Walt Williams

NASA SP-5002

TECHNOLOGY HANDBOOK

Office of Technology Utilization

RELIABLE ELECTRICAL CONNECTIONS

from George C. Marshall Space Flight Center
Huntsville, Alabama

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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TECHNOLOGY HANDBOOK

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RELIABLE ELECTRICAL CONNECTIONS

Third Edition

Prepared under the direction of
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

The Administrator of the National Aeronautics and Space Administration has established a Technology Utilization Program for "the rapid dissemination of information . . . on technological developments . . . which appear to be useful for general industrial application." From a variety of sources, such as NASA Research Centers and NASA contractors, space-related technology is screened and that which has potential industrial use is made generally available. Thus American industry will receive information from the Nation's space program about developments in operating techniques, management systems, materials, processes, products, and analytical and design procedures. This publication is part of a series designed to provide this technical information.

The Director of Technology Utilization
National Aeronautics and Space Administration
Washington, D.C.

PREFACE

A space vehicle is no more dependable than its components. Because most functional components of space vehicle systems are electrical or electromechanical, it is imperative to obtain the greatest possible dependability in electrical components.

Many companies produce electrical and electronic equipment acceptable for general commercial applications which utilize electrical connections primarily to provide electrical continuity. This equipment cannot withstand the vibration and G-loads imposed during vehicle flight.

To insure the desired quality and reliability in missile components, more rigorous standards and specifications must be developed than those now in general use by industry and the military services. Such standards and specifications must be adopted exclusively as the criterion for design, manufacture, and acceptance of space vehicle components.

Through years of testing and experience, ABMA and NASA have developed standards and specifications which will result in greater system reliability. These standards stress techniques, proper tools, correct materials, workmanship, and, most important, 100 percent inspection in all areas: receiving, in-process, and final.

Standards and specifications are futile unless the assembler has been trained in the proper techniques or the inspector has been trained to recognize unacceptable work. Good workmanship and quality control remain the key to dependability.

To achieve good workmanship and quality control, training sessions should be established in the plant to

instruct personnel in proper techniques, tools, materials, and standards. During this training it may be necessary for the students to unlearn common practices not acceptable for space vehicles.

Personnel training should also include shop foremen and supervisors so they can differentiate between proper and improper work. Satisfactory supervisory training will result in most improper work being detected prior to inspection, thus reducing time spent and expense incurred in rework.

Specifications and worker training are wasted, however, without thorough manufacturing inspection; therefore, it will be necessary to give inspectors training similar to that given the assemblers. The inspector trained for, and capable of, performing acceptable work becomes more capable of recognizing acceptable or unacceptable work performed by others.

After successful completion of the training course, it will be necessary to review and evaluate each individual assembler and inspector constantly to prevent a relaxation of the quality of workmanship. It may be necessary to return personnel to training sessions for refresher courses or to learn new techniques.

Design is another factor which can affect workmanship and reliability. Poor design, such as too many wires in a solder cup or terminal, may force compromises which conflict with the requirements of the specifications. It is imperative, therefore, that designers take specifications into consideration to preclude the possibility of compromise which could affect component reliability.

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A. Tools

A craftsman is known by the tools he keeps and how he keeps them. Good work may occasionally be turned out with poor tools, but this is the exception which helps to create poor reliability. The right tools, properly used and maintained, will increase your skill and the quality of your work, and will promote job satisfaction.

Always use the right tools for the job. The right tools will include at least the following:

- Round-nose bending pliers
- Long-nose pliers
- Diagonal cutting pliers
- Calibrated wire strippers
- Proper wattage solder iron and tip
- 60/40 rosin core solder
- Thermal wire strippers
- Solder aid
- Heat dissipator clamp
- Variable voltage control
- File
- Bristle brush
- Wet sponge
- Approved cleaning fluid

B. Work Area

Enough light, properly directed, is a prime requirement for quality work. Adjust lights to illuminate the work.

A neat and orderly work area contributes to quality work by reducing confusion to a minimum. Arrange tools within easy reach and have a specific place for each tool. Delays caused by misplaced or inaccessible tools can lead to poor workmanship and excessive rework.

C. Safety

The safety of a work area depends essentially on the development and maintenance of safety practices by all personnel in the area. A general list of these practices appears below; other practices, for special areas, should also be developed and maintained.

1. Place soldering iron where you don't have to reach across or around it. Place soldering iron in upper corner of work area when not in use.
2. When unsoldering a wire make certain there is no tension or spring to the wire. Safety glasses should be worn during this operation to keep hot solder from eyes.
3. Plug iron into proper socket and keep plug free from strands of wire or metal.
4. When cutting wires, keep open side of cutter away from body, keep wires in your own area, and prevent outside wires from entering your area.
5. Disconnect all power before working on a chassis.
6. Determine that tips of screwdrivers are square and sharp, and only use screwdrivers for the specific work they were designed: to screw and unscrew screws.
7. Plug air hose into connection nearest work area; keep hose out of aisle, and keep excess hose reeled in.
8. When cleaning with air hose, use pressure controlled nozzle with minimum pressure, making certain that air stream is kept away from people. Do not clean clothes with air hose.

9. When working with solvents, keep minimum amount of solvent in safety can, DO NOT SMOKE, and don't spill solvent over work area.
10. Wear safety glasses when cutting wires, soldering, using solvent, or using air hose.
11. Women in work area, including visitors, should wear low or cuban-heeled shoes with closed toes and heels. Slacks, overalls, and hair nets are among the items of apparel women workers should wear in certain designated areas. Loose clothing must not be worn around moving machinery.

D. Handling of Wires and Components

1. Insulation Stripping

a. Use thermal type stripper on wire sizes 22 awg and smaller. This type stripper should be used on all wire sizes wherever practicable. See figure 1.

NOTE

Teflon becomes toxic at 400° F and the toxicity increases with temperature increase. When stripping with thermal stripper, an adequate exhaust or ventilation system is necessary.

b. Non-adjustable, factory-set, cutting type strippers may be used on wires larger than 22 awg. See figure 2.

c. Use correct stripping hole for the gauge of wire being stripped when using cutting type stripper. Check calibration of cutter frequently.

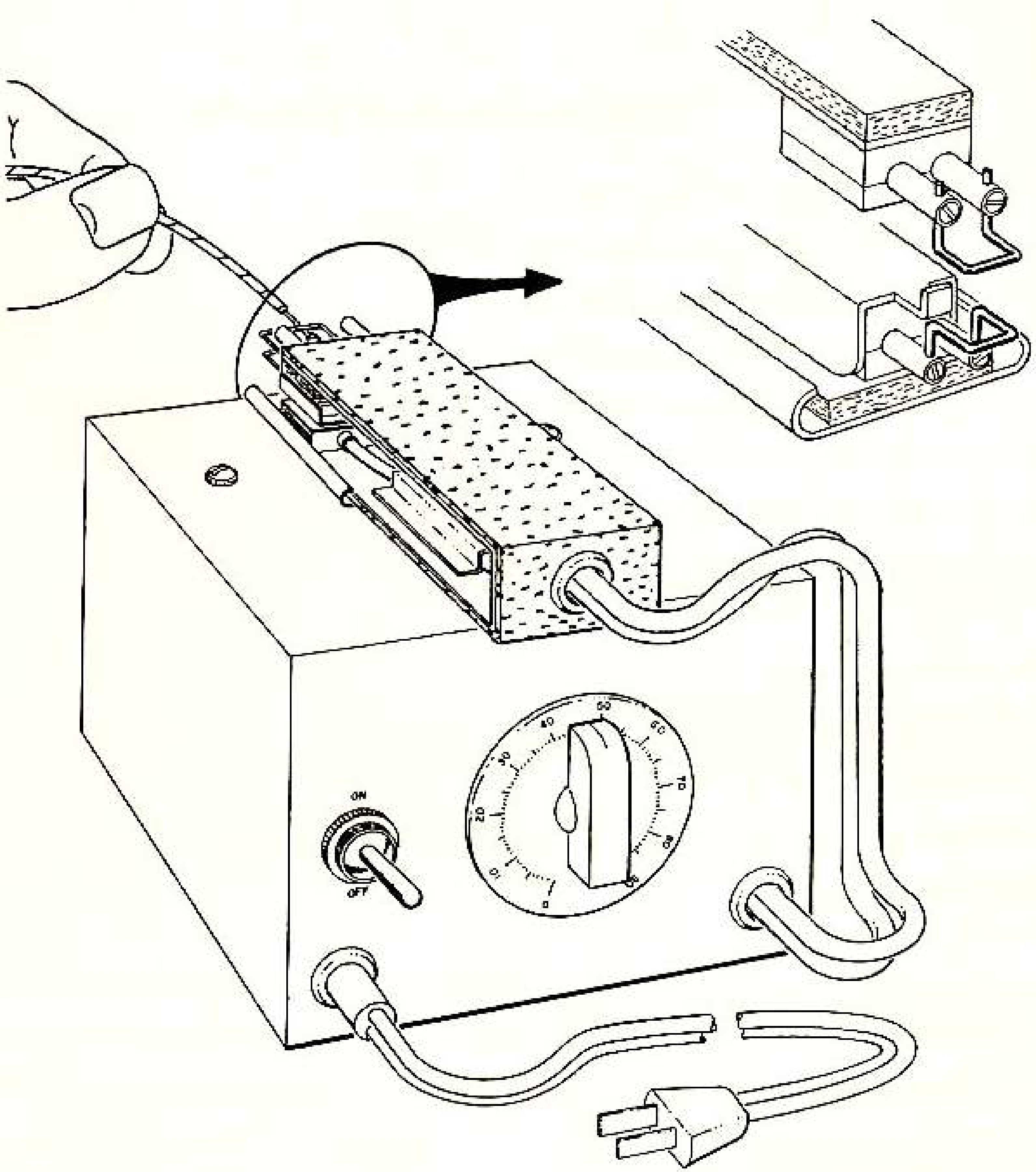


Figure 1. Thermal Stripper

d. After stripping, strands of wire should be twisted firmly together in the same direction as the normal lay of the wire.

e. Stripped wire with nicked or cut strands is not acceptable.

f. Certain types of cutting strippers must not be used under any circumstances. The type shown in figure 3 will invariably cut and nick strands of wire.

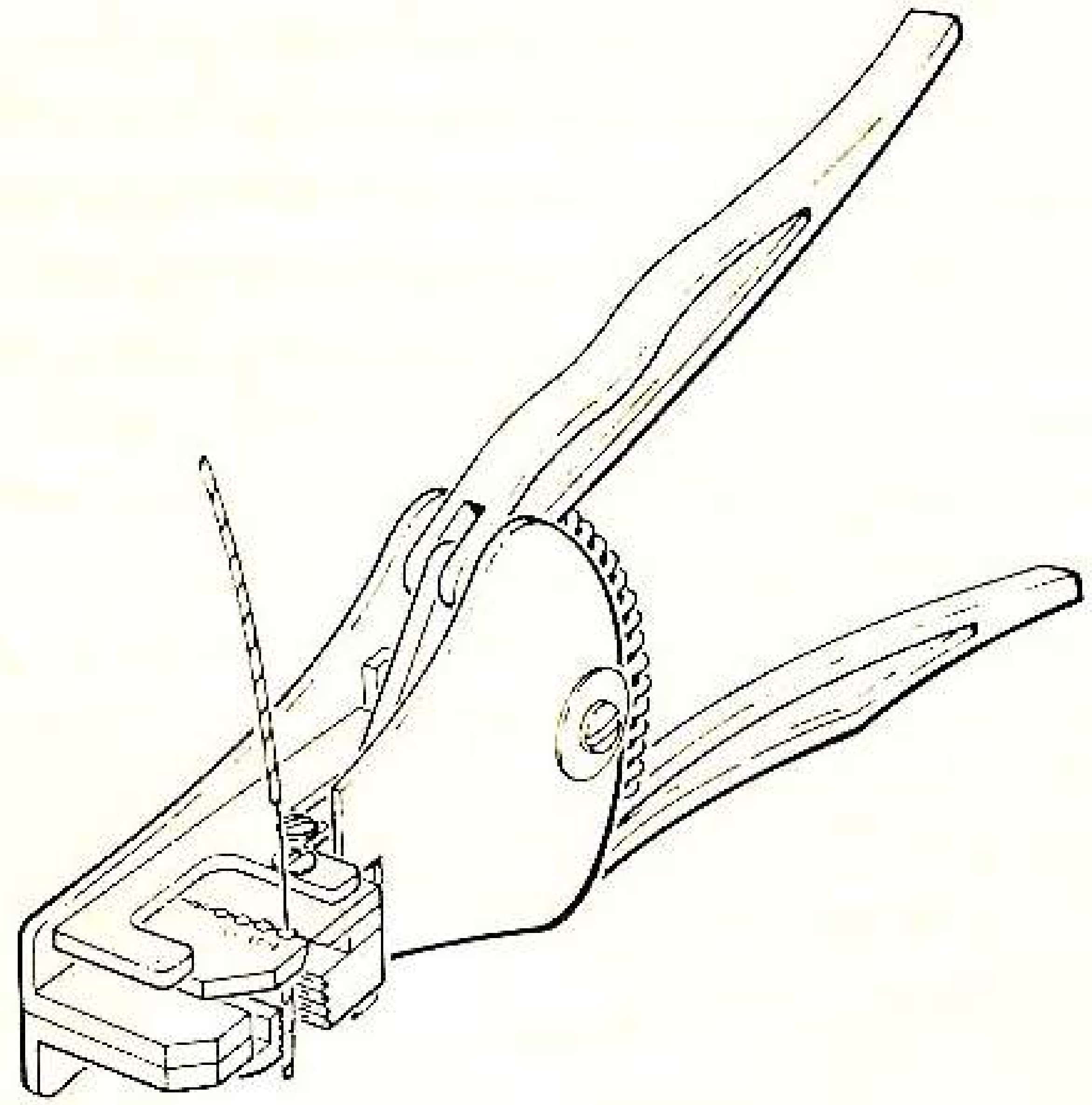


Figure 2. Proper Cutting Type Stripper

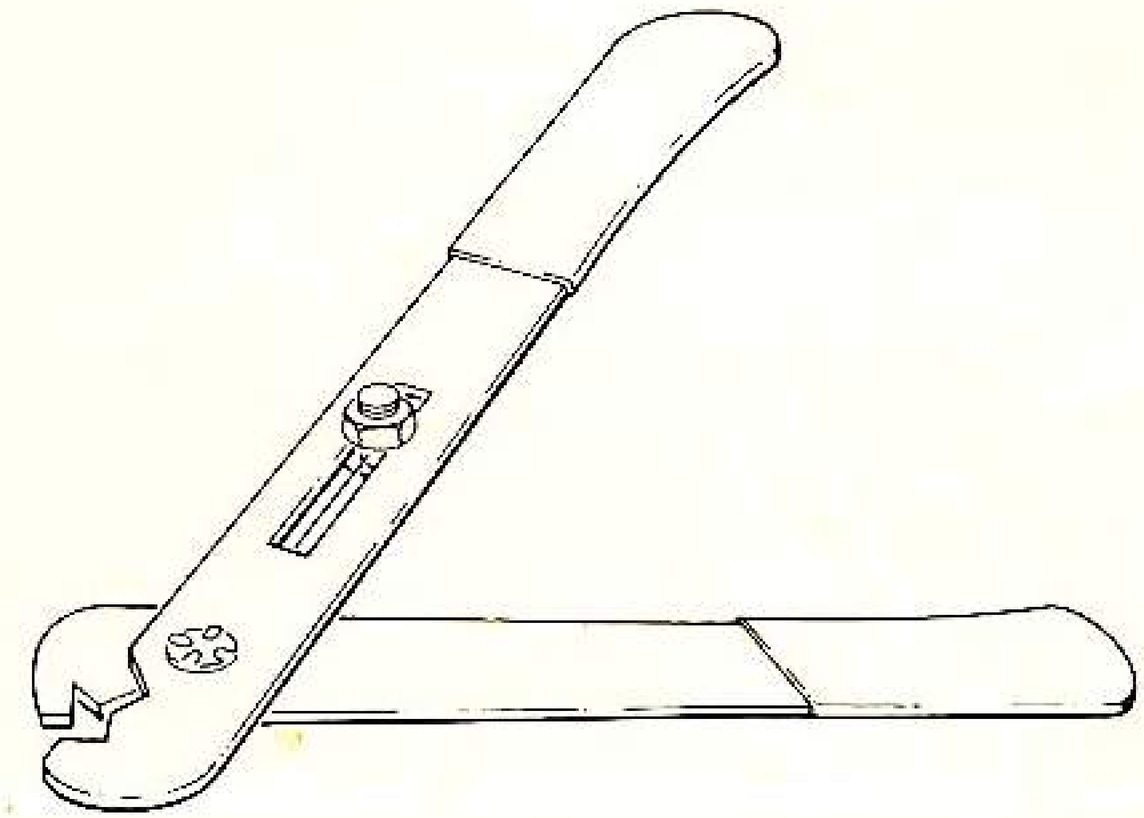


Figure 3. Improper Cutting Type Stripper

2. Insulation Damage

Insulation shall not show evidence of damage by excessive heat from the soldering operation. Slight discoloration as a result of thermal stripping is permissible.

3. Insulation Gap

The maximum distance that insulation will extend from the solder connection shall be no larger than the diameter of the wire, including the insulation. The minimum distance the insulation will extend from the solder connection shall be no less than 1/32 inch as shown in figure 4.

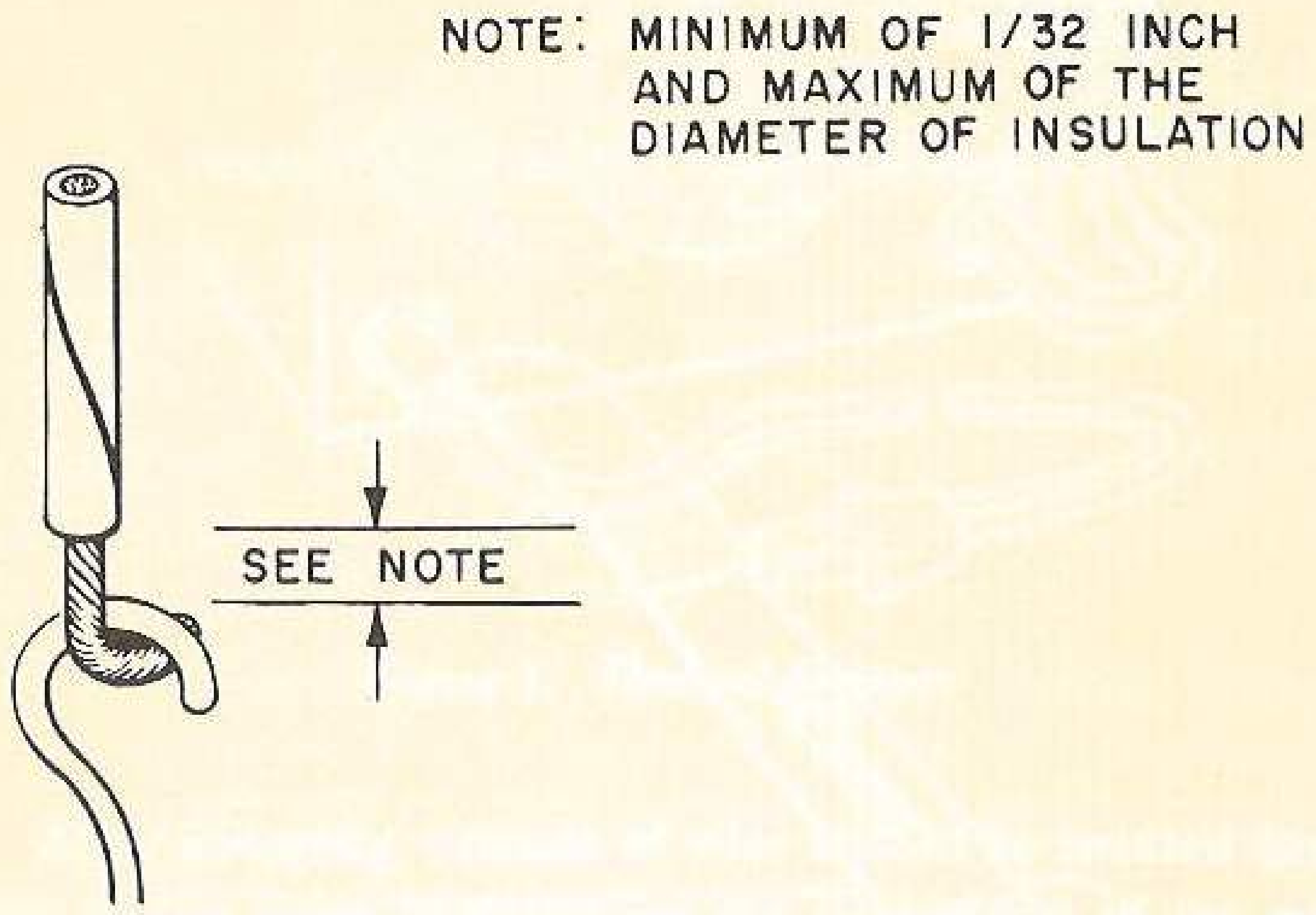


Figure 4. Distance of Insulation from Solder Connection

4. Cleaning Component Leads

Cleanliness is the key to reliable soldering. All dirt, grease, oxide, and scale should be removed from the surface to be soldered. Leads must be cleaned bright regardless of appearance, since necessary processing by the manufacturer often leaves an oxide formation on component leads. An efficient cleaning tool can be made by using ½ inch braid mounted in a spring-type tool such as the one pictured in figure 5.

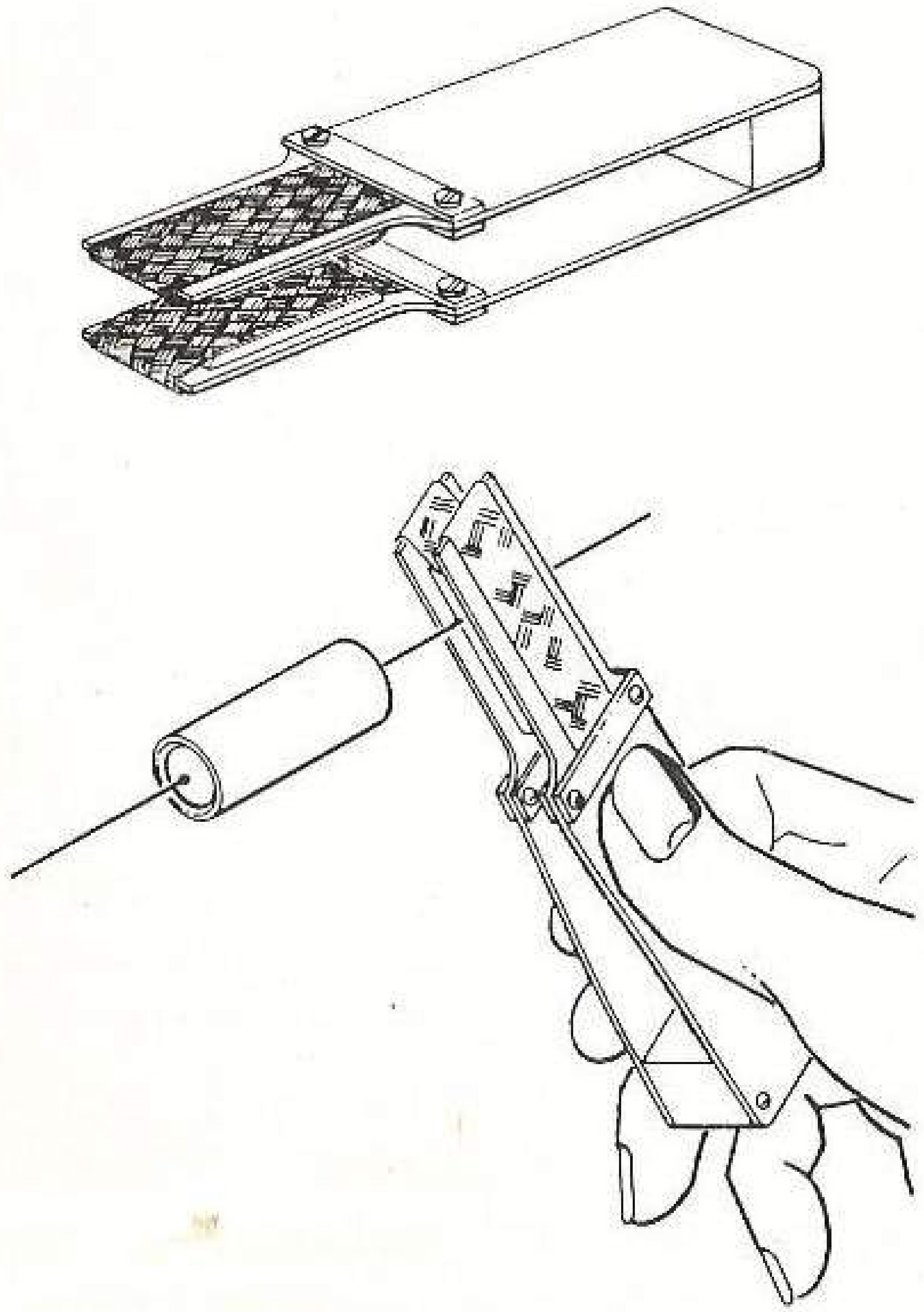


Figure 5. Cleaning Tool

5. Heat Shunts

a. A heat shunt must be used when soldering diodes, meters, or other parts and equipment which might be damaged by heat. Heat shunts shall be of such material, size,and shape as to afford adequate protection to parts while offering minimum interference to the soldering procedure. Shunts should also permit rapid application and removal with a minimum of effort. They may be held in place by friction, spring tension, or any other suitable means which will preserve the finish and insulation of the component being soldered. See figure 6.

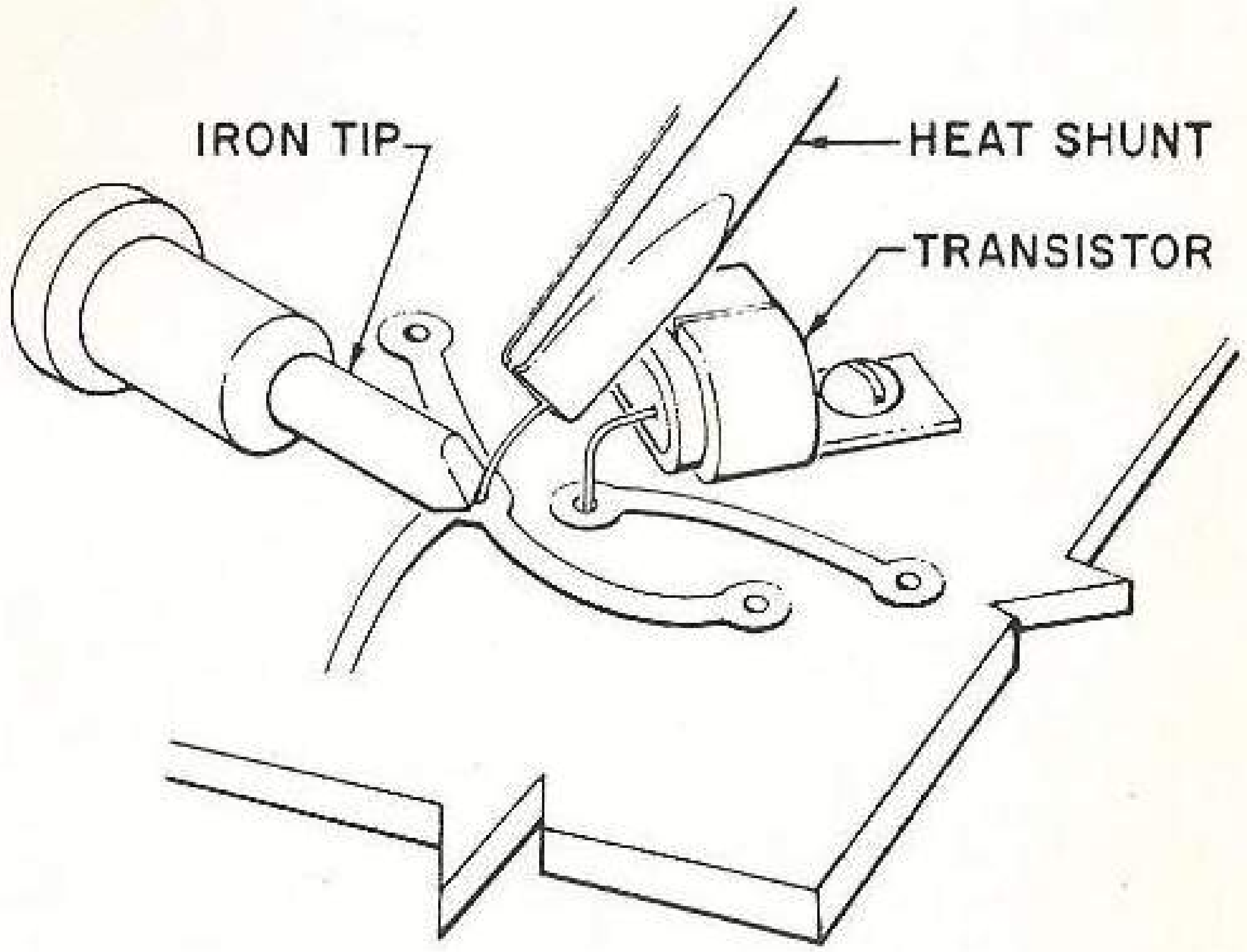


Figure 6. Heat Shunt

b. Movement of meters and other sensitive instruments in a box assembly must be protected by a shunt across the positive and negative terminals. This shunt must be maintained until the instruments become an integral part of their respective circuits.

6. Vibration Bend

All wires or leads terminated at a solder connection shall have sufficient slack in the form of a gradual bend. In applications where multiple wires are routed from a common cable trunk to equally spaced terminals, the vibration bends shall be uniform in length to prevent stress on any one wire. See figure 7.

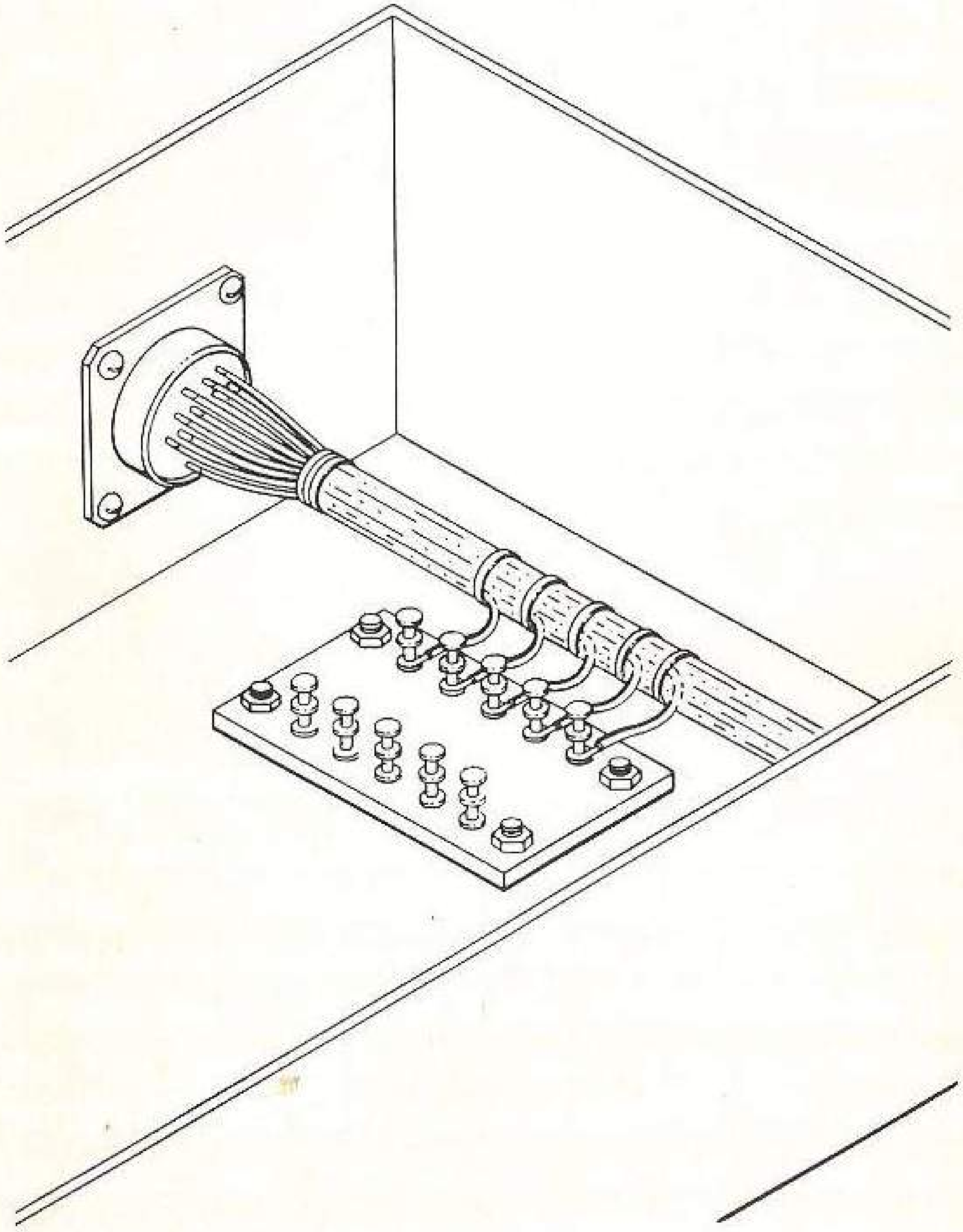


Figure 7. Vibration Bend

7. Hermetically Sealed Relays

a. A brittle glass material is used to seal the base of terminals on hermetically sealed relays. This glass seal is very fragile, and any flexing or bending of the terminal will usually cause the glass to break and destroy the seal.

b. Inspect each glass seal prior to installation.

c. Never straighten or bend the terminals.

d. Avoid placing stress on terminals when lacing wires that are terminated to a relay.

8. Tantalytic Capacitors

Special care should be exercised when bending tantalytic capacitors and other components with welded leads. The bend should be measured from the weld rather than from the component body. See figure 8.

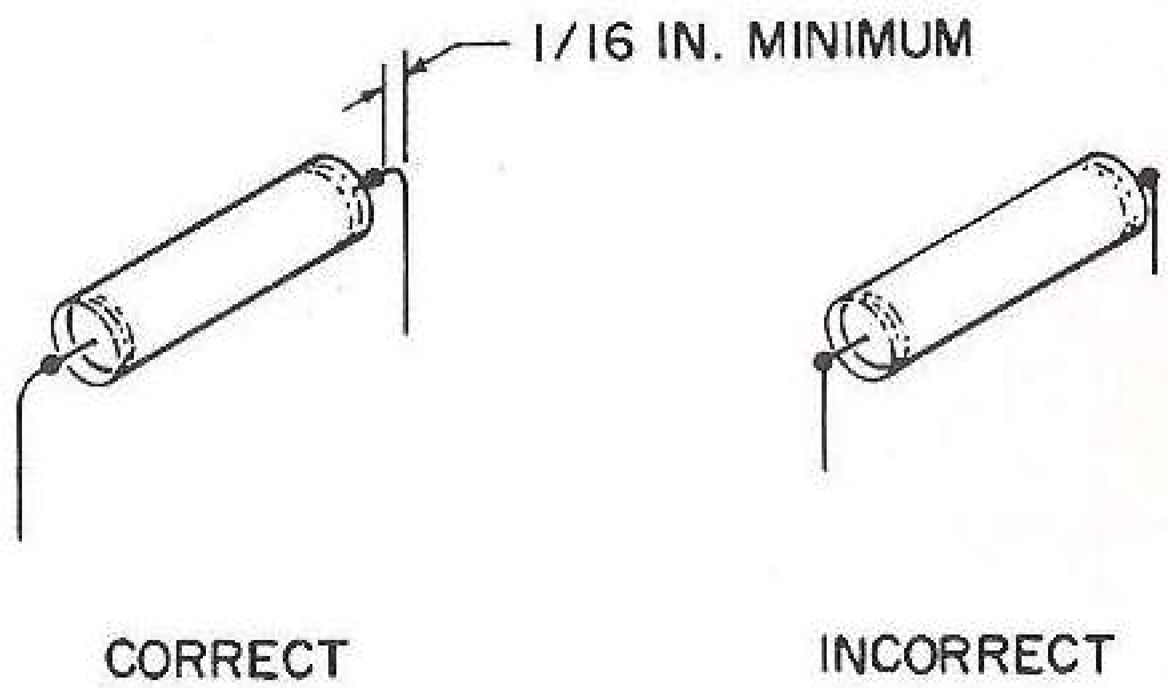


Figure 8. Welded Leads

E. Soldering

A good solder joint has the following characteristics: shiny bright appearance, no porosity, good fillet between conductors, good adherence to both parts, and no excess flux or solder. The contour of the wire shall be visible after soldering as shown in figure 9.

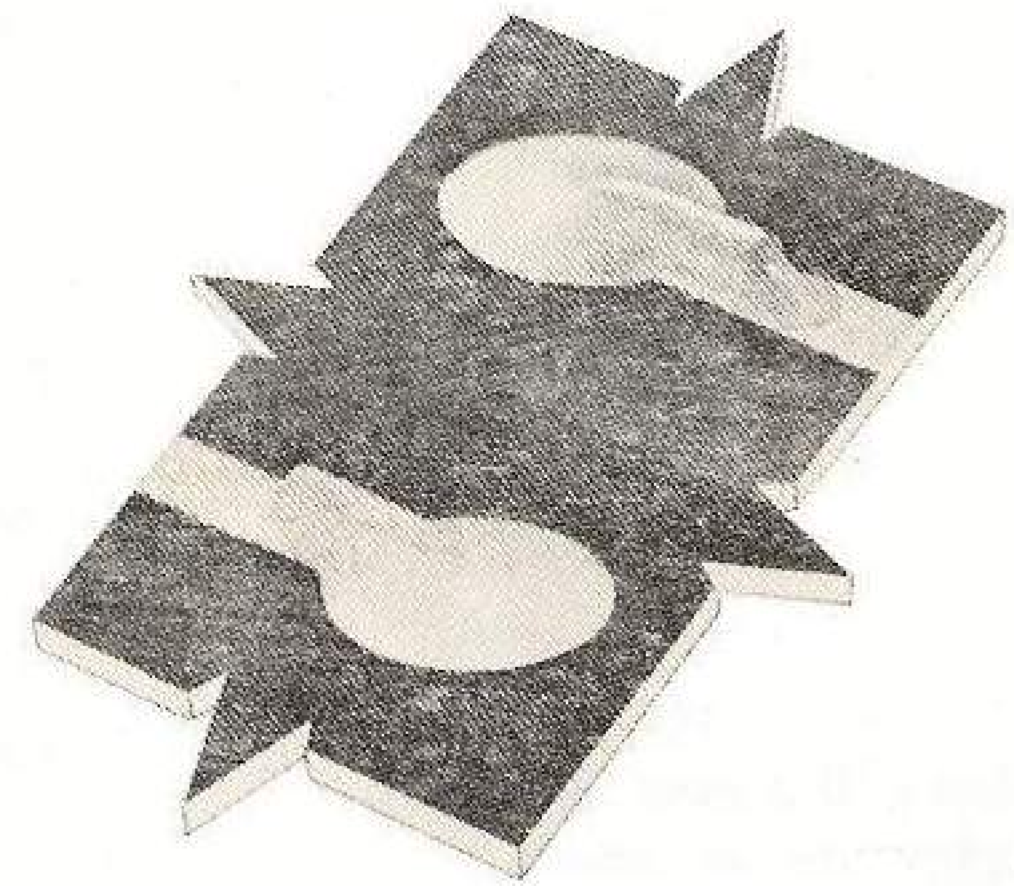


Figure 9. Good Solder Joint

1. Specifications

a. The solder core shall contain only noncorrosive and nonconducting rosin-type fluxes. The flux shall have a melting point below the liquidus of the solder with which it is used.

b. Solder paste, acid type fluxes, or other corrosive or conducting type fluxes shall not be used. Rosin core solder type SN 60 (60% tin, 40% lead) shall be used unless otherwise specified. Eutectic solder (63% tin, 37% lead) may be used on miniature printed circuits and other components adversely affected by heat.

c. Solder will usually contain sufficient flux; however, additional flux may be required for some applications, such as removing excess solder with stranded wire or soldering nickle-plated wire. This flux must also be non-corrosive and non-conductive; in addition, it should be compatible with the flux contained in the solder.

2. Solder Temperatures

Solder will melt at temperatures lower than the melting point of either of the base metals. Tin melts at 450 degrees F and lead melts at 621 degrees F. Solder melts at 361 F to 576 degrees F, depending on lead content, but does not melt sharply; it first becomes plastic, then mushy, and finally completely liquid. Actual soldering is done at the liquid stage.

Solder solidifies in much the same manner; that is, it does not solidify instantaneously: first it gets mushy, then plastic, and finally becomes solid. If the joint is moved during these transition stages the solder will become coarse grained, resulting in a poor connection.

The temperature at which solder is kept molten (liquid) and the time it is kept molten at any temperature is critical because molten solder will absorb atmospheric gases. If excessive temperatures have been used or the solder kept molten too long, the solder will appear granular and dull gray when cool. This could result in a poor, high resistance connection.

3. Fluxing and Heating

a. Flux must be applied to a surface before it gets hot enough to melt the solder. With a rosin core solder, application occurs automatically if the solder is held perpendicular to the work.

b. Flux will carbonize and hinder soldering rather than aid it if excessive temperatures are used.

c. Before solder is applied, the surface temperatures of parts being soldered must be equal to or above the solder melting point before the solder is applied. Never let solder flow onto a surface cooler than the solder temperature.

d. Solder applied to a properly cleaned, fluxed, and heated surface will melt and flow without direct contact with the heat source. It will have a smooth even surface, feathering out to a thin edge. Improperly applied solder will exhibit a "built-up" irregular appearance.

e. Soldered parts must be held rigidly until solder has set. A wire holding tool is shown in figure 10.

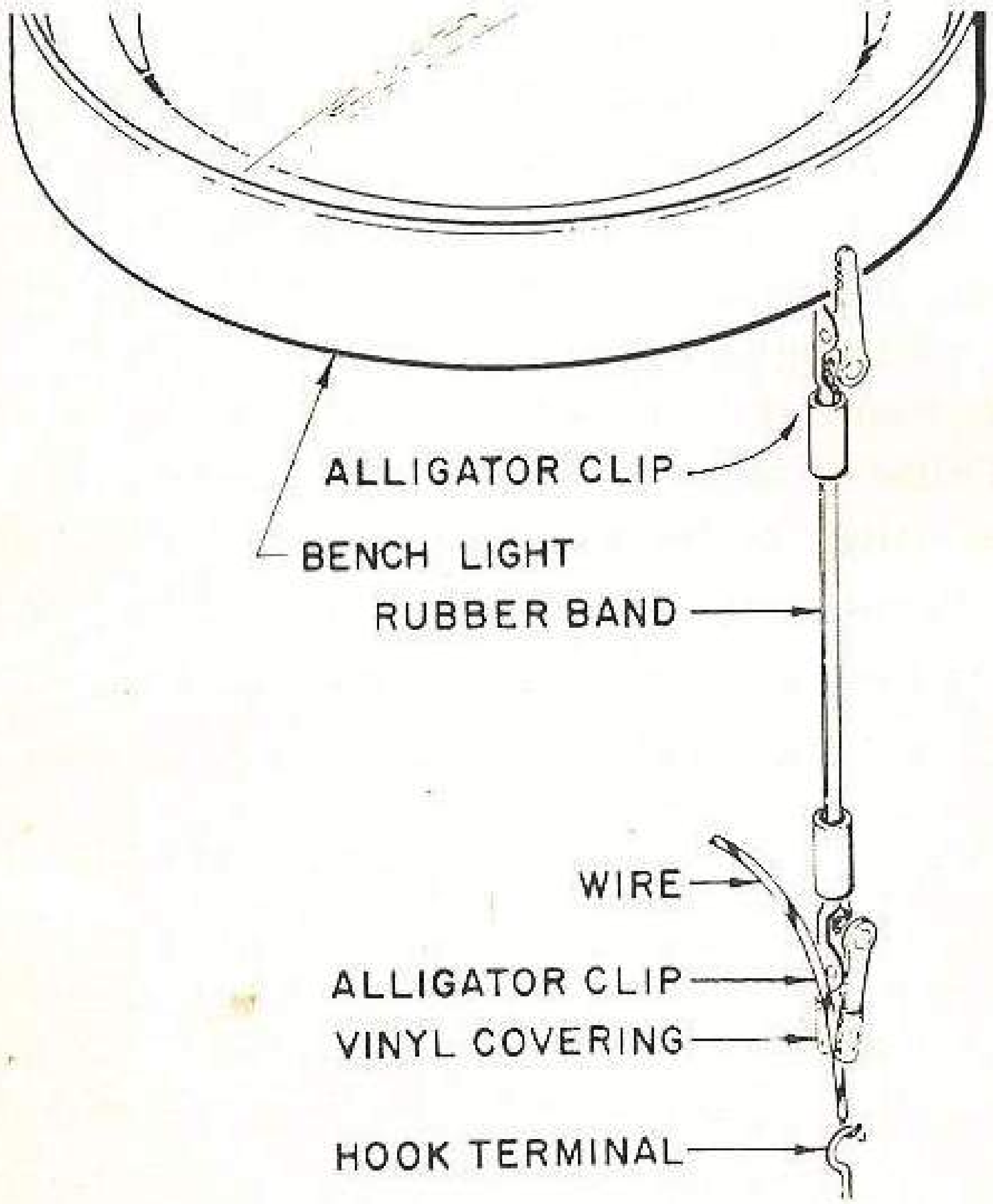


Figure 10. Wire Holding Tool

f. Excess flux shall be removed with a medium still bristle brush dipped into an approved solvent. See figure 11.

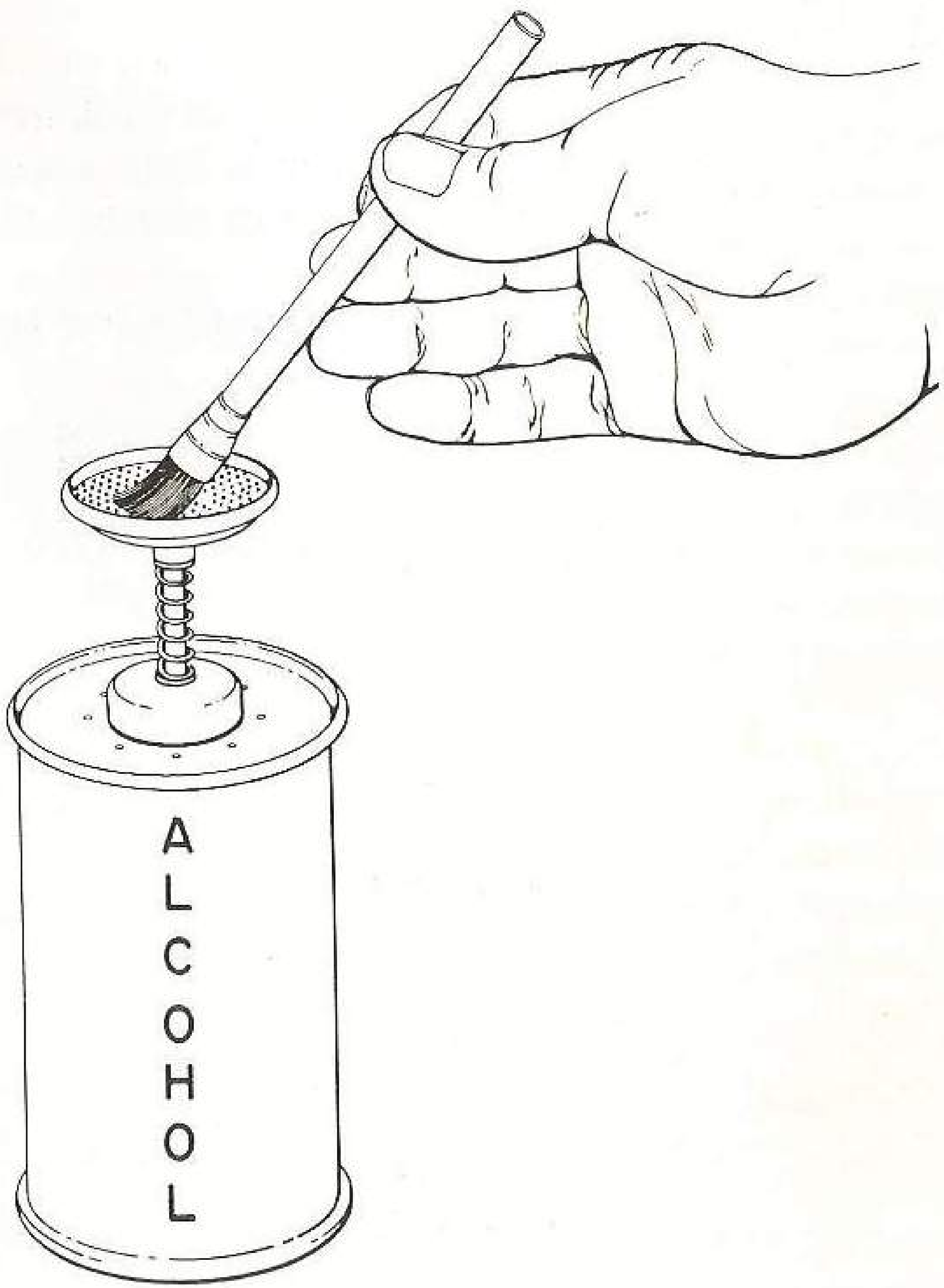


Figure 11. Brush and Solvent

4. Solder Application

a. Stranded conductors shall be tinned (pre-soldered) before soldering to terminals and other connections. A heat shunt, lightly gripping the wire, will prevent solder from flowing beneath the insulation during tinning and soldering operations. See figure 12. Tinning on the wire should only extend far enough to take full advantage of the depth of the terminal or solder cup. Tinning or solder beyond the terminals or solder pots on wire where flexing may occur will cause the wire to become stiff. This may result in broken connections. Care should be taken to avoid dripping or spraying solder when tinning conductors or terminals within equipment. Twist stranded wire in the original direction of the individual strands.

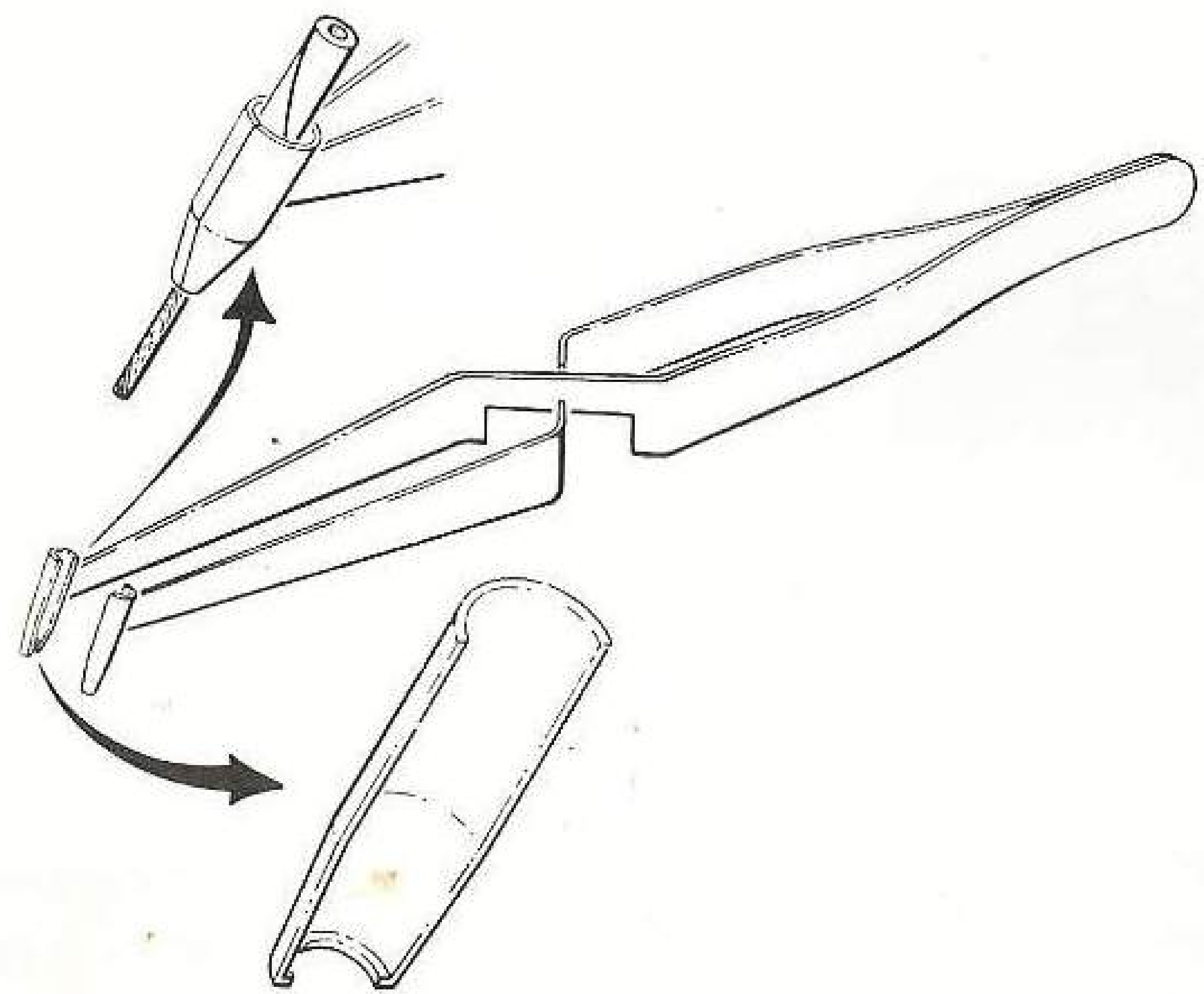


Figure 12. Heat Shunt

This will restore a rounded contour to the wire and thus facilitate the soldering operation. The correct method of tinning wire is illustrated in figure 13.

b. When soldering to a switch, relay, terminal board, etc., the joint shall be made with a minimum mechanical connection. Generally, the wire shall be formed into a small loop and hooked around the terminal through a guide hole; in no case shall a wire be hooked more then 180 degrees around a terminal. The parts to be joined shall be held together so they will not move in relation to one another during the soldering operation, and the joint must not be disturbed until the solder has completely solidified. All leads to a terminal should have slack in the form of a slight bend.

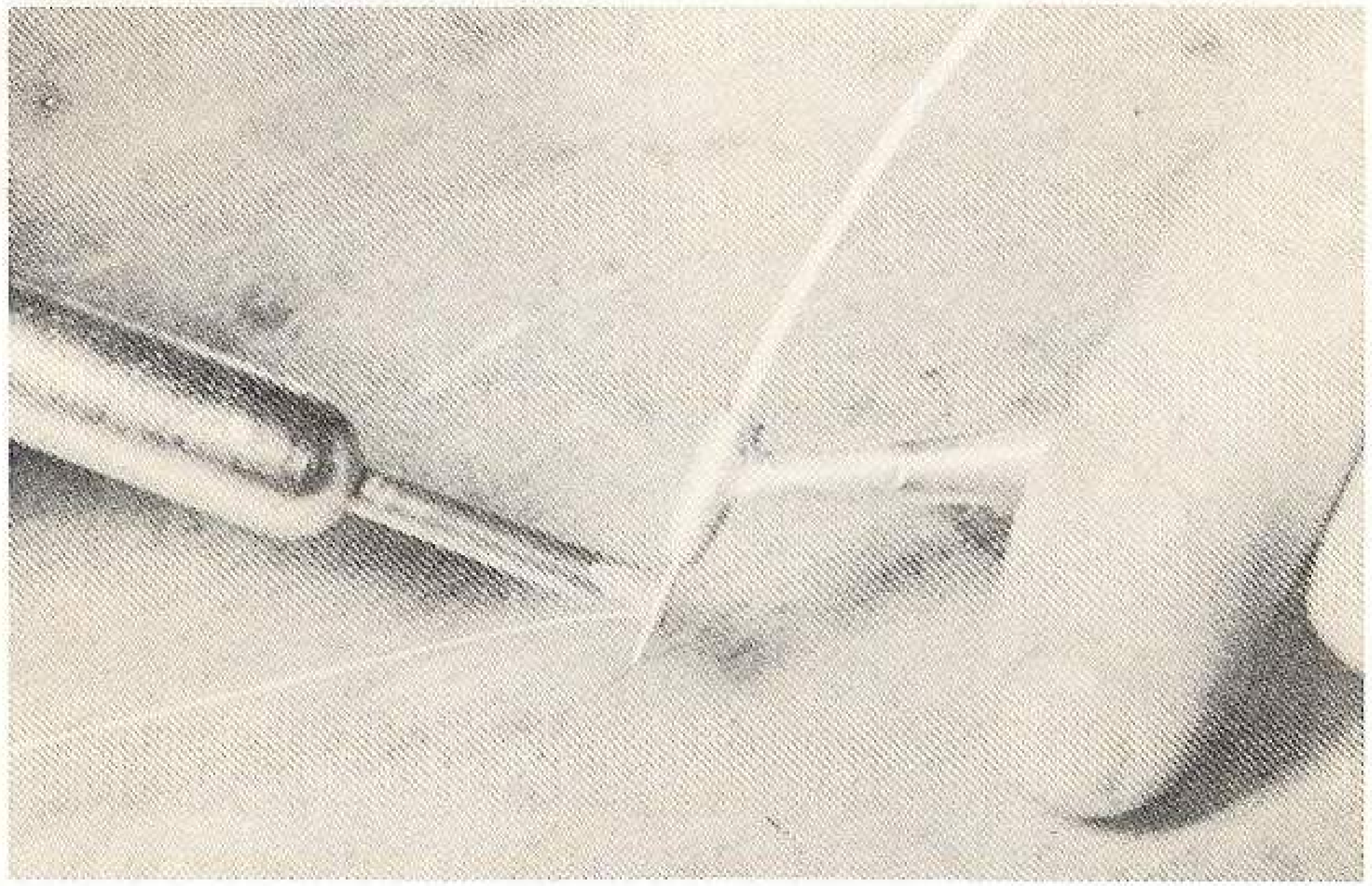


Figure 13. Correct Method of Tinning Wire

c. Apply soldering iron tip to terminal so maximum heat will be transferred to the part being soldered and

maximum protection afforded wire insulation or parts adversely affected by excessive heat. An example is shown in figure 14.

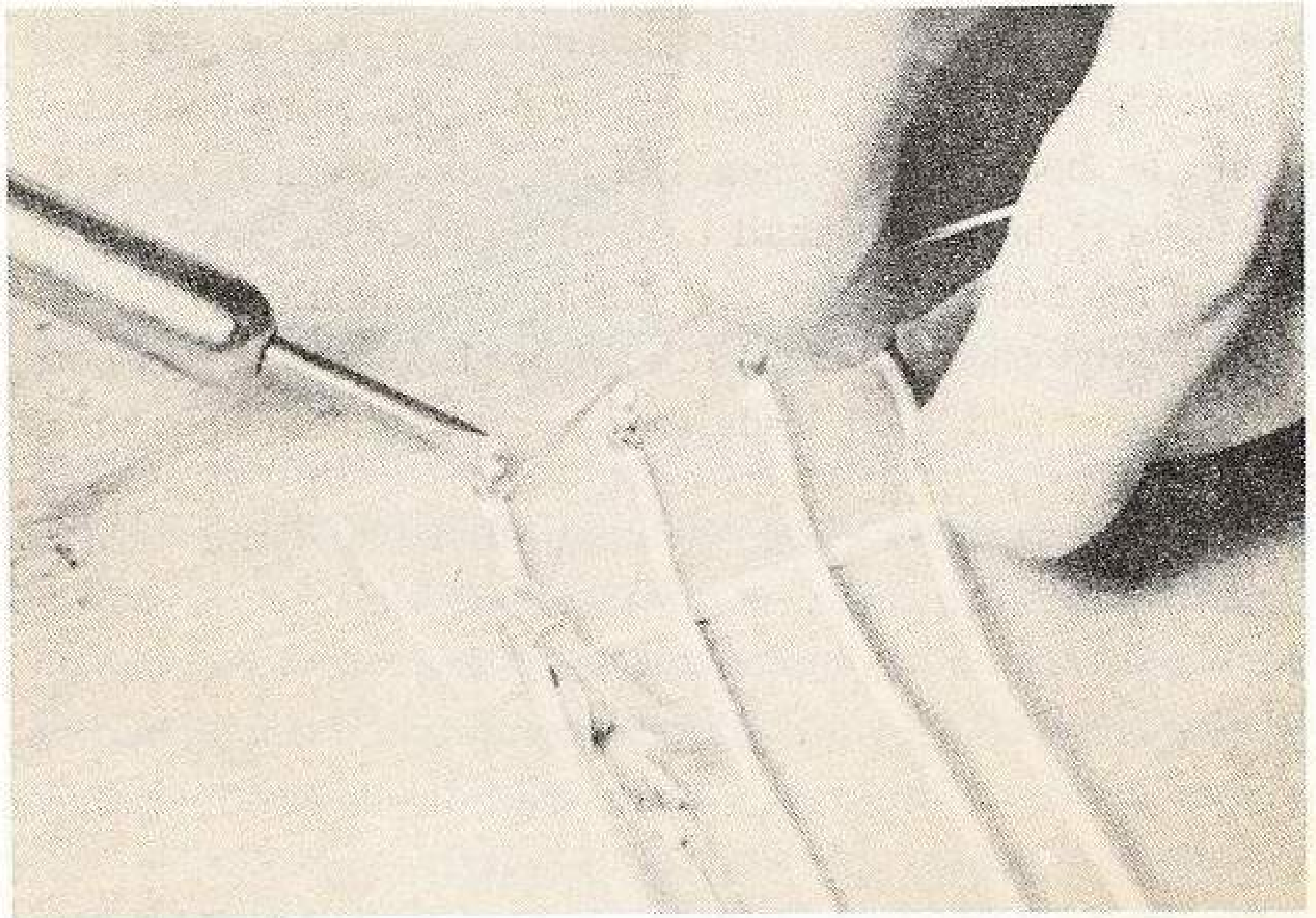


Figure 14. Proper Method of Heat Transference

d. Solder should be applied to the joint when the temperature of the joint will readily melt solder. The iron shall be tilted sufficiently to permit application of the solder to the junction of the heated wire and terminal. Solder shall not be melted against the soldering iron tip and allowed to flow over the joint. Sufficient solder shall be applied to form a slight fillet between wire and terminal.

5. Cleaning Soldered Joints

Flux residue is often "tacky" and tends to collect dust and other foreign matter which could cause a high resistance short; therefore, flux shall be completely removed with alcohol or other approved non-corrosive solvents. Reworked solder joints should be disassembled and excess solder removed before reassembling with fresh solder.

6. Unsoldering

a. Use a wet soldering iron tip to remove wires from terminal strips, relays, switches, and other related components. To remove wires from plugs or receptacles, use the resistance type probe. Using the appropriate soldering tool, melt the solder and apply a slight pressure. Keep wet tip or probe on the connection after solder has melted and hold the wire with appropriate tool (pliers, soldering aids, fingers, etc.) as near as practicable to the connecting point. Apply a light steady pull to the wire until it becomes unfused from the soldered surface. Disengage the wire from terminal, being careful to prevent solder splash.

b. If it is impracticable to clean terminals by first removing the assembled apparatus, excess solder can be collected from terminals (and solder cups) with a bare stranded wire and liquid flux. Nineteen strand wire is preferred. The amount of solder to be removed will govern the wire diameter selected. Strip approximately ½ inch of insulation from the wire and dip in liquid flux. Place the wire on the solder connections and place

the soldering iron tip on the wire. The iron tip and wire should be removed simultaneously as soon as the desired amount of solder has "wicked" into the stranded wire. See figure 15.

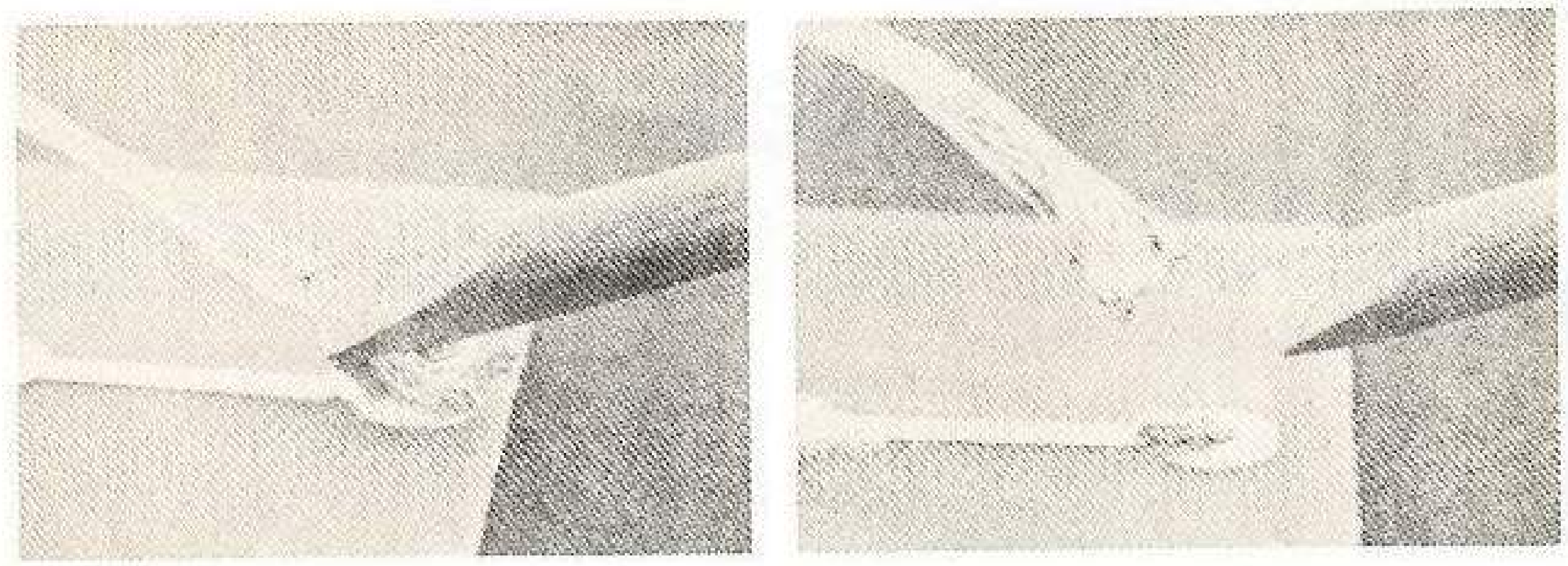


Figure 15. "Wicking" Operation

c. Equipment which has been resoldered must meet the same performance requirements as equipment which has been soldered for the first time; joints must be smooth, insulation must not be frayed or overheated, and excessive lengths of wire must not be exposed.

7. Electrical Resistance Soldering

Using electrical resistance is an old but effective method of supplying heat for soldering; the metal requiring solder is heated by the resistance it offers to the flow of electric current provided by a low-voltage transformer.

a. One application of this method is the use of carbon electrodes; when the metal is gripped between the electrodes an electric circuit is completed and the metal is heated.

b. The carbon pencil is the most common application. The metal acts as an electrode. When contact is made with the carbon pencil, which acts as the other electrode, heat is intense at the point of contact. Metal electrodes may be used where very low voltages are employed and arcing is not excessive.

NOTE

Place carbon tip on terminal before pressing foot switch. Release switch before removing tip. These precautions will prevent arcing and damage to plating.

Because resistance soldering generates heat directly in the metal area to be soldered, it affords a means of localizing or confining the heat to a given or selected area. This method is well adapted to the soldering of connectors. See figure 16.

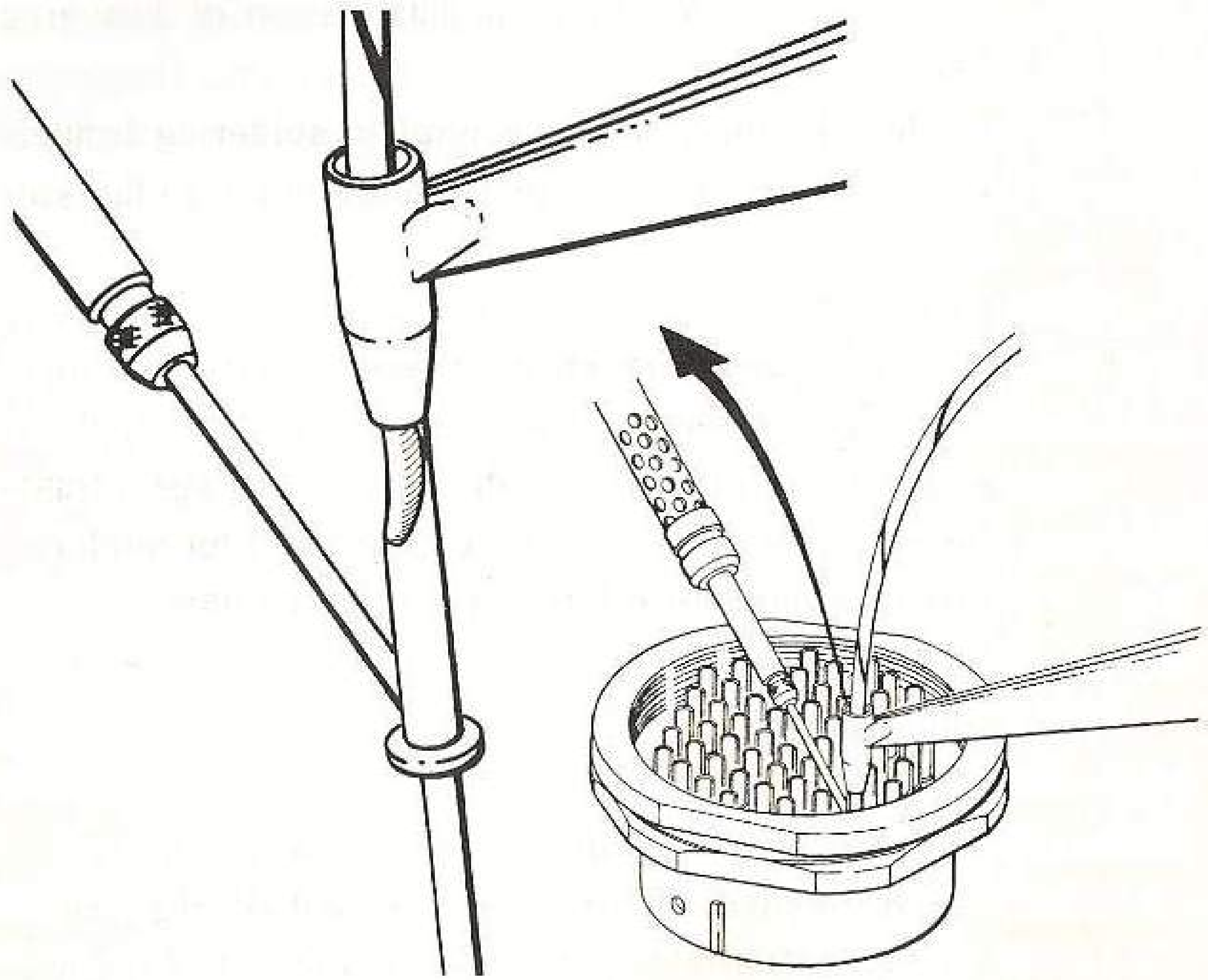


Figure 16. Electrical Resistance Soldering

8. Soldering Aids or Other Tools

Soldering aids or similar tools shall not be used to exert force on wires for security testing. The quality of a properly cleaned solder connection can be determined by a visual inspection. The practice of bending or pulling wires to ascertain security of the connection can present a serious reliability hazard.

9. Soldering Irons

Careful selection of the correct size, shape and wattage iron is a prerequisite for reliable soldering.

a. The size and shape of the iron and tip should permit soldering with maximum ease and with minimum danger of damaging the surrounding areas.

b. The tip should rapidly heat the joint to soldering temperature with only a negligible change in temperature of the soldering tip.

c. A variable voltage supply is recommended for controlling the soldering iron temperature when soldering printed circuits; it can also be advantageous in many other soldering applications. By proper selection of tips, and correct voltage adjustment, a single 50 watt pencil type iron can be used for soldering miniature printed circuits or relatively large terminals.

10. Soldering Iron Tips

The unplated copper tip will produce the best results and therefore is recommended. This does not exclude the use of plated tips for production work, provided the quality of the solder connections can be maintained.

11. Cleaning Copper Tips

Copper tips should be dressed smooth with a suitable file. To prevent oxidation, the iron should be unplugged and allowed to cool before filing. After filing, apply solder to the dressed face of the tip as soon as the tip reaches the minimum temperature required to melt the solder. Clean the tip by wiping on a wet sponge or other suitable material before each connection is made.

12. Cleaning Plated Tips

Allow the tip to cool and wipe lightly on fine emery paper. Clean the tip by wiping on a wet sponge or other suitable material before each connection is made.

F. Solder Connections

All solder connections should have a neat, well-soldered appearance and should be free from dirt and flux. Damage to any conductor or connection should be cause for rejection. A 60/40 type solder should be used and should not contain any corrosive agent; this also applies to flux and cleaning agents. A proper size soldering iron should be used to prevent components and solder from being damaged by excessive heat. Too little heat will cause the improper flow of solder and should be guarded against. Wicking of conductors, making them inflexible, can cause breakdown from vibration; this can be prevented in most instances by using a heat shunt while soldering. Rework and rejections can be kept at a minimum by using the proper tools and procedures.

NOTE

In all types of solder connections the wire should be held rigid until solder solidifies as shown in figure 17. Jaws of alligator clips, when used for this purpose, should be filed smooth and covered with a plastic tubing. The holding clip may be attached to the bench, overhead lamp, or any convenient fixture.

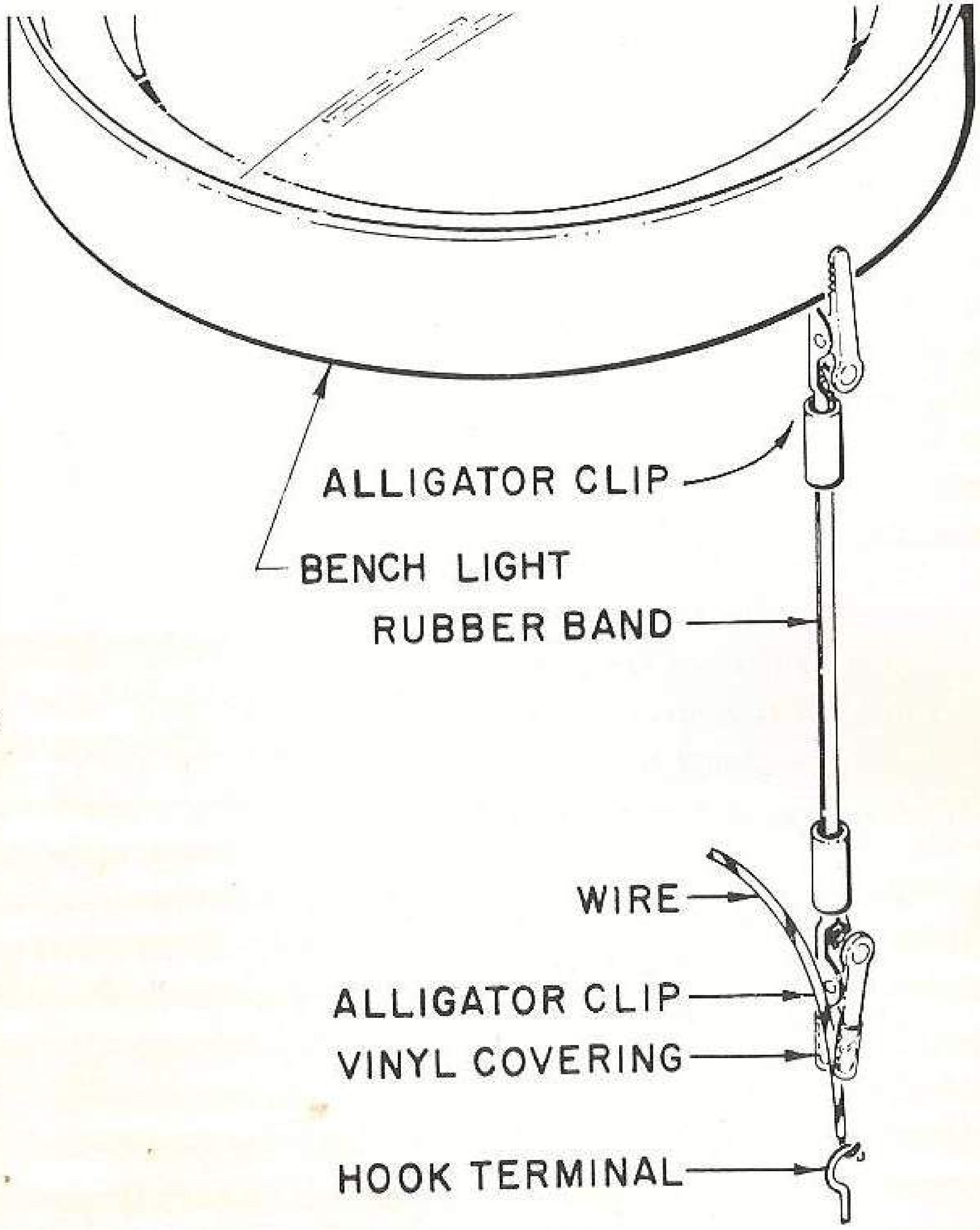


Figure 17. Solder Solidification

1. Hook and Eyelet Connections

This type connection is most often found on relays and lamp bases. The wire should be stripped, tinned, and bent 90 degrees. The wire should be cut extremely close to the angle to insure that a minimum length protrudes through the eyelet; however, sufficient bend should be maintained to help hold the conductor while soldering. This type connection should be protected by clear flexible tubing.

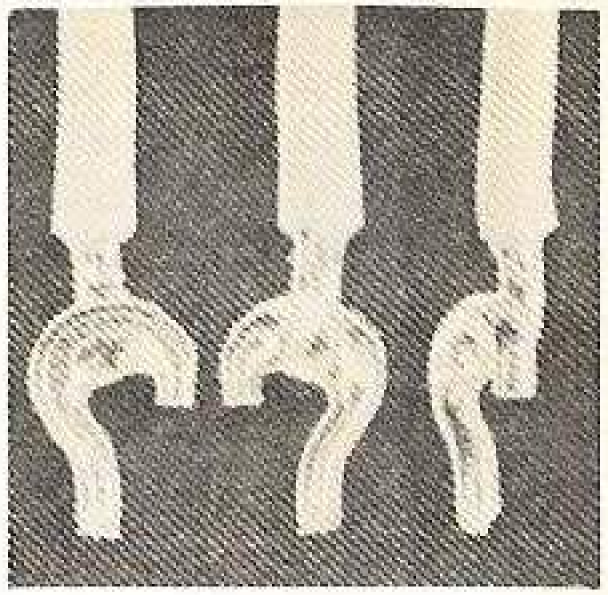


Figure 18. Hook and Eyelet Connections

2. Connector Connections

When wiring connectors, solder pots should contain precut solder of a length and diameter that will fill the cup and form a fillet around all sides of the cup when heat is applied and the pretinned wire is inserted. The solder should flow so it follows the contour of the cup entry slot. See figure 19. Solder should not flow over the edge onto the outside of the cup. The insulation should be no more than the diameter of the wire plus the insulation from the solder cup; nor should it be closer than 1/32 inch.

When potting a connector, no insulative sleeve is required; however, if the connector is not potted, a clear, vinyl flexible tubing will be used. Reduction of conductor size is not permitted for any reason.

The cup should be large enough to accommodate the attached conductor and should not be modified or enlarged to accept an oversized conductor. Do not reduce wire or conductor size.

Wires should not be spliced to other wires that enter the cup, and all wires terminating in the cup must bottom in cup.

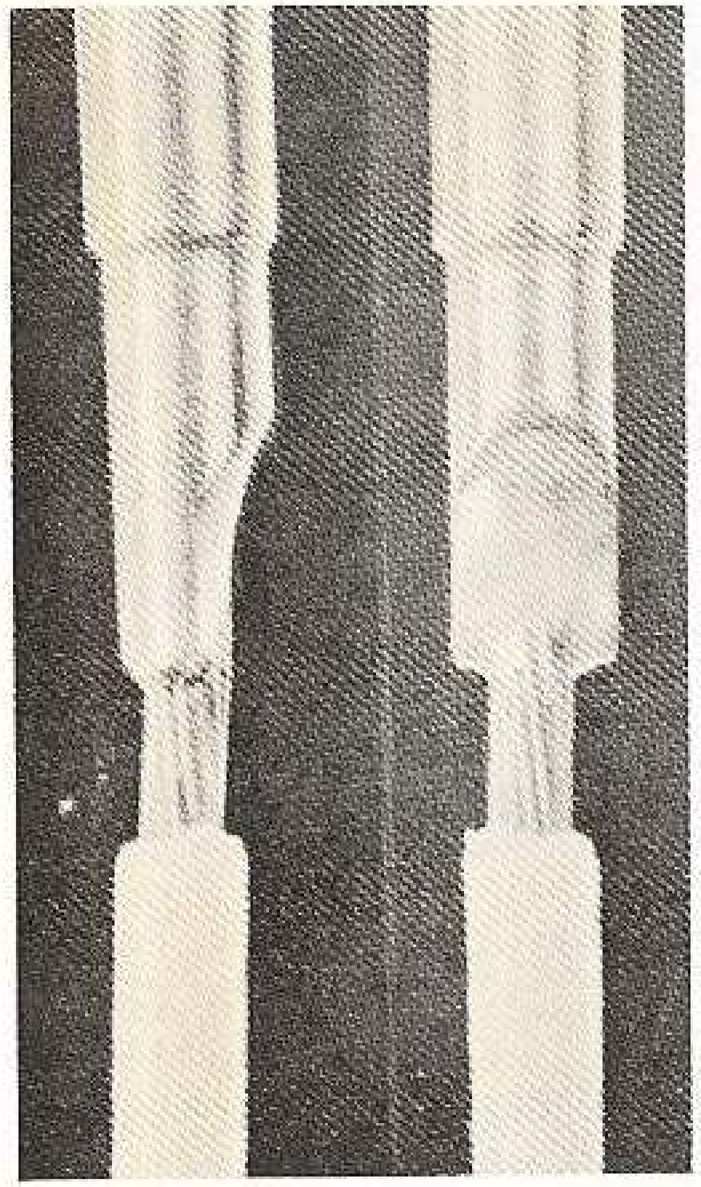


Figure 19. Good Connector Connection

3. Bifurcated Terminal Connections

Three of the more common bifurcated terminal connections are through the bottom of the terminal, from the side of the terminal, and straight in from the top of the terminal. In connecting the wire from the bottom of the terminal, the wire should be stripped sufficiently to permit the conductor to be wrapped around the terminal approximately 90 degrees, with the insulation not extending beyond the bottom of the terminal into the barrel. Insulation should be a minimum distance of 1/32 inch from the bottom of the barrel and the maximum distance should not be more than the diameter of the wire plus insulation.

In connecting wire to a terminal from the side, the conductor should be pretinned and have approximately a 90 degree bend. The bend will help hold the wire during soldering operations. The conductor must lie flat against the base of the terminal to allow a maximum bonding. The insulation should be no more than the diameter of the wire plus insulation from the solder connection.

When more than one connection is attached to a terminal, the connections should alternate as shown in the dual-wire connection in figure 20.

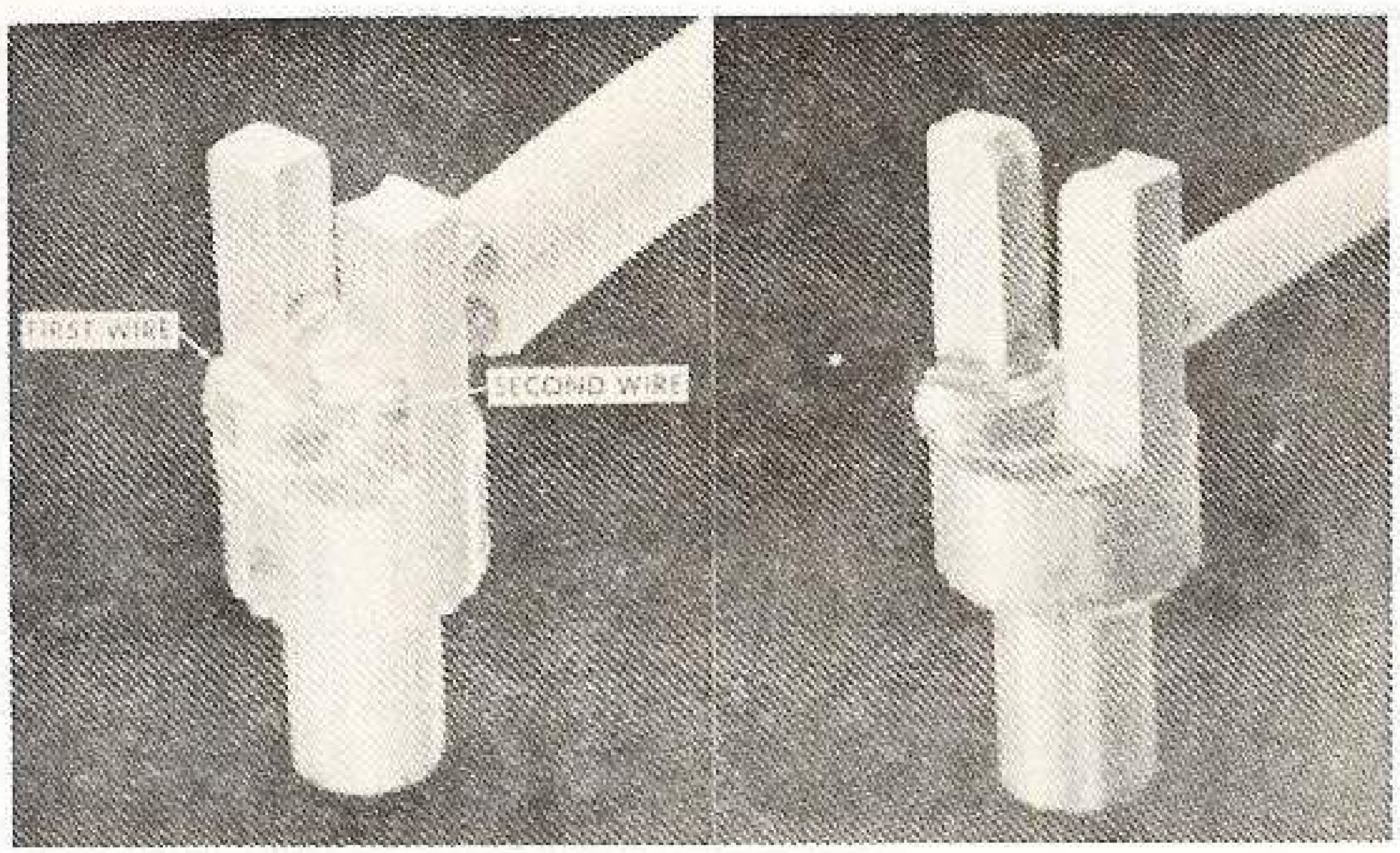


Figure 20. Bifurcated Terminal Connections

The straight in connection is probably less common but is occasionally used for specific applications. The wire should be stripped and tinned prior to connecting and should be accompanied by a stranded, tinned lead, while soldering, to help hold the wire in position. This also acts as a filler, insuring a better connection. See figure 21.

4. Turret Terminal Connections

The acceptable method of attaching a conductor to a turret terminal is to strip and pretin the conductor and wrap it approximately 180 degrees around the terminal. Under no circumstances should the conductor be wrapped more than half way around the terminal. The conductor should always be snug against the shoulder. See figure 22.

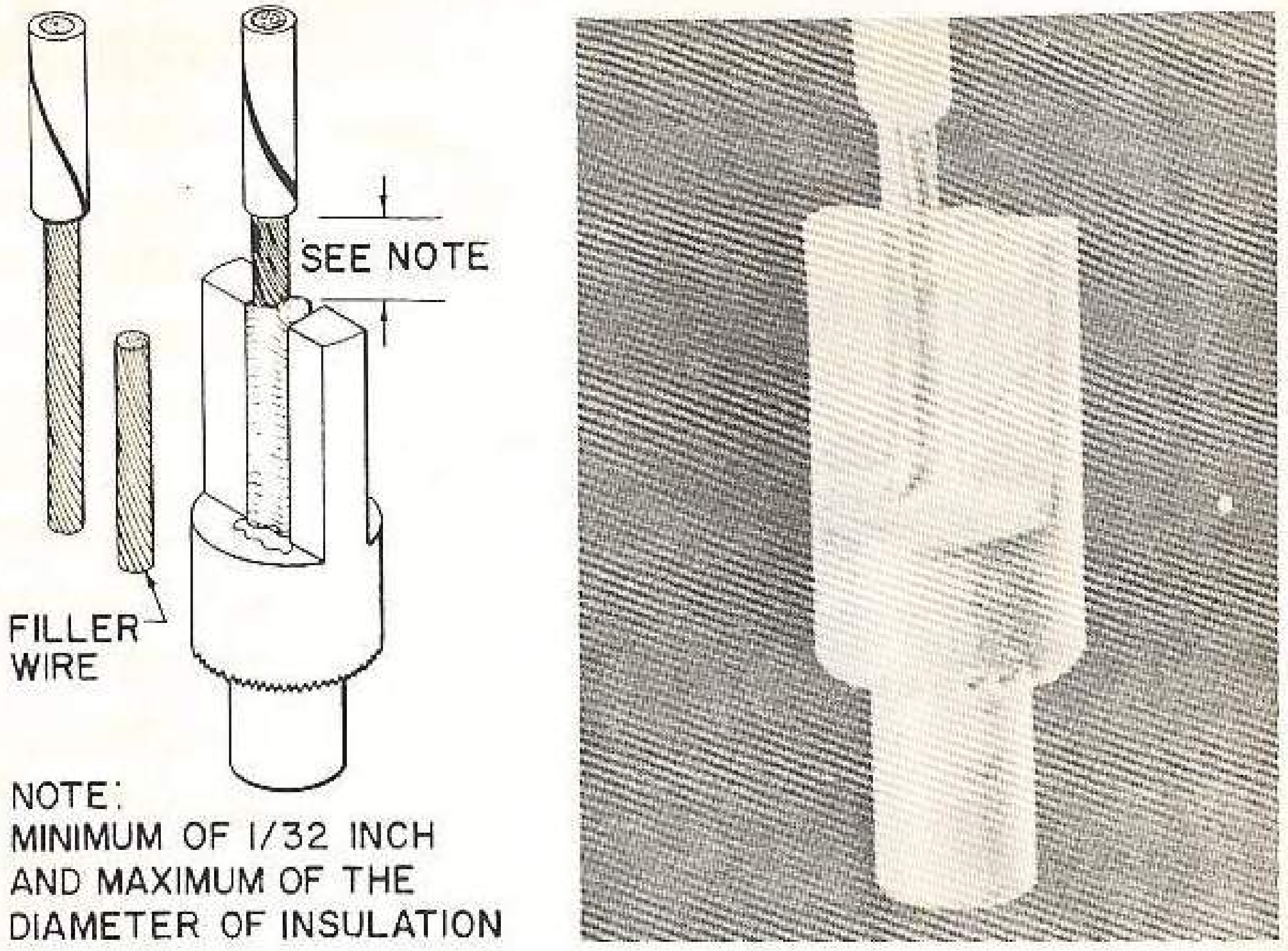


Figure 21. Straight In Connections

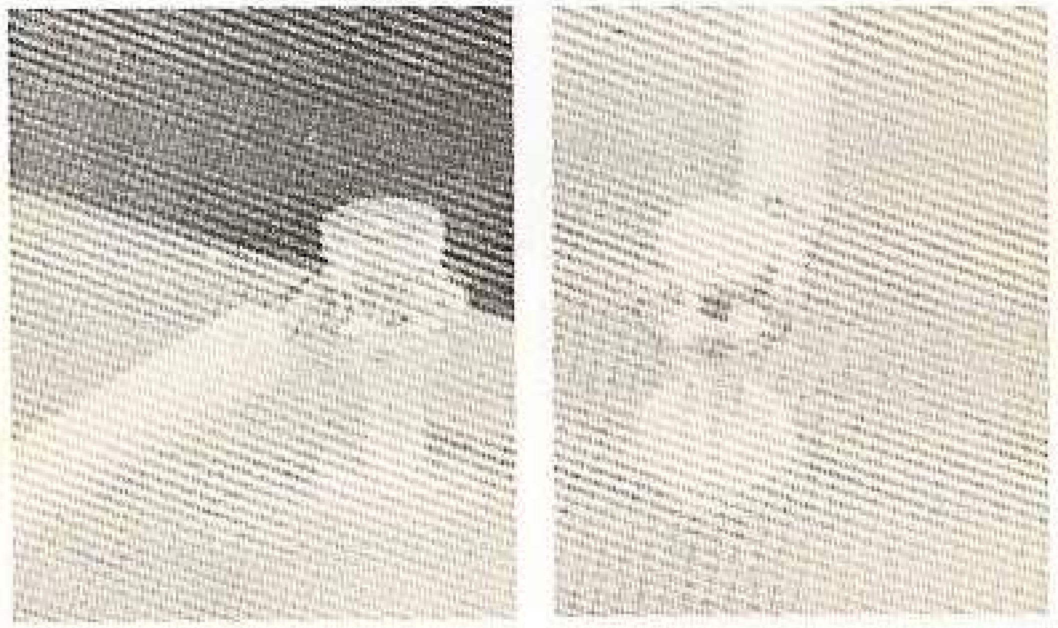


Figure 22. Turret Terminal Connections

5. Storage

Oxidized terminals shall not be used. Terminals should be stored in sealed plastic containers with a small bag of desiccant to prevent oxidation.

6. Fractured Joints

A poor connection may show evidence of a fractured joint. The solder will have a chalky or granular appearance rather than the usual metallic luster. This condition is usually caused by moving the conductors before the solder solidifies. See figure 23.

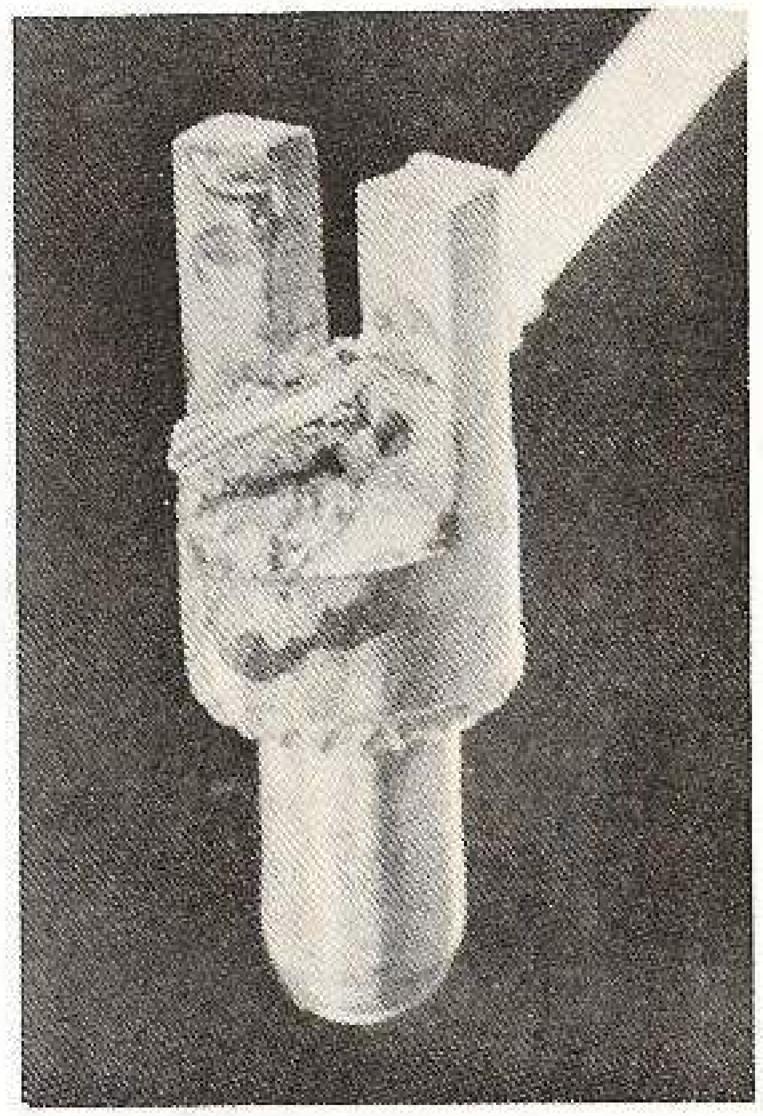


Figure 23. Fractured Joint

G. Insulative Tubing

At all terminations such as relays and plugs, except those protected by insulating grommets, appropriate clear flexible tubing shall be slipped over the conductors and terminals after the solder has cooled.

All routed wires in harnesses or box assemblies shall be protected at abrasion points, as designated by inspectors, by appropriate clear and transparent tubing.

H. Shielding

1. Definitions

Shielded wire consists of an ordinary tinned copper conductor, with appropriate insulation, covered with a wire mesh.

Wire shielding is a wire mesh which comes in assorted sizes and encompasses a group of two or more individually insulated or shielded conductors.

The wire mesh used on shielded wire and for wire shielding is made up of individual strands of interwoven (like a woven basket) tinned copper wire. It is used to protect the wire conductor from outside electrostatic or magnetic fields.

2. Shielded Single Conductor Termination

The shield is marked at the point where the conductor will break out. The shield is loosened by pushing it from the end toward the breakout point. A hole (large enough to pull the conductor through) is made with a pointed tool at the breakout point. The individual shield strands must not be damaged, and the shielding should be pulled taut to smooth out the shield.

When grounding a shield, the pigtail braid (the shield separated from the conductor) shall be securely tied at the breakout point, folded back and tied again approximately ¾ inch from the breakout point with a clove hitch secured by a square knot. The pigtail is then connected to a suitable ground through terminals specified on the detailed drawing.

When a ground connection is not required, the loose end of the shield is cut to approximately ¼ inch. The end is then bent back along the shield, and a length of tubing is fitted over the shield end to prevent unraveling and slipping caused by looseness.

The shield on the conductor shall terminate at a distance of 1 to 1 ½ from the terminal.

3. Shielding Multiconductor Cables or Harnesses

When protecting a group of conductors from outside electrostatic or magnetic fields, the group shall be inserted into the wire shielding specified on the detail drawing.

Shields for individual conductors, if required, shall be prepared in the usual manner.

After preparing individual shields, the outer shield is pulled smooth over the inner cables and a length of tubing slipped over the outer shields. Fold the outer shield back over the first layer of tubing and then over the individual shields. The shield may be twisted or plaited together. A second layer of tubing is applied over the folded shield. The cable is then placed in a connector clamp.

All shields shall be connected to a suitable ground through terminals specified on the detail drawing.

The shielding should end from 1 to 1½ inches from the terminal.

I. Potting Compound

Potting compound, an electrical insulation resin, is sometimes used in lieu of grommet and insulating sleeves. See figure 24. Potting compound will insulate soldered connections and protect them from dirt, oil, and moisture. The backshell must be tightened securely to the connector to avoid leakage while the potting compound is

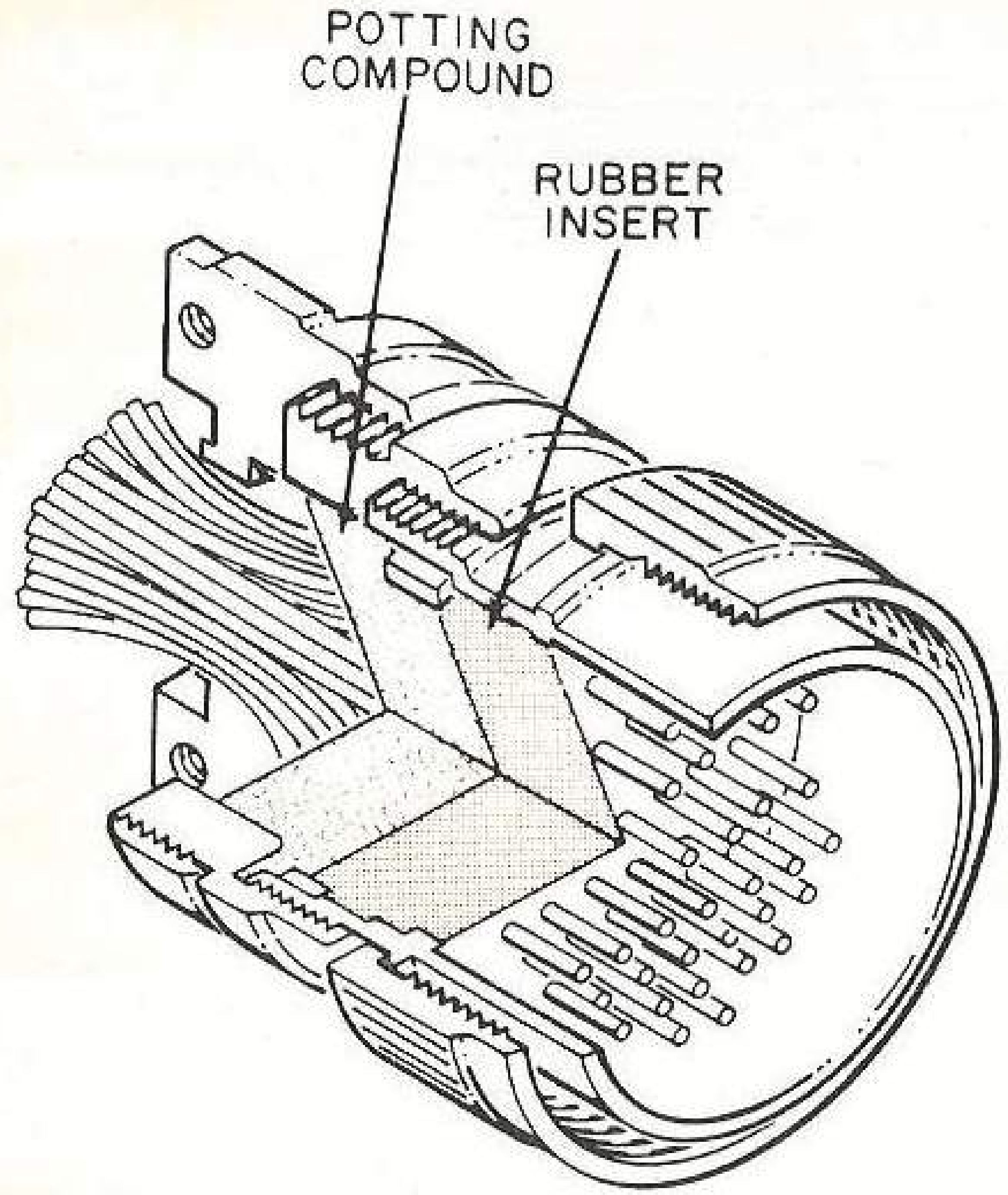


Figure 24. Potted Connector

in the liquid state. The liquid compound in the backshell or mold should remain undisturbed until it has hardened completely. To maintain alignment, the plug being potted should be connected with a mating plug.

CAUTION

Use potting compound in a well ventilated area. Avoid prolonged breathing of fumes. If resin should come in contact with skin, remove promptly with soap and water or solvent and avoid direct contact with eyes.

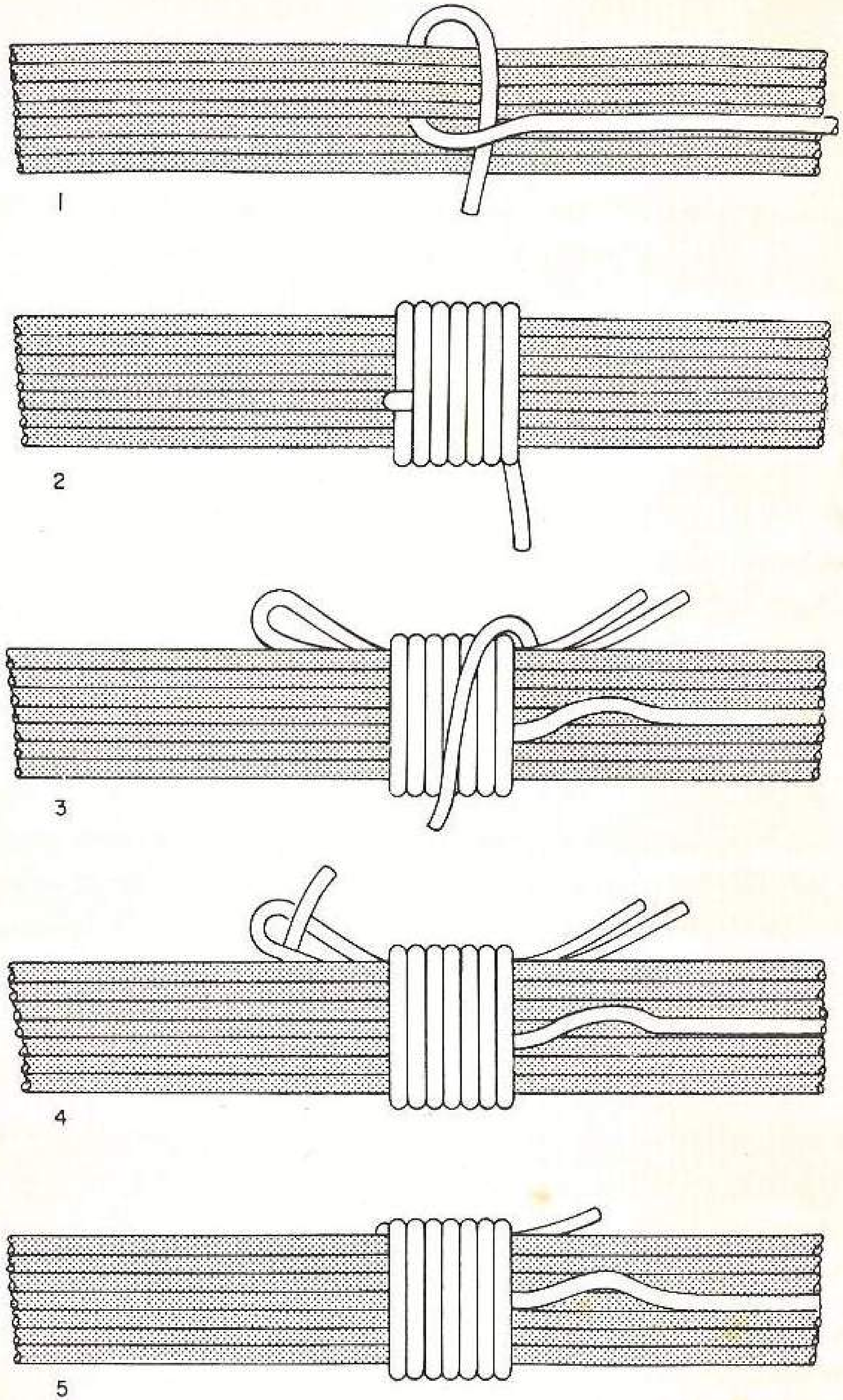


Figure 25. Originating Serve

J. Dust Covers

Plastic or metal dust covers as specified on the detail drawing shall be maintained on all connectors at all times, except when required by inspection, until connection is made with the mating part. Covers shall be replaced immediately after each inspection.

K. Lacing

1. Lacing of Cable and Harness Assemblies

All cable and harness assemblies shall be continuously laced, using the double lock stitch plus running hitch, unless otherwise specified on the detail drawing. To prevent the lace from loosening, the lacing shall be served at the point of origin and at the point of termination of the lacing operation. The originating serve shall be constructed as shown in figure 25, and the terminating serve shall be constructed as shown in figure 26.

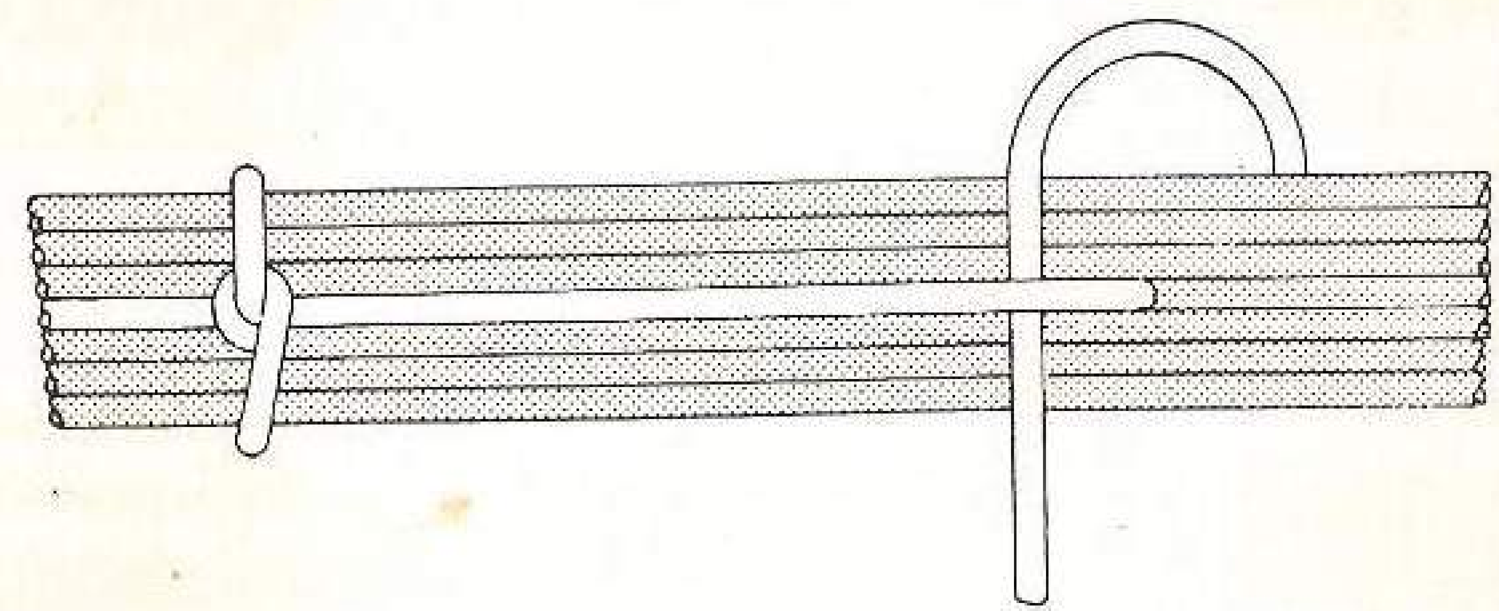
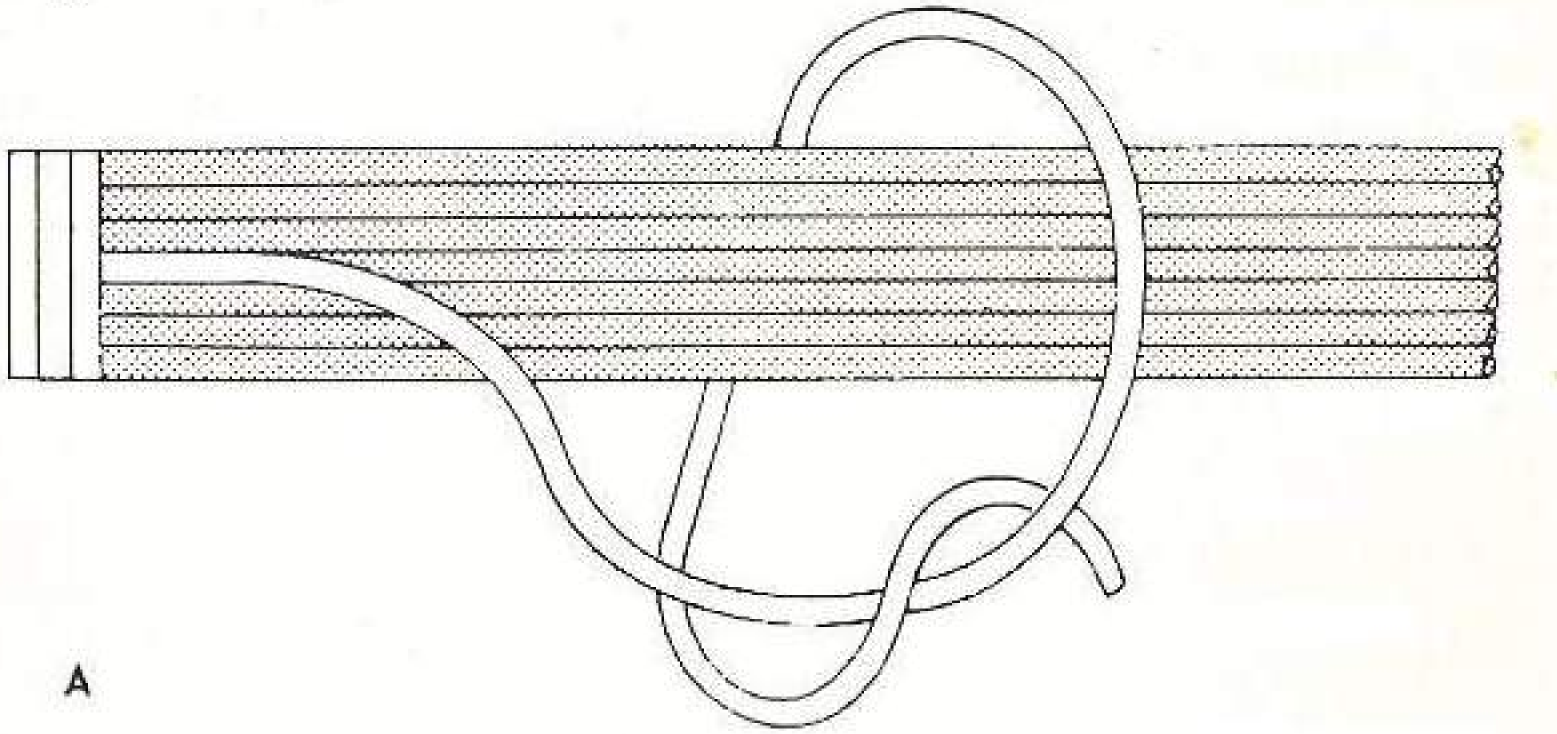


Figure 26. Terminating Serve

2. Double Lock Stitch and Running Hitch

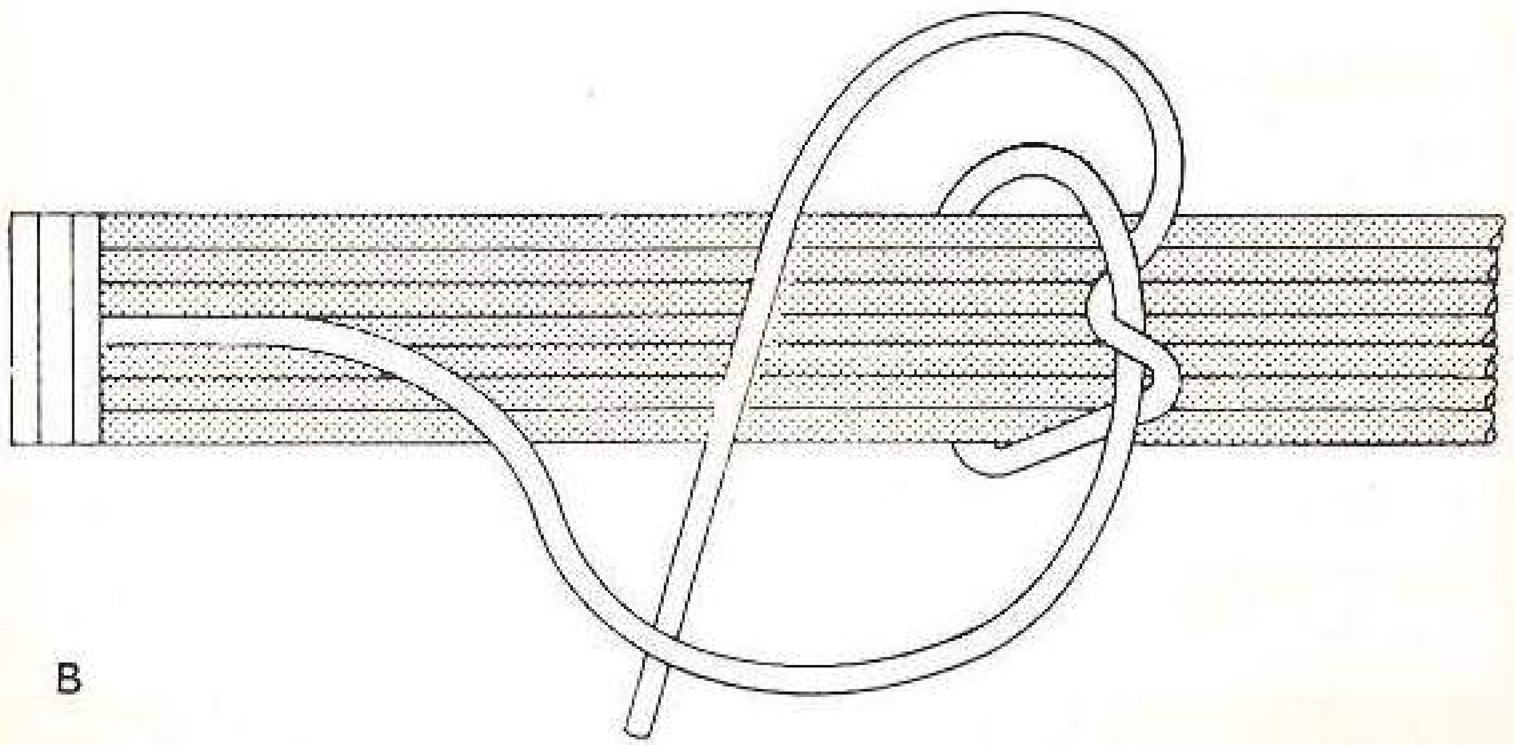
a. Take the lacing cord coming from the serve and loop it over the harness. Bring it around behind and insert it through the loop thus made as shown in figure 27A.



A

b. Tighten knot appropriate distance from the serve, leaving a loop between the serve and the knot as shown in figure 27B.

c. Insert end of lacing cord through the loop, leaving a loop through which the end of the lacing cord is again inserted as shown in figures 27B and 27C.



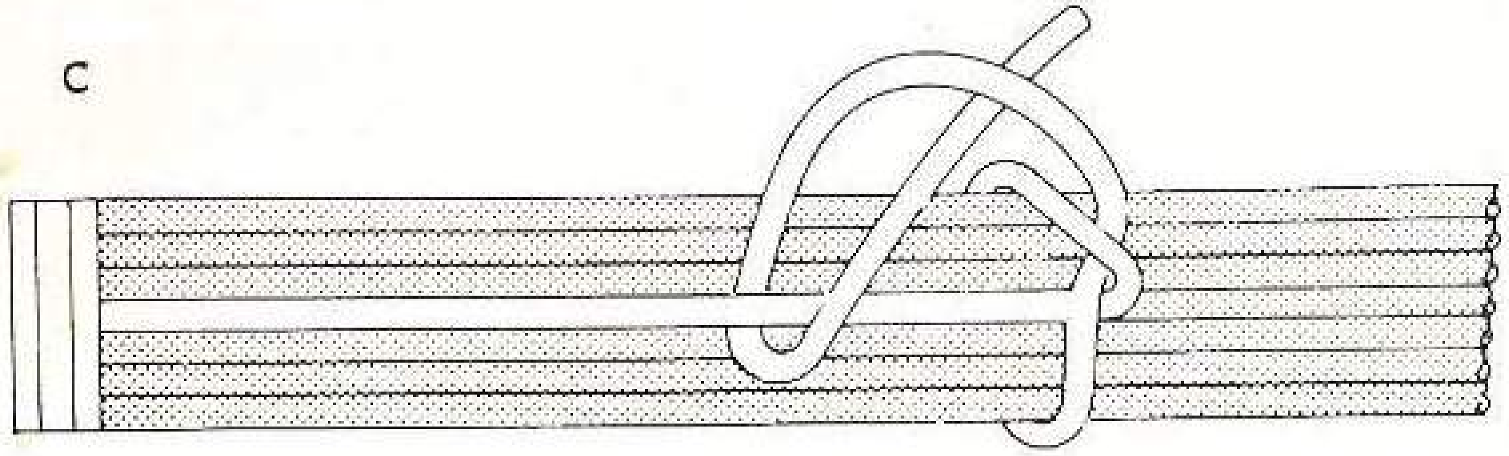
B

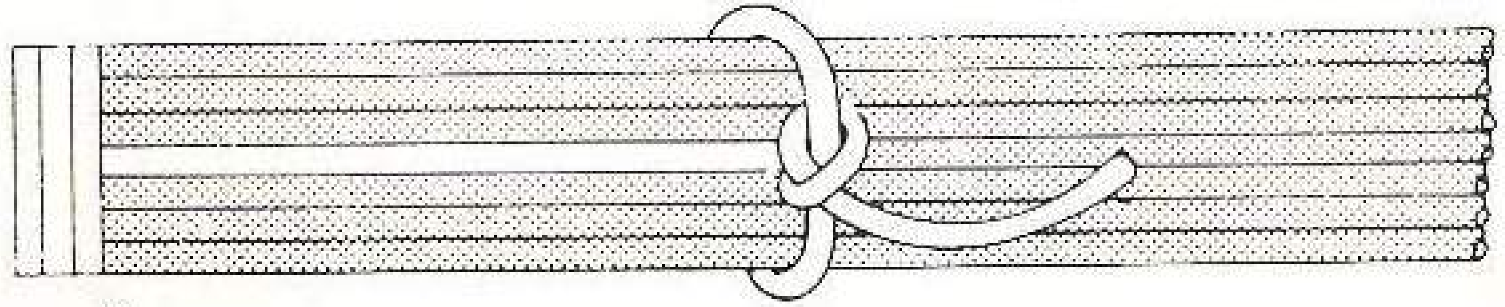
Figure 27. Double Lock Stitch and Running Hitch

d. Tighten loop left between serve and hitch, then tighten locking stitch as shown in figures 27C and 27D.

e. Using same method, continue lacing until job is complete.

C





D

Figure 27. Double Lock Stitch and Running Hitch (Cont.)

3. Originating Serve

a. Insert lacing cord between wires of the harness assembly.

b. Lay end of lacing cord parallel to the harness assembly.

c. Bring end of cord used for serve around harness, taking it under cord parallel to harness on the first wrap. Each succeeding wrap is placed over the parallel cord and butted against the preceding wrap. The cord must be kept tight during the entire serving operation.

d. When end of serve has been reached (approximately ¾ inch), fold in half a piece of lacing cord, forming a loop. Lay this on serve with loop facing the start of serve.

e. Wrap lacing cord back over the first layer and the looped piece of the lacing cord until the start of serve is reached.

f. When start of serve has been reached, insert end of the lacing cord through loop.

CAUTION

Do not relax tension on cord until you have started to pull cord through serve as instructed in step g.

g. Pull loop through serve, pulling the loose end of serve through with it by grasping loose ends of the loop firmly and pulling parallel to the wires.

h. Knot the two loose ends of lacing cord with a double knot, thus securing the serve. Cut the end the serve was made with so that approximately ¼ inch remains.

4. Terminating Serve

a. The terminating serve should start approximately ¾ inch farther from the final lacing hitch than is usually required. This will maintain the proper distance between stitches and allow ¾ inch for the serve.

b. The end of the lacing cord is inserted between the wires of the harness. It is then brought around the harness and under the lacing cord which comes from the final hitch.

c. Wrap end of lacing around harness, with each succeeding wrap going over the lacing cord coming from the final hitch. Continue wrapping, insert the loop, and pull cord through in the same manner as with the originating serve.

d. The length of originating and terminating serves shall be approximately ¾ of an inch, and the distance between each hitch of the lacing operation depends on the

diameter of the cables or harnesses as shown in table 1. Lacing shall be snug but not tight enough to cut or indent wire insulation or shielding.

Table 1

Cable or Harness Diameter	Lacing Intervals
1/4 inch	3/4 inch approximate
1/2 inch	1-1/2 inch approximate
1 inch	2 inches approximate
Larger diameter	3 inches approximate

e. To prevent undue stress on the wire and connection assemblies, the distance between the plug, receptacle, or other type terminal, and the beginning or termination of lacing will be as indicated in table 2.

Table 2

Cable Diameter	Distance "X"
Less than 1/2 inch	2 inches approximate
1/2 to 1 inch	3 inches approximate
1 inch or greater	4 inches approximate

5. Lacing of Box Assembly

a. The lacing of box assembly harnesses should start and terminate approximately 1 ½ inches from the plug, receptacle, or other terminal.

b. When relatively sharp bends are required, the spacing between stitches shall be shortened to provide a better lacing dress.

c. Employ previously outlined lacing methods in all operations except the following: when tying the pigtail braid of shielded wire at the point where pigtail breaks away from the conductor, and when wires are routed from a trunk a short distance to a relay, switch, terminal board, or other similar component.

d. In both of the above operations a clove hitch secured by a square knot must be employed. A clove hitch can also be used as a temporary tie to hold wires straight and can be employed to help determine the proper routing procedure in a box assembly. The clove hitch should be constructed as shown in figures 28 and 29.

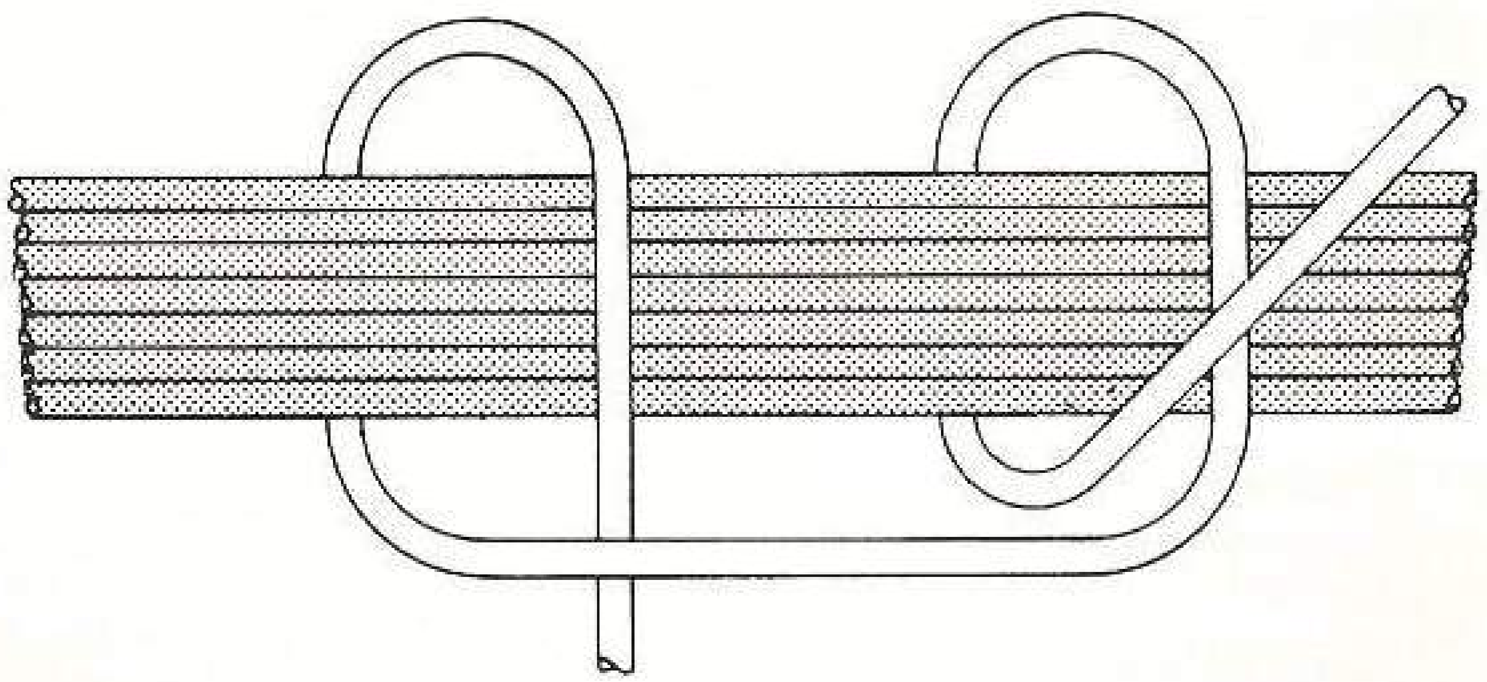


Figure 28. Clove Hitch Started

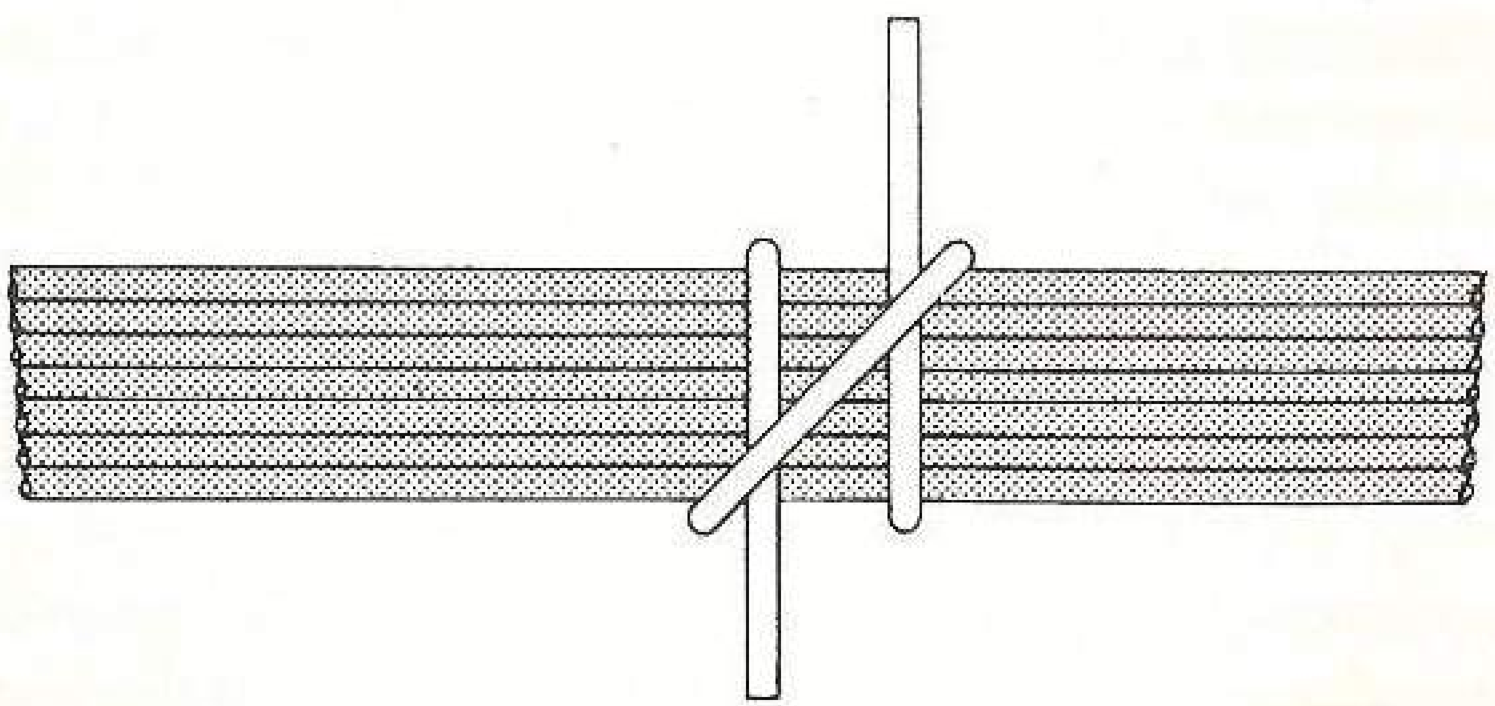


Figure 29. Clove Hitch Completed

L. Printed Circuit Boards

Printed circuit boards are being used for a continuing variety of applications. This growth is particularly noteworthy in vehicle design as the need for complex electronic circuitry becomes more evident. With the growth in design complexity there is a corresponding need for techniques and procedures which will insure reliability and performance.

1. Printed Circuit Board Holders.

To prevent damage during assembly and inspection, the wiring board shall be held by a jig or fixture to prevent it from being bent, warped, or deformed in any manner. The assembly illustrated in figure 30 will per-

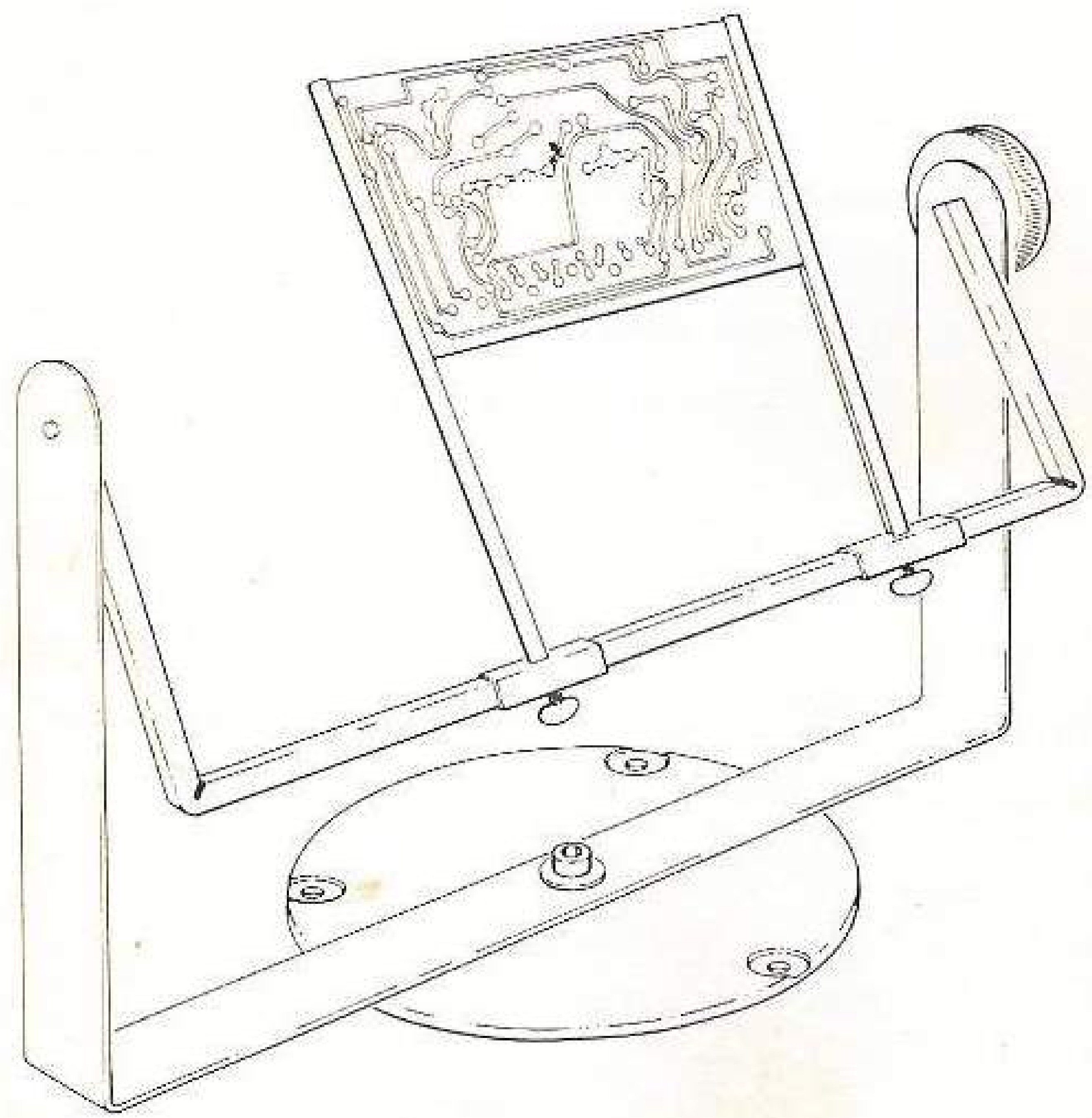


Figure 30. Printed Circuit Board Holder

mit the wiring board to be held at each end and fixed at any desired position by use of the wing-nut set screws in the shaft bearings.

2. Printed Circuit Board Care and Storage

Printed circuit boards should be kept in plastic bags and stored in cardboard boxes before being used. After being wired, inspected, and stamped, the boards should receive an insulative protective coating on both sides.

3. Insulation

On printed circuit boards with conductive patterns on each side, observe the following rules:

a. Both connections must be soldered when a component pigtail enters a pad on one side of a board and terminates at a pad or other connection point on the other side.

b. Components such as metal case capacitors will be insulated with approved clear tubing when mounted over conductor lines. See figure 31.

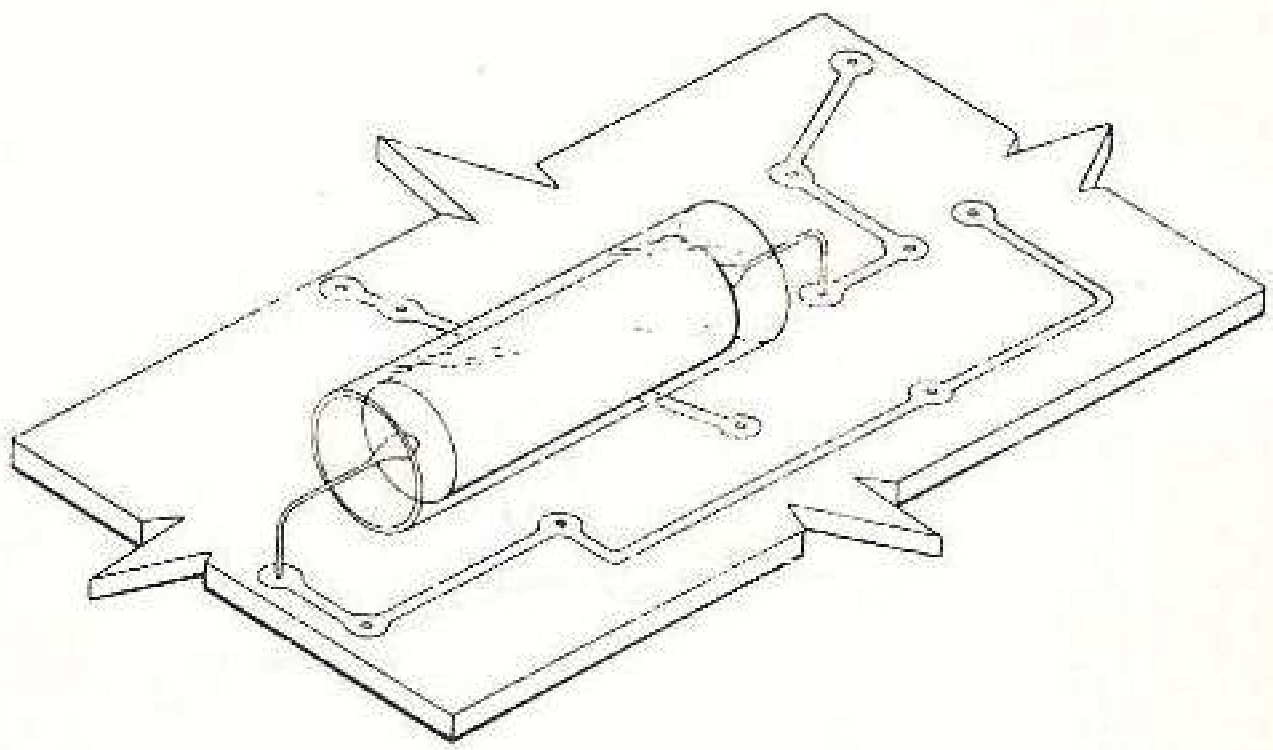


Figure 31. Crossing Conductive Lines

4. Bending Component Leads

a. Bend component pigtails with a suitable wire bending tool such as wire-bending pliers or tweezers. Long nose pliers may be used if sharp edges are covered with tubing or plastic tape. See figure 32. Flattened, nicked, or damaged pigtails will be rejected.

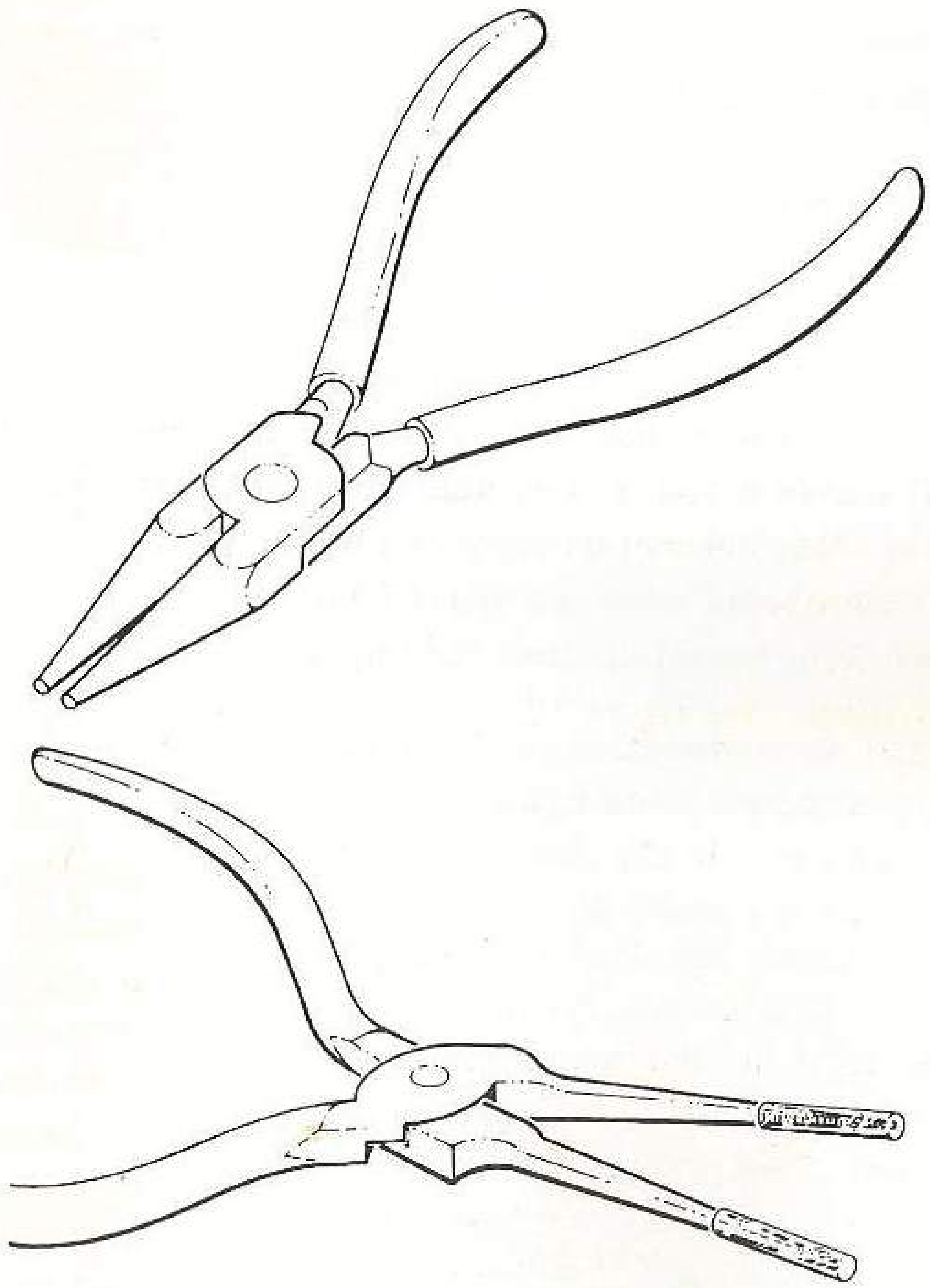


Figure 32. Proper Bending Tools

b. Pigtails should have a minimum clearance of 1/16 inch between bend and component body as shown in figure 33. When making the minimum bend, support end seal of component with wire-bending pliers.

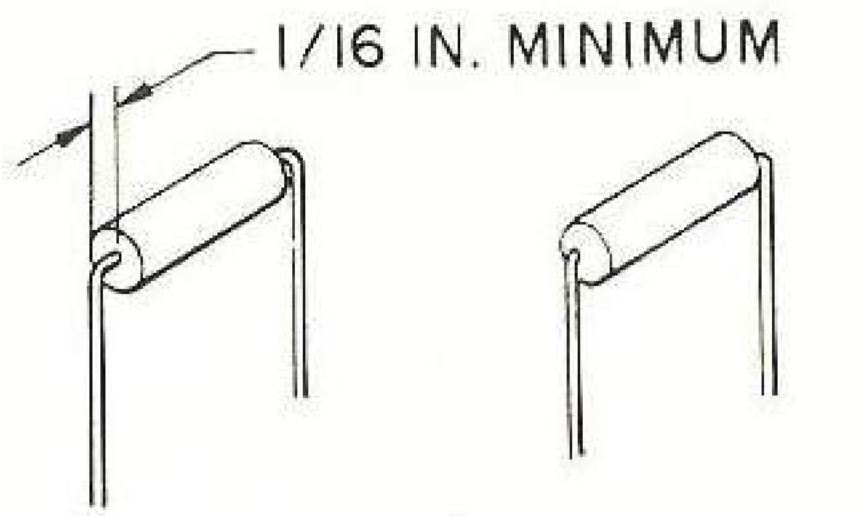


Figure 33. Minimum Pigtail Bend

c. Extremely sharp ninety-degree pigtail bends will not be accepted. All bends should be made with a gradual curve.

d. The radius of the bend shall be equal to, or greater than twice the lead diameter.

e. Component pigtails will extend through printed circuit boards a minimum of 1/16 inch to a maximum of 1/8 inch and will be clinched flush with the circuit. The bend or clinch must be in the same direction as the conductive line to which the pigtail is attached. See figure 34.

f. Component leads that cannot be bent or clinched flush with the circuit shall be properly cleaned and cut to a length that will permit the lead to extend 1/32 inch above the solder pad. Components mounted in the above manner shall be secured rigid to the board with a suitable mounting clamp or approved epoxy resin. To minimize this type of connection, components designed for printed circuit application should be used when obtainable. See figure 35.

g. With tantalytic capacitors and other components which have welded leads, the bend should be measured

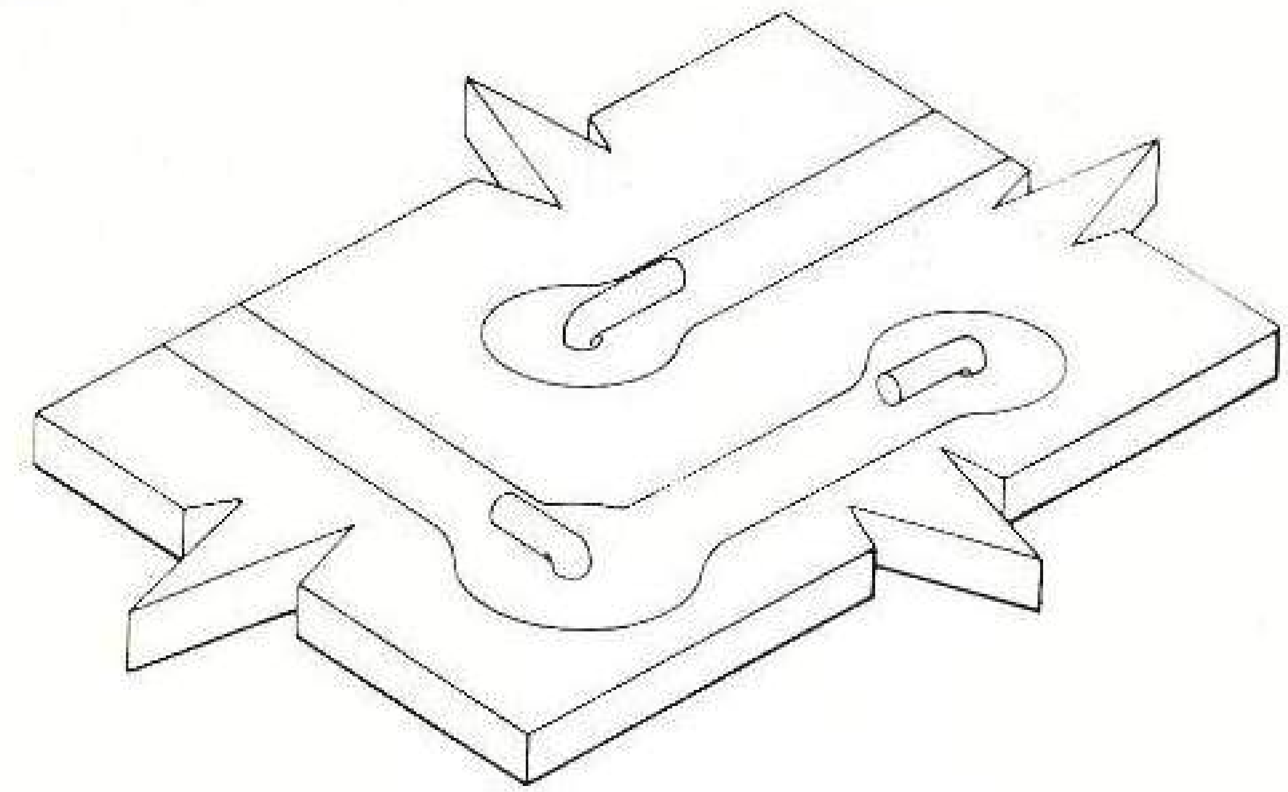


Figure 34. Direction of Pigtail Clinch

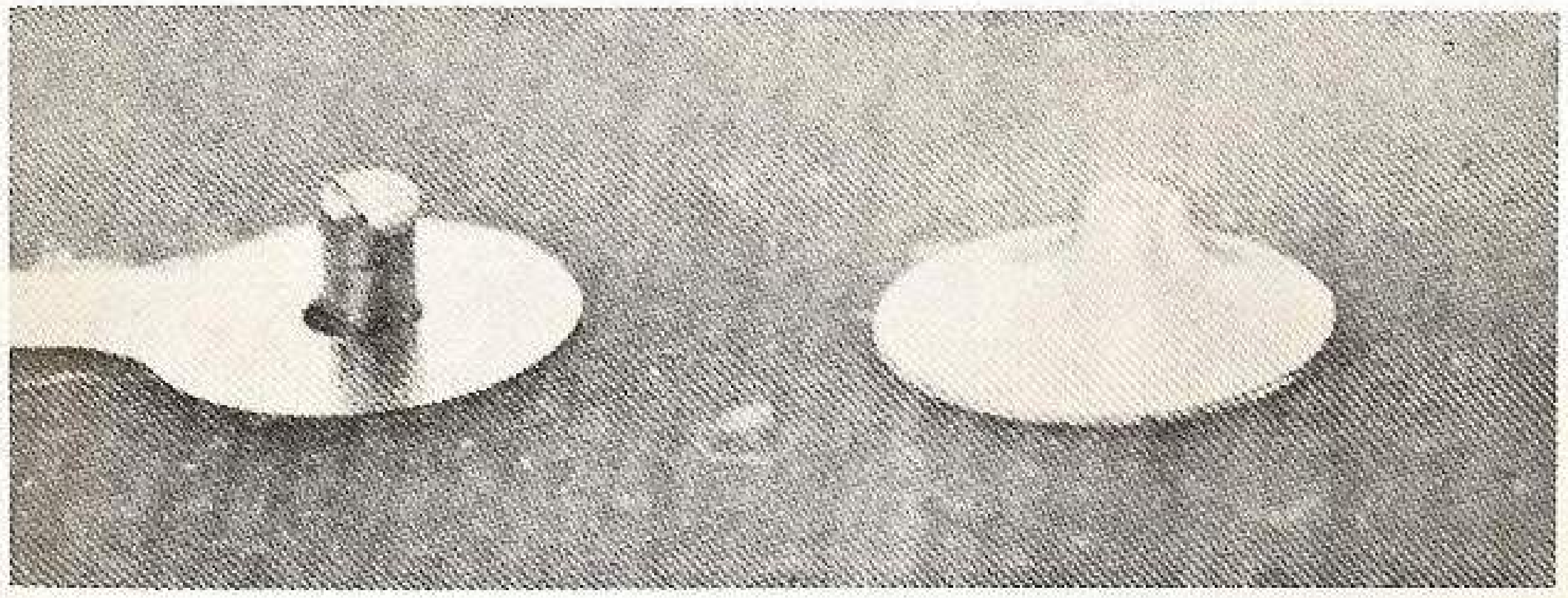


Figure 35. Clipped Component Leads

from the weld rather than from the component body. See figure 36.

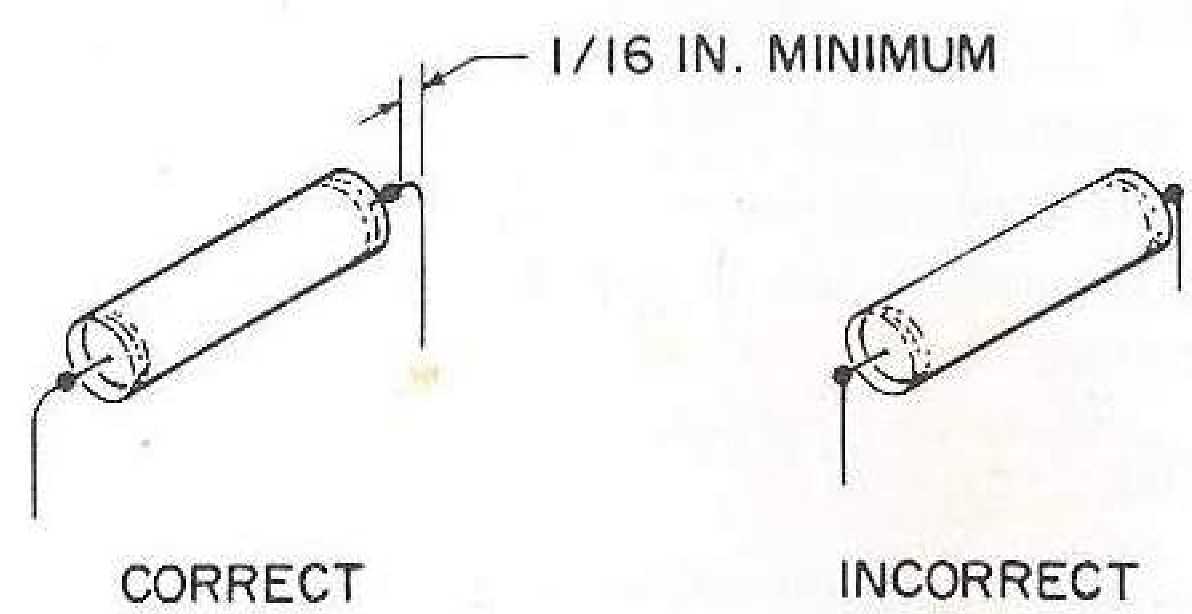


Figure 36. Welded Lead with Proper Bend

5. Handling

Wherever practicable, the manual handling of printed circuit pads, terminals, component leads, etc., should be avoided. When manual handling is unavoidable, finger tabs or white gloves should be employed.

6. Component Mounting

Components shall be mounted flush with the circuit board unless potted or supported by a suitable retaining clamp. See figure 37.

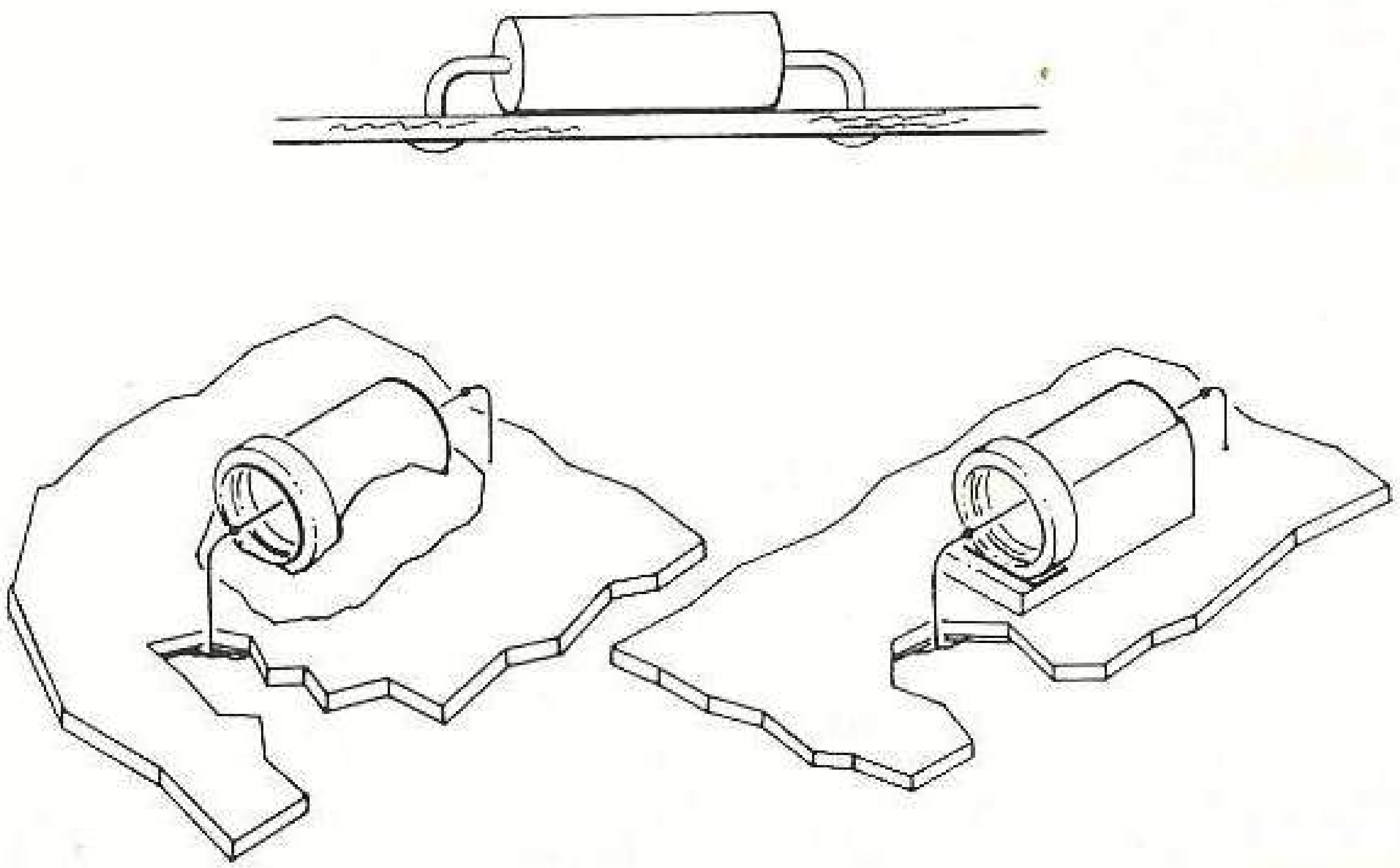


Figure 37. Examples of Flush Mounting

7. Cleaning

When soldering gold plated printed circuits, clean circuit pad with white typewriter eraser. Apply very light pressure and clean only the pad. See figure 38. Brush lightly to remove eraser particles.

8. Soldering

An example of a good solder joint, with outline of wire visible under solder, is shown in figure 39.

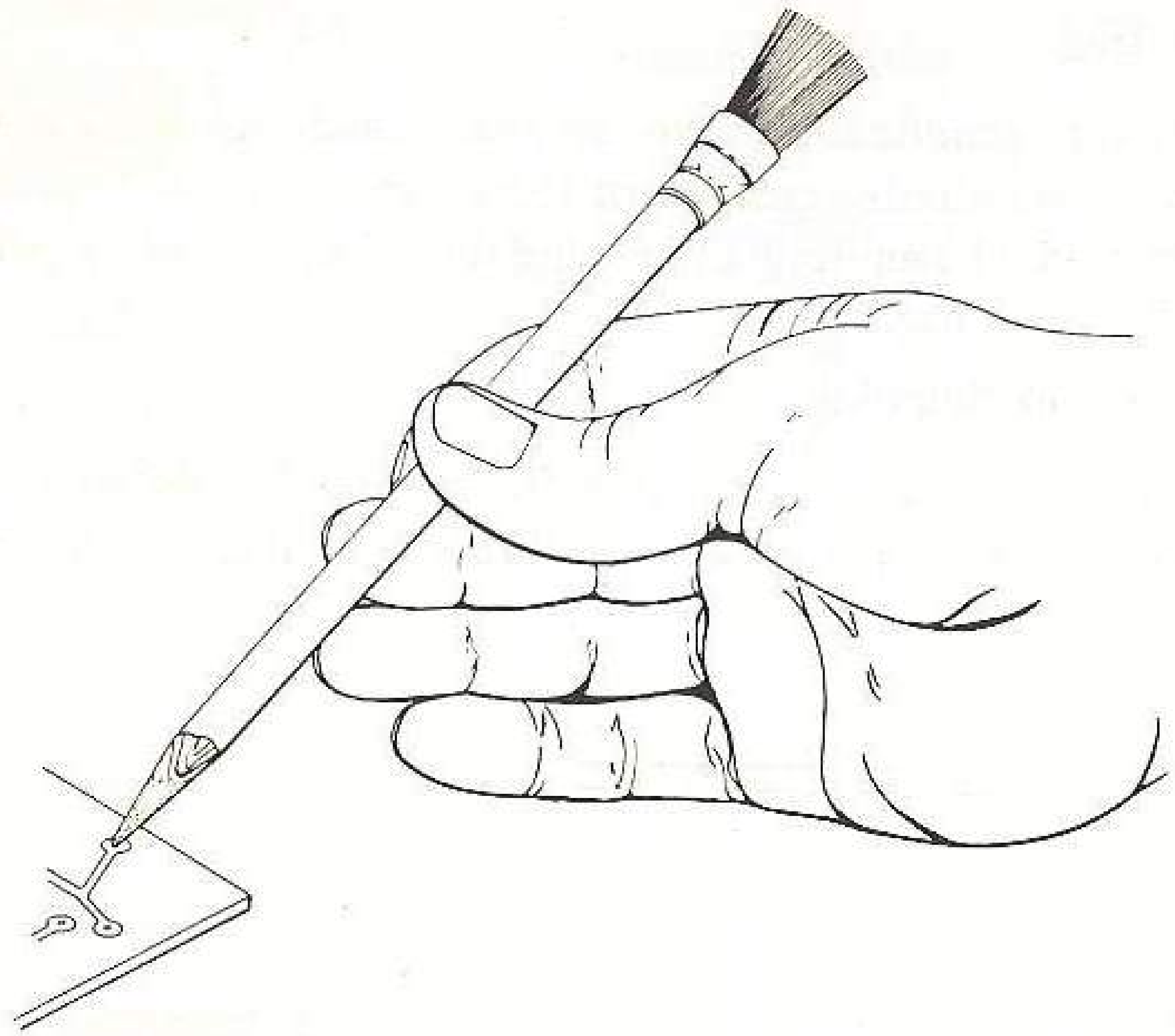


Figure 38. Cleaning Circuit Pad

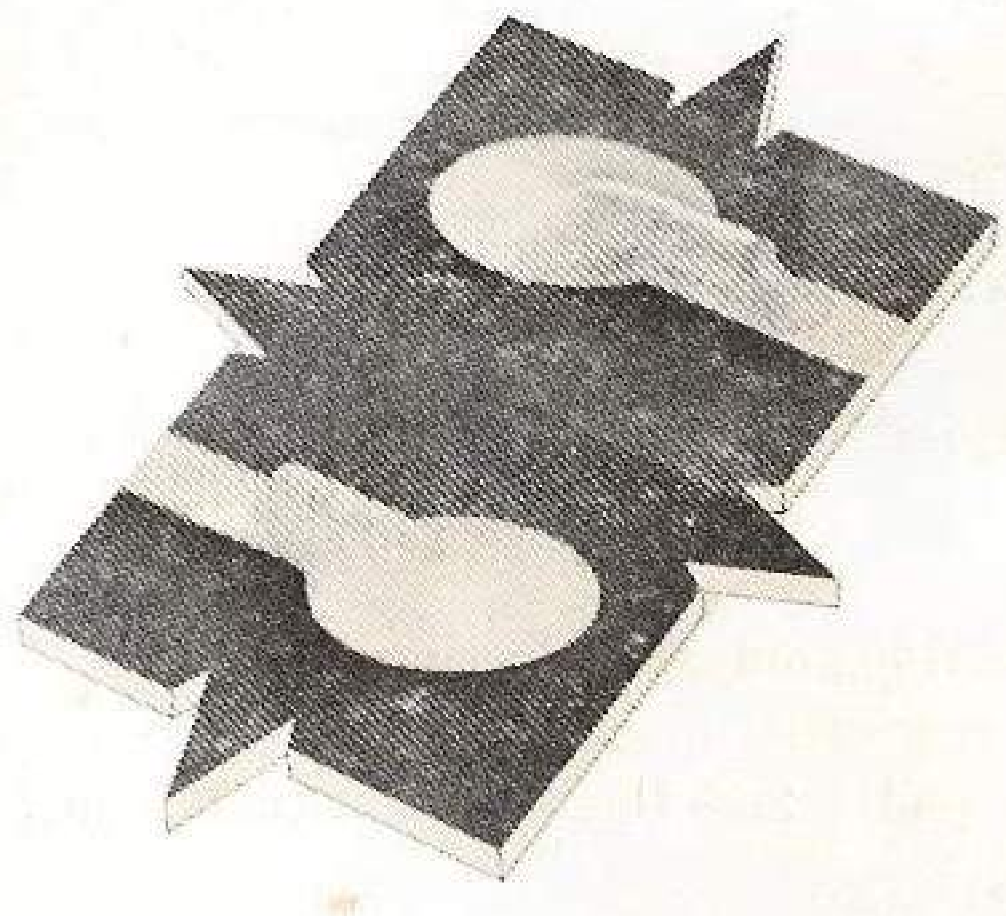


Figure 39. Good Solder Joint

9. Component Weight

Component parts that weigh ½ ounce or more shall be secured by a suitable mounting bracket or potted with an approved epoxy resin.

10. Mounting and Soldering Terminals

When mounting and soldering terminals to printed circuit wiring boards, the procedure outlined below shall be followed:

a. Drill the pad hole to a diameter that will permit the terminal shank to be pressed through the board by hand. A press fit is not necessary, but the terminal should fit snugly enough to prevent it from falling out.

b. Clean the terminal pad with a typewriter eraser, or a device of equal material. Apply very light pressure and clean only the pad.

c. Press the terminal shank through the board and align the terminal as shown in figure 40.

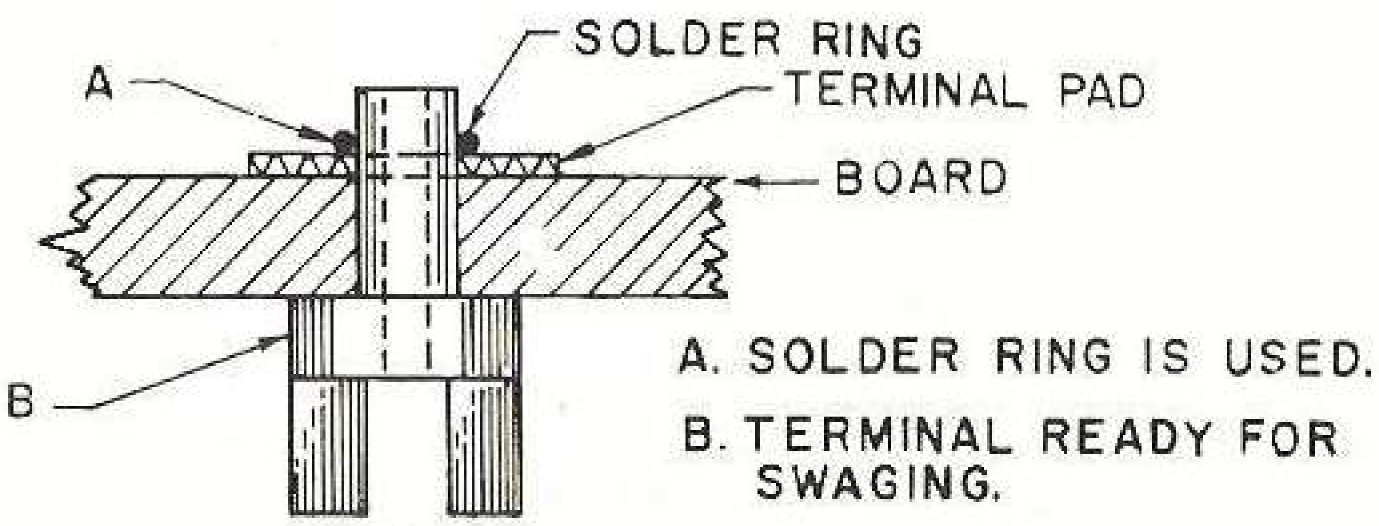


Figure 40. Terminal Before Swaging

d. Make a V or funnel type swage on the terminal. The point of the V swage should enter the terminal shank only far enough to produce a hand tight fit of the terminal. See figure 41. If solder rings are used, place the ring over the terminal shank before swaging. Solder rings are recommended since they give a more uniform and thus reliable solder joint.

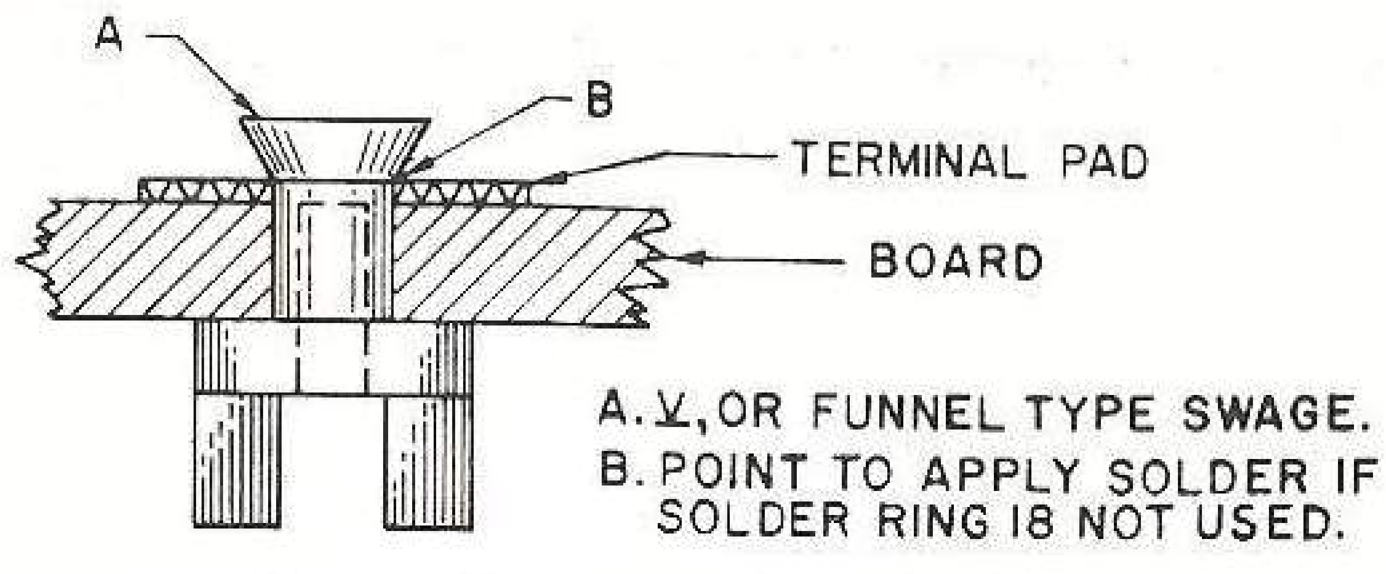
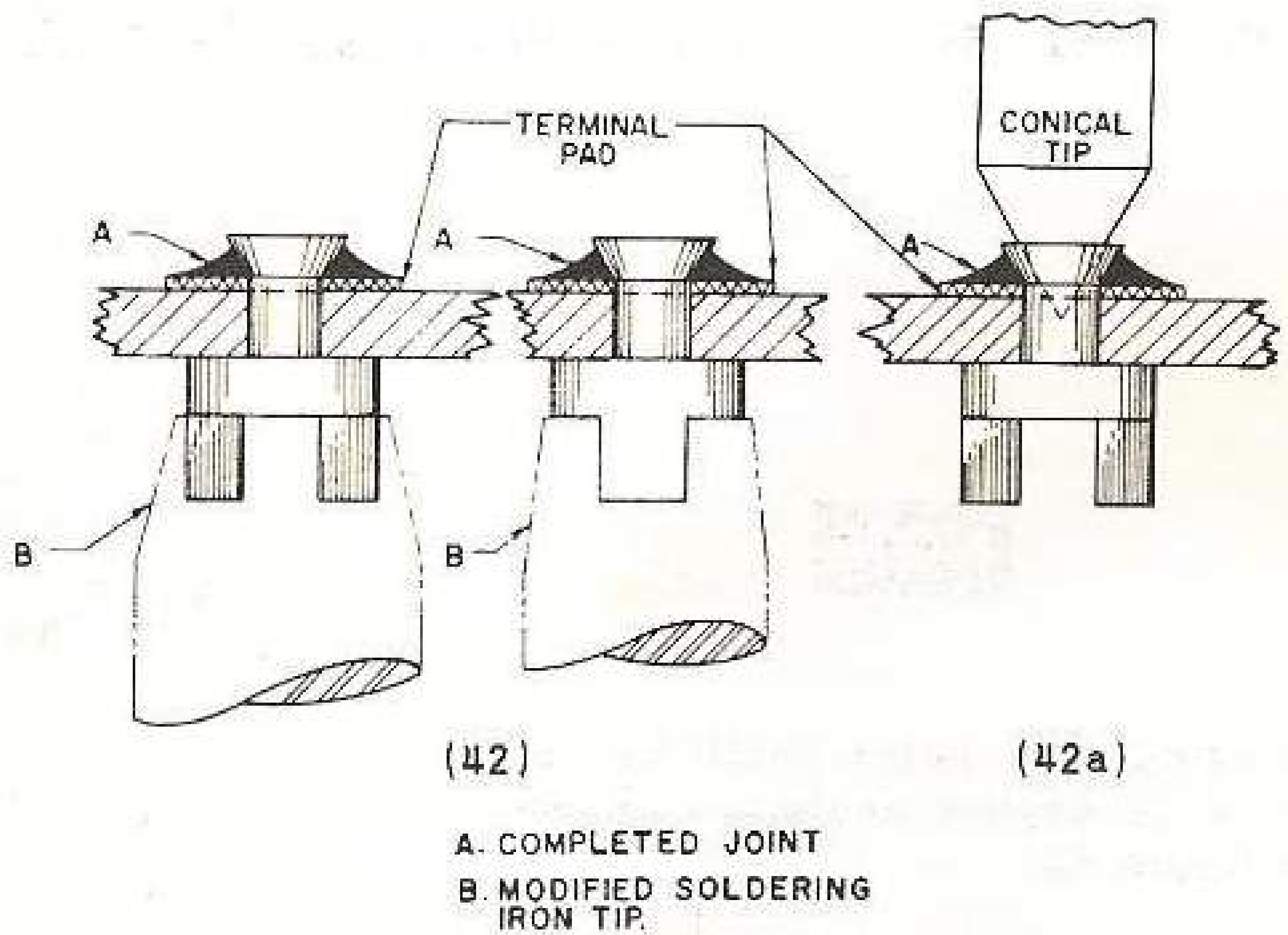


Figure 41. Terminal After Swaging

e. Place the soldering iron tip over the terminal head as shown in figure 42, and apply solder (if a solder ring is not used) to the joint where the terminal shank and pad intersect. Allow the solder to flow properly and then remove the soldering iron tip from the terminal head. The solder should completely cover the pad and form a neat uniform joint.



Figures 42 and 42a. Soldering Swaged Terminals

An alternate method may be used. Place conical soldering tip in barrel of terminal as shown in figure 42a.

f. Carefully clean the soldered joint with an approved solvent and a medium stiff bristle brush.

g. Inspect all joints. If any joint should require resoldering, add a small amount of new solder.

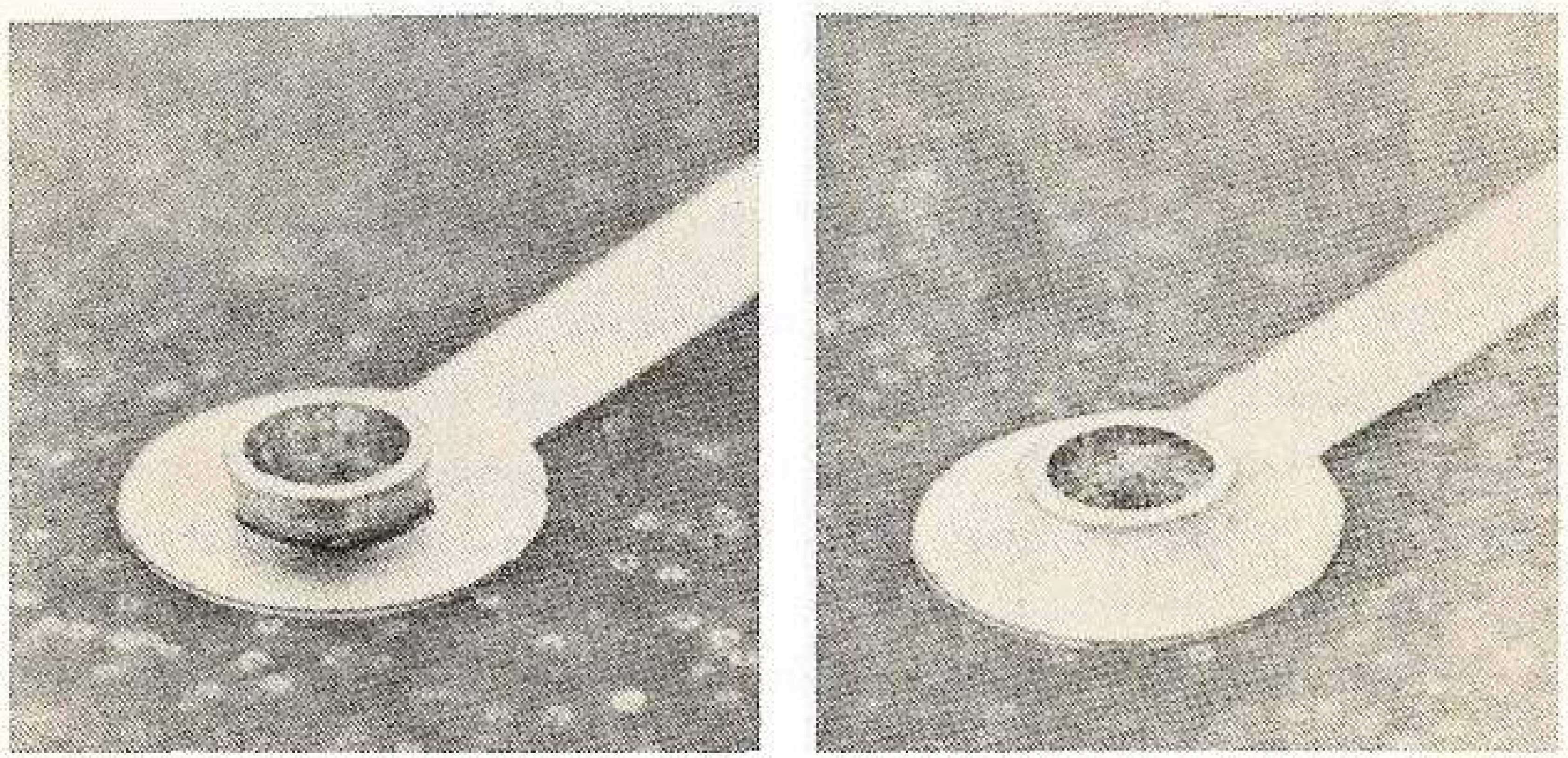


Figure 43. Swaged Terminal Before and After Soldering

NOTE

Swaging tool point shall be cut on a 30-degree angle as shown in figure 44.

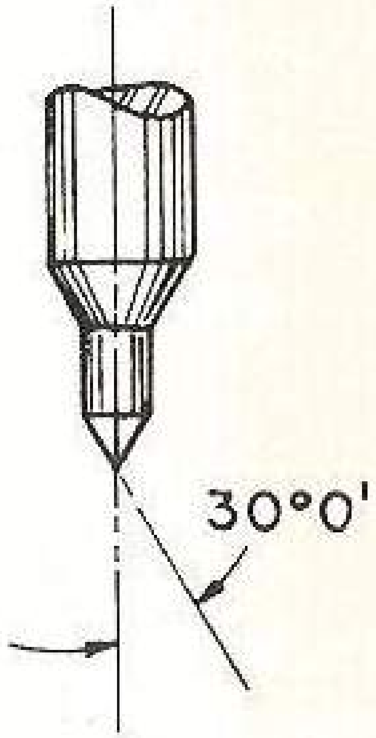
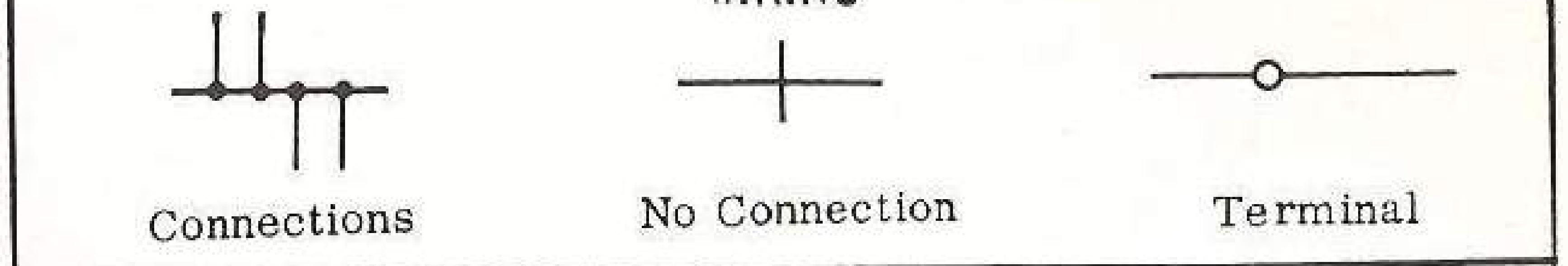


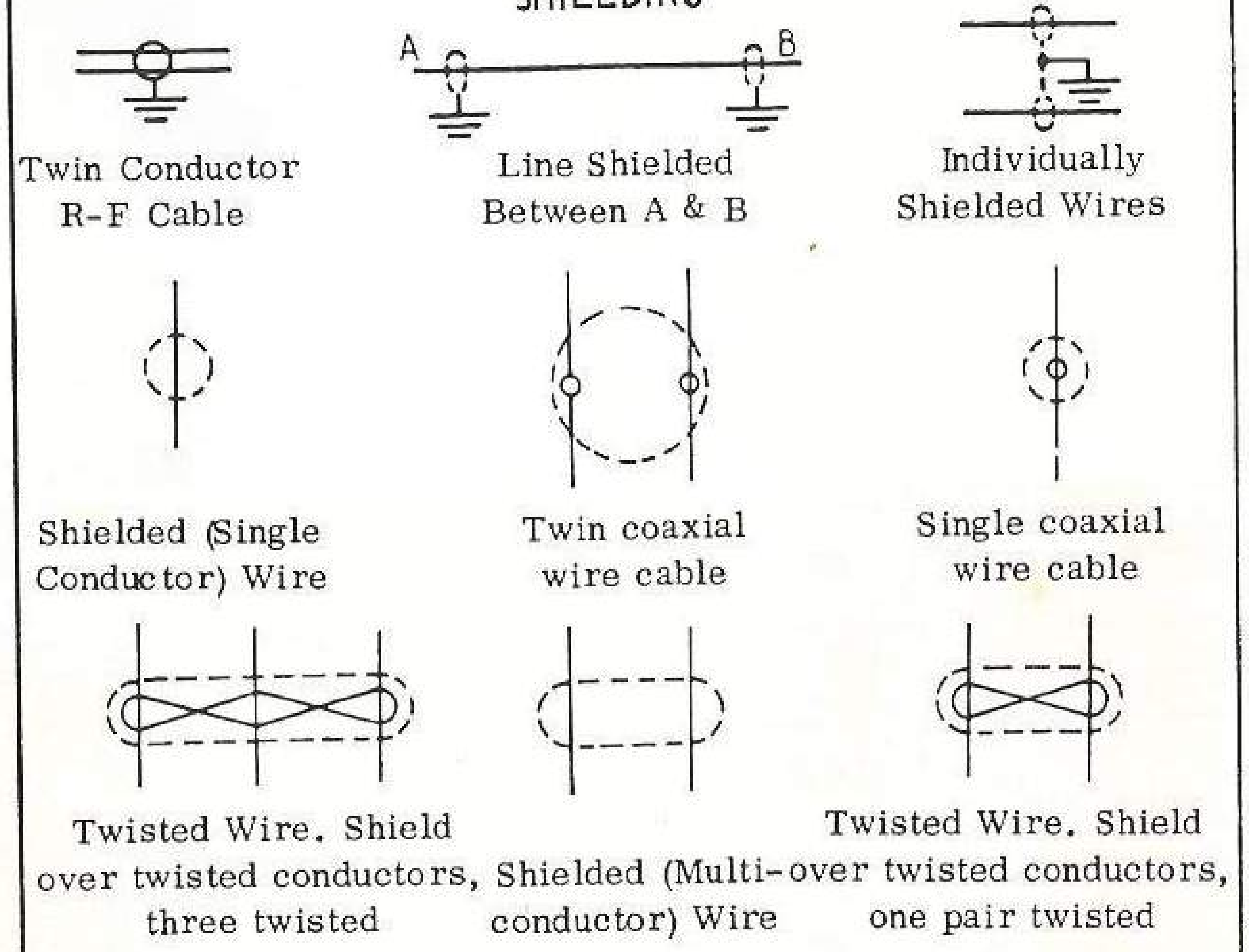
Figure 44. Swaging Tool

APPENDIX

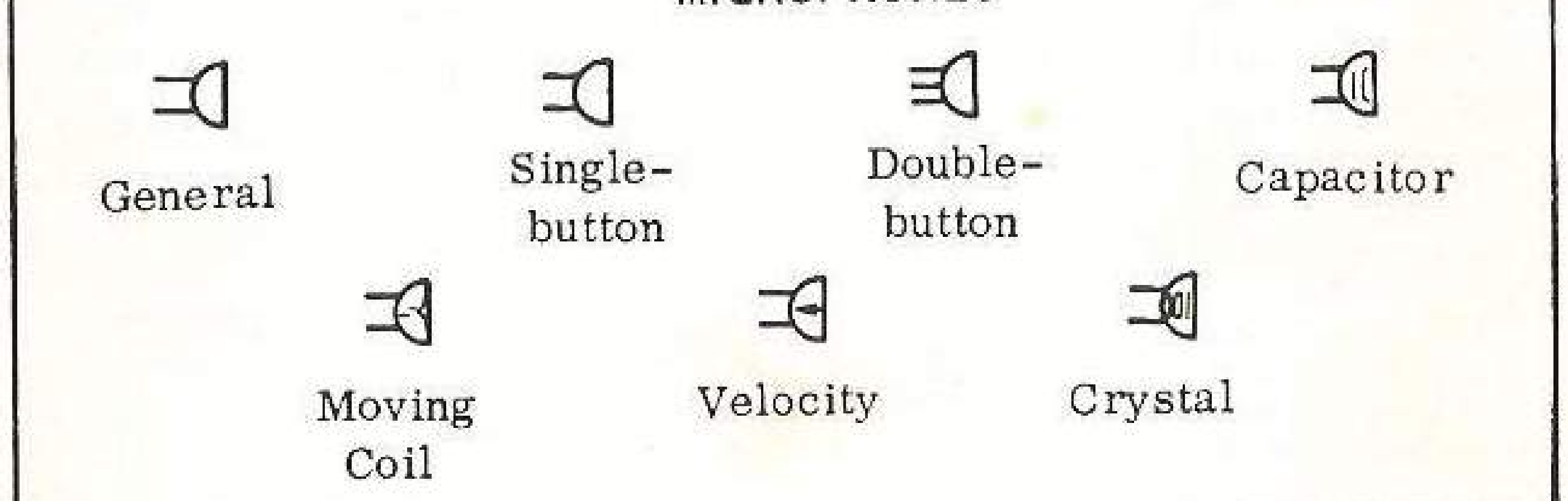
WIRING



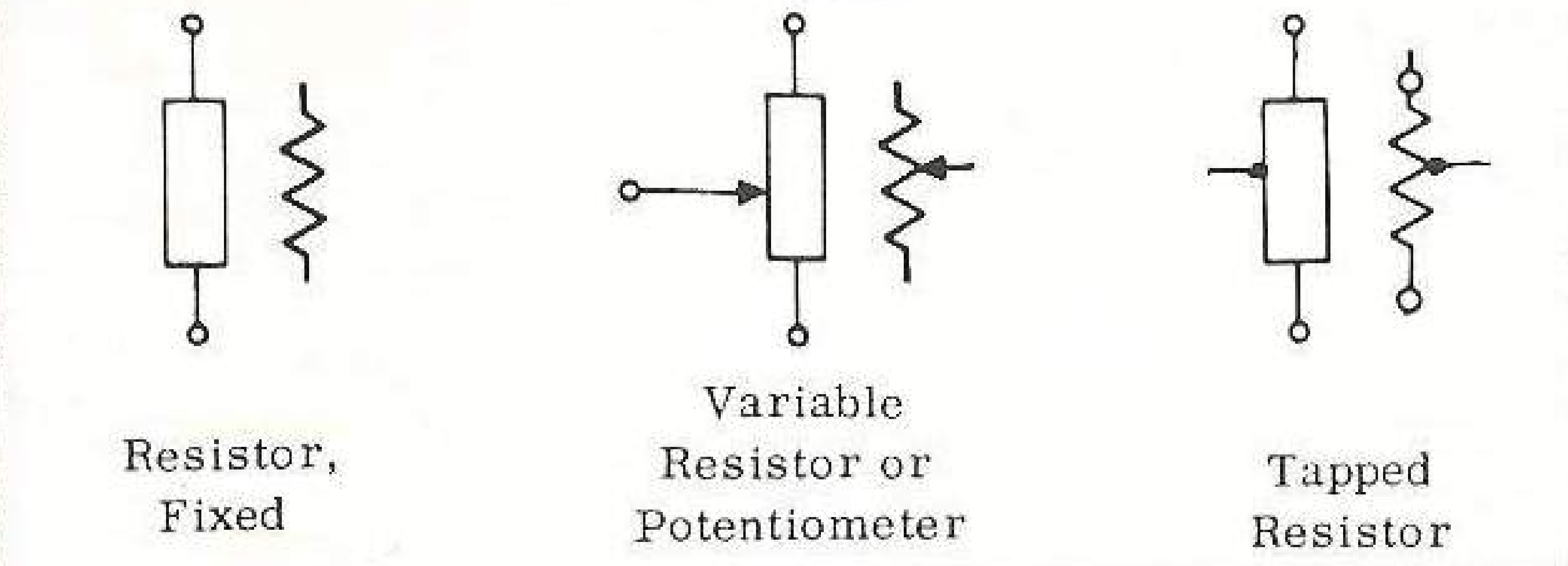
SHIELDING



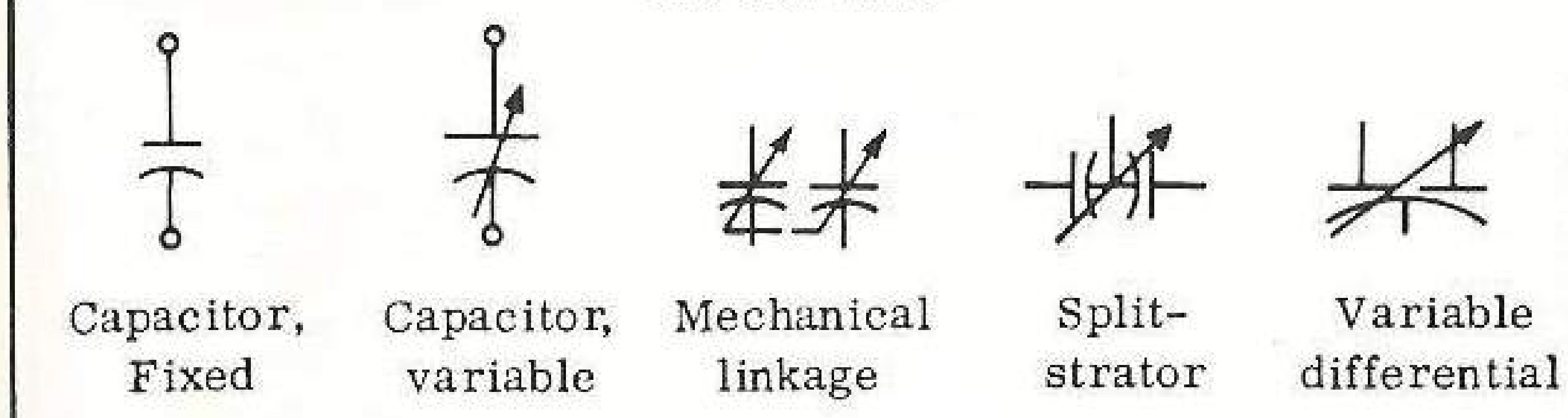
MICROPHONES



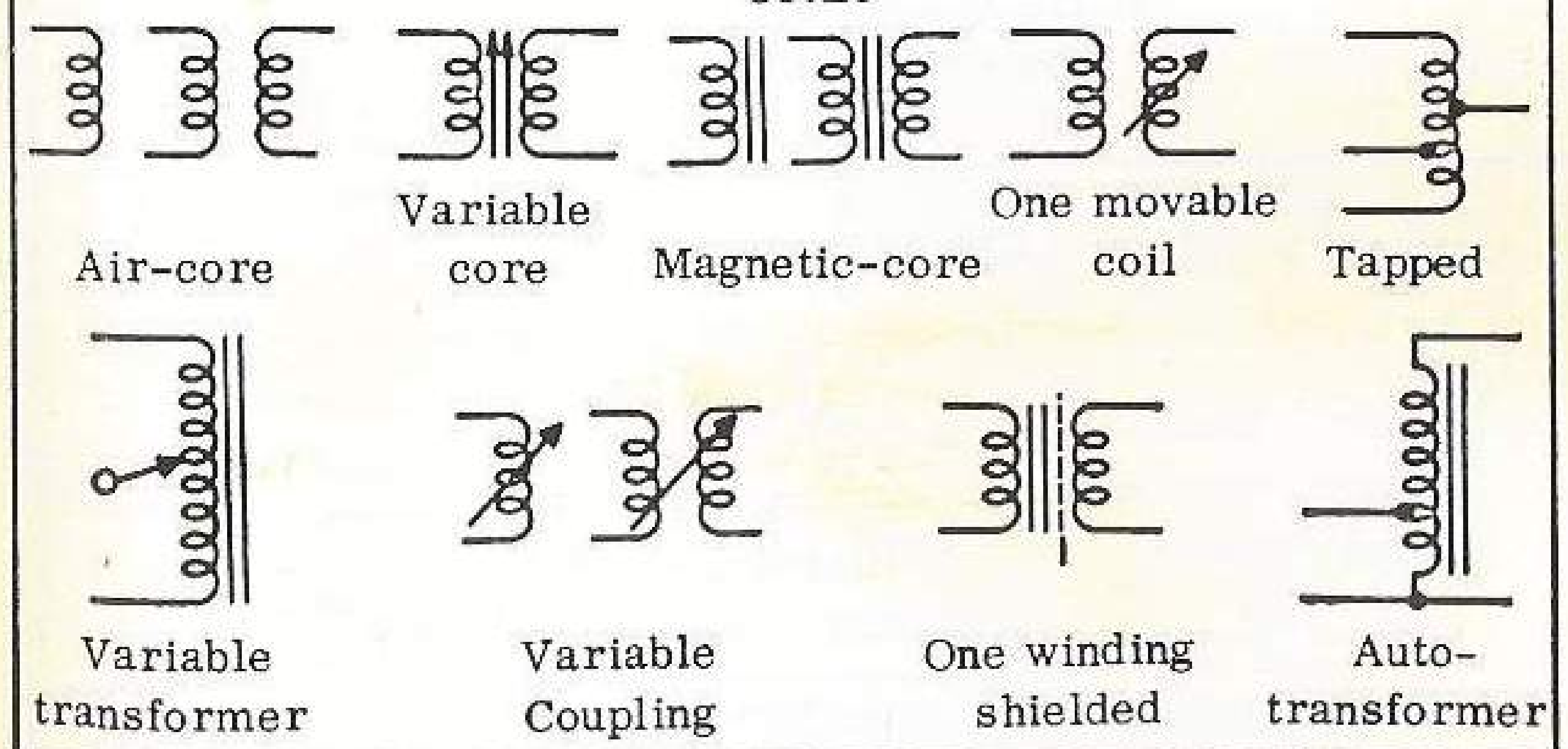
RESISTORS

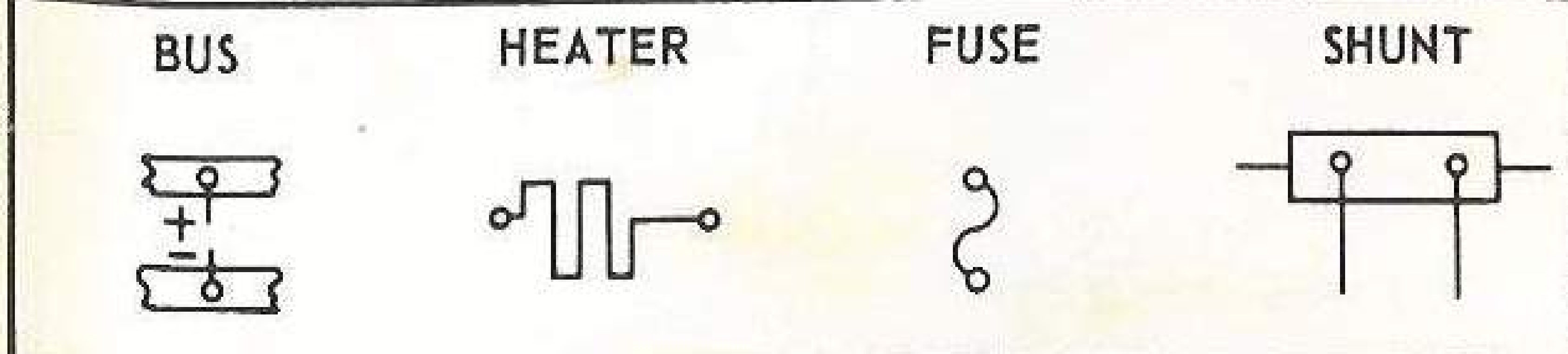


CAPACITORS

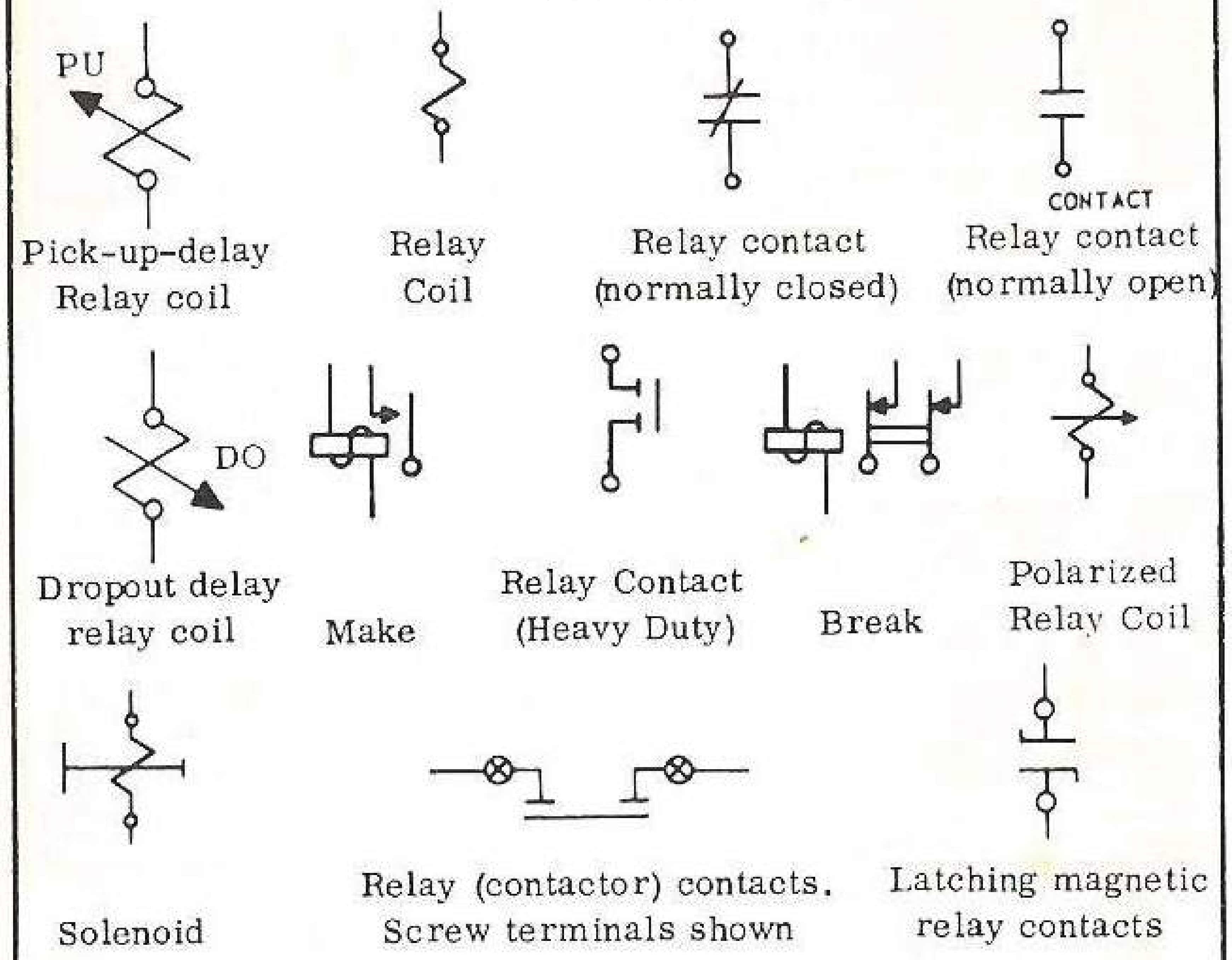


COILS

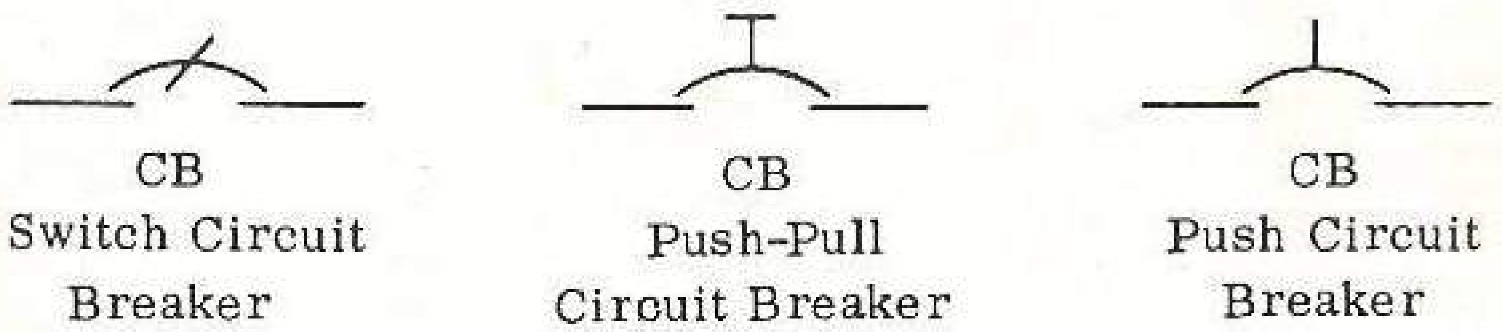




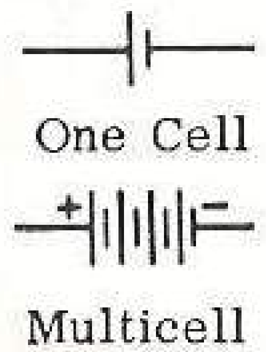
RELAYS



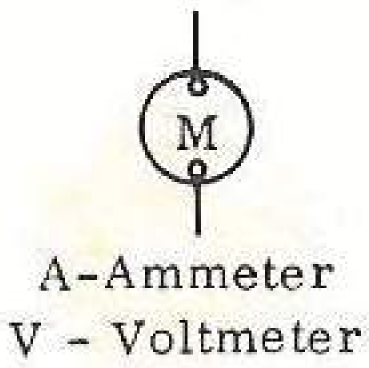
CIRCUIT BREAKERS



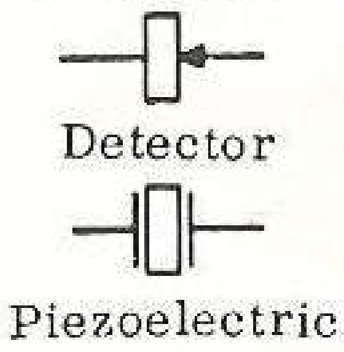
BATTERIES



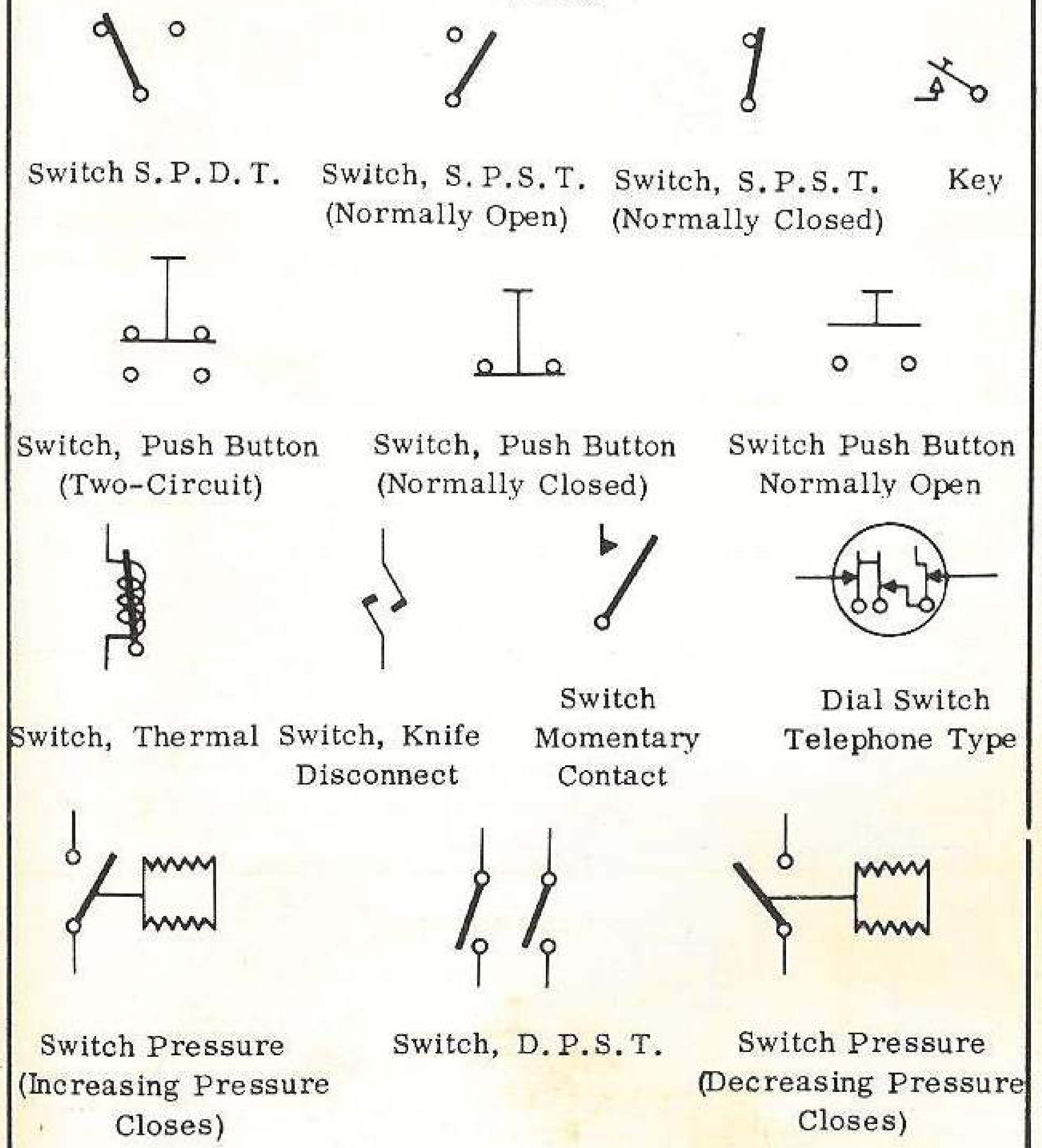
METER



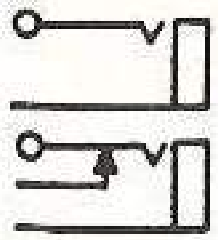
CRYSTALS

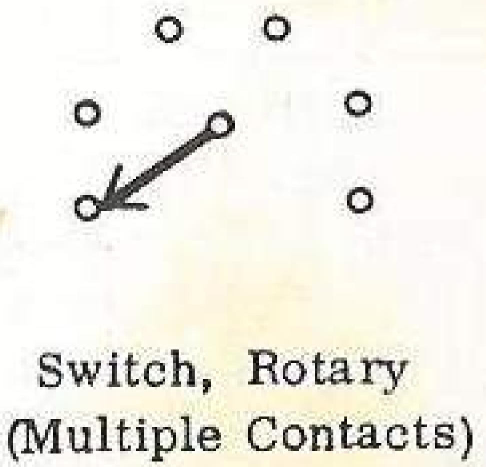


SWITCHES

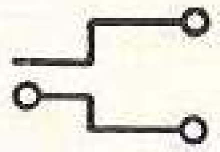


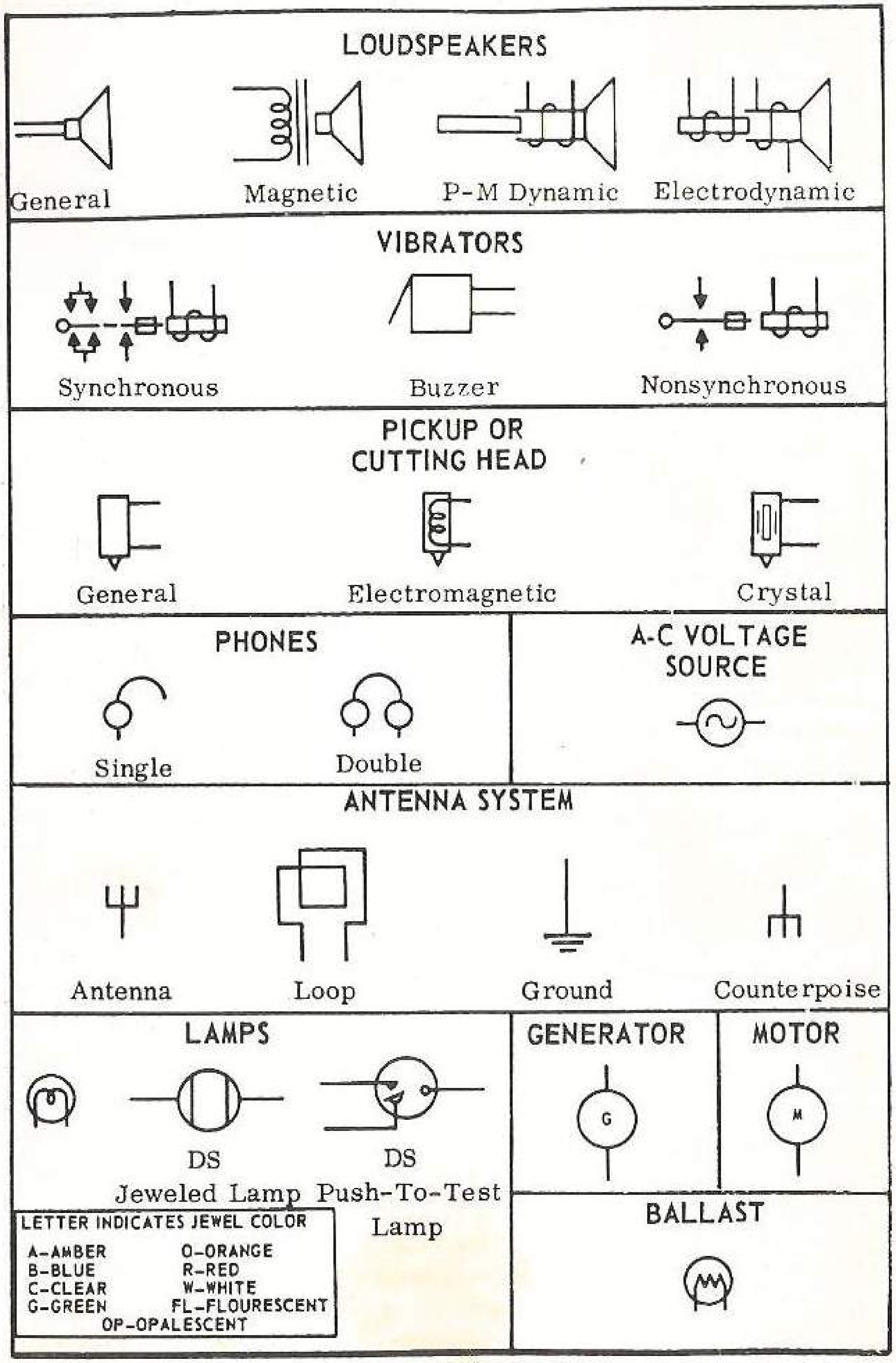
JACK

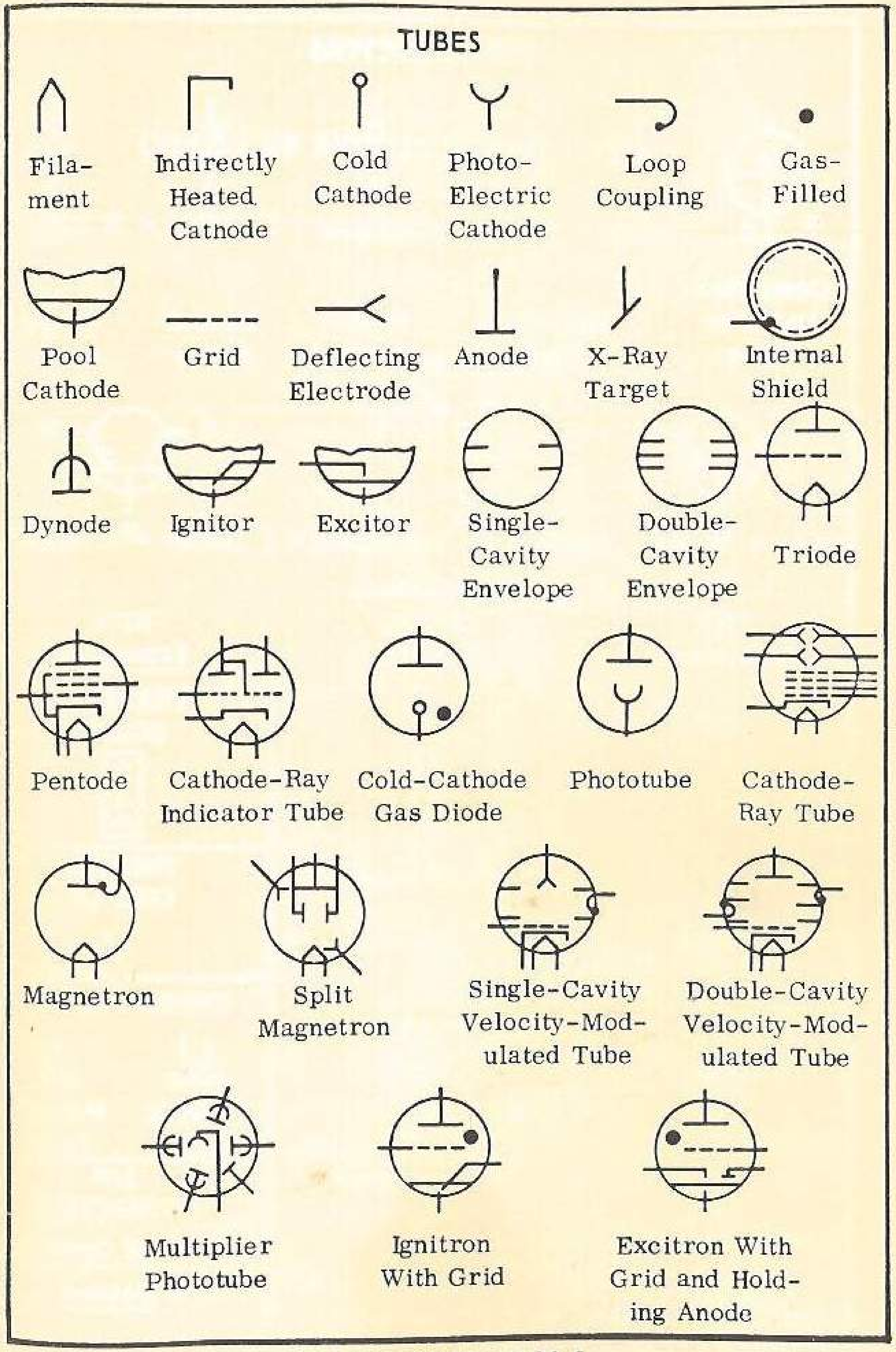


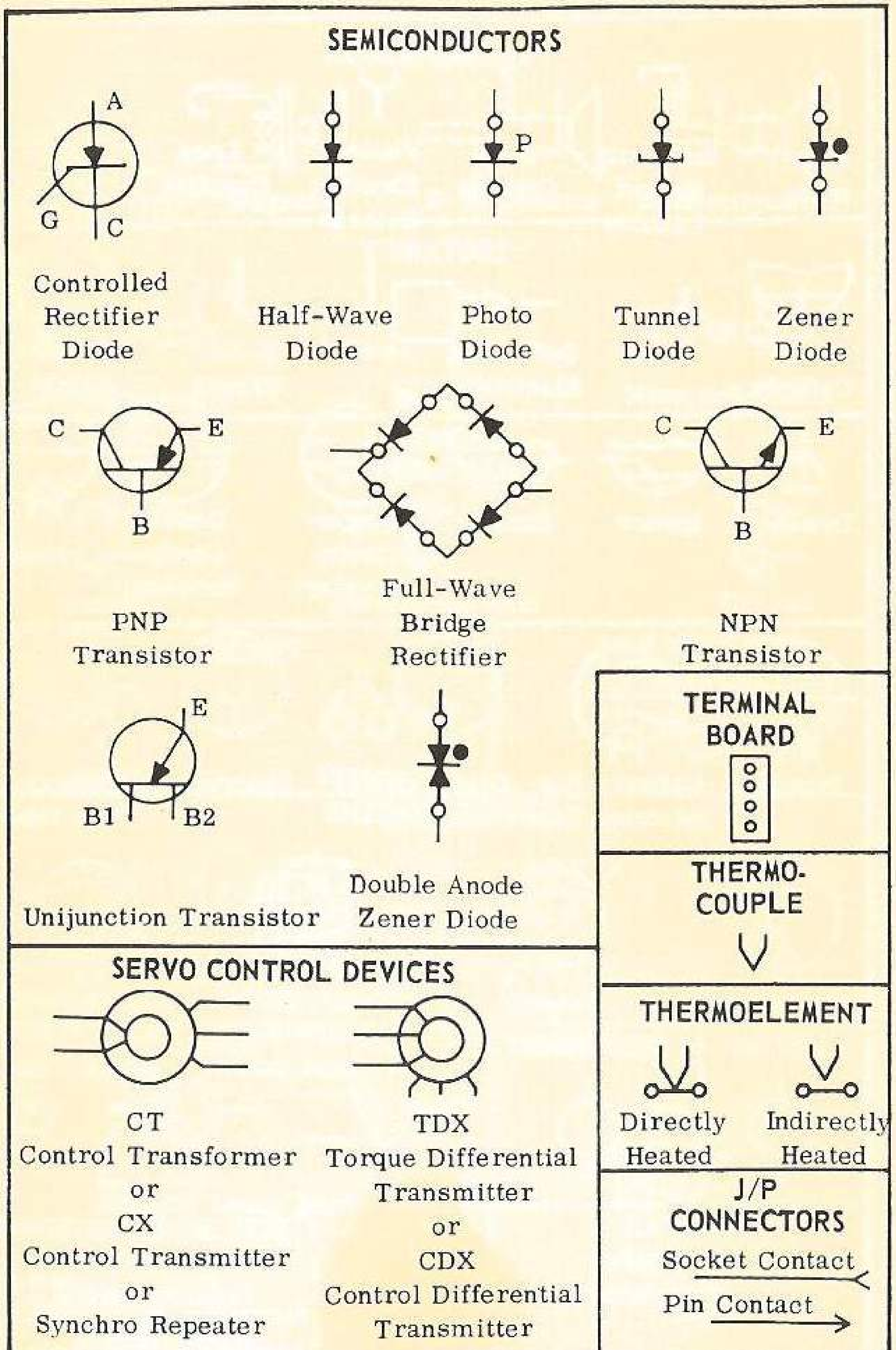


PLUG




LOUDSPEAKERS
General
Magnetic
P-M Dynamic
Electrodynamic
VIBRATORS
Synchronous
Buzzer
Nonsynchronous
PICKUP OR CUTTING HEAD
General
Electromagnetic
Crystal
PHONES
Single
Double
A-C VOLTAGE SOURCE
ANTENNA SYSTEM
Antenna
Loop
Ground
Counterpoise
LAMPS
DS
Jeweled Lamp
DS
Push-To-Test Lamp
LETTER INDICATES JEWEL COLOR
A-AMBER
B-BLUE
C-CLEAR
G-GREEN
O-ORANGE
R-RED
W-WHITE
FL-FLOURESCENT
OP-OPALESCENT
GENERATOR
G
MOTOR
M
BALLAST


TUBES
Fila-ment
Indirectly Heated Cathode
Cold Cathode
Photo-Electric Cathode
Loop Coupling
Gas-Filled
Pool Cathode
Grid
Deflecting Electrode
Anode
X-Ray Target
Internal Shield
Dynode
Ignitor
Excitor
Single-Cavity Envelope
Double-Cavity Envelope
Triode
Pentode
Cathode-Ray Indicator Tube
Cold-Cathode Gas Diode
Phototube
Cathode-Ray Tube
Magnetron
Split Magnetron
Single-Cavity Velocity-Mod-ulated Tube
Double-Cavity Velocity-Mod-ulated Tube
Multiplier Phototube
Ignitron With Grid
Excitron With Grid and Hold-ing Anode



GRAPHIC SYMBOLS

OHM'S LAW AND ITS DERIVATIVES

Where E = volts, I = amperes, and **R = ohms**,

$$I = \frac{E}{R}$$

$$E = I \times R$$

$$R = \frac{E}{I}$$

Where E = volts, I = amperes, **R = ohms, and W** = watts,

$$W = I^2 \times R$$

$$I = \sqrt{\frac{W}{R}}$$

$$R = \frac{W}{I^2}$$

$$W = I \times E$$

$$I = \frac{W}{E}$$

$$E = \frac{W}{I}$$

$$W = \frac{E^2}{R}$$

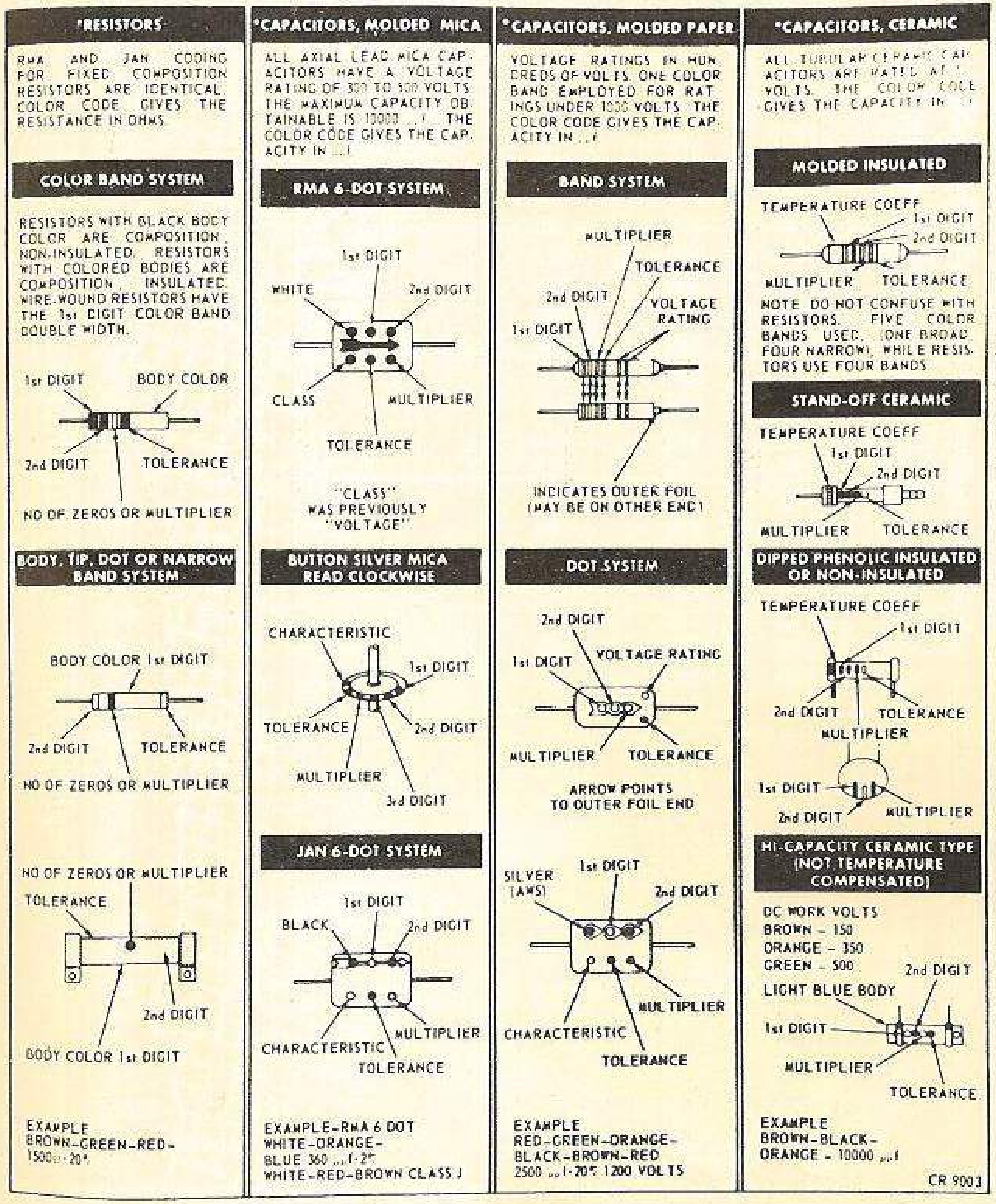
$$E = \sqrt{W \times R}$$

$$R = \frac{E^2}{W}$$

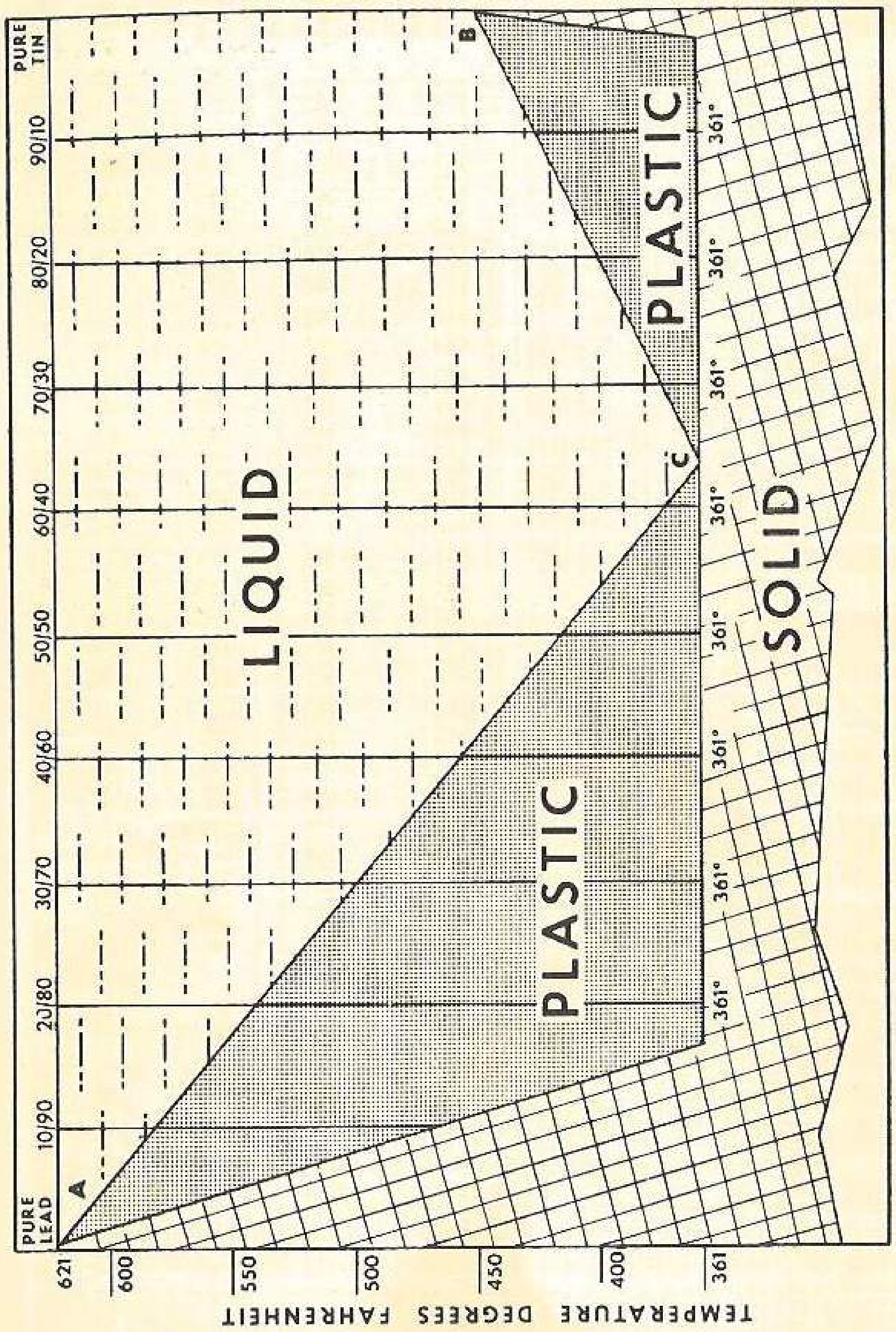
COLOR CODE DESIGNATIONS

Color	Digits or No. of Zeros	Resistors RMA or JAN: Multiplier	Resistors RMA or JAN: Tolerance	Capacitors Molded Mica RMA and JAN: Multiplier	Capacitors Molded Mica RMA and JAN: Tolerance	Capacitors Molded Mica RMA and JAN: Class or Characteristic	Capacitors Molded Paper: Multiplier	Capacitors Molded Paper: Tolerance	Capacitors Ceramic: Multiplier	Capacitors Ceramic: Tolerance C 10 µµf	Capacitors Ceramic: Tolerance C 10 µµf	Capacitors Ceramic: PTS/Mil/°C	Color	Digits or No. of Zeros
BLACK	0	1		1	20%	A	1	20%	1	20%	2.0	0	BLACK	0
BROWN	1	10		10		B	10		10	1%		-30	BROWN	1
RED	2	100		100	2%	C	100		100	2%		-80	RED	2
ORANGE	3	1000		1000	3% (RMA)	D	1000		1000	2.5% (RMA)		-150	ORANGE	3
YELLOW	4	10^4		10^4		E	10^4	5%	10^4			-220	YELLOW	4
GREEN	5	10^5			5% (RMA)	F (JAN)				5%	0.5	-330	GREEN	5
BLUE	6	10^6				G (JAN)						-470	BLUE	6
VIOLET	7	10^7										-750	VIOLET	7
GRAY	8	10^8				I (RMA)					0.25	+30	GRAY	8
WHITE	9	10^9				J (RMA)		10%		10%	1.0	*	WHITE	9
GOLD		0.1	5%		5% (JAN)		0.1	5%					GOLD	
SILVER		0.01	10%		10%			10%					SILVER	
NO COLOR			20%					20%					NO COLOR	

* −350 +500 JAN
+120 −750 RMA



COLOR CODES FOR RESISTORS AND CAPACITORS



TIN-LEAD FUSION DIAGRAM

%Sn	%Pb	%Ag	%Sb	Temperature at which solder becomes plastic C°	F°	Temperature at which solder becomes liquid C°	F°
0	100					327	620
5	95			272	522	314	597
10	90			224	435	302	576
15	85			183	361	290	554
20	80			183	361	280	536
25	75			183	361	268	514
30	70			183	361	257	496
35	65			183	361	247	477
38	62			183	361	242	468
40	60			183	361	238	460
45	55			183	361	225	437
48	52			183	361	218	424
50	50			183	361	212	414
55	45			183	361	200	392
60	40			183	361	188	370
63	37			Eutectic		183	361
65	35			183	361	184	364
70	30			183	361	186	367
75	25			183	361	192	378
80	20			183	361	199	390
85	15			183	361	205	403
90	10			183	361	213	415
95	5			183	361	222	432
100	0					232	450
95			5	232	450	238	460
35	63		2	187	369	237	459
27	70	3		179	354	312	594
40	57	3		179	354	289	543
50	47	3		179	354	260	500
61.5	35.5	3		179	354	248	478
62.5	36.1	1.4		Eutectic		179	354
96		4		Eutectic		221	430
95		5		221	430	240	465
	97.5	2.5		Eutectic		305	581
	95	5		305	581	365	689
0.75	97.5	1.75		Eutectic		310	590

A eutectic alloy is that composition of two or more metals that has one sharp melting point and no plastic range. Sn-Tin; Pb-Lead; Ag-Silver; Sb-Antimony.

MELTING TEMPERATURE OF ALLOYS USED IN SOLDERING

ALPHABETICAL INDEX

C (Cont'd)

D

E

F

G

H

I

J

L

NASA-Langley, 1964