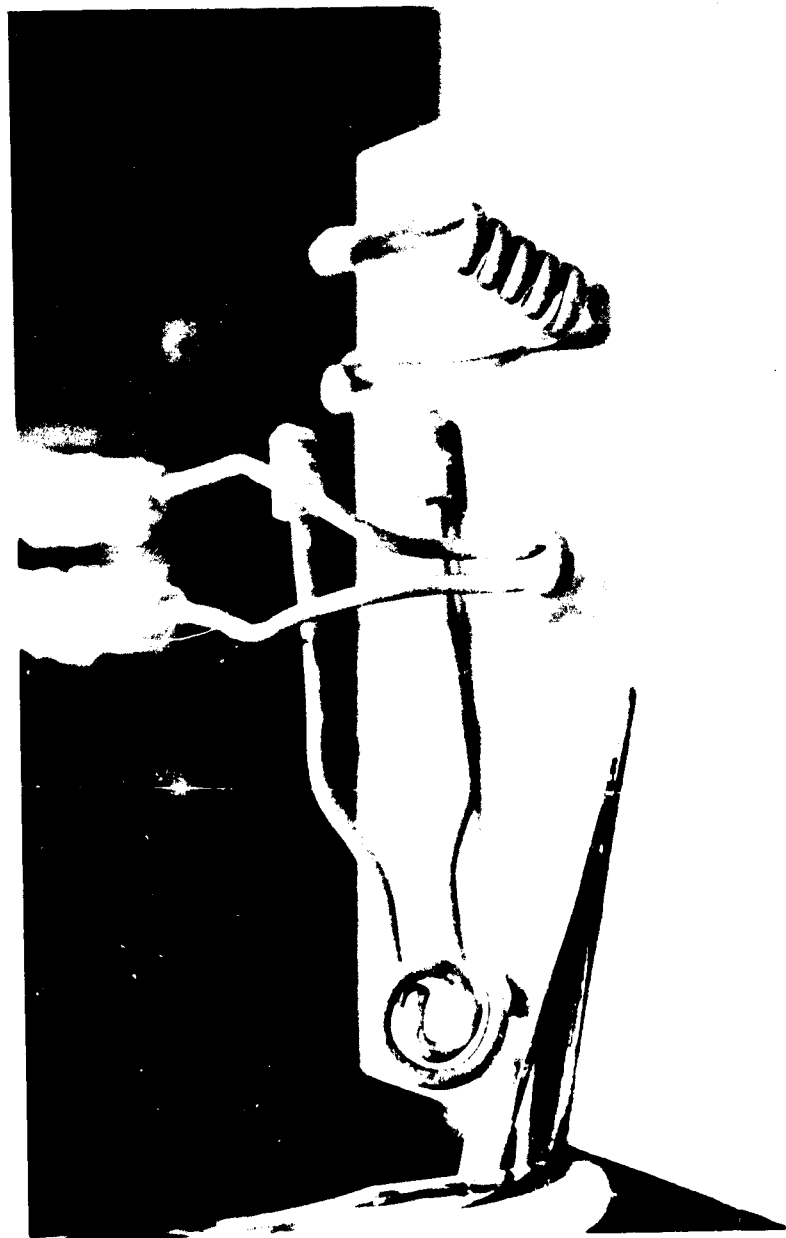


FIGURE 3

FROM LEFT TO RIGHT: MULTI-TURN PANCAKE COIL, SINGLE-TURN PANCAKE COIL (CONNECTED TO GENERATOR), AND MULTI-TURN HELICAL COIL. THESE COILS CAN BE USED INTERCHANGEABLY ON THE INDUCTION HEATER.

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B. Preparation of Specimens

The test specimens were all mounted on printed circuit boards, except for the wire-wrap specimens. In the case of soldered specimens, each copper pad on the board constituted one element of the terminations under test. For the welded specimens, the circuit boards provided a convenient mounting block for test purposes. The wire wrap specimens consisted of purchased connectors, whose terminals were wire-wrapped. Figures 4 through 7 show typical test configurations for each of the four basic termination types tested.

For each of the fifteen test configuration groups, thirty specimens were tested except for the wire wrap specimens, where twenty-five were tested. Where printed circuit boards were used, all thirty of a given configuration were mounted on a single board 3" x 4" in size, and 1/16" thick. The wire-wrap specimens were made up on Mupac 54-pin connectors, with only 25 pins wrapped.

Further details on specimen preparation prior to testing may be found in Appendix D.



FIGURE 4

CLINCH JOINT ON PRINTED CIRCUIT BOARD, SOLDERED BY INDUCTION HEATING, USING 24-GAUGE PREPLACED SOLDER RING.

E24607A

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E24684A

FIGURE 5

PERCUSSIVE ARC WELDED BUTT JOINT; 19-STRAND
COPPER TO SOLID ALUMINUM

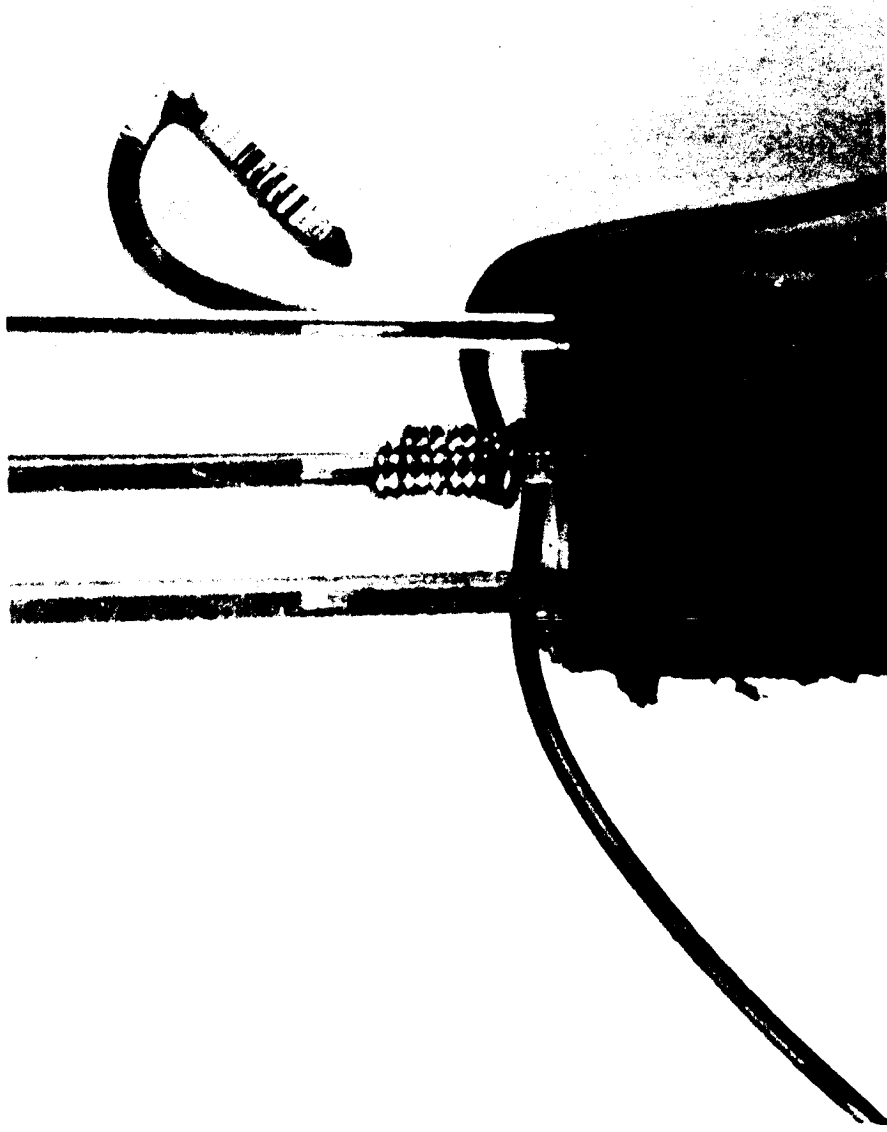
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E24684B

FIGURE 6

RESISTANCE-WELDED JOINT; NICKEL RIBBON
TO TINNED SOLID COPPER



E24684C

FIGURE 7

SOLDERLESS WIRE-WRAP JOINT: CLASS A

VII. TEST PROGRAM

A. Introduction

The Test Program was carried out according to the previously mentioned Test Plan, Appendix D. One factor that showed up throughout the tests was that the DC resistance measurements taken on each test specimen before and after each test showed no significant change, as long as no actual physical separation of termination elements took place. Therefore, the controlling criterion for determination of failure was visual examination under 10X magnification. Of course, the DC resistance measurement was necessary because if a significant change in resistance had taken place, it could have been an indication of partial failure.

The following DC resistance measurement ranges, in milliohms, are shown (1) before the beginning of the test series, and (2) before the pull test.

<u>Specimen Group No.</u>	<u>Before Beginning Tests</u>	<u>Before Pull Test</u>
1	6-8	6-8
2	7-10	7-9
3	6-7	5-7
4	8-10	7-9
5	8-18	9-19
6	9-19	8-19
7	6-15	8-15
8	7-11	5-10
9	21-39	20-25
10	25-42	20-25
11	5-10	4-10
12	6-10	4-12
13	19-28	5-13
14	9-24	8-16
15	25-32	15-25

B. Series I - Cumulative Tests

Test results will be presented in succeeding sections, with reference to the test specimens by group number as listed in the Test Plan.

<u>Group No.</u>	<u>Before Beginning Tests</u>	<u>Before Pull Test</u>
1	No visual defects	No failures
2	Specimen A6 overheated; specimens A2, A5, B2, B5, C2, D1, D5, E2, E4 did not completely wet pad to edges	A6 pad delaminated during vibration test
3	Specimen E2 overheated	No termination failures; specimens D1 and E2 resistor bodies* damaged in vibration test

*Resistors were mounted on a PCB and their leads were terminated to pads on the PCB in groups 1 through 4.

<u>Group No.</u>	<u>Before Beginning Tests</u>	<u>Before Pull Test</u>
4	Specimens C2, C5, E5 did not completely wet pad to edges	No failures
5	Specimen B4 showed off-center weld	(1) After fatigue test, 19 specimens showed solder plating on copper wire cracked adjacent to weld (2) After torque test, 1 more specimen showed solder plating cracked as in (1) above (3) No additional defects showed up after remaining tests
6	No visual defects	(1) After fatigue test, specimen A5 showed separation from stranded wire (2) No additional defects showed up after remaining tests
7	Specimens A1, B1 and D3 showed off-center welds	(1) No defects after fatigue, torque, thermal shock and 20g vibration tests (2) After 40g vibration test 9, specimens showed complete failure in stranded wire adjacent to weld. Numerous strands were broken in 3 additional specimens, and one strand was broken in 1 other specimen
8	No visual defects	(1) No defects after fatigue, torque, thermal shock, and 20g vibration tests (2) After 40g vibration test, 10 specimens showed complete failure in stranded wire, 16 additional specimens showed failure of one or more strands
9	No visual defects	No failures
10	No visual defects	No failures

C. Series II - Life Limit Tests

<u>Group No.</u>	<u>At Start of Test Series</u>	<u>At End of Test Series</u>
11	Control sample overheated	No failures
12	No defects	No failures
13	Specimen C6 showed off-center weld	No failures
14	Specimens B4, D2, D5, E6, 14E showed off-center welds	No failures
15	No defects	No failures

D. Pull Tests - Series I Specimens

Pull tests were made on welded specimens only, according to the Test Plan. Fewer "After Test" specimens were pulled, because of failures during the vibration tests. Results of the pull tests are tabulated below:

<u>Group No.</u>	<u>Before Test</u>		<u>After Test</u>	
	<u>Avg. Strength (lbs)</u>	<u>Std. Deviation</u>	<u>Avg. Strength(lbs)</u>	<u>Std. Deviation</u>
5	11.3	0.94	10.1	1.7
6	17.1	2.54	16.4	3.5
7	20.6	1.87	16.3	4.9
8	20.5	2.01	8.1	4.4

E. Gas-Tight Test on Wire-Wrap Specimens

The gas-tight test in Paragraph 5.6.2 of MIL-STD-1130: "Connections, Electrical, Solderless Wrapped," was conducted on wire-wrap specimens from both test series. Table 4 shows the results of this test. As shown, all specimens showed gas-tight corners on at least 75% of the terminal corners, which meets the specification requirements.

F. Metallographic Sectioning

Metallographic sectioning was done on specimens from Groups 1, 3, 5, 6, 7, and 8. A section was also done on an experimental induction soldered termination using solder paste, which was not in either test series. Two of each test series specimens were sectioned: one before testing, and one after testing. The photomicrographs are shown in Figures 8 through 18. A discussion of the sectioned specimens follows.

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TABLE 4
GAS TIGHT TEST - WIRE WRAP ELECTRICAL TERMINATIONS

Specimen Number	Total Number of Wraps	Number of Wraps Minus First & Last	Number of Gas Tight Areas Per Turn					Average	Test Series Identification	Exposure Time
			2nd Turn	3rd Turn	4th Turn	5th Turn	Average			
15A	6	4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Life Limit Humidity	2 Days
15B	6	4	4 100%	4 100%	4 100%	3 75%	3 75%	94%	Std. Wrap, Life Limit Humidity	4 Days
15C	6 1/4	4 1/4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Life Limit Humidity	6 Days
15D	6 1/4	4 1/4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Life Limit Humidity	8 Days
15E	6 1/4	4 1/4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Life Limit Humidity	10 Days
15F	6	4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Life Limit Humidity	0 Days
9#1	6	4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Cumulative Test	
9#2	6	4	4 100%	4 100%	4 100%	3 75%	3 75%	94%	Std. Wrap, Cumulative Test	
9#3	6	4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Cumulative Test	
9#4	6	4	4 100%	4 100%	4 100%	3 75%	3 75%	94%	Std. Wrap, Cumulative Test	
9#5	6	4	4 100%	4 100%	4 100%	4 100%	4 100%	100%	Std. Wrap, Cumulative Test	

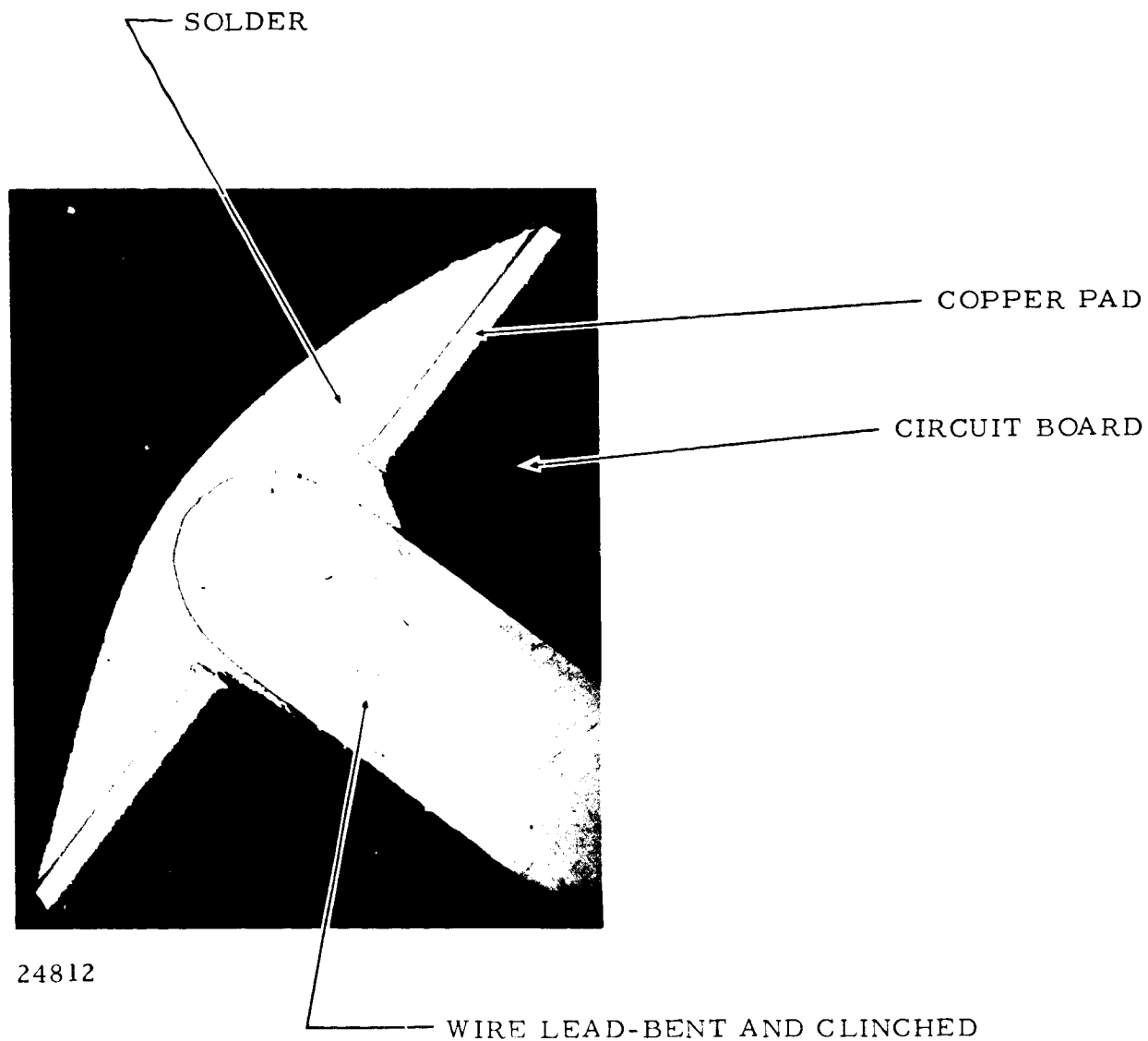
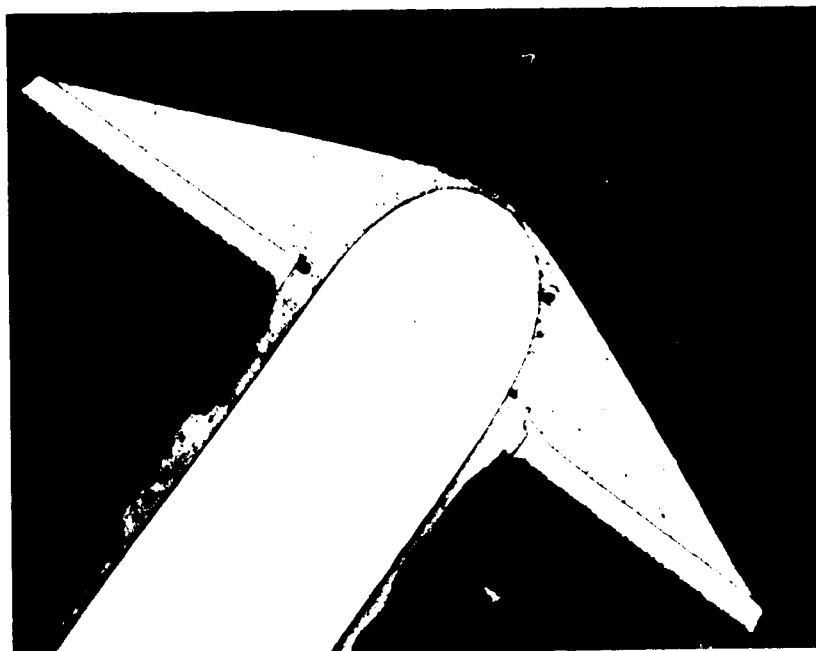
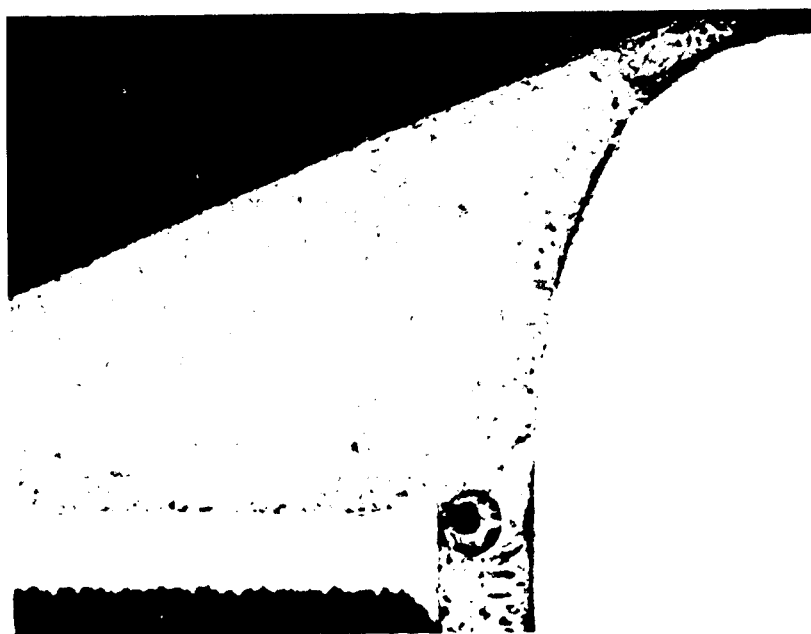


FIGURE 8
NOMENCLATURE FOR SOLDER JOINTS



24817

A - 50X



24818

B - 150X

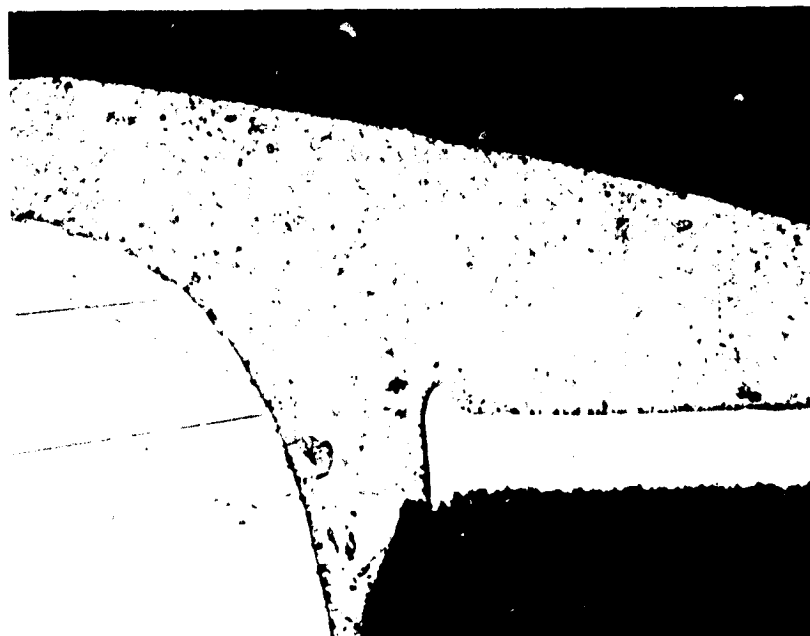
FIGURE 9

GROUP 1: INDUCTION HEAT SOLDER #22 GAUGE
TIN-PLATED SOLID ROUND COPPER CONDUCTOR
TO CIRCUIT BOARD, WITH CLINCHED END,
BEFORE CUMULATIVE TEST SERIES.



24809

A - 50X

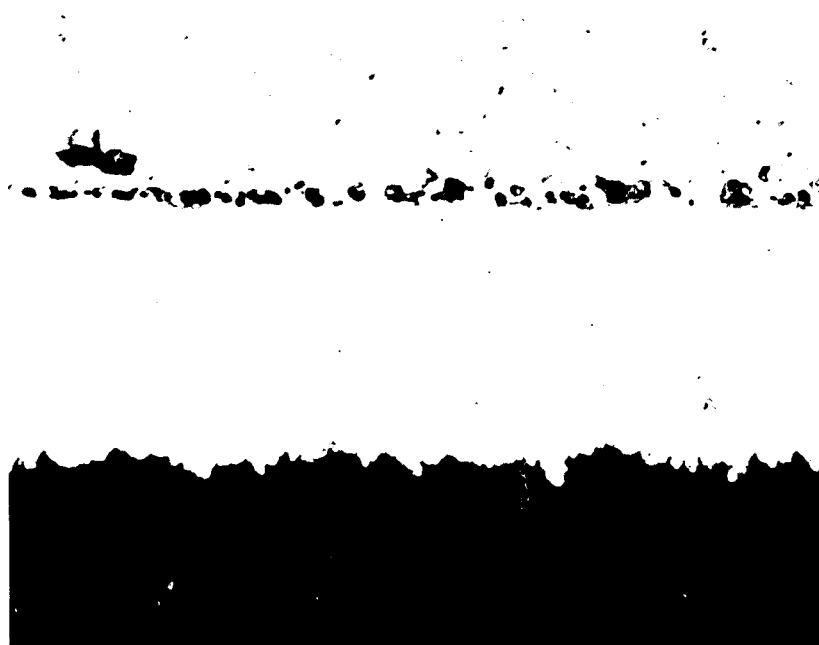


24810

B - 150X

FIGURE 10

GROUP 1: INDUCTION HEAT SOLDER #22 GAUGE
TIN-PLATED SOLID ROUND COPPER CONDUCTOR
TO CIRCUIT BOARD, WITH CLINCHED END,
AFTER CUMULATIVE TEST SERIES.

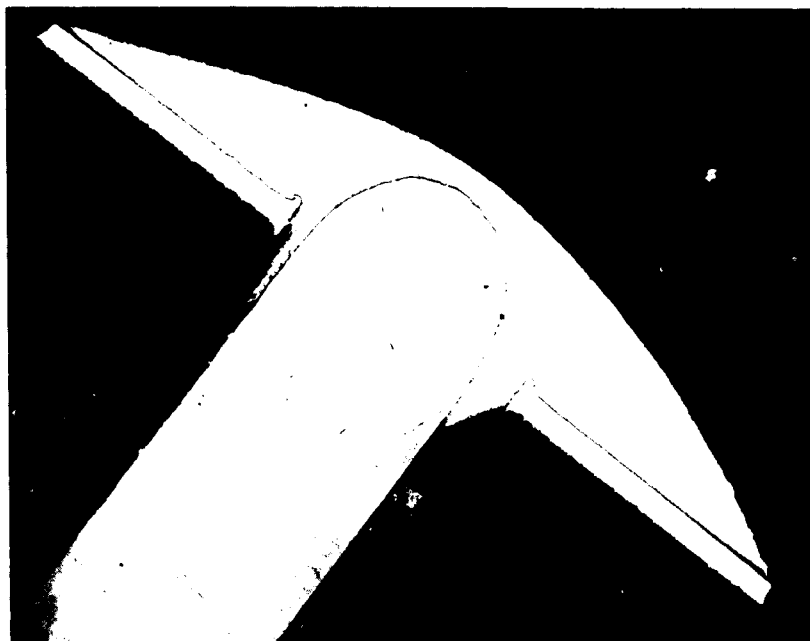


24811

500X

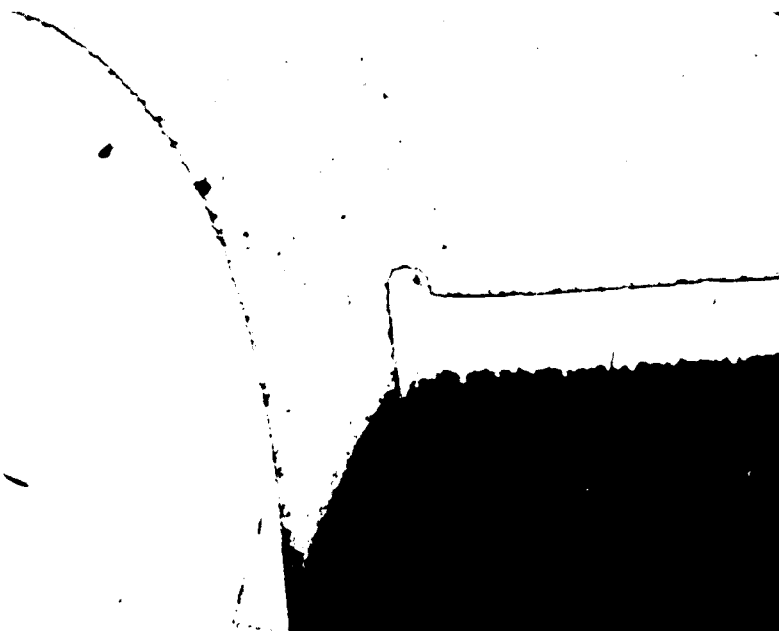
FIGURE 11

GROUP 1: INDUCTION HEAT SOLDER #22 GAUGE TIN-
PLATED SOLID ROUND COPPER CONDUCTOR TO CIRCUIT
BOARD, WITH CLINCHED END, AFTER CUMULATIVE
TEST SERIES - 500X MAGNIFICATION.



24812

A - 50X

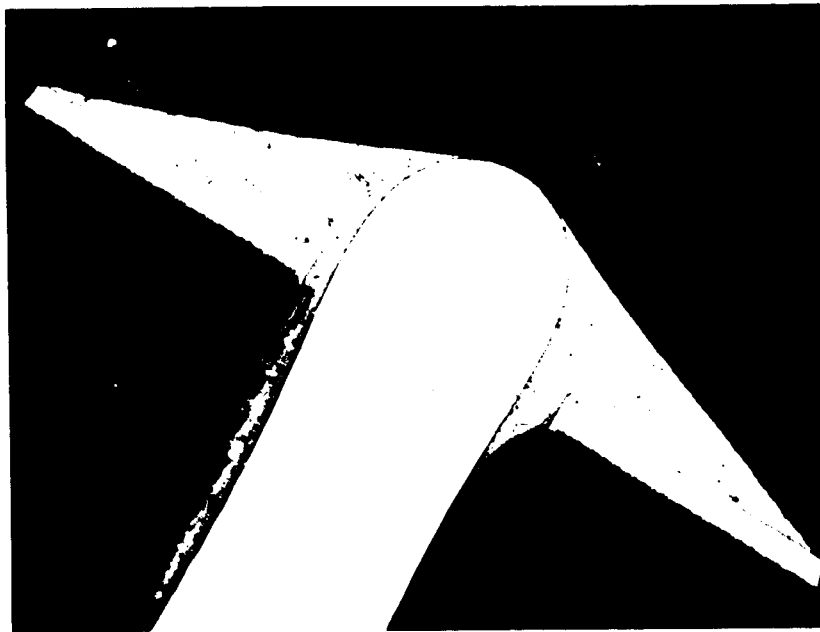


24813

B - 150X

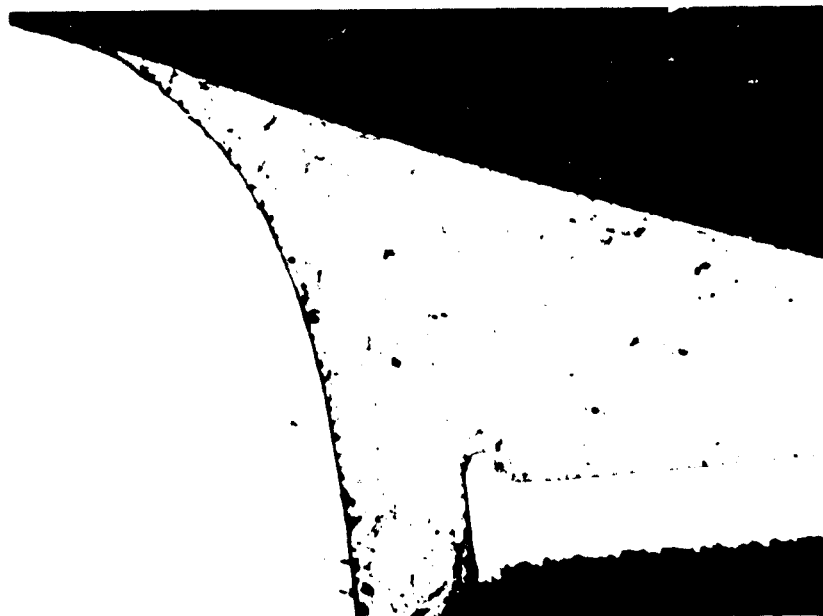
FIGURE 12

GROUP 3: #22 GAUGE TIN-PLATED SOLID ROUND COPPER
CONDUCTOR TO CIRCUIT BOARD, WITH CLINCHED END,
HAND SOLDERED TO NASA SPECIFICATIONS; BEFORE
CUMULATIVE TEST SERIES.



24815

A - 50X

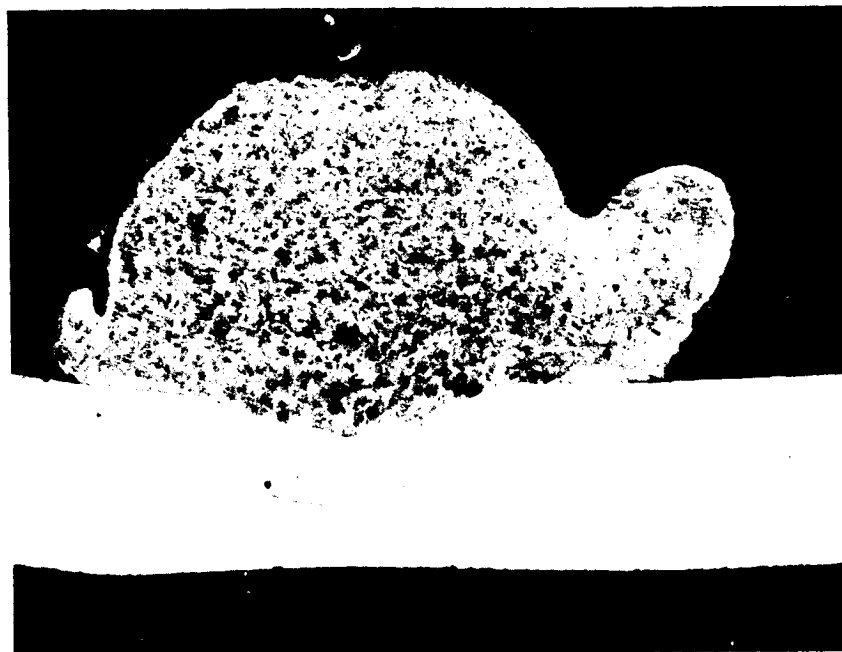


24816

B - 150X

FIGURE 13

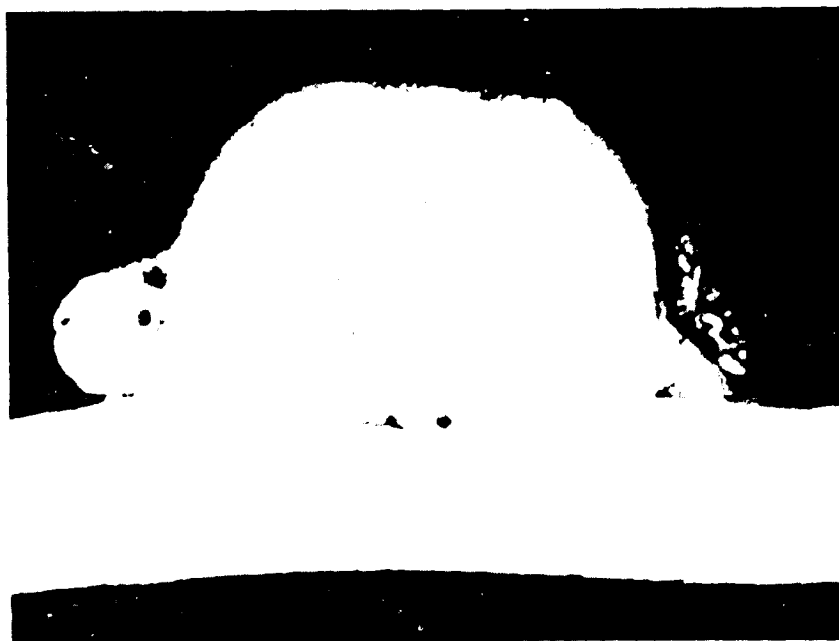
GROUP 3: #22 GAUGE TIN-PLATED SOLID ROUND COPPER
CONDUCTOR TO CIRCUIT BOARD, WITH CLINCHED END,
HAND SOLDERED TO NASA SPECIFICATIONS; AFTER
CUMULATIVE TEST SERIES.



25187

100X

A - BEFORE CUMULATIVE TEST SERIES



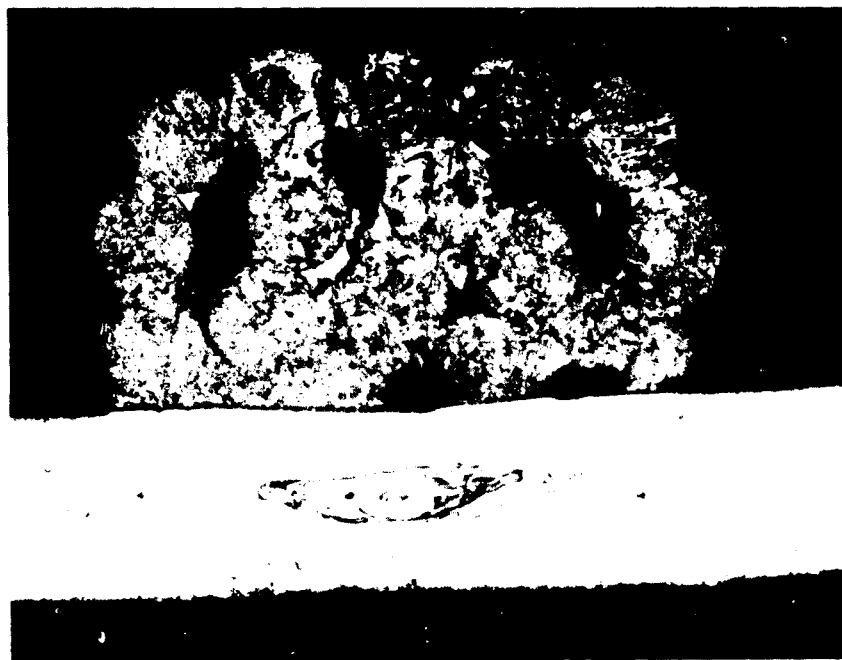
25188

100X

B - AFTER CUMULATIVE TEST SERIES

FIGURE 14

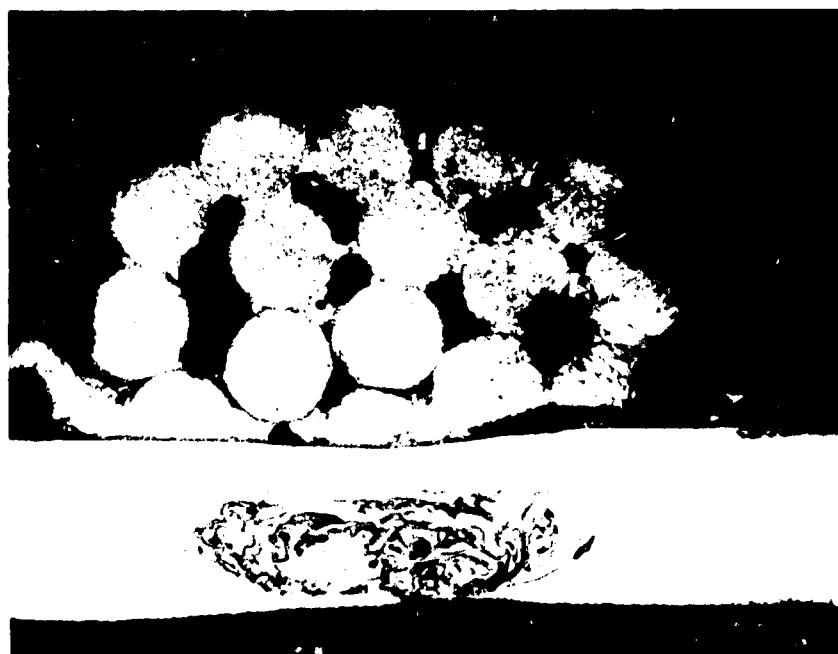
GROUP 5: RESISTANCE WELD .010" x .031"
NICKEL RIBBON TO .025" DIAMETER
TINNED SOLID COPPER



25180

100X

A - BEFORE CUMULATIVE TEST SERIES



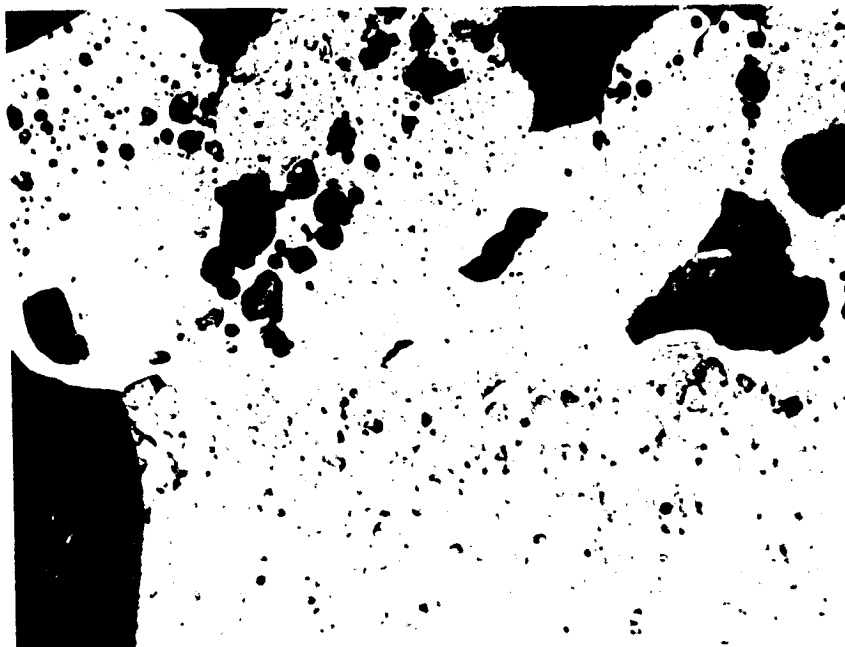
25185

100X

B - AFTER CUMULATIVE TEST SERIES

FIGURE 15

GROUP 6: RESISTANCE WELD .010" x .031"
NICKEL RIBBON TO #22 GAUGE TEFLON-INSULATED
ELECTROPLATE-TINNED 19-STRAND COPPER



100X

A - BEFORE CUMULATIVE TEST SERIES



25181

50X

B - AFTER CUMULATIVE TEST SERIES

FIGURE 16

GROUP 7: PERCUSSIVE ARC WELD #22 GAUGE
19-STRAND COPPER WIRE TO .051" DIAMETER
SOLID ALUMINUM CONDUCTOR (BUTT WELD).



25186

50X

A - BEFORE CUMULATIVE TEST SERIES



25185

50X

B - AFTER CUMULATIVE TEST SERIES

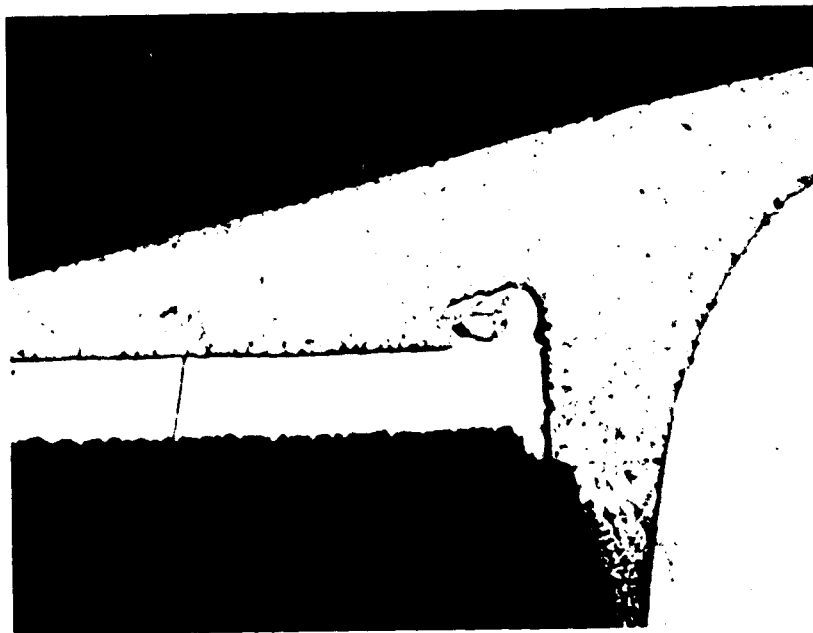
FIGURE 17

GROUP 8: PERCUSSIVE ARC WELD #22 GAUGE
19-STRAND COPPER WIRE TO A GOLD-PLATED
BRASS CONNECTOR PIN.



24805

A - 50X



24806

B - 150X

FIGURE 18

EXPERIMENTAL INDUCTION HEATED JOINT
MADE WITH SOLDER PASTE AND
TIN-PLATED COPPER WIRE

The metallographic sectioning was not a major effort in this program; the intention was to find out whether such sectioning would show up any significant changes in the specimens before and after the test series were run. As it turned out, no "before-and-after" differences were found. Therefore, the photomicrographs are presented in Figures 8 through 18 and brief comments made concerning them. It should be pointed out that because the specimens were sectioned, and after sectioning could not be tested, the "before" and the "after" photomicrographs are not of the same identical specimen but are different specimens from the same test group. Also, since a minimal number of specimens were sectioned, the comments made below are not to be taken as definite conclusions.

Figure 8 was prepared to identify elements of the solder joint configuration and applies to Figures 9-13 and Figure 18. Figures 14-17 are welded specimens.

Figure 9: The dark line between wire and solder in some areas may indicate a discontinuous bond.

Figure 10: Good bonding is indicated in this specimen. Polishing scratches show across the wire; this is because the amount of polishing was intentionally limited to prevent excessive relief between hard and soft components of the termination. (This applies to other sections also.)

Figure 11: This is an enlargement of a portion of the same specimen shown in Figure 10. The three layers, from top to bottom, are: (1) solder, (2) copper pad, and (3) circuit board. The dark particles at the interface of the first and second layers may result from a metallurgical reaction between solder and copper or from trapped flux.

Figure 12: Good bond indication; dark line between solder and copper is due to polishing.

Figure 13: Generally good bond indication; very small areas of possible voids or contamination.

Figure 14: Indication of good bonds except for a few small voids. Nickel ribbons each show an area of localized melting near the mid-section which are not alloying defects.

Figure 15: Good bonding where copper strands contact nickel ribbon; localized melting in mid-section of nickel ribbon; more fusing of copper strands in Figure A than in Figure B.

Figure 16: Appears to be a distinctly different alloy (probably aluminum-rich) at the bond interface. This may or may not weaken the bond and may be a characteristic of percussive arc welding certain material combinations.

Figure 17: Good bonding in central area; voids in weld overflow at periphery of junction do not affect joint strength.

Figure 18: Apparently a very good bond throughout; no evidence of voids or contamination. (This specimen was experimental and not tested.)

G. Analysis of Results

1. Cumulative Test Series

(a) Specimen Groups 1-4 (All soldered)

No failures occurred in any of the soldered specimens. In Group 2 one specimen which had been overheated during preparation resulted in a pad delamination during the vibration test. This is not considered a failure, since the specimen had not been properly prepared.

(b) Specimen Groups 5 and 6 (Resistance Welded)

Twenty specimens out of thirty in group 5 showed cracks in solder plating after the fatigue and bending tests. However, these are not considered failures. One specimen out of thirty in group 6 showed stranded wire separation from the nickel ribbon, which is a failure.

Pull tests on the group 5 specimens showed an average 11% decrease in strength after all other tests had been completed. The group 6 specimens showed an average strength decrease of 4%.

(c) Specimen Groups 7 and 8 (Percussive-arc Welded)

No failures were experienced in these specimens up through vibration testing at the 20 g level. At the 40 g level, nine of the group 7 specimens showed complete failure, with four more showing partial failure. Also at the 40 g level, ten of the group 8 specimens showed complete failure, and sixteen showed breakage of one or more strands.

Even though a large percentage of failures occurred at the 40 g level in these two specimen groups, it should be emphasized that the use of unlike materials (such as copper and aluminum) and the use of stranded wire made these terminations unusual. In applications at g levels up to 20, the capability of the percussive arc welding process to join dissimilar metals and stranded-to-solid wire should be utilized.

(d) Specimen Groups 9 and 10 (Wire Wrap)

These specimen groups showed no failures throughout the test series. They appear to be extremely reliable, as indicated in the state-of-the-art review, and in their wide-spread use in present-day electronics packaging.

2. Life Limit Test Series

None of the specimens in any of the groups in this test series showed failures, nor did the control samples show progressive deterioration. It can be concluded that the terminations evaluated were well suited to the environments in which they were tested, as follows:

Groups 11 and 12 (Soldered) - Thermal cycling

Groups 13 and 14 (Resistance Welded and Percussive-arc Welded) -
Thermal shock

Group 15 (Wire Wrap) - Elevated temperature, high humidity

VIII. TECHNIQUE SELECTIONS

The four termination techniques evaluated and tested all performed very well except for the percussive arc welded specimen failures at the 40 g vibration level. Even those failures may not have occurred had the specimens not been made up from dissimilar metals and not utilized one stranded wire component in each specimen.

The resistance-welded specimens showed only 4% to 10% loss of strength after the complete cumulative test series had been run, and this is not considered serious.

The two remaining terminations, induction soldered and wire-wrap, showed no failures, and therefore either one could have been selected as the candidate for the end-item fabrication and inspection plan. Since the wire-wrap method is so well-known and widely used, it seemed pointless to write another plan for that method. Therefore, the induction soldered method was selected and a fabrication and inspection plan written for it. This plan appears as Appendix E, and is entitled, "Fabrication Guidelines and Inspection Criteria for Induction-Soldered Electrical Terminations."

IX. RECOMMENDATIONS FOR FURTHER INVESTIGATION

A. Induction Soldering

The potential of the induction soldering technique for producing reliable electrical terminations appears very promising on the basis of testing and evaluation carried out in this program. Controlled heat, freedom from contamination, the use of preplaced solder and less dependence on operator judgment are major advantages of the process.

Because of the many other techniques reviewed and investigated in this program, induction soldering received only a portion of the effort expended. Further investigation should be carried out to refine the technique, examine other termination configurations, develop induction coil configurations, evaluate further the use of solder pastes and creams and optimize generator size with respect to power and frequencies required.

B. Explosive Bonding

Explosive bonding has a potential application for use in making electrical terminations, particularly in joining dissimilar metals. The sprayed-on explosive used in this program apparently did not allow the deposition of sufficient explosive to produce a satisfactory bond in most cases. Further work with an explosive of paste consistency should overcome the problem.

APPENDIX A
SELECTED BIBLIOGRAPHY WITH ABSTRACTS

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WELD

Mehta, H. I., "Technique for Resistance Brazing of Thin Copper Conductors," Welding Journal, October 1973, pp. 652-657.

Article concerns primarily the problem of resistance brazing of copper ribbon 3 to 6 mils thick.

"This article tells how a method was developed for producing rather complex assemblies of thin copper conductors. Resistance brazing was the inevitable choice for joining the 64 electrical connections required for each solenoid sleeve assembly. The conductors were made of DHP (deoxidized, high residual phosphorus) copper less than 0.003 in. thick.

Emphasis is placed on the selection and evaluation of (1) the brazing filler metal as an alloy and as cladding for the one conductor common to all joints, (2) the equipment used, (3) the optimization of the process variables and (4) the simple visual examination used for testing joint reliability.

Although the methods discussed were used to develop a satisfactory manufacturing procedure for a special application, the approach is fundamental and intended to inform the general reader. Specialists, however, may find the work in optimizing parameters an aid in dealing with other complex joining problems."

Purpose

"This paper will present the development of the resistance brazing application used for joining thin copper straps. The author intends to demonstrate the methods used for determining the process parameters and nondestructive testing technique. First, the factors considered during the development of the joint design and brazing process are described. Experimental procedures, results, and their significance are discussed later, in the description of the brazing process and testing."

Conclusions

A typical brazing application for joining thin straps of copper to a copper ribbon is discussed. For this application, the resistance brazing method was proved to be the most reliable and economical process. The use of a bimetallic clad brazing ribbon

having a copper core sandwiched between claddings of a brazing filler metal of Ag-Cu-P alloy was appropriate for the given joint. This brazing process eliminated a need for separate filler metal, and demonstrated many other advantages related to physical and metallurgical characteristics.

It was concluded from the experiments that inferior brazed joints could be avoided by controlling all process variables, electrode shapes, and conditions of the base metal and clad brazing ribbon. Values of the process and design variables were established for the production application. Moreover, visually checking fillets on the joint was the most economical, practical, and reliable method of process checking.

Finally, it is anticipated that the material presented here may help the engineer in evaluating other complicated metals joining applications.

Green, Richard G., "Welding With Electrons," *Automation* 19, No. 9, September 1972, pp. 71-76.

Description of Electron Beam welding in both "hard" and "soft" as well as no vacuum.

No application due to x-ray hazards and sophistication required.

Seaman, Frederic D., "Solving EB Welding's Vacuum-Work Handling Equation," *Metal Progress* 101, No. 6, June 1972, pp. 75, 76 & 78.

Article discusses optimization of Electron Beam welding system.

Walther, Robert H., "Wire Bonds: Determining a Meaningful Value for Strength," *Solid State Technology* 15, No. 8, August 1972, pp. 41-42.

A method for making wire bond strength measurements more meaningful is described. Rather than relying on simple dynamometer readings, this method takes wire loop geometry into account when measuring and reporting strength values. By considering the mechanical forces involved, dynamometer readings are easily converted to tension actually placed on the wire bond. Aside from a basic analysis, a workable table and explanation is provided making this method usable in the production mode.

"Light and Sound are Used to Monitor Ultrasonic Welding at IBM,"
Welding Journal, April 1973, p. 252.

Article describes manner in which reflected light and sound pressure are used to monitor motion of ultrasonic bonding tips.

"Destructive Testing" (of welds), Welding Data Book, 1974/75.

Article describes peel test, impact test, and twist testing. Micro-etch test and macro-etch test descriptions are also given.

"Current Activities of the AWS Committee on Brazing and Soldering,"
Welding Journal, October 1973, pp. 177-178.

Article describes briefly what the title denotes. Of interest may be the "Revised Soldering Manual" to be published "some-time" in 1974.

Warner, Allan, "Tang Termination of Aluminum Wire," New Horizons for Interconnection Technology, Electronic Connector Study Group, Inc., 1972.

Description of patent applied for technique for fusing or resistance welding wire terminations, made of soft alloys such as aluminum.

Warner, Allan, "Tang Termination of Copper Conductors," Conference on Copper, Joyal Products, Inc., 1972.

Similar description of "Tang Termination" as in above, but addressed primarily to copper.

"Terminal Crimping and Fusing Machine," Joyal Mfg. Corp., 1233 West St. George Ave., Linden, N.J. 07036, 1967.

Catalog description of manufacture product. Directed primarily toward production facilities.

Dybas, R. J., "Arc Welding Process for Making Electrical Connections in Small Aluminum Wire," Alcoa Process Development Laboratories, New Kensington, PA., July 1, 1961.

Terrill, James R., and H. H. Caldwell, Jr., "New Processes for Joining Aluminum in Transformers," AIEE Conference Paper, January/February 1962.

Summary

New and improved joining methods, coupled with substantial initial conductor cost savings, now permit more economical use of aluminum transformers. With the Alcoa R-260 Process, aluminum rectangular magnet wire and bus can be carbon block brazed more readily than copper. Capacitor Discharge Welding is particularly useful for joining copper lead wires to aluminum windings in transformers and small motors. Metal Inert Gas Spot Welding provides a simple means of terminating magnet wire and strip windings to aluminum bus.

NASA Technical Note No. NASA TN D-6236, dated March 1971, "Parallel Gap Welding Kovar Ribbons to Copper Conductor Printed Wiring Boards."

This investigation showed that parallel gap welding of Kovar Ribbons to copper conductor printed wiring boards is feasible. Success is dependent on the type of plating or coating over the copper conductors, but is not particularly dependent on the ribbon and conductor size combinations. Optimum combinations for welding are gold-plated Kovar ribbons to solder coated or plated (500 to 1,000 micro-inches thick) copper conductors.

Contract No. AT(29-1)-613 USAEC, dated May 1971, "Percussive-Arc Versus Pulse-Arc Welding", Bendix Corp., Kansas City Division.

The characteristics of both percussive-arc and pulse-arc welding were evaluated. Extensive tests revealed that the most significant difference between the two processes is that percussive-arc welding permits aluminum to be joined to other metals, whereas the pulse-arc process is suitable for joining aluminum wires to aluminum only. The processes have approximately equal capabilities in other areas. Both are suitable for joining many different metals in many metal-to-metal combinations which do not involve brass or other high-zinc content alloys. Securing the joints before welding is not required with the percussive-arc process, whereas pulse-arc welding requires that the wires or other piece-parts be staked or otherwise secured before they are welded.

Report No. FTD-NT-24-2111-71, dated June 1972, "The Development of the Equipment and Technique for Welding the Leads of Integrated Circuits to PC Boards".

This document is a translation from the Russian by the Air Force Systems Command. A circuit is described where the condenser welding equipment is dynamically controlled from the voltage on the electrodes, and an increase or decrease in the cross-section of the elements to be welded is automatically compensated by an increase or decrease in the welding current. This technique was found satisfactory for nickel plated copper circuit boards but was not satisfactory for ordinary copper clad circuit boards.

Contract No. NAS 7-100, Technical Memorandum 33-544, "Development of Automatic Through-Insulation Welding for Microelectronic Connections", Jet Propulsion Laboratory, December 1972.

This report describes an engineering model of equipment with the capability to automatically route, remove insulation from, and weld small-diameter solid conductor wire. Whereas early work in the use of welded magnet wire interconnections was concentrated on opposed electrode systems and generally used heat to melt the wire insulation, the present method is based on a concentric electrode system (U.S. patent 3,596,044) and a wire feed system (Patent on Wire Feed System is pending) which splits the insulation by application of pressure prior to welding. It was concluded that the process is feasible for the interconnection of complex miniature electronic assemblies.

Contract No. AT(29-1)-613 U.S.A.E.C., "Strength Measurements on Transistor Header Lead Welds", dated March 1973, Bendix Corp., Kansas City, Missouri.

This report deals only with the manufacturing processes involving butt welding of leads on transistor headers. Strength test procedures to evaluate lots for acceptance tests are described.

CONDUCTIVE ADHESIVES

"Electrically Conductive Materials and Components," Teknit Design Guide, Technical Wire Products, Inc., 129 Dermody St., Cranford, N.J. 07016, 1974.

72-00009 - Epoxy Solder, Conductive, Rigid Cure, Operates Up to 260°F, Two-Component

This system is designed primarily for joining where the bond is expected to provide high conductivity at high operating temperatures up to 260°F.

Pure silver assures stability, unlike epoxy cements employing copper, silver-copper or carbon fillers, which lose conductivity at elevated temperatures. Highly moisture resistant, the two components are easily mixed in equal volumes or weights to produce a creamy paste. Application may be made with usual dispensing techniques, such as syringe or pressure caulking gun.

Applications include preparing conductive surfaces, repair of printed circuits, bonding waveguide sections, replacement of fired-on coatings, and making high-reliability electrical connections.

Machine Design, Fastening and Joining Issue 45, No. 28, Sec. 11, pp 182-188; 22 Nov. 1973.

The article considers the selection and application of various types of adhesives, whose prime purpose is mechanical fastening.

Certain other uses for adhesives of the "doped" variety are electrical and/or thermal conductors, prevention of electromechanical corrosion between dissimilar metals and provision for resistance to vibration fatigue.

The article stresses the importance of the mechanical properties of adhesives to meet their intended uses; the preparation and design of mating surfaces to be joined and their individual properties.

Types of adhesives, with their general properties are given in a table categorized by adhesive types, general descriptions of which are given in the text. A list of manufacturers is also given.

No specific data is available for direct application. However, the article presents source material from which to obtain further data for possible application.

"Replacement for Gold Epoxy," Solid State Technology, Jan. 1974, p. 74.

Short description of Ablebond 66-1, a one component non-migrating conductive epoxy costing approximately 1/5 the cost of gold-filled types. Vol. resistivity $.002\Omega/\text{cm}$. Shear strength 1600 psi.

Although prime application is for microelectronics, the product may have possible application for non-soldered electrical connections for small wires.

Anhalt, J. and D. Goodman, "Solderless and Nonmetallic Contacts", Electronic Products 16, No. 2, 20 May 1974, pp 40-43.

Comments concerning interconnection of IC's with printed wiring boards and the problem of installation with "removal for repair" in mind.

Article describes problem and presents some solutions by ITT Cannon for whom the author works.

Also discussed are the various materials i.e. phosphor bronze, beryllium copper, etc. used for contact material with their advantages and disadvantages discussed.

Laurier Associates, Inc., Catalog fly sheets, 550 Newton Rd., Littleton, Massachusetts 01460. (No Date).

Describes line of equipment for dispensing epoxies, etc. for micro-bonding conductive solder-epoxy "Able Bond" and "Able Stik" conductive epoxies specifications given.

"ECCOAMP" Electrically Conductive Adhesives Coatings & Casting Resins, Emerson & Cuming, Inc., Canton, Massachusetts, (No Date).

Literature describing products.

"Electrically Conductive, Silver Filled, Epoxy Film Adhesive" Able Film ECF 535, Ablestik Laboratories, 833 West 182nd St., Gardena, California 90248, (No Date).

Preformed material up to 5 mils thick. Primarily useful for micro electronics.

Conap, Inc., Technical Information: (Electrical) Conductive Epoxies, Bulletin A-108, 184 E. Union St., Alegany, New York 14706, (No Date).

Various (5 ea.) conductive epoxies used for conductive adhesives, sealants and silk-screen patterns.

Dexter Corporation, Hysol Division: Electrical Insulation Materials, Olean, New York 14760, (No Date).

Several conductive epoxy cement specifications are given, some of which may be useful for evaluation as stress relief and contact build-up or repair.

Metachem Resins Corporation, Mereco Products Information, 530 Wellington Avenue, Cranston, Rhode Island 02910, (No Date).

"Conductive Silver Compositions", Dupont Electronic Products, Wilmington, Delaware 19898, April 1973.

Conductive silver compositions various (numerous) epoxy blend formulations, some of which can be directly soldered to are given.

SOLDER

"Can the U.S. Afford the 'Cosmetic Look' in Soldered Joints?",
Assembly Engineering, Hitchcock Publishing Company, Parts
1 & 2, Oct./Nov. 1973.

Article concerns itself with "cosmetic look" versus functional quality of solder joints. Of interest are several paragraph headings among which are the following:

1. FIT defines Hi Rel. Objectives
2. Visual inspection is ineffective
3. All leads are solderable
4. Solder wicking no problem
5. Joints look like gems (radiography proves differently)
6. Joint variations analyzed
7. Single side PC joints are stronger
8. "Looks" and function are unrelated

Thwaites, C. J. (Tin Res. Inst., Perivale, Greenford, England),
"The attainment of reliability in modern soldering techniques
for electronic assemblies." International Metallurgical Reviews,
(GB), Vol. 17, p. 149-74, September 1972.

The advantages to be gained from printed-circuit techniques and the use of mass-soldering methods to make several hundred soldered connections at once may be nullified even if only a few joints are faulty and subsequently have to be located and repaired by hand. To obviate such occurrences it is essential that the correct surface finishes be chosen to obtain good solderability, especially in the more sophisticated computer and aerospace fields. With the three factors of correct surface preparation or choice of surface coatings, assured solderability by prior testing, and use of the correct flux and solder alloy, the soldering operation itself provides little difficulty, and there is, in general, a considerable tolerance in the parameters such as time and temperature. It follows that the majority of commercial difficulties arise, not from faults in the soldering operation, the solder, or the flux but from the presoldering stages of preparation for soldering, and the importance of considering these factors at an early stage in the design of equipment cannot be over-emphasized.
(131 refs.)

Studnick, W. R. (Western Electric, Hawthorne, USA), "A transmissive fixture for infrared soldering of round conductors to printed wiring circuitry." Western Electric Eng. (USA) 16, No. 4, P. 27-8, October 1972.

A contoured infrared transmissive fixture has been designed for use in infrared soldering of multiple, simultaneous connections of round conductors to printed circuit terminal strips. The fixture's design enables reflowed solder to be drawn up and over each of the round wires, while infrared energy volatilizes the conductor insulation within the section of wire to be soldered. (3 refs.)

Faulstich, K. (Tech. Univ. Dresden, Germany), "Nondestructive testing of soldered joints." Feingeraete Tech. (Germany) 22, No. 1, P. 13-14, January 1973. (In German)

About 15% of the failures of electronic equipment are due to defective soldered joints. Ultrasound, X-rays, ultraviolet light, radioactive isotopes, infrared radiation emitted by the heated joint, and measurements of the noise voltage, distortion voltage, and contact resistance are used for the testing of these joints, and the various methods are briefly outlined. The visual examination under ultraviolet light takes much time. The addition of radioactive isotopes to the flux has certain inherent dangers. None of these testing methods is suitable for industrial use, but they are convenient for use in the laboratory. (7 refs.)

Electrovert, Inc., Catalog fly sheets, 86 Hartford Avenue, Mount Vernon, New York 10553.

Electrovert, Inc. catalog material describing product line of wavesoldering systems, ultrasonic cleaning equipment, degreasing equipment and other production line equipment.

Manko, Howard H., "Solders and Soldering," McGraw-Hill, 1964.

MECHANICAL

Dinger, Leon, "All About Crimp-Type Terminals," Electro Procurement 12, No. 10, October 1972, pp. 32-37.

Davies, D. G., "Micro-Mechanisms of Solderless Wrapped Joint Formation," IEEE Trans. PHP-8, No. 1, March 1972, pp. 48-62.

Abstract

The manner in which the various surfaces interact during wire wrapping, and the structure at the contact sites in the completed joint, have received only cursory attention. This paper describes an investigation designed to elucidate these phenomena using metallographic, scanning electron microscopic and electron microprobe analysis techniques.

Series of joints made under known sets of parameters are examined to provide data on post-into-wire penetration, metal displacement and contact area for different wrapping loads. It is shown that at high wrapping loads, the wrapping system tends towards an unstable state analogous to the onset of necking in tensile strain.

Scanning electron microscopy and microprobe analysis of the surfaces of dismantled joints are used to show irrefutably that a substantial amount of cold welding occurs during the wrapping sequence. The transfer of metal from wire to post, and vice versa, by a welding-followed-by-fracutre mechanism is clearly demonstrated for a variety of materials. This contradicts currently held views on the subject and indicates additional guide-lines for wrapped joint design. Above all, it is evident that the presence, and subsequent behaviour during wrapping, of thin plated layers on wire and terminal post cannot be ignored, and indeed plays a significant role in joint formation.

A theoretical model is used to derive variation in contact area with wire diameter for typical joints. A change in wire diameter from 0.050 cm to a micro-wrap dimension of 0.017 cm is seen to reduce the area of individual contact sites by an order of magnitude, i.e. to approximately 10^{-4} cm². It is argued that as the contact areas of wrapped joints tend towards this microscopic level, the phenomena discussed under the heading of "micro-mechanisms of wrapped joint formation" assume great significance.

Ginsberg, Gerald L., "Course: Packaging With ICs Part Four,"
The Electronic Engineer 31, No. 6, June 1972, pp. 27, 29,
31, 41, 42, 46, 47, 49-53.

A generous though general treatise on the subject of wire wraps without solder. Chapter titles are self explanatory and content covers each respectively with some overlap.

Page 41 (Chapter 3) states the solderless wrap to be considered the most reliable of all types and is backed in this conclusion by Mil Hbk-217. However, the actual wrap as discussed in Chapter 5 is critical to its reliability. Several undersirable examples are illustrated and compared with the acceptable.

Pesek, M. (Zse, Prague, Czechoslovakia), "Termination of conductors." Elektrotechnik (Czechoslovakia) 28, No. 1, 1973, pp. 2-7. (In Czech)

Various connections which can be disconnected without or without tools are described. Some disadvantages of soldering in manufacturing of reliable connectors are discussed. A technique of pressing on various elements is dealt with in detail. It is stressed that the pressure during the pressing-on process must be kept to a certain level. Effects of its variation on the quality of connections are discussed. Various types of connectors using this method are described, e.g. pin connector, open and closed cable sockets, etc. (0 refs.)

OK Machine Tool Corp., Catalog #36, March 1974.

Descriptive literature describing wire-wrap tool and hardware manufactured by OK.

Application for wire-wrap methods and hardware.

MISCELLANEOUS

"Conductive Elastomer Connectors," Electromechanical Design 18,
No. 4, April 1974, pp. 8 & 9.

Article describes a conductive elastomer connector invented by Chomerics, Inc., Woburn Ma. This is pressure-sensitive.

Material described as a "solid state connector" is made conductive on a go or no-go basis depending upon pressure applied to material. Pressure points also determining the conducting paths within the material. The article states that resistances can approach 0.5 ohm (for contacts up to 2 mils thick). The material requires constant pressure for conduction and loading springs or equivalent components must be utilized.

There appears to be no direct application in the area of this project's concern, due primarily to the high resistance (relative) of the connection under "ideal" conditions as the specifications show.

SPECIFICATIONS FOR INTERCONNECTORS*

Specific Gravity	3.1
Volume Resistivity	0.9 Ω -cm @ 100 psi
Compression Set	Less than 2% ASTM D-3950
Tensile Strength	400 psi @ 150% Elongation ASTM D-412
Tear Strength	50 lb/in ASTM D-624
Abrasion Resistance	175 (Taber Wear Index CS-20)(500 gm 100 cycles)
Current Density	150 A/in ² @ 100 psi
Moisture Absorption	0.04% @ 24 hr. 0.25% max. @ Room Temp.
Durometer	58 ASTM D-6376
Aging	Greater than 4 months @ 125°C (257°F) with no change (> 20 yrs. @ R. T.)
Deformation/Load	4.4% compression/100 psi load up to 1000 psi

*All tests on 20 mil sheet.

"Explosive Bonding of Electrical Interconnections," IEEE Trans. PHP-8,
September 1972, pp. 27-32.

Abstract

Primary explosive systems, as described, are now being used as a safe and predictable energy source to bond metals on a size scale comparable to microcircuit electrical interconnections.

Basic primary explosive reaction characteristics have been analyzed and related to effective bond mechanisms for solid-phase explosive bonding of several metal combinations. Methods and materials systems were devised to accurately deposit a specific quantity and configuration of explosive with predetermined reaction characteristics. This has permitted a significant advance in use of explosive bonding on a microscale. The theoretical explosive bonding mechanism is supported by experimental data. Included in considerations are surface jetting characteristics which influence interface structures and are responsible for removing surface oxides and contaminants.

A large variety of similar and dissimilar metal pairs was joined reliably and repeatedly with bond strengths greater than those of the parent metals. Explosive bonding advantages and disadvantages considering materials and bonding equipment requirements are cited.

Bement, L. J., "Small Scale Explosive Welding of Aluminum," NASA Tech Brief B72-10002, 1972.

"Application of New Methods and Techniques for Failure Analysis," Solid State Technology 17, No. 1, January 1974, pp. 62-63.

This article presents a summary of papers on new methods and techniques for failure analysis presented at the 11th Annual Reliability Physics Symposium. Las Vegas, Nevada, April 3-5, 1973. Table I is meant to define problem areas, indicate the advantages of the currently presented method over previous methods, where they exist, and the actual reference to the paper in the symposium proceedings. For those having similar problems, it is suggested that the entire text be consulted. The order of presentation in Table I follows the symposium proceedings; however, not all papers are summarized, only those presenting what are believed to be new methods or techniques.

In addition to the above new methods, tutorial papers were presented on failure analysis tools having wide application in the physics of failure analysis and research. Table II lists the instrument or tool being described, a brief description of the material presented and the reference in the proceedings.

Stepien, S., "Electrical connections in electronic equipment." *Przeegl. Telekomun. (Poland)* 45, No. 12, December 1972 (In Polish), pp. 406-12.

General problems of electrical connections and links in electronic equipment are discussed. The character of the connection itself, its quality and reliability as well as selection criteria are outlined. The classification of connections is mentioned and wire parameters are given. (5 refs.)

Schafft, H. A., "Testing and fabrication of wire-bond electrical connections: A comprehensive survey." Report NBS TN 726, Nat. Bur. Stand., Washington, D.C., USA, September 1972, 129 pp.

The fabrication and testing of wire-bond electrical connections used in integrated circuits, hybrid circuits, and low-power discrete semiconductor devices are surveyed comprehensively. The survey is generally restricted to wire-bond electrical connections where the wire diameter is less than 2 mils and where the wire is bonded either by thermosompressive or ultrasonic means. Under the general heading of fabrication, the essential features of the thermocompression and ultrasonic bonding processes, the fabrication procedures, and the characteristics of the constituent materials of the wire bond pertinent to high reliability are surveyed. Also included is a review of the interaction of gold and aluminum as one of the primary failure mechanisms in wire bonds.

Stepien, S., "Wire-wrap and pressure connectors." *Telekomun (Poland)* 46, February 1973 (In Polish), p. 2, pp. 63-70.

The pressure, wire-wrap, crimping and termipoint connections are described as applied in electronic equipment. Design and technological aspects are considered. The operation features and the influence of various factors on technical parameters and reliability are examined. (11 refs.)

Stepien, S., "Miniature connectors for electronic equipment."
Wiad. Telekomun (Poland) 13, No. 1, 1973 (In Polish)
pp. 16-28.

The author surveys the characteristics of various types of commercially available connectors: contact resistance and its components, loading capability, contact force, reliability, life, possibility of repairs, universality, and cost. Selection criteria for particular applications, contact material, wiring methods and miniaturization problems are also discussed. (0 refs.)

Selby, R. P., "Interconnection Techniques," Electronic Display and Data Systems: Constructional Practice, C. J. Richards (Ed.), Maidenhead, Berks, England: McGraw-Hill, 1973, pp. 173-229.

Deals with discrete wire interconnections, interconnecting cable and wire identification, cable and wire supports, termination panels (12 refs.)

Schafft, Harry A., "Wire-bond Electrical Connections: Testing, Fabrication and Degradation - A Bibliography 1957-1971," NBS Technical Note 593, Solid State Technology 15, No. 8, Aug. 1972.

Includes entries dealing with wire-bond type electrical connections used in microelectronics and low-power discrete and hybrid devices where wire diameter is less than 50 μm (2 mils) and where bond is made by either thermocompressive or ultrasonic means. More than 245 published articles, U.S. Government reports, U.S. patents, and conference presentations related to testing, fabrication, and degradation of these wire bonds are compiled. The search for entries (a source list is provided) concentrated on publications which appeared in the period describe subject matter in each entry; bibliographical list is indexed according to author and subject matter (key words).

Anaconda Coppermetal Electrical Conductors, Anaconda American Brass Company, Waterbury, Conn. 06720, C-25 Eleventh Edition, 1971.

A general - yet comprehensive - work describing the attributes of copper (electrically). Definite application to project.

Markal Company, 270 N. Washtenaw Ave., Chicago, Ill. 60612,

Temperature indicating material described.

"Aluminum Joining Processes for the Electrical Industry," Aluminum Company of America, 1969.

Descriptive catalog outlining various methods of joining aluminum wire, with recommended methods for various connections.

"Precision Welding and Reflow Soldering Equipment," Unitek Corp. Equipment Division, 1820 South Myrtle, Monrovia, California, Cat. #111, (No Date). - Also numerous product bulletins.

Catalog describes company equipment for use in:

1. Capacitor Discharge Welding
2. AC Welding
3. AC Reflow Soldering

Contract NAS 2-4166, dated March 1968, "Study and Development of Nondestructive Weld Inspection Techniques," Walter V. Sterling, Incorporated.

This program had three major tasks. The first was a study of the existing literature relating to microwelding operation and evaluation techniques, augmented by visits to Aerospace Organizations interested in and using wire-welding for electronic assembly. The second task was concerned with the selection of weld attributes for NDT instrumentation, and the development of the applicable instrumentation. The third task area covered all aspects of evaluating the effectiveness of the NDT techniques that were developed. Six techniques were selected for detailed consideration for an NDT system to evaluate weld quality. These six were eddy current measurement, weld joint resistance measurement, sonic and ultrasonic measurement, weld voltage pulse monitoring, infrared radiation measurement, and setdown measurements. The last three techniques were selected and used in combination to form an NDT system with the ability to provide consistent and valid indications of weld quality. It was clearly established that weld quality could be evaluated on the production line with such a combination instrument. The details involving circuitry and mechanical arrangements for this instrument were not given.

NASA Technical Note NASA TN D-5304, dated August 1969, Goddard Space Flight Center. "Development of a Weld Quality Monitor."

A realization that the visual external inspection of a finished weld joint cannot be expected to yield reliable judgement concerning the integrity of the joint, led to a search for parameters which could be measured directly and that were indicative of quality. The setdown or imbedment defined as the reduction in thickness of the joint members as a result of welding, was found to be such a parameter. A model system utilizing a linear voltage displacement transducer to measure setdown was constructed and evaluated. Correlation between setdown and weld quality was found. A go/no-go logic was incorporated into the system to lock out the welder if setdown deviated outside prescribed limits. A contract was negotiated with Neotec Corporation to modify and improve the system and to fabricate a working model.

Contract No. NAS2-4166, dated March 1970, "Nondestructive Testing of Interconnections and Microjoints", Walter V. Sterling, Inc.

This a continuation of previous work by this company. This report contains a detailed description and drawings of the NDT prototype weld system. In the present report, a total of 45,000 individual welds were tested and evaluated. The conclusion reached was that the NDT system was quite effective in indicating potentially weak weld joints. The system would indicate weak joints which were not detectable by visual inspection. The system also served as a prime indicator of operator errors. The report also discussed possible applications of nondestructive testing to microjoints used in integrated circuit assemblies.

Contract No. NAS5-21395, dated November 1971, "Study Program of NASA/GSFC Weld Quality Monitor System", Martin Marietta Corp.

This program seems to be directed toward the evaluation of the weld quality monitor developed at Goddard Space Flight Center and described in report TN D-5304. The conclusions reached were that the weld quality monitor system can distinguish between low strength and sound welds, but will require updating of circuitry and readout components to ready it for production.

Contract No. AT(29-1)-613 U.S.A.E.C., "Nondestructive Testing of Percussive Arc Welds" dated July 1973, Bendix Corp., Kansas City Division.

This report discusses several techniques to nondestructively test percussive arc welds. Techniques investigated included infrared measurements of weld thermal gradients, liquid crystals, thermoelectric characteristics, in-process measurement of arc temperature, heat conduction measurements, microvolt measurements, acoustic emission detection, ultrasonic testing.

"Handbook of Wiring, Cabling and Interconnecting for Electronics,"
Charles A. Harper, Editor-in-Chief, McGraw-Hill, 1972.

- a. Chapter 1 - Soldered, Welded and Mechanical Terminating Systems, Keister and Varga.
- b. Chapter 12 - Microelectronic Interconnection Systems, McCormick.

"Electronic Display and Data Systems: Constructional Practice,"
C. J. Richards, Editor, McGraw-Hill, 1973.

- a. Chapter 6 - Interconnection Techniques, Selby.

Fogiel, Mac, "Microelectronics: Principles, Design Techniques,
Fabrication Processes," Research and Education Assn., 1968.

APPENDIX B
PATENTS ON ELECTRICAL CONNECTIONS AND TERMINATIONS

PATENTS ON ELECTRICAL CONNECTIONS AND TERMINATIONS

2,251,709	Klein	Method of Connecting Wires to Sleeves
2,858,516	Lindahl et al	Connector for Electrical Conductors
2,859,424	Berndt	Connector for Stranded Cables
2,958,929	Vineberg et al	Flush Ferrule Conductor Joint
3,065,532	Sachse	Method of Making Metallic Joints
3,100,830	Hagner	Apparatus for Percussively Welding Electrical Components to Circuit Boards
3,132,239	Schollhammer	Electron Beam Compression Welding
3,138,658	Weimer, Jr.	Electrical Connector for Very Thin Sheet Metal Member
3,177,458	Buchanan	Connector System and Method of Making Wire Connections
3,201,852	Yonkers	Method of Soldering
3,252,203	Alberts et al	Welding Process
3,315,133	Walker	Integrated Circuit Interconnect and Method
3,324,231	Miller	Electrical Connection of Metal Sheathed Cables
3,375,343	Du Pre	Electron Discharge Device Assembly Method
3,422,529	Nuding	Method of Making a Superconductive Joint
3,439,395	Claypoole et al	Method of Attaching Leads to Electrical Components
3,443,256	Holton et al	Electromagnetic Device with Terminal Connections and the Method of Making the Connections
3,489,879	Salzer	Thermoswaging Method for Fixing Pins to Ceramic Wafers
3,495,207	Keller et al	Wire Terminals
3,513,249	James	Explosion Connector with Improved Insulating Means
3,520,055	Jannett	Method for Holding Workpieces for Radiant Energy Bonding

PATENTS ON ELECTRICAL CONNECTIONS AND TERMINATIONS (Cont)

3,590,140	Robb et al	Cable-Insulation-Piercing Crimp Tool, Terminal, and Method of Forming
3,622,685	Crowl	Flexible Electric Connector
3,626,433	Schultz	Method for Interconnecting Plated Wires Used in Magnetic Memory Frames
3,626,590	Miller	Methods and Apparatus for Accomplishing Electrical Wiring
3,639,978	Schurman	Method for Making Flexible Electrical Connections
3,641,660	Adams et al	The Method of Ball Bonding with an Automatic Semiconductor Bonding Machine
3,643,321	Field et al	Methods and Apparatus for Tailless Wire Bonding
3,643,327	Jackson	Method of Making a Series of Electrical Connections
3,663,741	Cushman	Terminal and Wrapped Wire Assembly
3,673,314	Zimmermann et al	Cable Connectors
3,678,176	Reimer	Wire Clamp Terminal Clip of the Flanged Tubular Type
3,688,397	Cleaver et al	Method of Jointing and Terminating Electric Cables
3,691,656	Mochizuki et al	Method of Making a Joint
3,699,640	Cranston et al	Compliant Bonding
3,702,500	Gorinas et al	Method for Obtaining Electrical Connections, Especially for Microcircuits
3,708,878	Mann, Sr. et al	Wire Connection, Method, and Connecting Apparatus
3,723,590	Anderson	Method for Terminating an Electrical Component
3,740,839	Otte et al	Cryogenic Connection Method and Means
3,751,624	Banks et al	Butt Brazing Apparatus and Method

PATENTS ON ELECTRICAL CONNECTIONS AND TERMINATIONS (Cont)

3,751,801	Praeger et al	Method and Apparatus for Terminating Electrical Ribbon Cable
3,767,101	Genrich	Pulse Vibrator for Thermocompression Bonding
3,795,786	Chanowitz	Method of Tungsten Inert Gas Welding Electronic Components and Burning Away Contaminants
3,797,100	Browne	Soldering Method and Apparatus for Ceramic Circuits
3,806,019	Diepeveen	Wire Bonding Apparatus
3,871,071	Luongo	Method of Forming an Electrical Connection
3,889,364	Krueger	Method of Making Soldered Electrical Connections
26,685	Broske	Explosively-formed Electrical Connection

APPENDIX C
FEASIBILITY OF WELDING ELECTRICAL CONNECTIONS
USING A SPRAYED EXPLOSIVE

FEASIBILITY OF WELDING ELECTRICAL CONNECTIONS USING A SPRAYED EXPLOSIVE

by

E. D. Esparza

October 11, 1974

I. Introduction

A quick-look experimental study was conducted by the Department of Mechanical Sciences to determine the feasibility of using sprayed silver acetylide-silver nitrate (SASN) explosive to weld electrical connections on a size scale comparable to microcircuits. The use of explosives to weld or bond one metal to another is not a new phenomenon.⁽¹⁾ However, until the last 2 years, explosive welding of metals has been used exclusively for joining large metal pieceparts.⁽²⁾

Explosive bonding is in fact a special case of impact bonding in which the energy source is a detonating explosive. In impact bonding, any method which can generate the required relative velocity will serve the purpose. The term explosive welding may at times be confusing in the sense that it implies fusion (melting) bonding. Although fusion can occur in an explosively bonded joint, unless it is controlled, it can also lead to undesirable properties of the bond.⁽³⁾

There are basically three types of metallurgical bonds that result from high velocity collisions produced by the explosive:⁽²⁾

- (1) A straight solid-phase metal-to-metal bond,
- (2) A molten layer between the metals,
- (3) A wave or ripple pattern which is basically a solid-phase bond that may exhibit small molten zones.

The third type of bond⁽³⁾ is usually preferred in commercial cladding applications for its physical strength. This wavy interface, unique to explosive bonding, is a function of the materials being joined and the velocity of the impinging metals.

II. Development of SASN Sprayed Explosive

Several years ago, staff members of SwRI began investigations of some unusual applications in explosive technology. The original purpose of these

investigations was to develop a technique for impulsive loading of structures and materials. Since one of the requirements in impulsive loading is to achieve a very short loading time compared to characteristic response times of the test structures, light initiation of the explosive was very desirable.

The first work on light initiation of explosives was motivated by studies of the physical chemistry of explosion processes, rather than by use of explosives for impulsive loading. In 1951, Eggert⁽⁴⁾ was apparently the first to show that some sensitive explosives could be caused to detonate by exposure of light flash.⁽⁵⁾ He and his co-workers have identified at least sixteen solid compounds which can be initiated by light flash from gas-discharge tubes, and have arranged them in the order of their sensitivity of such initiation.^(6,7) The compounds are all classified as primary explosives, and the majority are inorganic, heavy metal salts. Eggert's list⁽⁷⁾ includes the explosives lead azide and silver acetylide-silver nitrate. The first experiments directed toward development of light-initiated explosives as impulsive loading source were apparently those of Roth⁽⁸⁾ in 1964 to 1966. In these experiments, layers of lead azide were detonated with intense light from an argon flash bomb. Nearly simultaneously, Nevill and Hoese⁽⁹⁾ considered the use of a number of primary explosives for impulsive loading of structures, chose SASN as the most suitable, and conducted initial experiments. They chose SASN because it could be made relatively easily from readily available chemicals which are not in themselves explosive, because it is quite safe when stored under acetone, because it can be safely spray-deposited in an acetone slurry, and because it is more sensitive to initiation by light flash than most other primary explosives. Also in this initial study, the authors ascertained that detonation of spray-deposited SASN could be initiated by flash from photographic flash bulbs and xenon flash tubes, and obtained preliminary calibrations of the impulses generated by layers of explosive of various thicknesses which had been sprayed on a flat surface. The initial work appeared promising enough to warrant further development, and such development was continued, partially under Sandia Corporation sponsorship⁽¹⁰⁾ and partially under an internal research project. This continuing effort advanced the technique to the status of a useful and reproducible method for impulsive loading of structures of both simple and complex geometry, with surface areas up to 250 in². Hoese, et al.,⁽¹¹⁾ has reported this development. A versatile light source for simultaneous initiation was developed consisting of an expendable xenon flash tube or tubes, with suitable reflectors, energized by discharge from a bank of capacitors.

Under another internal research project Baker, et al.,⁽¹²⁾ further developed the impulsive loading technique and searched for other applications. The new applications included studies in explosive forming and welding, shock loading of brittle materials, and use of the primary SASN as a simultaneous initiator for a more powerful secondary explosive. The experiments conducted to demonstrate explosive welding capabilities of SASN were minimal. They consisted of a few tests using 0.007 in. aluminum alloy being driven into a

thick aluminum alloy target by the explosive. Good welding was achieved, and these few tests demonstrated that SASN could be used for explosive welding. In this case relatively large pieceparts were used.

III. Bonding Process

The explosive welding process depends on the use of explosives to accelerate metal plates into a high velocity collision. The fundamental condition necessary for bonding is to create an oblique jetting collision. This is defined by Ezra⁽¹⁾ as an oblique collision in which the plate velocity, pressure, collision angle and point velocity are controlled such that a jet or spray of metal is formed at the apex of the collision and is forced outward from between the colliding plates at very high velocities. The conditions for jet formation are:⁽¹⁾

- (1) The pressure generated immediately ahead of the collision point must exceed the dynamic elastic limit of the material to ensure deformation of the metal surfaces into the jet.
- (2) If the velocity of the collision point is maintained subsonic, jetting should occur at any oblique angle. In practice, a minimum angle is required to satisfy the pressure requirement above.
- (3) If the collision velocity is supersonic, jetting will only occur above some critical angle which is dependent on the metal systems and the velocity of the collision point.

IV. Bonding Experiments

The primary purpose of the experiments conducted was to determine the feasibility of using SASN to bond a variety of metal foils and ribbons to printed circuit boards, to solid pieces of metal and to each other. Because explosive welding requires a running detonation, the SASN was detonated using the spark generated from an automobile coil system.

Some preliminary experiments were first conducted by spraying SASN on 0.008-cm-thick aluminized mylar coupons 0.4 cm wide by 3 cm long. A length of one cm was coated with the explosive in an attempt to obtain some experience in spraying areas much smaller than had ever been attempted before. At the same time some feel was obtained in determining the amount of explosive being deposited during each spraying operation so that a given areal density could be obtained when desired. It was found that because of the small area being sprayed it was difficult to spray evenly above 50 mg/cm² without some flaking of explosive occurring. However, in some cases, a fairly even distribution was achieved up to areal densities of 100 mg/cm². At higher densities than this it sometimes required several attempts to achieve a fairly

even distribution. In these cases the coupon was washed down anytime excessive flaking occurred and resprayed. Using these mylar samples, it was determined that an areal density of at least 6 mg/cm^2 was required to obtain detonation using the car coil.

After the preliminary tests, a number of experiments were conducted using nickel ribbon (.0076 cm), copper foil (.0051 cm), aluminum foil (.0025 cm), and brass shim stock (.0076 cm). All these specimens were about 0.4 cm wide by 3.0 cm long and covered with SASN over a length of 1.0 cm. An attempt was made to weld these items to square samples of printed circuit boards approximately 0.125 cm thick and 2.5 cm per side. The metal strips were loaded with SASN of areal density varying from 24 gm/cm^2 up to 100 mg/cm^2 . Each strip was offset from the PCB a distance equal to its thickness. The PCB was clamped to an aluminum table fixture and the loaded strip and spacers were held down with masking tape. The only strips that welded were the thin aluminum foil. All the others were deformed, but no bonding occurred. Furthermore, it was noted that in a number of instances the back side of the PCB fractured around the area of impact. Slight fractures occurred for densities as low as 30 mg/cm^2 . However, there were cases in which visible fracture did not occur for densities as high as 50 mg/cm^2 . Although a sufficient number of experiments were not conducted to determine a more exact damage threshold, it does appear to depend not only on explosive density but also on the type and thickness of the metal impacting the PCB.

Following these initial experiments it was concluded that the PCB was not rigid enough to allow proper impact of the loaded ribbons and except for the thinnest and lightest samples tested, no bonding took place. Therefore, the next set of experiments were made using solid aluminum and copper plates (0.160 cm thick) instead of PCB's. Also, some estimates were first made to determine the welding parameters required to achieve successful bonds for the metal combinations to be tested. Ezra⁽¹⁾ recommends the following method to estimate weld parameters in the absence of conflicting prior experience or data. This method does not pretend to provide parameters that will result in optimum welding but does provide a starting place from which to improve or refine as experiments are conducted for each application. The steps to follow are:

- (1) Consider the extent of welding the application requires. If the area is large (greater than four to six flyer plate thicknesses in length in any direction), then the parallel geometry is probably called for. If not, then the preset angle geometry should be used.
- (2) An explosive should be selected that has a detonation velocity of about one-half to two-thirds of the sonic velocity of the slower of the two metals that are being joined.
- (3) The stand-off, S, should be approximately the following:

- (a) $t/3 < S < 2t/3$ for flyer plates with specific gravities less than 5
- (b) $t/2 < S < t$ for flyer plates with specific gravities between 5 and 10
- (c) $2t/3 < S < 2t$ for flyer plates with specific gravities greater than 10

S = stand-off

t = flyer plate thickness

- (4) Estimate the desired plate impact velocity, V_p , by calculating from equation of state data the flyer plate velocity that will give a pressure of ten to twelve times the yield stress of the stronger of the two metals being welded.
- (5) Using the Gurney method, determine the explosive mass per unit area that will accelerate the known plate mass per unit area to 120% of the calculated impact velocity. The 20% "over-velocity" figure is selected because impact probably occurs when the flyer plate is accelerating before it reaches terminal velocity.

After some experience with a particular explosive it becomes possible to by-pass calculations of impact pressure for most metals with yield strengths in the 28,000 lb/in² to 42,000 lb/in² range. It will be obvious what explosive loadings to use for a particular plate mass, that is what m/c values will produce welding.

Although the above method is primarily for larger pieceparts, it was used to estimate the parameters needed to obtain a starting point. For the experiments under consideration the welding area was large and consequently the parallel geometry was used. Since SASN was used in all cases, its detonation velocity is about 1/6 the sonic velocity of the slower of the two metal combinations joined. Keller⁽¹³⁾ predicts the collision point velocity, which for the parallel geometry is approximately equal to the detonation velocity, should be 1/2 to 3/4 the sonic velocity of the colliding metals for optimum welding. However, many investigators have reported that low to medium detonation velocities increase the ease of obtaining good welds.⁽¹⁾ Since no lower limit has been established, the low detonation velocity of SASN does not appear to be a drawback.

The three types of metals used to impact the solid plates were aluminum, copper, and nickel. The aluminum has a specific gravity less than five, while

the copper and nickel have a specific gravity between five and ten. In all cases the stand-off distance was approximately as suggested in Step (3). From particle velocity-impact pressure curves⁽¹⁾ estimates were made of the impact velocity required for each combination of flyer plate and base materials. These velocities are

<u>Metal Combinations</u>	<u>Plate Velocity (mm/μ sec)</u>
Cu-Cu	. 125
Cu-Al	. 225
Ni-Cu	. 268
Al-Al	. 220

The final step is to determine the explosive mass needed to impart 120% of the calculated impact velocity. The plate mass to charge mass ratio (m/c) for each metal combination was estimated using two different equations. The first one developed by Gurney⁽²⁾ based on the conservation of momentum and containing the detonation velocity V_D is

$$V_P = \frac{V_D (0.612) (c/m)}{2 + c/m} \quad (1)$$

This equation is supposedly only applicable for values of c/m greater than 2.5. The second equation called the Gurney equation for open-faced sandwich geometry⁽¹⁴⁾ is

$$V_P = \sqrt{2E} \left[\frac{(1 + 2m/c)^3 + 1}{6(1 + m/c)} + \frac{m}{c} \right]^{-1/2} \quad (2)$$

and has been plotted by Kennedy⁽¹⁴⁾ in the form of dimensionless velocity, $V_P/\sqrt{2E}$, versus the loading factor, m/c . The quantity $\sqrt{2E}$ is known as the Gurney characteristic velocity for a given explosive. For SASN this quantity has not been established and therefore had to be estimated to use Equation 2. For high density explosives the value of E is about 70% of the specific chemical energy of the explosive and $\sqrt{2E}$ is about 2.5 mm/ μ sec. However, low density explosives such as SASN have in general very low values of $\sqrt{2E}$ ⁽¹⁴⁾ and a value of 0.21 mm/ μ sec has been estimated for using Equation 2. The results are as follows:

<u>Flyer Plate</u>	<u>Base Plate</u>	<u>Equation 1 c/m</u>	<u>Equation 2 c/m</u>
Cu	Cu	1.4	1.2
Al	Cu	5.6	3.2
Ni	Cu	14.0	7.0
Cu	Al	5.6	3.2
Al	Al	5.1	3.0

For these experiments two sizes of aluminum foil strips (.002 and .0076 cm thick), two sizes of copper foil strips (.0025 and .013 cm thick), and one size nickel ribbon (.0076 cm thick) were used as flyer plates against the solid aluminum and copper base plates. Explosive was sprayed on the strips to achieve areal densities that would approximate the estimated c/m value for each combination. Since SASN reacts with copper it was necessary to spray the explosive on the .002 cm thick aluminum foil and place it over the copper foil. In most cases the explosive would disintegrate the thin aluminum foil and loaded the copper sufficiently to produce a bond.

Explosive bonds were achieved for all the combinations of flyer and base plates used. As a rule it was easier to bond thin flyer plates of the same material. It was also easier to bond against the copper base plate, with the copper foil being the easiest and nickel the hardest. Against the Al base plate aluminum foil was the easier to bond.

No tests were made to determine the quality of the bonds. Also, no attempts were made to determine the threshold quantity of explosive required for any of the combinations. All experiments were essentially go-no go to determine if bonding was possible with SASN. A few additional experiments were conducted to see if ribbon to ribbon connections were possible and if two ribbons could be bonded to a copper base plate. In both cases bonds were achieved.

V. Conclusions

The purpose of this quick-look experimental study was to determine if sprayed SASN could be used to bond small electrical ribbons to printed circuit boards, and solid copper and aluminum plates. The results indicate that certain combinations can indeed be bonded readily. Bonds to solid copper plate were the easiest to make while those against PCB the hardest.

It was determined that PCB's are susceptible to localized damage at relatively low explosive areal densities making bonds very difficult, except for the very thin foils (.002 cm), if no damage to the board is required. It

was also very difficult to build up the SASN evenly beyond 100 mg/cm^2 without excessive flaking occurring. The maximum average density that can be achieved is about 200 mg/cm^2 for a flyer plate that is 0.4 cm wide. This precludes repeatable bonds of thicker ribbons, especially for high-yield strength materials such as nickel.

Finally, it is not possible to spray specimens much smaller than those tested with any consistency or repeatability. For such small specimens the spraying operation becomes cumbersome and difficult to control. Furthermore, the explosive will begin flaking at even lower areal densities so that bonds may occur only with thinner flyer plates. Other techniques for depositing the explosive on the plates will have to be used that provide more adhesion between explosive particles themselves, and the explosive and the flyer plate. One possibility is to formulate the explosive so that it becomes almost a paste that can be troweled on the test specimen. Some development work has been done in this area, but more would be necessary to see if it can be used to weld connectors of smaller size that is possible with the sprayed SASN.

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APPENDIX D
ELECTRICAL TERMINATION TEST PLAN

ELECTRICAL TERMINATION TEST PLAN

NASA Contract No. NAS 9-13890

SwRI Project No. 16-3905

Southwest Research Institute
San Antonio, Texas
October 10, 1975

FOREWORD

The test plan contained herein was designed specifically for this program, although it contains certain tests taken or adapted from standard NASA and military test specifications. Since this test plan deals with the evaluation of terminations alone, rather than electrical systems or components which include terminations, the specification test plans were not considered applicable as written.

Two separate test series are included in the plan. Series I - Cumulative Test Plan - consists of different types of tests run consecutively on the same specimens in order to compare their overall reliability under a variety of conditions. Series II - Life Limit Test Plan - consists of environmental tests wherein each type of termination undergoes only one type of test considered critical for that termination. The purpose of this test series is to attempt to establish the useful life limits of particular types of terminations under particular environmental conditions.

There are 10 groups of termination test specimens for Test Series I, and five groups for Test Series II. Identification of these terminations are included as the last section of this document.

NOTE: The test plans and termination identifications herein were prepared and submitted to NASA separately earlier in the program. They have been consolidated in this document to facilitate their use at NASA's request.

SERIES I - CUMULATIVE TEST PLAN
ELECTRICAL TERMINATIONS - GROUPS 1 THROUGH 10

I. INTRODUCTION

A. General

This test plan contains the method which will be used to evaluate the effectiveness of the electrical termination techniques selected for test in this program. The techniques selected are: (1) Induction Heat Soldering, (2) Resistance Welding, (3) Percussive Arc Welding, (4) Wire Wrap (Solderless).

Each of the six tests in Section II of this test plan shall be carried out as described, except that it may be necessary to modify procedures and conditions of a given test to some extent in order to achieve a satisfactory evaluation. This may occur, for example, in the vibration test, where the peak acceleration may require adjustment to a level which will neither fail all the samples, nor pass all the samples. Any modifications to the test plan as written shall be recorded along with the test data.

B. Approach

In addition to the candidate terminations, terminations hand soldered to NASA requirements will be tested for comparison. Twenty five terminations of each type will be evaluated.

Before and after each test, the DC resistance of the terminations shall be measured, and the terminations shall be visually inspected for evidences of mechanical failure under 10X magnification. Mechanical

failure is defined as full or partial separation of the termination components at the interface. A comparison of DC resistances before and after each test will indicate any deterioration in electrical quality of the terminations due to the test.

The following tests are accumulative and shall be conducted in the order listed. Failed terminations are to be removed from the test series, and an analysis of the failure made. Termination evaluations shall be based on a statistical analysis of (1) failures which occurred during the test series, (2) the number of samples which survived all the tests, and (3) the results of the pull test.

II. PROCEDURES

A. Termination Preparation

Thirty-five of each type of termination shall be prepared, of which twenty-five shall be tested, and the remaining ten shall be spares. After the terminations are completed and cleaned, the DC resistance of each one shall be measured and recorded. The terminations shall also be examined under 10X magnification. All terminations exhibiting mechanical defects such as cracks, pits, improper amounts of solder, over or under heating, improper physical mating, unusually high joint resistance, etc. shall be rejected and replaced with satisfactory terminations from the ten spares.

Conductor-to-terminal terminations shall be mounted for testing by attaching the terminal to any suitable rigid medium. The conductor shall be joined to the terminal and one-half inch of free, unsupported conductor

shall extend from the terminal. Conductor-to-conductor terminations shall be made by joining the two conductors, then rigidly mounting one conductor to any suitable medium and leaving one-half inch of free unsupported conductor on the other side of the termination. The rigidly mounted conductor shall be as short as possible.

B. Fatigue Test

Each conductor shall be bent 90° and restored to its original position three times. The bend shall be accomplished by loading the wire .50 inches from the joint. After the three bends have been completed, the terminations shall be given the standard DC resistance measurement and the 10X visual examination. Where a termination is made directly to a printed circuit board, this test shall not be conducted.

C. Torque Test

Each lead shall be rotated 30° and then returned to its original position. The torque required for rotation shall be applied 0.25 inches from the termination on the free end of the conductor. Each lead shall be rotated only once. After the conductors have been restored to their original position, each termination shall be given the standard DC resistance measurement and the 10X visual examination. Where a termination is made directly to a printed circuit board, this test shall not be conducted.

D. Thermal Shock Test

The terminations shall be subjected to a thermal shock test to ascertain any degradation that might be caused by rapid thermal expansion and contraction. The first step of the test shall consist of placing the

terminations in a temperature chamber at ambient temperature and then lowering the temperature to -65°F . This temperature shall be maintained for two hours. The terminations shall then be transferred to another chamber with a temperature of 160°F . This transfer shall be made within five minutes or less. The terminations shall remain in the 160°F chamber for two hours after which they shall be transferred to the -65°F chamber.

The exposure of the terminations from low to high and back to low temperature shall constitute one cycle. A total of four cycles of exposure shall be conducted. For purposes of convenience, the test cycle may be interrupted and restarted at any time providing the terminations are exposed to either temperature extreme for two hours prior to transfer to the other chamber.

After the four cycles have been completed, the terminations shall be removed from the chamber and allowed to return to room ambient temperature. Each termination shall then be given the standard DC resistance measurement and the 10X visual examination.

E. Thermal Cycle Test

The terminations shall be placed in a temperature chamber and the following temperature cycle conducted. The temperature shall be raised to 150°F in six hours and remain at 150°F for six hours. The chamber temperature shall then be lowered to -40°F during the next six hours and shall remain at -40°F for six hours.

This 24 hour cycle shall be repeated 15 times after which the terminations shall be removed from the chamber and allowed to return to room temperature. Each termination shall then be given the standard DC resistance measurement and the 10X visual examination.

F. Vibration: Three-axis Sinusoidal Test

The terminations shall be mounted on the vibration equipment such that one end is fixed as rigidly as possible to the vibrating table. Simple harmonic motion shall be applied to the terminations along each of three mutually perpendicular axes. The frequency shall be swept from 20 to 2000 to 20 hertz in not less than 4 minutes logarithmically; four complete sweeps shall be completed on each axis of vibration. This results in a total of twelve sweeps of not less than 4 minutes each.

Initially the acceleration level shall be set at a constant value of 20 g's peak for one sweep in each axis on each type of termination. This acceleration level may then be changed by the test engineer to either 50 g's or 70 g's peak. The test engineer shall attempt to select the acceleration level which will highly stress the terminations but which will not break the majority of the terminations.

At the conclusion of the vibration test each termination shall be given the standard DC resistance measurement and the 10X visual examination.

G. Examination Before Pull Test

Before the pull test, a thorough examination of all test specimens shall be made. Higher magnification shall be used for visual examination when necessary, and appropriate specimens may be sectioned for metallographic examination if deemed advisable. Either or both of these steps shall be taken whenever the standard DC resistance measurement and 10X visual examination has suggested the possibility of a failed termination, and other means of examination are required for a more accurate evaluation.

H. Pull Test

The final test shall be a destructive pull test on 15 of each 25-unit group of terminations. A gradually increasing load shall be applied along the longitudinal axis of the free end of the conductor until either the termination or the conductor breaks. The recorded data shall include the amount of load applied and a description of the break. It shall be permissible to wick solder to the free end of the conductor to assist in gripping the conductor. Terminations made directly to a printed circuit board shall not be subject to this test.

III. TEST RESULTS

The test results shall be compiled and analyzed for statistical significance of the number and types of failures of the terminations tested. A similar analysis shall be made on the strength of the terminations based on pull test results.

A test report shall be prepared, in which the test results will be tabulated, and recommendations for end use of each type of termination tested shall be made.

July 22, 1975

SERIES II - LIFE LIMIT TEST PLAN
ELECTRICAL TERMINATIONS - GROUPS 11 THROUGH 15

I. Introduction

A. General

This test plan describes the methods which will be used to establish "life limit" of certain types of electrical terminations when subjected to environmental conditioning. The types of terminations to be tested are: (1) Induction Heat Soldering, (2) Resistance Welding, (3) Percussive Arc Welding, (4) Wire Wrap (Solderless). The results of these tests shall describe the "use" limitations of each termination technique within the given environmental criteria.

B. Approach

Twenty-five terminations of each type shall be tested. An additional five control samples shall be interspersed within the twenty-five samples prepared for test of each termination technique, making a total of thirty samples. One control sample shall be removed from the test chamber after each one-fifth of the total time or total number of cycles for each test. For example, if the test consists of 200 cycles, control samples shall be removed after 40, 80, 120, 160 and 200 cycles. Each of these control samples shall be labeled to show the number of cycles (or time duration in some cases) experienced by that sample. The control samples shall be inspected for evidence of mechanical and/or electrical failure using the same criteria described in the next paragraph for the twenty-five test samples.

Before and after each test, the DC resistance of the terminations shall be measured, and the terminations shall be visually inspected for evidences of mechanical failure under 10X magnification. Mechanical failure is defined as full or partial separation of the termination components at the interface. A comparison of DC resistances before and after each test will indicate any deterioration in electrical quality of the terminations due to the test.

II. Procedures

A. Termination Preparation

After the terminations are completed and cleaned, the DC resistance of each one shall be measured and recorded. The terminations shall also be examined under 10X magnification. All terminations exhibiting mechanical defects such as cracks, pits, improper amounts of solder, over or under heating, improper physical mating, unusually high joint resistance, etc. shall be rejected and replaced with satisfactory terminations.

B. Humidity Test for Wire-Wrap Terminations (Group 15 Samples)

The wire-wrap terminations shall be subjected to a steady state, elevated temperature/humidity test consisting of the following steps. The terminations shall be placed in an environmental chamber and subjected to a relative humidity of 90 to 95 percent and a temperature of $104^{\circ} \pm 4^{\circ}\text{F}$ ($40^{\circ} \pm 2^{\circ}\text{C}$) for 240 hours. The chamber and accessories shall be constructed and arranged in such a manner as to avoid condensate dripping on the terminations under test, and such that the terminations shall be exposed to circulating air.

Every forty-eight hours, one control sample shall be removed from the chamber, conditioned at room ambient conditions for a period of at least four hours and appropriately labelled or tagged, after which the standard visual and electrical resistance checks shall be made.

Upon completion of the 240 hour exposure period, the terminations shall be removed from the chamber and conditioned at room ambient conditions for a period of at least four hours. A thorough examination of all test terminations including control samples shall be made. The terminations shall be given the standard DC resistance measurement and the 10X visual examination. Higher magnification shall be used for visual examination when necessary and appropriate specimens may be sectioned for metallographic examination if deemed advisable.

C. Thermal Cycling Test for Soldered Terminations (Groups 11 and 12)

The soldered terminations shall be placed in a temperature chamber and the following temperature cycle conducted. The temperature shall be raised to 240°F in six hours and remain at 240°F for six hours. The temperature shall then be lowered to -65°F during the next six hours and shall remain at -65°F for six hours.

This 24 hour cycle shall be repeated 15 times after which the terminations will be removed from the chamber and allowed to return to room temperature. One control sample shall be removed at the end of every three 24 hour cycles, appropriately labelled or tagged, and subjected to the standard visual and electrical resistance checks.

A thorough examination of all test samples, including the control samples, shall be made. The terminations shall be given the standard DC resistance measurement and the 10X visual examination. Higher magnification shall be used for visual examination when necessary, and appropriate specimens may be sectioned for metallographic examination if deemed advisable.

D. Thermal Shock Test for Percussive Arc Welded and Resistance Welded Terminations (Groups 13 and 14)

The percussive arc welded and resistance welded terminations shall be subjected to a thermal shock test to ascertain any degradation that might be caused by sudden exposure to extreme changes in temperature. The first step of the test shall consist of placing the terminations in a chamber at a temperature of -67°F (-55°C). The terminations shall remain in the chamber for five minutes after the temperature stabilizes at -67°F . The terminations shall then be transferred within 15 seconds to a second chamber at a temperature of 302°F (150°C) and shall remain in the chamber for five minutes after the temperature stabilizes at 302°F . The terminations shall then be transferred back to the -67°F chamber within 15 seconds.

The exposure of the terminations from low to high and back to low temperature shall constitute one cycle. A total of 200 cycles of exposure shall be conducted. For purposes of convenience, the test cycle may be interrupted and restarted at any time providing the terminations are exposed to either temperature extreme for five minutes prior to transfer to the other chamber. One control sample shall be removed from the test series each time after 40, 80, 120, 160 and 200 cycles.

After the 200 cycles have been completed, the terminations shall be removed from the chamber and allowed to return to room ambient temperature. The terminations shall be given the standard DC resistance measurement and the 10X visual examination. Higher magnification shall be used for visual examination when necessary, and appropriate specimens may be sectioned for metallographic examination if deemed advisable.

III. Test Results

The test results will be compiled and analyzed for statistical significance of the number and types of failures of the terminations tested.

A test report will be prepared in which the test results will be tabulated, and recommendations for the useful life limit of each type of termination tested will be made.

June 27, 1975

IDENTIFICATION OF ELECTRICAL TERMINATION TEST SPECIMENS

A. Cumulative Test Series

Group 1: Induction heat solder #22 gauge tin-plated solid round copper conductor to circuit board, with clinched end.

Group 2: Induction heat solder .020" diameter tinned solid Dumet round conductor to circuit board.

Group 3: Same configuration as Group 1, except hand soldered to NASA specifications.

Group 4: Same configuration as Group 2, except hand soldered to NASA specifications.

Group 5: Resistance weld .010" x .031" nickel ribbon to .025 diameter tinned solid copper.

Group 6: Resistance weld .010" x .031" nickel ribbon to #22 gauge teflon-insulated electroplate-tinned 19-strand copper.

Group 7: Percussive arc weld #22 gauge 19-strand copper wire to .051" diameter solid aluminum conductor (butt weld).

Group 8: Percussive arc weld #22 gauge 19-strand copper wire to a gold-plated brass connector pin.

Group 9: Wire wrap 6 turns of uninsulated #30 gauge silver plated copper wire on a .025" square gold over nickel plated phosphor bronze terminal.

Group 10: Wire wrap one turn Kynar insulated #30 gauge silver-plated copper wire plus six turns of same wire, with insulation removed, on a .025" square gold over nickel plated phosphor bronze terminal.

B. Life Limit Test Series

Group 11: Induction heat solder #22 gauge tin-plated solid round copper conductor to circuit board, with clinched end.

Group 12: Same configuration as Group 1, except hand soldered to NASA specifications.

Group 13: Resistance weld .010" x .031" nickel ribbon to .025 diameter tinned solid copper.

Group 14: Percussive arc weld #22 gauge 19-strand copper wire to .051" diameter solid aluminum conductor (butt weld).

Group 15: Wire wrap one turn Kynar insulated #30 gauge silver-plated copper wire plus six turns of same wire, with insulation removed, on a .025" square gold over nickel plated phosphor bronze terminal.

APPENDIX E
FABRICATION GUIDELINES AND INSPECTION CRITERIA
FOR INDUCTION-SOLDERED ELECTRICAL TERMINATIONS

1.0 INTRODUCTION

After materials and parts have been selected for an electronic assembly, proper soldering equipment and techniques must be ascertained to obtain the highest quality joint. Soldering equipment can best be classified by the mode of heat transfer utilized and the four categories generally used are: conduction, convection, radiation and special devices.

Conduction - Conduction means the transmission of heat through or by means of a thermal conductor in physical contact with the body, without appreciable displacement of the molecules of the material. Equipment which solders primarily by conduction are soldering iron, solder pot, hot-plate, wave soldering.

Convection - Convection means the transfer of heat by moving masses of matter. Heat transfer occurs by mixing the molecules of one portion of the fluid or gas with another. Soldering techniques in this category are, flame soldering, furnace soldering and hot gas soldering.

Radiation - Radiation is the total effect of emitting, transmitting and absorbing energy. The most common technique in this category is light which may range from pure white to infrared and may be focused or unfocused.

Special Devices - The previous categories have classified heat sources by the type of heat transfer used, but this approach is inadequate for some techniques such as resistance and induction soldering. The two techniques are similar in that the thermal heating required for soldering is generated when a large current is passed through a high-resistance material. In resistance soldering the current is applied to the work piece by electrodes which are in contact with the work piece. In induction soldering, the work piece is used as the secondary of a transformer converting electrical energy into heat. In this method, no contact with an external heat source is necessary.

Some of the more important advantages of induction soldering are:

1. No contact is required between the workload and the heat source.
2. Rapid heating of the work piece is easily achieved.
3. Heat may be restricted to localized areas.
4. Heat generation can be restricted to a surface zone of the load.
5. Control of processing and production is simplified.
6. Minimizes external contaminates.

2.0 INDUCTION SOLDERING

Although induction heating is widely used by various industries, it has found only very limited use in the electronics industry for soldering applications. Only the use of induction soldering for soldering component leads to printed wiring boards will be considered here.

2.1 Basic Principles

In induction soldering the heat required to raise the work pieces and solder to soldering temperature is generated in the work due to the lines of flux surrounding the work-coil cutting into the surface of the work and inducing circulating currents (eddy currents). Therefore, those parts of the work lying in the magnetic field will become heated.

The value of the induced current is dependent upon the magnitude or strength of the magnetic field. Since the field is strongest in the area immediately adjacent to the coil and diminishes as the square of the distance from the coil, the rate of heating can be controlled by altering the distance or coupling between the coil and the work. If the distance is small, it provides a "tight" coupling which gives fast heating, and vice versa.

Induced high-frequency currents tend to flow in the outer layers of the work piece. This phenomenon is known as "skin-effect" and is of special importance in induction soldering applications. As the frequency increases, the depth of the current carrying layer decreases. This surface heating is advantageous in induction soldering, since only the surface needs to be raised to a proper temperature for good wetting action. However, in many printed wiring board applications, the diameter or thickness of the material being heated is so small that through heating takes place rather than just surface heating.

Physical properties of the work load must be considered in induction soldering. The two most important properties are the magnetic permeability μ and the electrical resistivity ρ . The ferrous metals which normally have a high permeability will heat up much faster than the nonferrous metals. However, these metals normally also have a high resistivity and therefore tend to limit the induced current. Since the heat generated is a function of I^2R , the high resistivity which limits the I offsets the heating effects of the high permeability. In the nonferrous metals such as copper which have a low permeability, the low resistivity allows large currents to flow and thereby induction heating is possible in nonferrous metals.

2.2 Work Coils

In order to better understand the function of work coils and inductors, it is necessary to review the basic theory of induction heating.

If an electrical conductor is carrying a current, it will be surrounded by lines of magnetic flux as shown in Figure 1. If the conductor is wound into the form of a helical coil the lines of flux will surround the coil in the manner indicated in the cross-section of the coil as shown in Figure 2A. Because of the tendency of the currents in the conductor to follow the shortest possible path, there will be a concentration of current on the inside of the turns of the coil. Because of this, the resulting magnetic field will be appreciably stronger inside the coil than adjacent to the outside of the turns. If an iron bar is placed inside the coil as shown in Figure 2B, lines of flux cut into the surface of the iron and by the laws of electromagnetic induction, a current will be produced.

As previously mentioned, high frequency currents concentrate in the outer layers of a conductor (skin effect) and as the frequency increases, the depth of the layer carrying the induced current decreases. In a conductor carrying current at a frequency of 50 hertz, the current is distributed fairly evenly over the entire cross-section. If a similar section was taken of a conductor carrying current at a frequency of one megahertz, the current density around the edge will be found to be considerably greater than at the center of the conductor. Since it is desirable to have only surface heating in induction soldering, higher frequencies are used. These normally range from 200 K hertz to 500 K hertz.

There are certain basic fundamentals of coil design which if adhered to will simplify the construction of efficient work coils. These are:

1. Heating occurs only in the vicinity of the turns of the work coil. Because of this, the coil should embrace only that area of the work piece which it is desired to heat.
2. The closer the turns of the work coil are to the surface of the work, the faster will be the rate of heating. It is possible, therefore, to adjust the heating rate by altering the coupling. Care must be taken to not allow the coil to touch the work.
3. In coils with more than one turn, the adjacent turns should be as close together as possible to obtain the most even heat pattern; however, adjacent turns must not be allowed to touch each other.
4. The work coil should have the maximum number of turns allowable considering the physical dimensions of the conductor and the ability to obtain the desired heat pattern.

The heat pattern produced by the coil is of utmost importance in induction soldering applications. Incorrect heat distribution will result in poor quality work.

Heating coils can be formed in a variety of shapes. For induction soldering of component leads to a printed wiring board, the pancake coil will perform best because it provides the most efficient heating of a flat

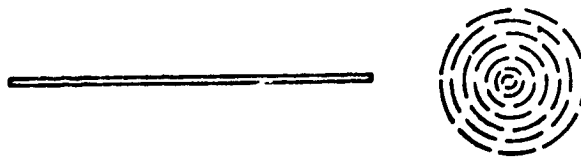


FIGURE 1 - LINES OF FLUX SURROUNDING A CONDUCTOR

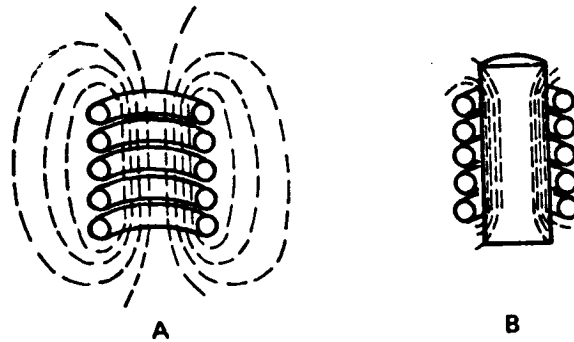


FIGURE 2 - LINES OF FLUX SURROUNDING A COIL

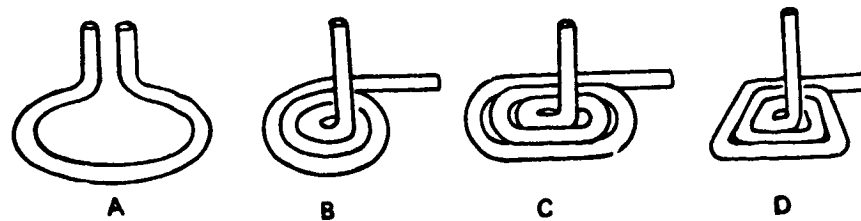


FIGURE 3 - PANCAKE COILS (A) SINGLE-TURN (B) CIRCULAR (C) OVAL (D) SQUARE

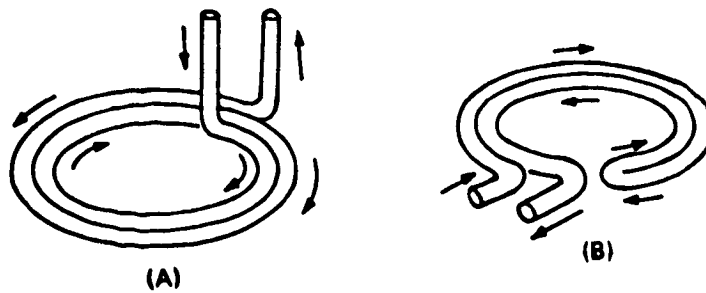


FIGURE 4 - FLUX CANCELLATION: (A) CORRECT; (B) INCORRECT

surface. Figure 3 illustrates several types of pancake coils. The inside diameter of a single-turn coil should be large enough to completely surround the solder joint without making contact. The solder connections illustrated in Section 5 were all fabricated using a single-turn pancake coil. For this type of termination, it is recommended that a single-turn coil be tried first.

In winding coils, care should be taken to ensure that the turns are so placed that the current in adjacent coils is flowing in the same direction. If this is not done, flux cancellation will occur with a loss in heating efficiency. Figure 4 illustrates flux cancellation.

2.3 Soldering

The process of soft soldering consists of joining together metal parts without softening or melting the surfaces of the parent metals. The solder must be capable of wetting the surfaces of the parent metal, must adhere strongly to the parent metals on solidifying and must be capable of filling the space between the surfaces to be joined. Solder normally used for electronics soldering is either SN63 or SN60 (63% or 60% tin and 37% or 40% lead) and has a melting range of 183°C or 188°C. To ensure good wetting the solder and the metals to be soldered must be raised to a temperature which is approximately 50°C higher than the melting temperature of the solder.

Application of solder in induction soldering differs from that in hand soldering since a preform must be used. For soldering component leads to a printed wiring board, a short section of wire solder can be used. The diameter and length of the piece of solder must be determined experimentally to provide the optimum solder fillet. For best results the solder preform should completely surround the clinched component lead. The diameter of the preform is selected to yield a solder connection which has a fillet in between the minimum and maximum limits set forth in Section 5.

In hand soldering the only flux that is normally used is that which is available in cored solder. This works quite well since the flux melts and becomes active at a temperature lower than the melting point of the solder. This activated flux cleans the metals to be soldered and provides an air barrier to these cleaned surfaces until it is displaced by the molten solder. Although cored solder may be used for solder preforms, in induction soldering, the flux in the solder will not function properly because it cannot be liberated from the solder until the solder has melted. Being less dense than the solder it will float to the surface and provide very little, if any, cleaning action on the metals to be soldered. Because of this, when using induction heating, a liquid rosin flux must be applied to the materials being soldered before the solder preform is placed in the joint area.

3.0 MATERIALS AND EQUIPMENT

The materials and equipment used must not degrade the quality of the solder connection and the parts being joined.

3.1 Solder

Solder shall conform to Federal Specification QQ-S-571d, Type RA or RMA for cored solder; and type S, form B or I for solid solder and shall be composition SN60 or SN63 unless specified otherwise.

3.2 Flux

The flux shall be liquid rosin and conform to MIL-F-14256, Type A. Liquid flux used with flux cored preforms shall be chemically compatible with the solder core flux and with any materials with which it will come in contact.

3.3 Solvents

The following cleaning solvents are acceptable for cleaning the solder connections upon completion.

1. Ethyl alcohol, ACS grade, 99.5% or 95% by volume
2. Isopropyl alcohol, best commercial grade 99% pure
3. Trichlorotrifluoroethane, clear, 99.8% pure
4. Any mixtures of the above.

3.4 Equipment

The induction soldering generator must be capable of providing energy levels which allow for the completion of the soldering operation in 1 to 3 seconds. Most equipment suitable for printed wiring board soldering will operate in the 400 to 500 K hertz frequency range. The frequency used must not degrade the parts being mounted nor degrade the bond between the copper conductor and the base laminate.

4.0 PARTS MOUNTING

All parts should be mounted parallel to and in contact with the printed wiring board. When the shape of a part is such that only a point contact can be made with the mounting surface, additional support must be provided. Parts which weigh more than 14 grams shall be supported mechanically.

4.1 Lead Cleaning

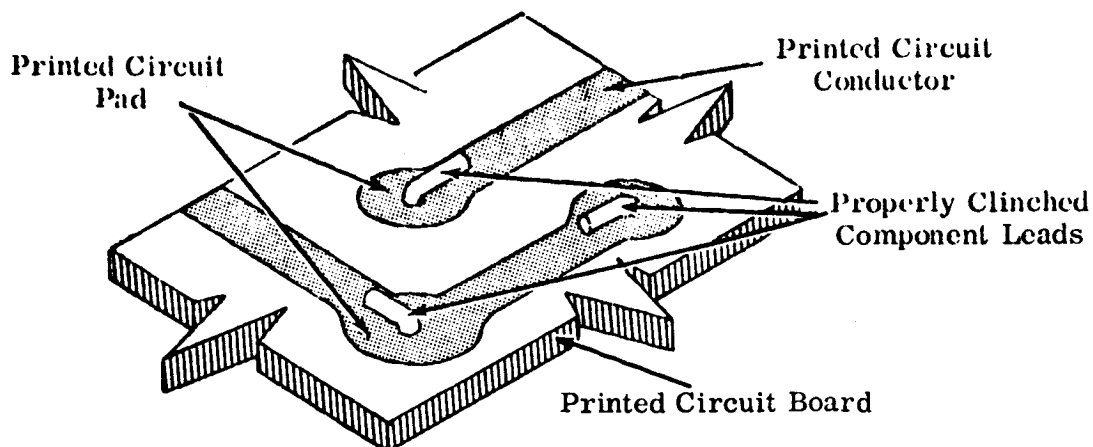
To assure a good wetting action between parts to be soldered, all impurities such as dirt, grease, or oxide film must be removed. Surface contamination or corrosion formed on the part lead during processing, storage or handling should be removed.

4.2 Lead Bending

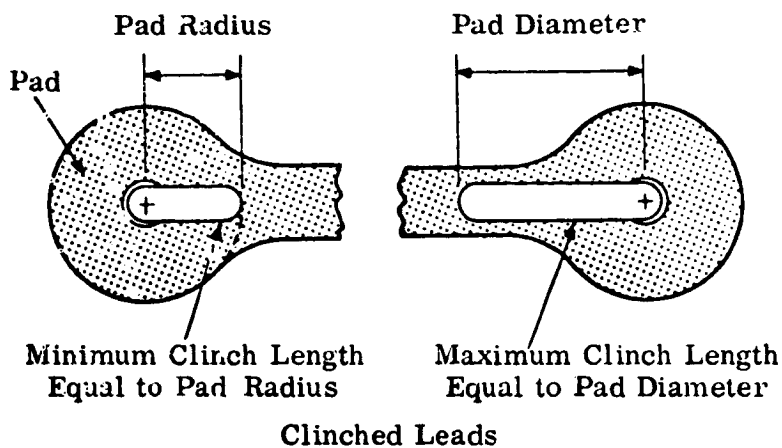
During bending or cutting, part leads should be supported to minimize axial stresses and avoid damage to seals or internal bonds. The inside radius of bend should not be less than the lead diameter. The distance from the bend to the end of the body should be approximately equal at each end and this distance should be a minimum of two lead diameters. Where the lead is welded, as on tantalum capacitors, the minimum distance is measured from the weld.

Leads which cannot be bent should be cut so that when mounted, the leads protrude through the board from .8 mm to 2.4 mm. The outline of the end of the lead should be evident after soldering.

Figure 5 illustrates properly clinched leads on a circuit board.

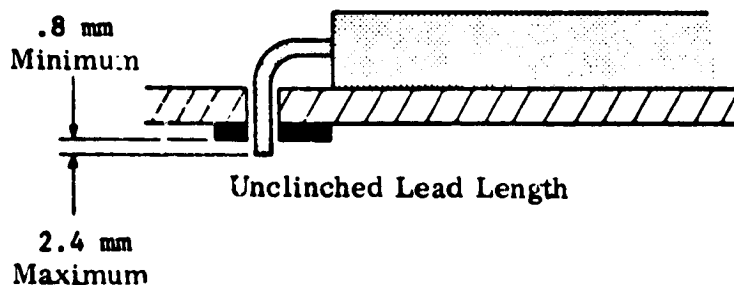


a. Component leads clinched in direction of, parallel to, and in contact with circuit patterns.



b. Minimum Clinch Length Equal to Pad Radius

c. Maximum Clinch Length Equal to Pad Diameter



d. Unclinched Lead Length

Figure 5. Properly Clinched Component Leads on a Circuit Board

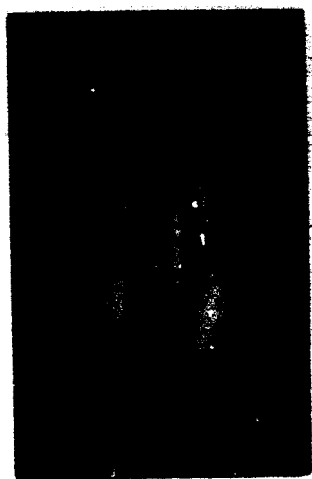
5.0 INSPECTION CRITERIA

The intent of this section is to clarify the acceptance and rejection criteria for workmanship where the basic measure of quality is largely subjective. The photographs in Figure A-1 depict unacceptable connections because of insufficient and excessive solder, minimum and maximum acceptable and the optimum solder connection.

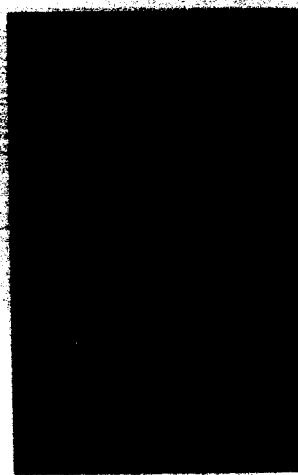
Figure A-2 illustrates the effects of insufficient heat. In A-2a there is no evidence of wetting of the component lead. This can be attributed to insufficient heat or possibly no flux on the component lead. In A-2b the solder did not wet completely to the edge of the pad. A-2c is a classic example of insufficient heat since neither the pad nor the lead wet properly. Close examination of A-2d reveals non-wetting of the component lead along the left edge of the lead.

Figure A-3 illustrates the effects of excessive heat. Excessive heat is evidenced by the grainy, dull appearance of the solder connection. A-3a and A-3b illustrate the effects of slight overheating. A-3c not only shows the effects of overheating but also excessive solder. In A-3d the overheating was so great that the solder pad delaminated from the base material.

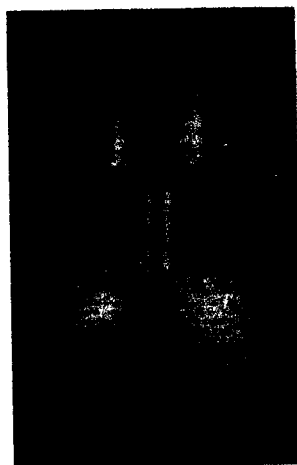
Figure A-4 illustrates various cases of non-wetting. In A-4a the solder did not wet completely to the edge of the pad and in A-4b it did not wet properly at the component lead end of the pad. Insufficient solder in A-4c prevented the solder from totally bridging between the lead and the pad. A-4d illustrates pad dewetting which was probably caused by excessive pad contamination or insufficient flux.



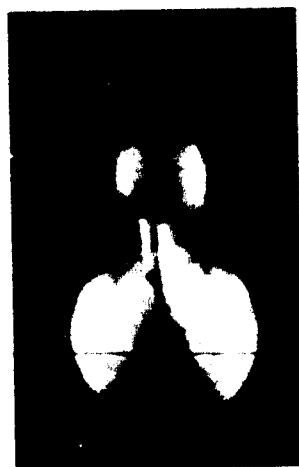
**(a) Unacceptable
Insufficient Solder**



**(b) Acceptable
Minimum Solder**



**(c) Acceptable
Optimum Solder**

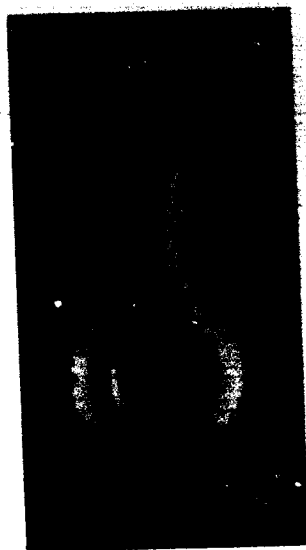


**(d) Acceptable
Maximum Solder**

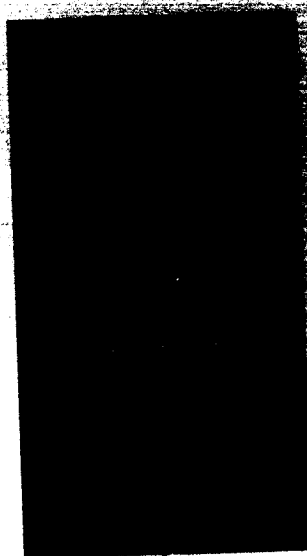


**(e) Unacceptable
Excessive Solder**

Figure A-1. Workmanship Standards for Soldering of Printed Wiring Boards



(a) Optimum Solder



(b) Insufficient Solder



(c) Non-wetting of
lead and pad

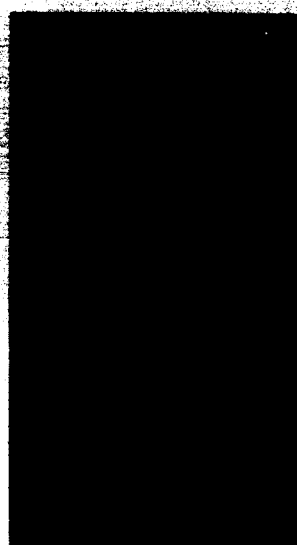


(d) Non-wetting
of lead

Figure A-2. Solder Connections Illustrating Insufficient Heat



(a) Optimum Solder



(b) Insufficient Solder



(c) Excessive Solder

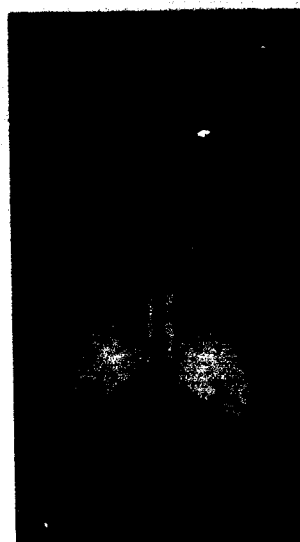


(d) Pad Delamination

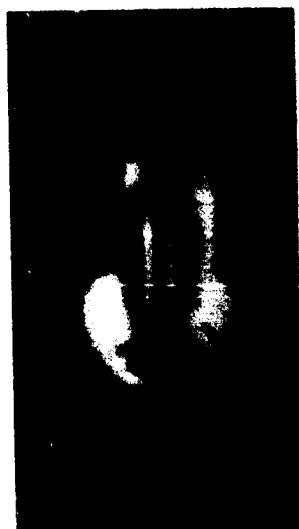
Figure A-3. Solder Connections Illustrating Excessive Heat



(a) Did not wet to edge of pad



(b) Did not wet on the copper run end



(c) Did not bridge between lead and pad



(d) Dewet on pad

Figure A-4. Solder Connections Illustrating Non-wetting