NASA TECHNICAL MEMORANDUM

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MOUNTING OF COMPONENTS TO PRINTED WIRING BOARDS

By E. Ray Van Orden
Research and Development Operations

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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Chairman, Solder Committee
George C. Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT

A Solder Committee designated to investigate a solder cracking phenomenon occurring on the SATURN electrical/electronic hardware found the cause to be induced stress in the solder termination rather than faulty soldering techniques. The design of the printed wiring board (PWB) assemblies did not allow for thermal expansion of the boards that occurred during normal operation. The difference between the thermal expansion properties of the boards and component lead materials caused stress and cracking in the soldered joint.

Various PWB component mounting configurations are presented in this report. Future design considerations to provide adequate strain relief in mounting configurations are included to ensure successful solder terminations.

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RESEARCH AND DEVELOPMENT OPERATIONS
ASTRIONICS LABORATORY

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SUMMARY

A Solder Committee was designated to investigate a solder cracking phenomenon that was occurring on the SATURN electrical/electronic hardware. It was found that the cause was due to the design of the printed wiring board (PWB) assemblies and not faulty soldering techniques. The design did not allow for thermal expansion of the PWB during normal operating conditions and the different expansion characteristics of the board and component leads induced stress in the solder joint resulting in cracking.

Effective techniques for assembling conventionally approved components to PWB's (excluding multilayer boards) are detailed. Future design considerations to provide adequate strain relief in mounting configurations are included to ensure successful solder terminations. Solder joint integrity is verified by the test procedure also included.

A. SOLDER JOINT FAILURE MECHANISM

The phenomenon of cracked solder joints on printed wiring boards (PWB) used in Saturn electronic and electrical hardware is the basis for establishing this document. In many instances, the best quality control requirements for fabrica ion and workmanship failed to produce a reliable solder joint. A Solder Committee was thus formed at George C. Marshall Space Flight Center to investigate the cause of solder joint failures and to establish criteria for solder joint reliability. Various phases of component mounting were studied, to include PWB materials, component and lead materials, various methods and materials used in fastening or mounting the component to a PWB, lead strain relief, and lead terminations. The results of the study, to date, show the primary cause of solder joint failure to be accumulative effects of permanent stresses and fatigue introduced by environment in the soldered connections. (See NASA Technical Memorandum NASA TMX-53653.)

B. COMPONENT MOUNTING STANDARDIZATION

Based on current testing and evaluation, various types of component mounting and lead terminations are discussed herein. These termination methods may not necessarily be covered by current specifications and may conflict with existing requirements. However, when used and soldered to the requirements of NASA Quality Publication NPC 200-4, the joints will least likely fail. Careful consideration should be given to any proposed design and should be supported by engineering evaluation, such as life testing and thermal cycling, prior to implementation.

C. MATERIALS

The selection of lead materials and fastening materials is a design problem and should be based on thermal expansion coefficients, solderability, configuration of strain relief, and environment. The following standard materials are used in fabricating PWB's and in mounting components to PWB's:

1. PWB's: MSFC-SPEC-377A, MSFC-SPEC-154.

2. Plated-Thru-Holes: MIL-STD-275.

3. Terminals: MSFC-SPEC-278B.

4. Fluxes: MIL-F-14256, Type A, and Federal Specification QQ-S-571, Type RA.

5. Solders: QQ-S-571, composition SN60 or SN63.

NOTE

The tin content of tin-lead solders used for retinning, coating or plating, or machine soldering shall be not less than 55 percent nor more than 70 percent. Solder plated surfaces shall be hot fused prior to soldering.

6. Conformal coatings: MSFC-PROC-257A, MSFC-PROC-293A.

7. Ruggedizing and/or staking: MSFC-SPEC-222-Type III. (A'so used in place of staking material specified in Conformal Coating procedures.)

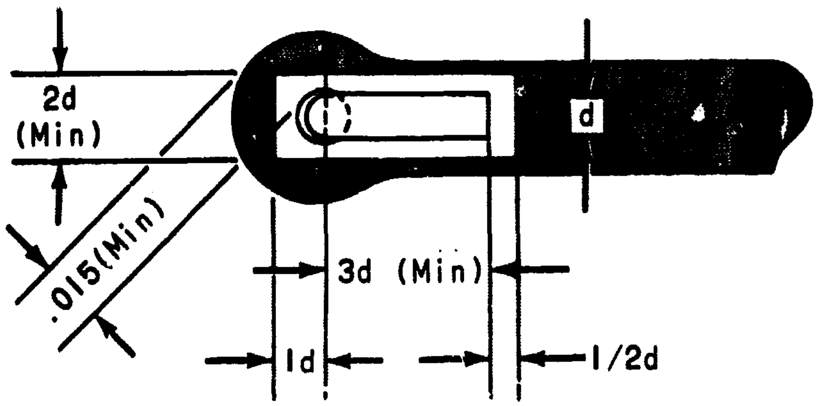
D. LEAD TERMINATIONS

All termination surfaces shall be solder tinned prior to soldering. Lead terminations discussed are of four general types, i.e., clinched, stud, off-pad/lapped, and swaged or flared. Clinched terminations are recommended for components having axial or radial leads under 40 mils diameter. Stud terminations are used when the leads cannot be properly clinched such as found on relays, transformers, variable resistors and connectors. Off-pad/lapped terminations are used with flat packs, multi-lead components where the spacing between the leads does not allow clinch or stud terminations, or when leads, due to their inherent stiffness, require additional length for strain relief on the soldered side of the PWB's. Swaged or flared terminations are used with terminals and some connectors.

The combination of using plated-thru-holes with the above terminations (except off-pad/lapped) will increase the solder shear area and add strength to the joint.

1. Clinch. A typical clinch termination is shown in figure 1. The shape of the solder pad is unimportant if the minimum solder area is maintained. Excessively large pads should be avoided. The lead should be bent in contact with the PWB (except for spring back) and soldered according to NPC 200-4 using maximum allowable solder for added strength. See figure 21. Strain relief of the lead is necessary, see figures 19 and 20 for typical methods.

2. Stud. A typical stud termination is shown in figure 2. This type of joint is generally accompanied by several similar joints closely spaced on the same component. Strain relief by bending leads is usually not possible but the forces to the joint can be reduced by using resilient materials and minimum conformal coatings. Distribution of forces or the forces applied to each joint is reduced by the number of joints per unit area of the component. The strength of the joint is improved by using maximum allowable solder and plated-thru-holes. See figure 17.



NOTES

1. Solder pads should provide a minimum solder area of 2d wide and 4 1/2d long in the direction of the clinch.
2. The clinch length should be a minimum of 3d long when measured from the hole center.
3. The size of holes should not exceed the nominal lead diameter by more than 0.008 inch.
4. The solder pad configuration should provide a minimum of 0.015 inch of copper around the hole after all registration, etching, and drilling operations.

Figure 1. Clinch Termination.

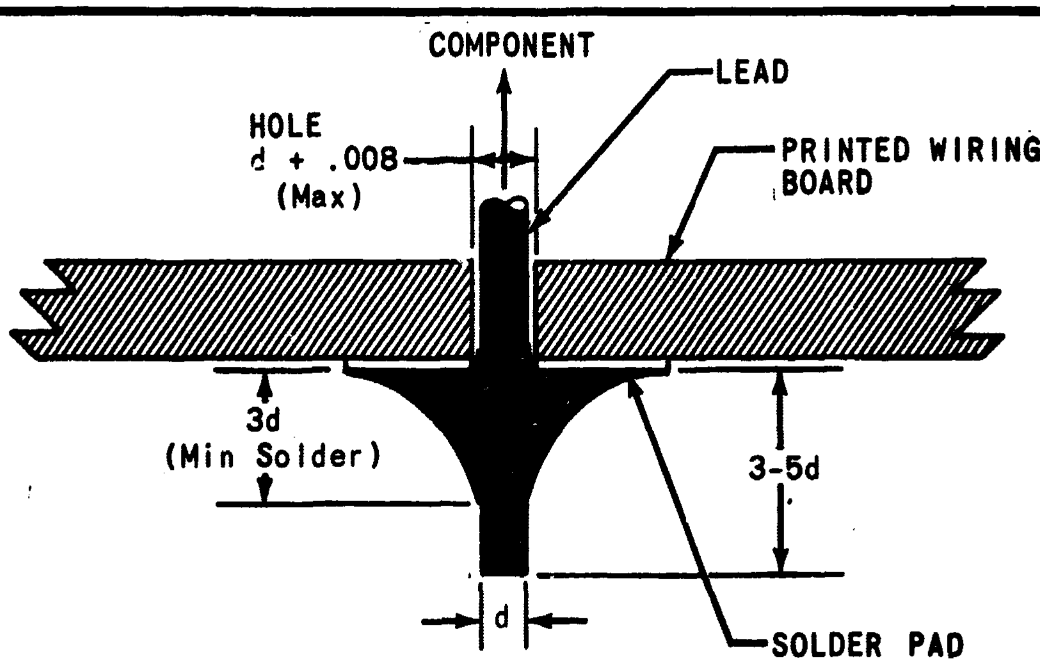
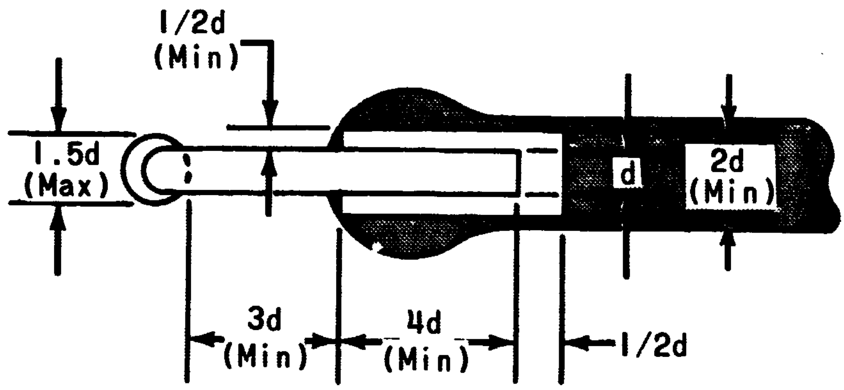


Figure 2. Stud Termination.

3. Off-pad/lapped. A typical off-pad/lapped termination is shown in figure 3. This type of configuration provides strain relief to the solder joint. The space between the component lead hole and the solder pad is dictated by the stiffness of the lead material and size. Worse case condition is transistor Kovar leads. This space should be two times the dimension (6d) shown in figure 3.



NOTES

1. Solder pads with off-pad holes should provide a minimum solder area equal to 2d wide and 4 1/2d long.
2. The component lead should lap the solder area a minimum of 4d.
3. The size of the hole should not exceed the nominal lead diameter by more than 1/2d and should provide a minimum spacing of 3d between solder pad edge and adjacent hole edge.

Figure 3. Off-Pad/Lapped Termination.

4. Swaged or flared. Typical swaged or flared terminations are shown in figures 4, 5, 6, and 7. The minimum solder pad area for the flared end is the same as the stud termination shown in figure 2. If a terminal is soldered on the shoulder, the pad must extend 0.015-inch minimum beyond the edge of the terminal shoulder. Do not solder to each side of the board on the same terminal unless a plated-thru-hole is used.

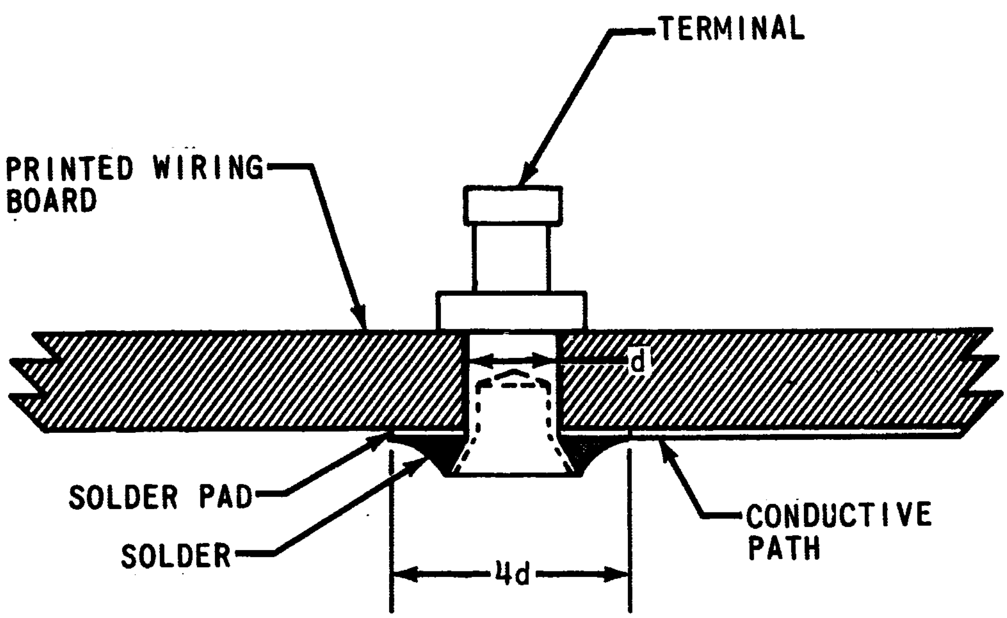


Figure 4. Terminal Solder Joint With Flared End.

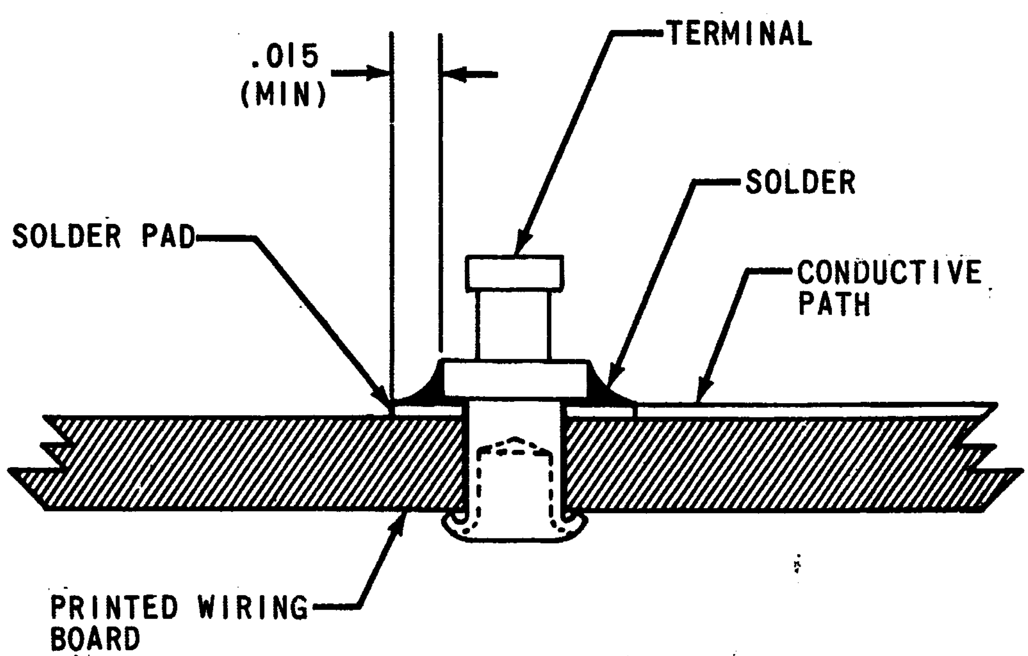


Figure 5. Terminal Solder Joint with Swaged End.

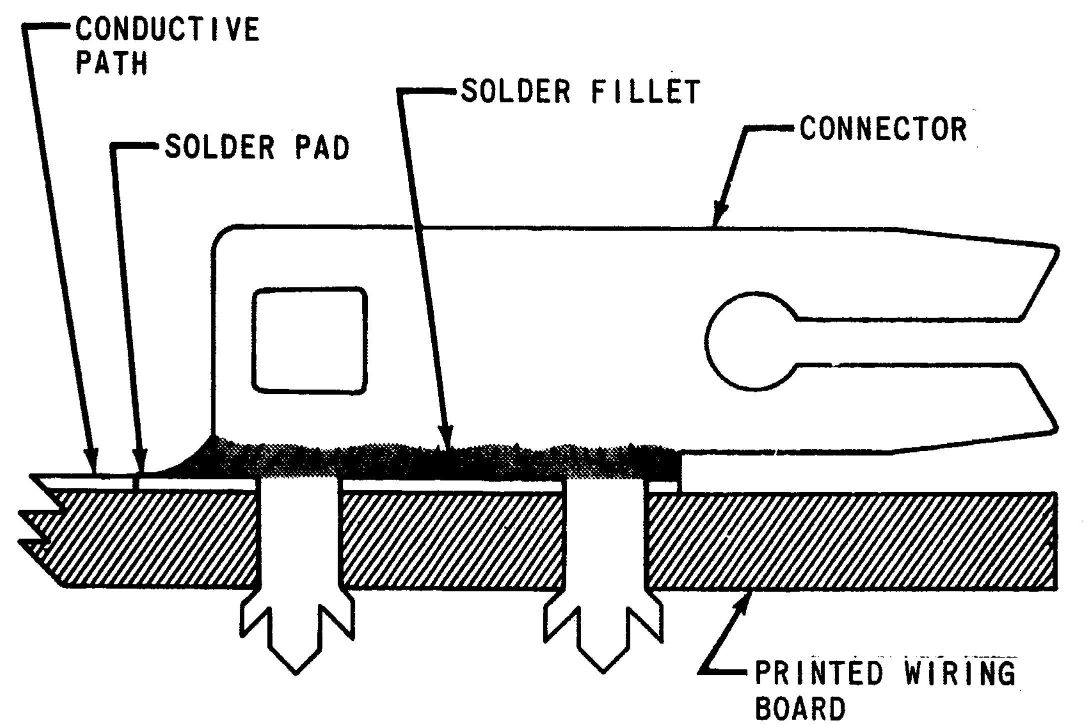


Figure 6. Edge Connector Solder Joint.

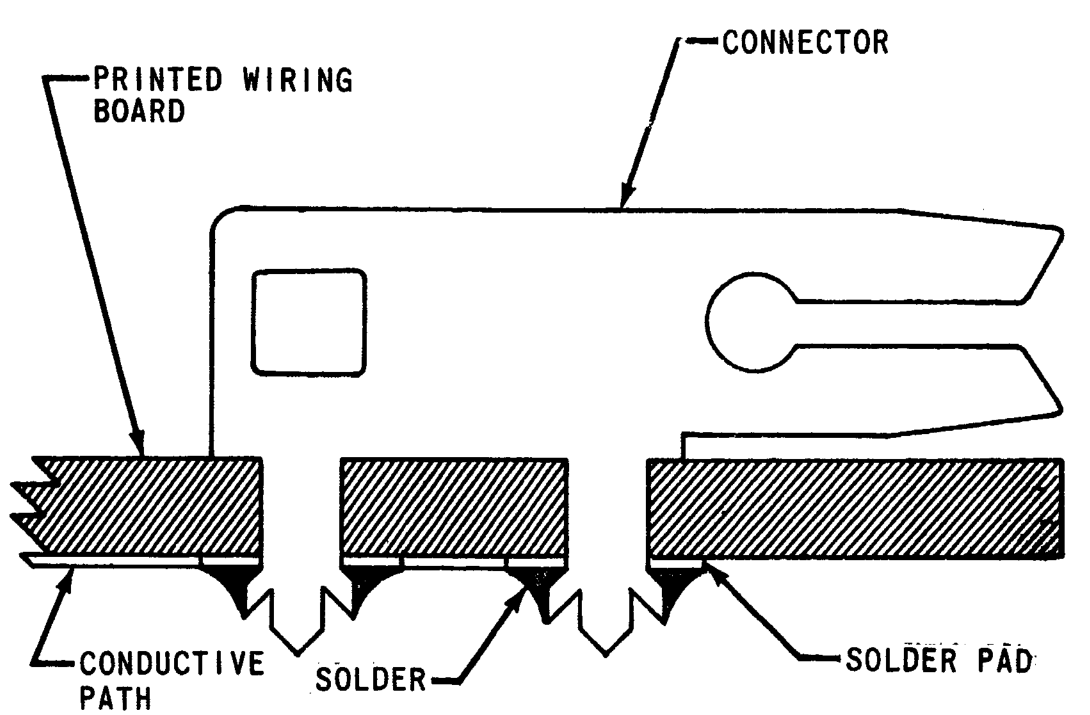


Figure 7. Edge Connector Solder Joint.

5. Plated-thru-holes. - Plated-thru-holes shall not be used alone as an electrical connection between the printed wiring on each side of a board. The use of solder tinned plated-thru-holes, figure 8, will give added mechanical strength to each termination. When using plated-thru-holes on a single sided PWB, a full size solder pad is not necessary on the non-conductor side. The finished hole size should be 0.010 to 0.020 inch larger than the nominal lead diameter (d) for terminations.

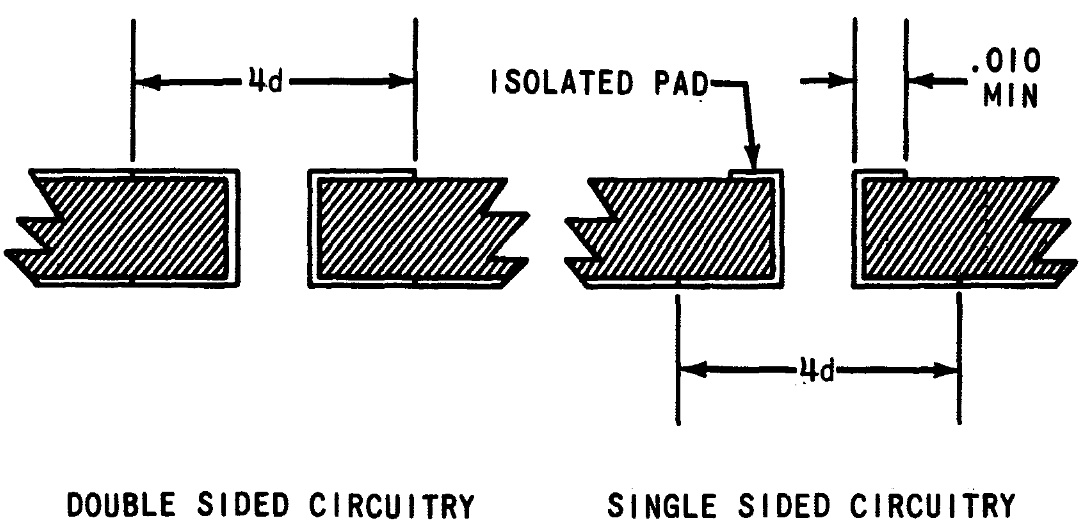


Figure 8. Plated-Thru-Hole Pad Sizes.

6. Eyelets. - Terminations using eyelets have proven unsatisfactory and are not acceptable.

E. INTERCONNECTION

Jumper wires, component leads, terminals, or connector leads are used to electrically connect double sided PWB's. Interconnections are basically combinations of clinch or stud terminations with off-pad/lapped terminations as shown in figures 9 and 10. A combination of clinch or stud terminations can be used for interconnections providing plated-thru-holes are also used. See figures 11, 12, 13 and 14. Swaged or flared terminations may be used as interconnections only if plated-thru-holes are incorporated for added solder joint strength. See figures 15 and 16.

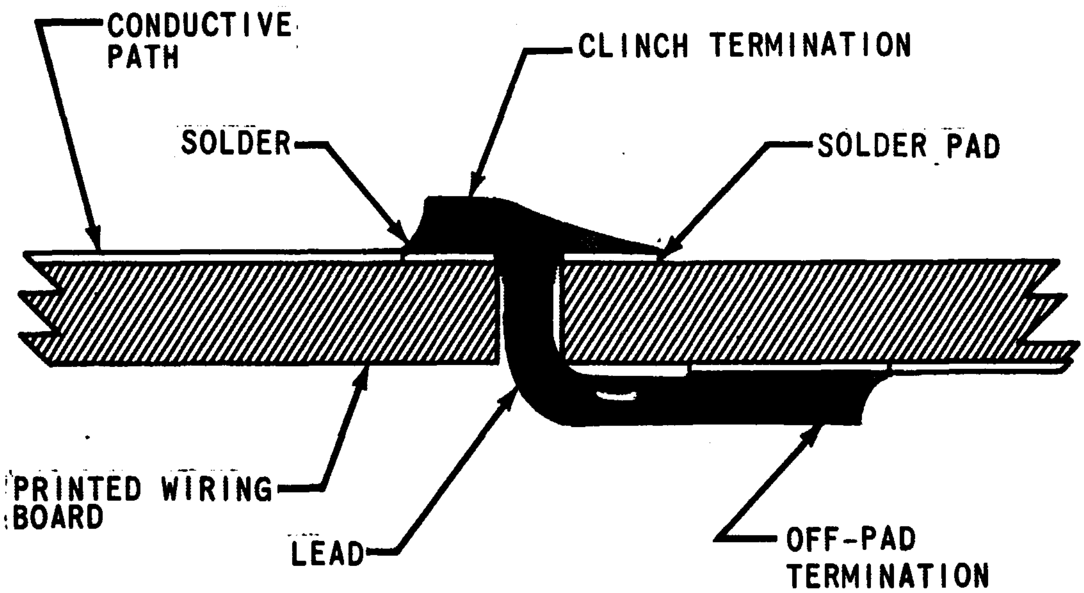


Figure 9. Clinch and Off-Pad/Lapped Interconnection.

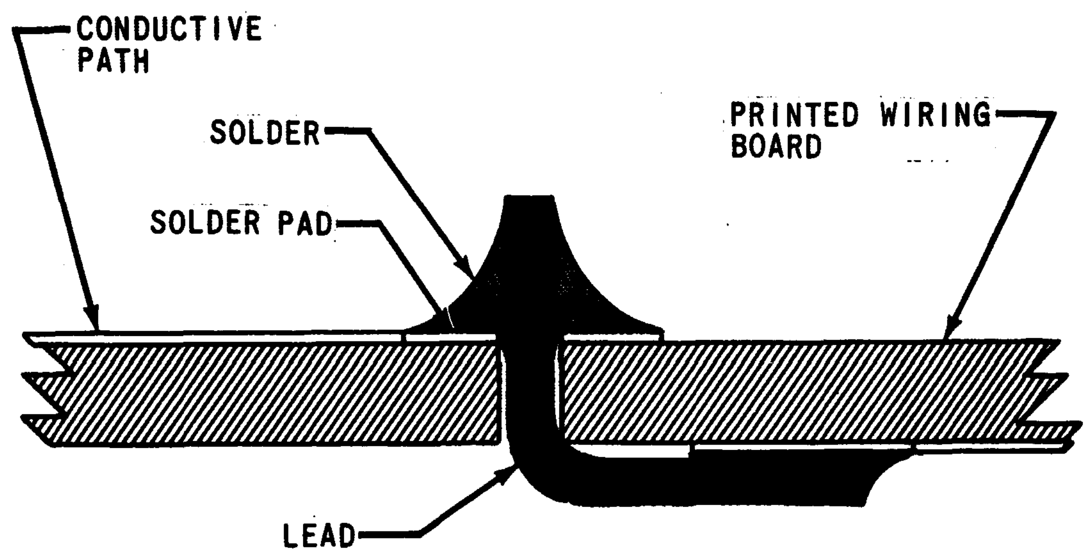


Figure 10. Stud and Off-Pad/Lapped Interconnection.

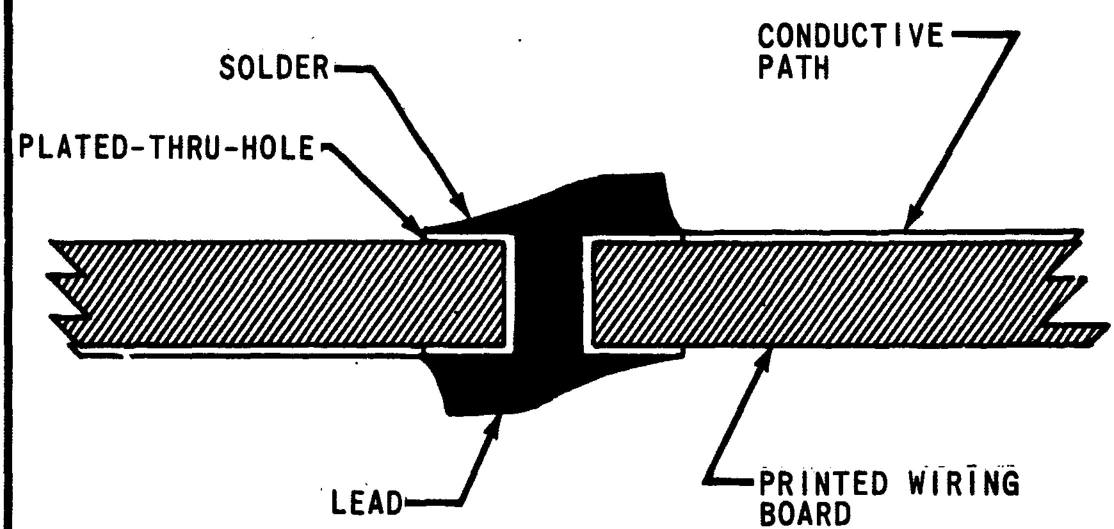


Figure 11. Clinch Terminations Used for Interconnection.

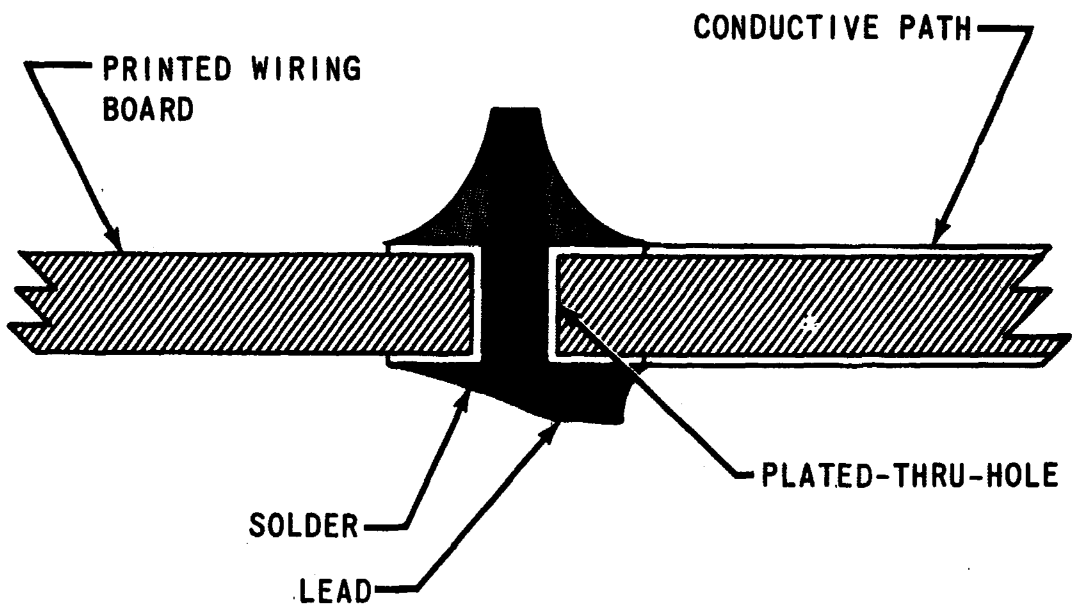


Figure 12. Combination Stud and Clinch Terminations Used For Interconnection.

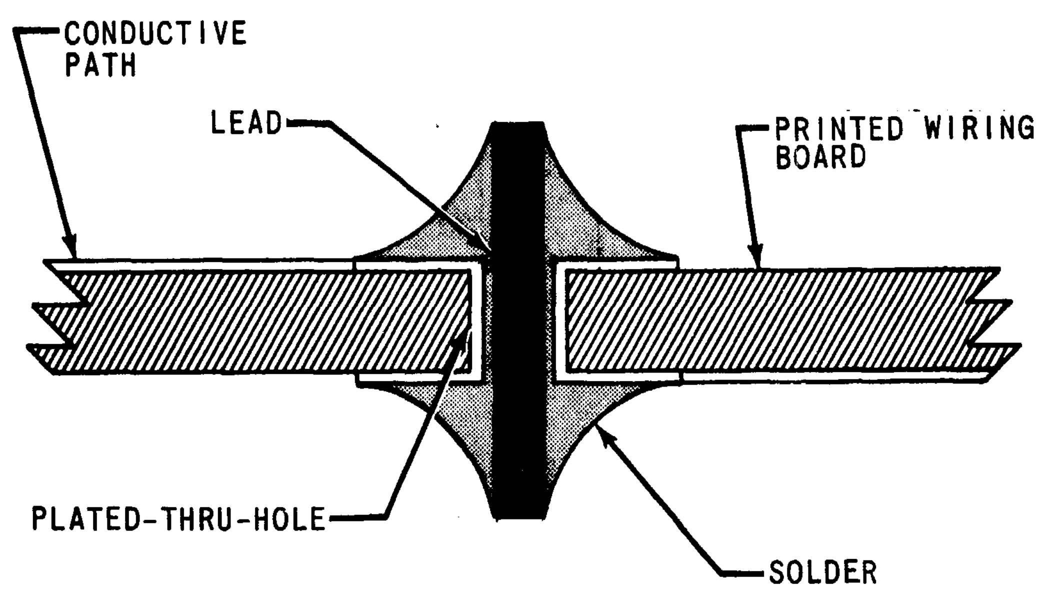


Figure 13. Stud Terminations Used for Interconnection.

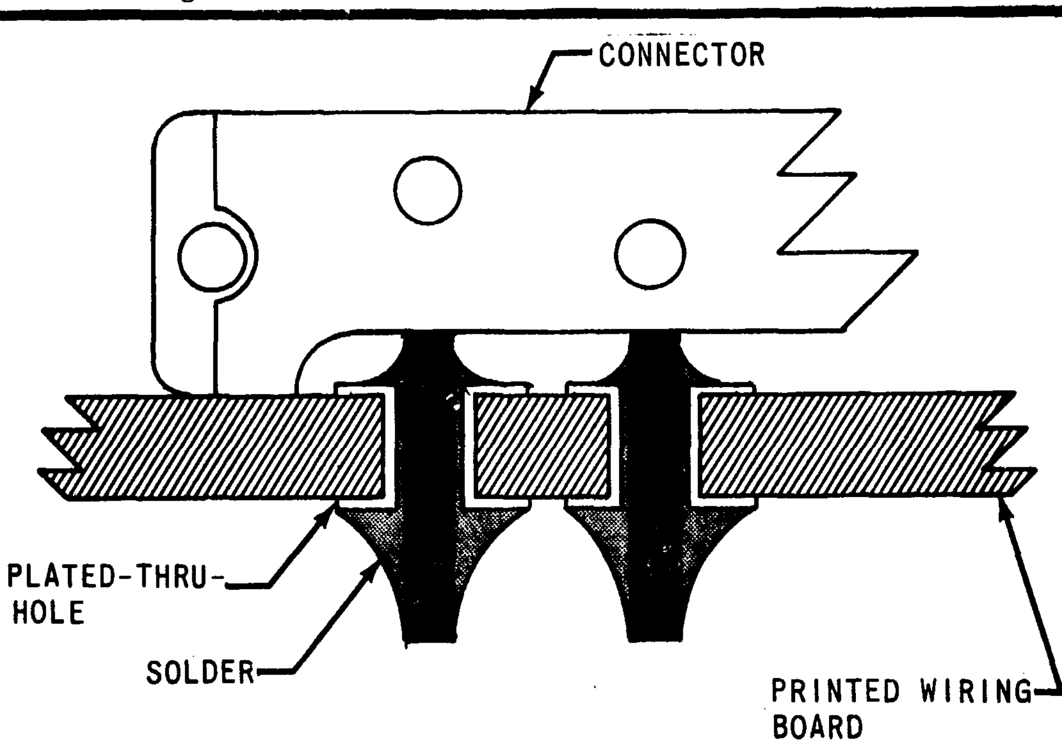


Figure 14. Molded Edge Connector Interconnection.

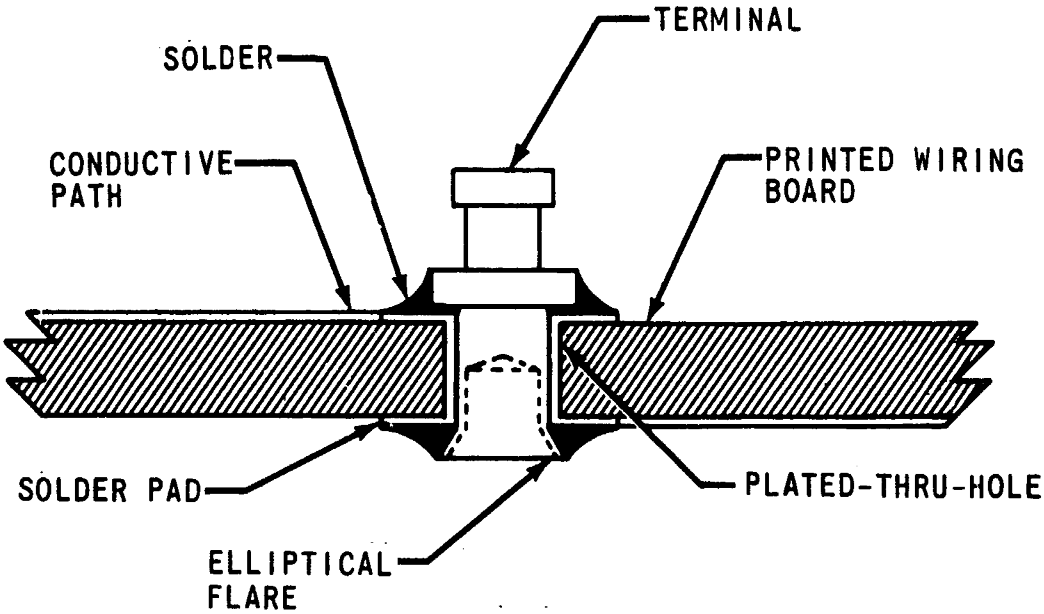


Figure 15. Terminal Interconnection.

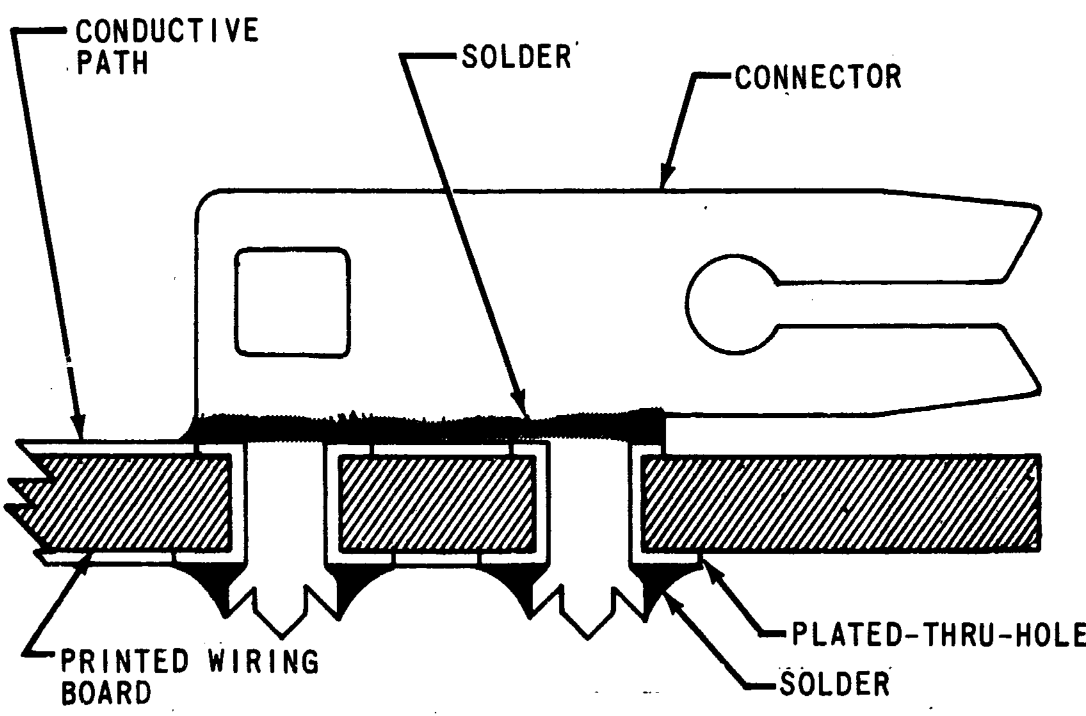


Figure 16. Edge Connector Interconnection.

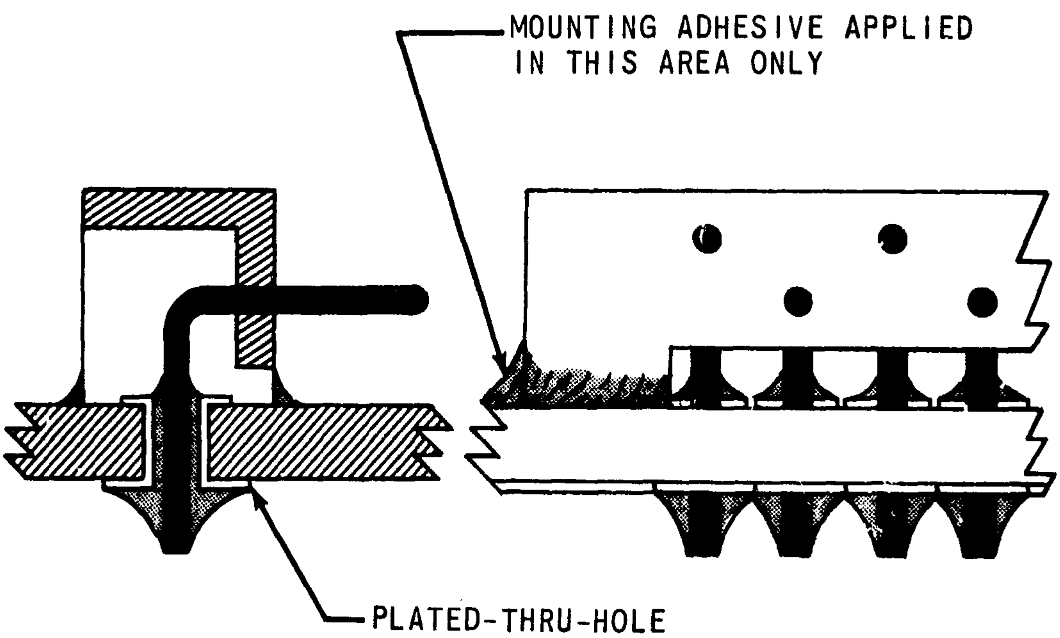


Figure 17. Molded Edge Connector Solder Joint.

F. STRAIN RELIEF

Strain relief to a solder joint is best accomplished by mechanically fastening the component and using a flexible electrical link between the component and the solder joint. The ideal approach to strain relief is to use components having small, stranded or ribbon leads for flexibility. See figure 18. Unfortunately, the present concept of packaging electronic hardware is to have component leads strong enough to support the component. As a result, manufacturers provide large lead sizes and a variety of lead materials. These are usually overrated, electrically. To use components that are available today, lead configurations must be created that minimize stresses to the joint. This is accomplished by permitting the leads to flex, as shown in figure 19.

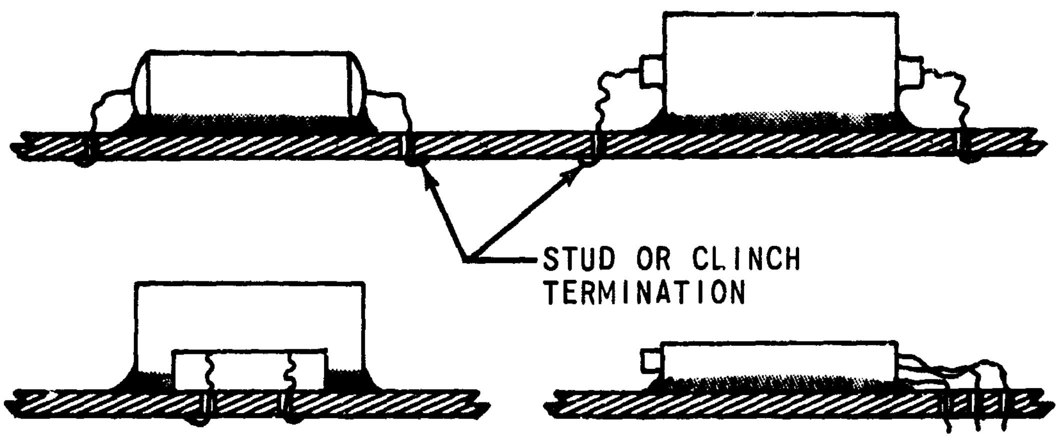


Figure 18. Flexible Lead Components.

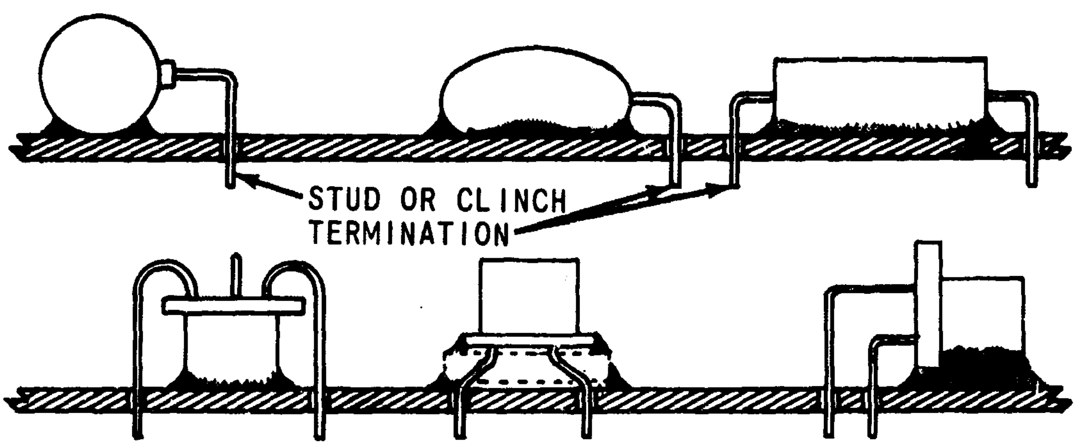


Figure 19a. Strain Relief Between Component and PWB.

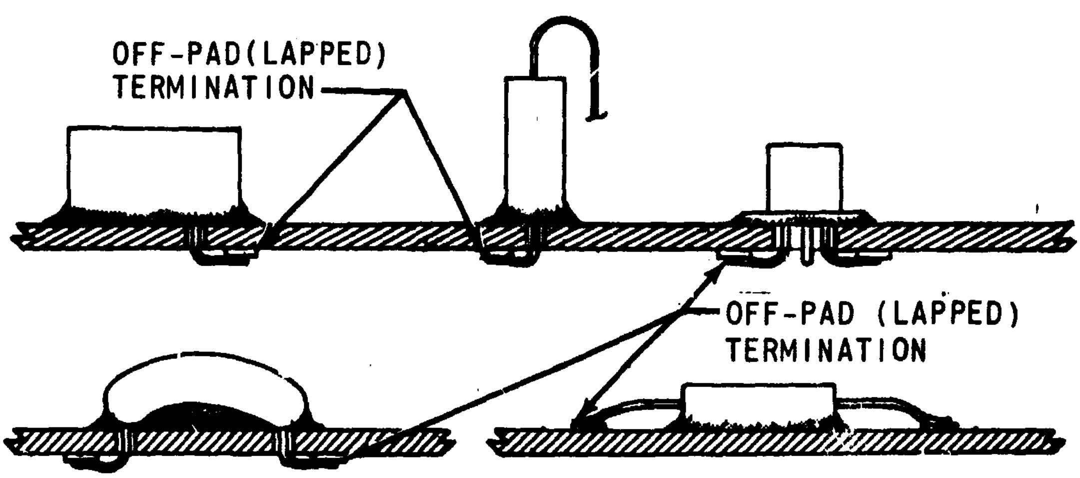


Figure 19b. Strain Relief Between Lead Hole and Solder Pad
Figure 19. Strain Relief with Standard Lead Components.

Flexing of the PWB is usually overlooked as a means of reducing the stresses to solder joints. Often without deliberate designing, flexibility between the components and the solder joint exists to some degree. Two methods are shown in figure 20. Fundamentally, the components are securely mounted to a base and utilizing the heavy leads to support a thin small flexible PWB, the connections are soldered. Both methods are conformally coated with a flexible material. The second method requires additional staking to secure the components. If the density of terminations by component leads is not sufficient to mechanically support the PWB mass, additional wire struts are used. Some of which may also be used as interconnections between the two board circuits in the first method. Some advantages a designer should consider are:

Thermal dissipation

Thermal uniformity

Component derating

Electrical shielding

High density packaging

Weight and size reduction

G. BASIC DESIGN CONCEPT

Based on extensive review of electronic hardware and found by current testing, it is imperative that the design minimize the mechanical forces, as generated by thermal mismatch of materials or produced by vibration, from being developed on the solder joint. The component should be independently secured with a flexible link for electrical interconnection to reduce the solder cracking problem. The following are basic considerations necessary for packaging design. In all cases the movement of the flexible link must not be restricted by coating, potting, etc.

a. Provide stress relief by length, size and bend of the component lead.

b. Interconnect component to solder termination by a highly flexible lead wire.

c. Mount components with heavy leads to a structural base and solder the leads to a thin flexible PWB which is free to yield under stress.

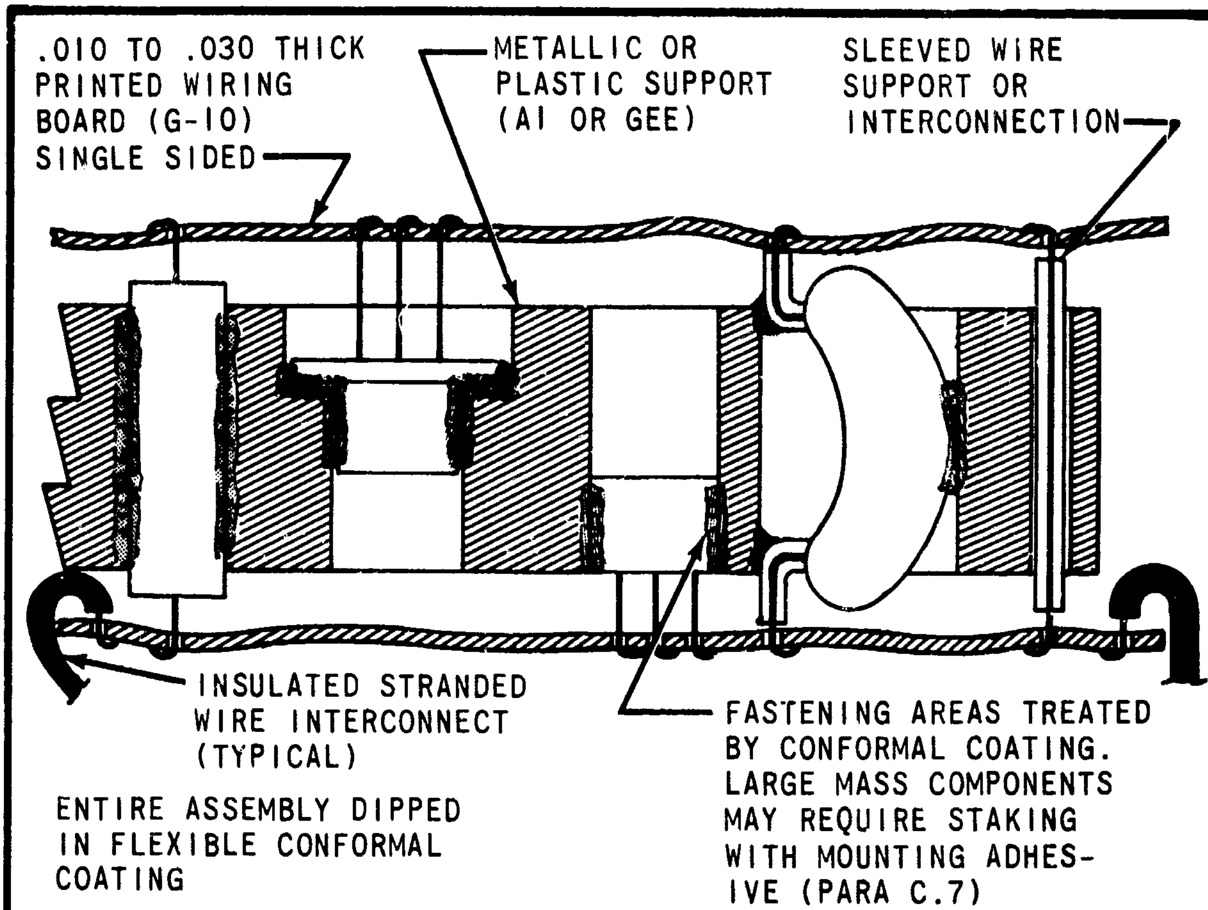


Figure 20a. Double Board Construction

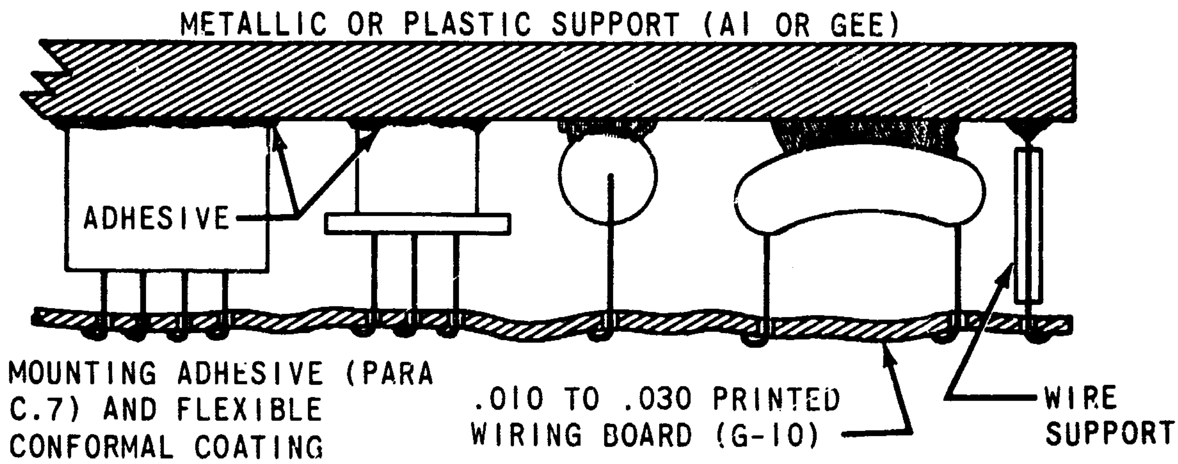


Figure 20b. Single Board Construction

Figure 20. Strain Relief with Flexible PWB and Standard Lead Components (Materials Shown are Typical)

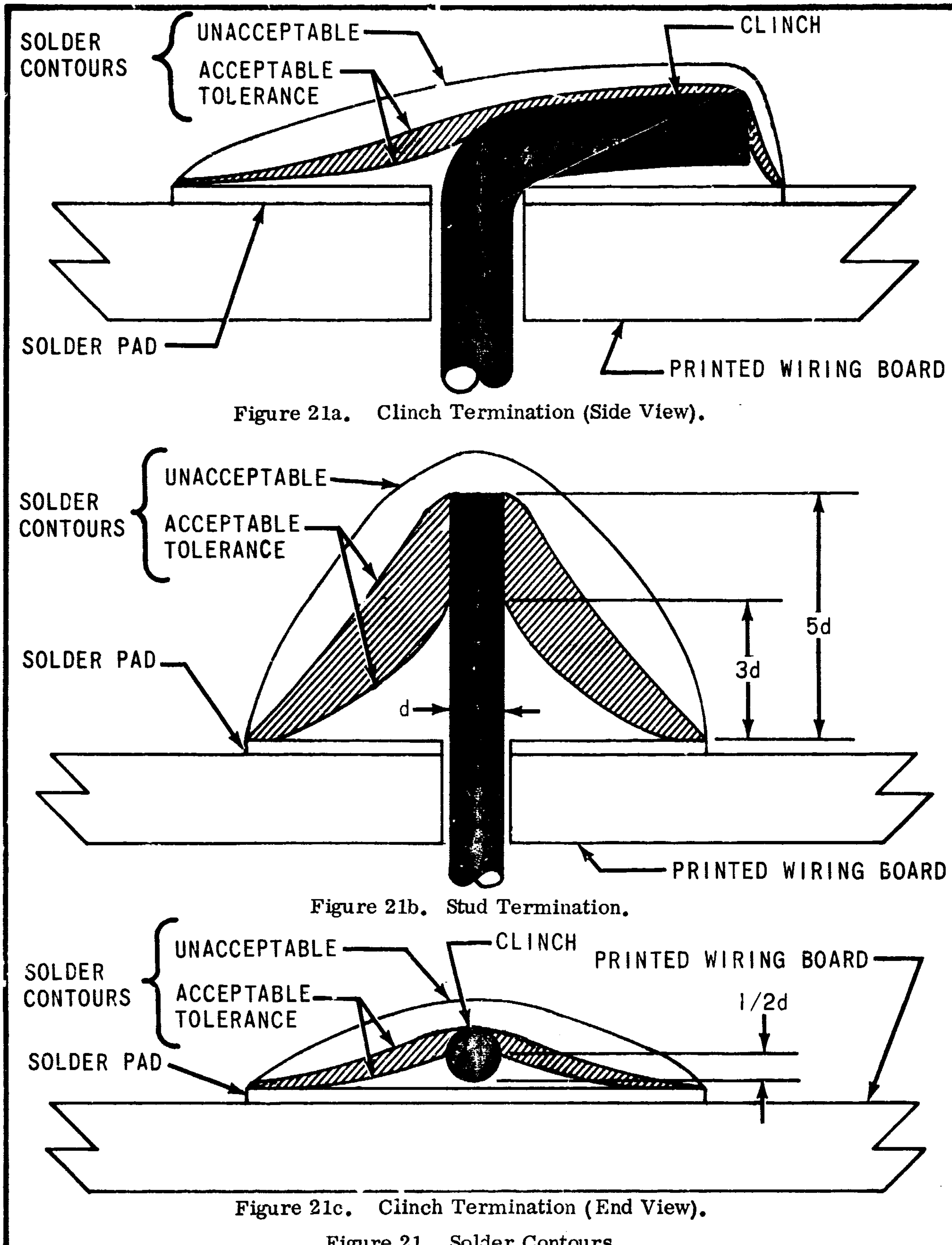


Figure 21a. Clinch Termination (Side View).

Figure 21b. Stud Termination.

Figure 21c. Clinch Termination (End View).

Figure 21. Solder Contours.

H. BASIC DESIGN VERIFICATION

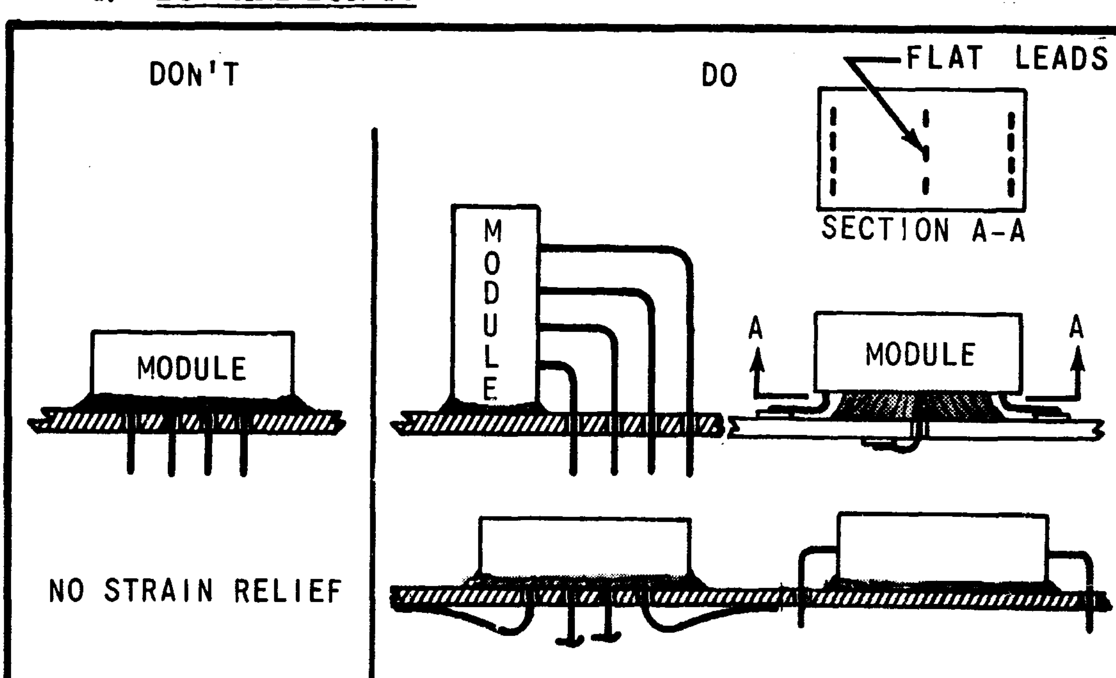
1. It is anticipated that many more packaging configurations, some of which may be more complex than the fundamental concepts discussed herein, will become evident. In order to establish confidence in the reliability of new packaging configurations, the following tests have been standardized by the Solder Committee. New packaging configurations should have been successfully tested prior to implementation.

a. Temperature cycling. The sub-assemblies should be temperature cycled in an air circulating oven from room temperature to -55°C to 100°C and back to room temperature at a rate not to exceed 5°C per minute. Soak time at each temperature extreme should be 15 minutes, minimum. The duration of each cycle should average 2 hours. An inspection of each joint under 15X magnification should be performed prior to test and after 10, 25, 100 and 200 cycles.

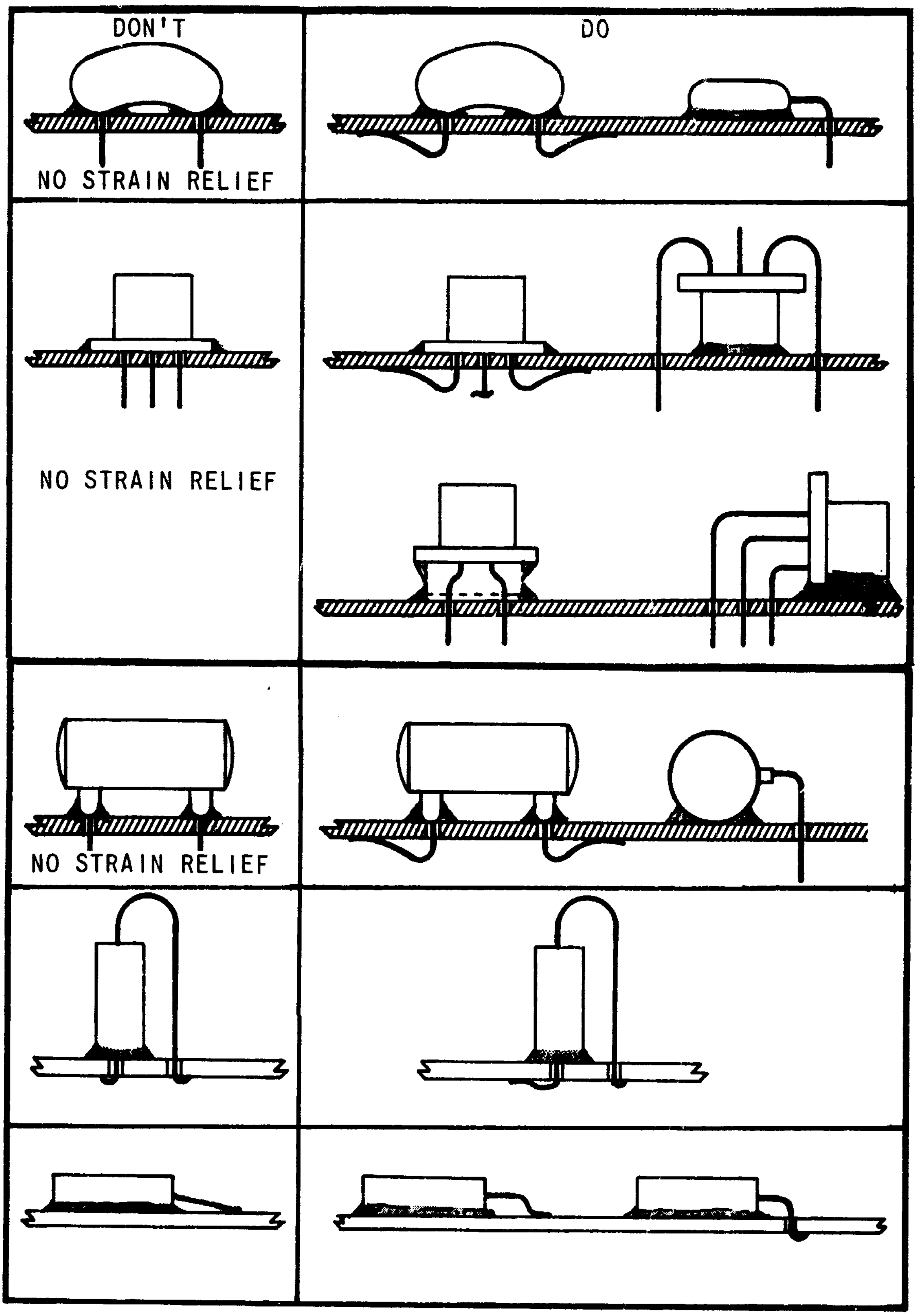
b. Vibration. After completing the temperature cycling test, the sub-assembly should be subjected to vibration equivalent to the requirements, plus a safety factor, dictated by design that the sub-assembly will see in usage or acceptance testing.

2. Complete assurance is established if there are no cracked solder terminations found after 200 thermal cycles and vibration testing when examined under a minimum of 15X magnification.

I. DO'S AND DON'TS



I. <u>DO'S AND DON'TS</u> (con't)



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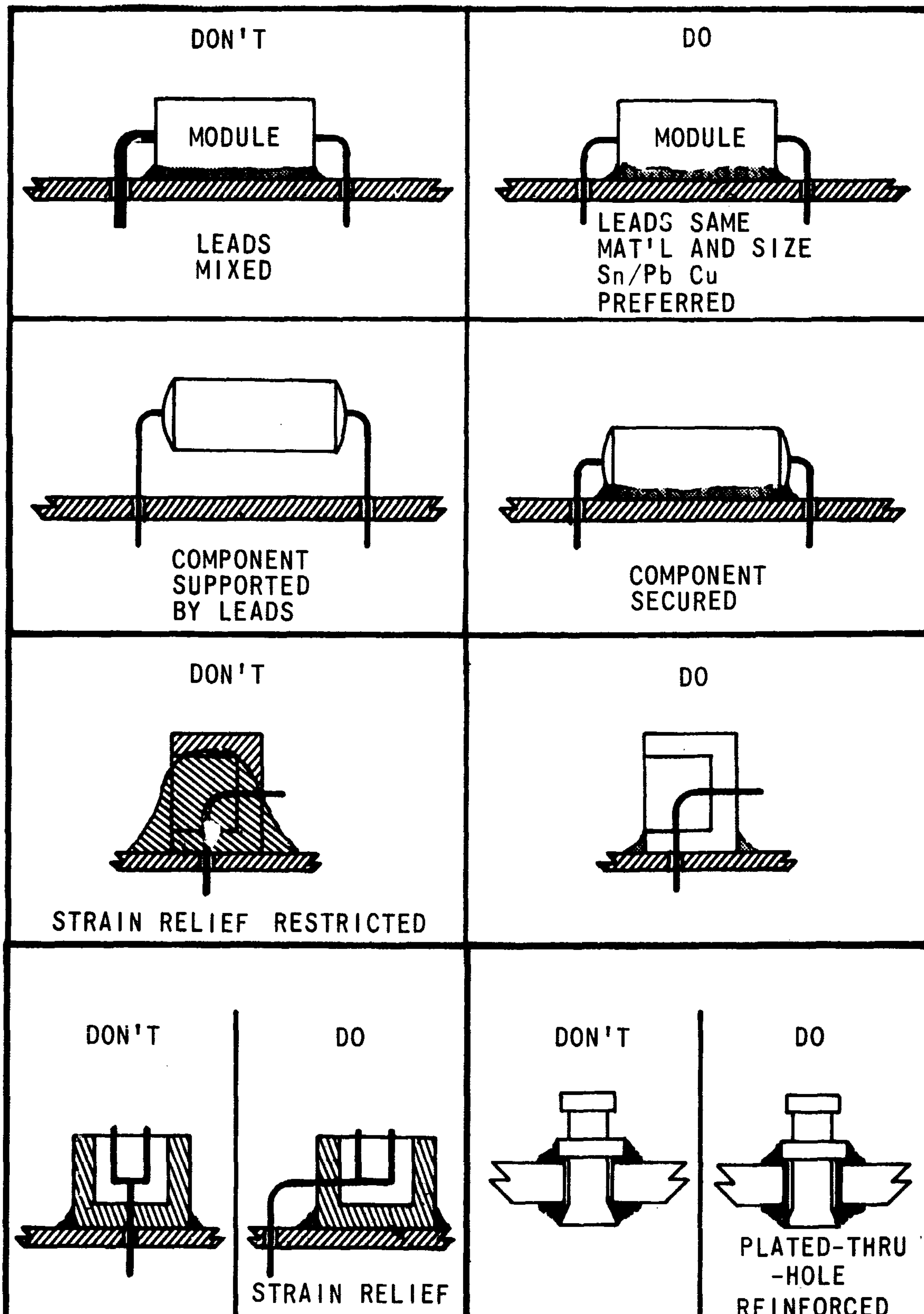
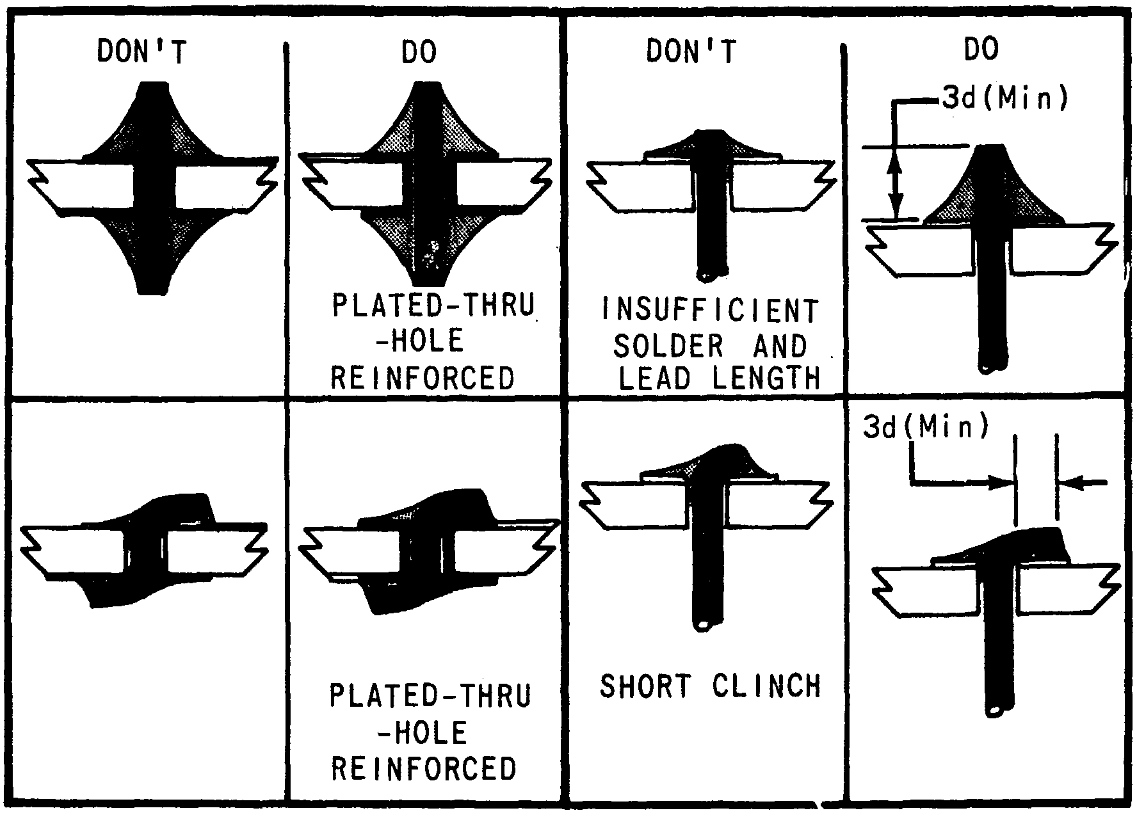


I. DO'S AND DON'TS (con't)



J. CONCLUSION

It is concluded that the reliability of electronic hardware can be improved by placing more emphasis on packaging design and by understanding the causes of structural failure in solder joints.

K. SOLDER COMMITTEE

The Solder Committee was formed by direction from Mr. Hermann K. Weidner, Director, R&D Operations, to investigate cracked solder joints in printed wiring boards. The committee operates under a Charter dated 7 February 1967, titled "Cracked Solder Joint Ad Hoc Committee". The committee consists of the following:

Mr. E. Ray Van Orden, Chairman, R-ASTR-P
Mr. Joe H. Burson, R-P&VE-PMS
Mr. Marlin J. Berkebile, R-QUAL-RP
Mr. R. B. Gibson, R-SE-P

April 15, 1968 APPROVAL NASA TM X-53731

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

E. Ray Van Orden

E. Ray Van Orden
Chairman, Solder Committee

Hermann Weidner

Hermann K. Weidner, Director
Research and Development Operations