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AIRCRAFT

MICROMINIATURE CIRCUITS

PRINTED WIRING BOARD REPAIRS

1 INTRODUCTION When in service, a printed wiring board assembly may fail for either a mechanical or electrical reason, and once the reason has been established, an accurate assessment should be made not only of the actual repair task to be accomplished, but also of peripheral supporting tasks. The importance of such assessment and of decisions subsequently taken cannot be over emphasized, since the aim of any repair scheme should be to restore a board assembly to its original design and manufacturing specifications.

NOTE: Information on printed wiring techniques, manufacturing methods and inspection procedures, is given in Leaflet MMC/1-1.

1.1 Although there is a basic similarity between certain repair procedures for printed wiring boards and for the more conventional electrical equipment, e.g. the soldering of connections, it does not necessarily follow that there can always be a common application of requisite tools, equipment and skill. There are a number of factors to be taken into account, e.g. the type of board, its construction, circuit track configuration, the degree of miniaturisation, nature and handling of components, soldering temperatures and frequency of application. All such factors highlight the need for adopting a specialized approach to repair tasks, the selection and training of personnel being of particular importance (see also paragraph 7).

1.2 Detailed procedures are laid down in the relevant manufacturer's repair and design specifications, or in specifications which are otherwise approved, and reference should, therefore, always be made to the appropriate documents before undertaking a repair. Attention should also be paid to any limits which may have been imposed on the amount of repair work permissible on any one board.

1.3 The information given in this Leaflet, although based on methods which have proved to be practical and acceptable in service when carried out by properly trained personnel, is intended to serve only as a general guide to the establishment of certain minimum standards of repair.

1.4 The Leaflet is set out as follows:—

2 DAMAGE TO BOARDS The details given in the following paragraphs are intended as a general guide to damage leading to possible failures of printed wiring boards.

2.1 **Cracks.** Cracks in the base laminate can produce mechanical distortion and breakage in conductor tracks, and no repair should be attempted. A cracked board should always be replaced by a serviceable unit.

2.2 **Warping.** A warped board may sometimes be repaired by clamping it flat in a special jig and then subjecting it to high temperature cycling in an oven for a specified time period account being taken of temperature effects on the board and its components. It is, however, recommended that a warped board be replaced by a serviceable unit because, apart from the need for specialized equipment beyond the scope of a normal workshop, it is not uncommon for warping to re-occur.

NOTE: A warp should not be taken out of a board by manually bending it against the warp, as this can cause cracking or breaking of the board and conductor tracks.

2.3 **Blistering.** This is a fault which may occur in the base laminate of a board, particularly a multilayer type of board. It may affect the electrical characteristics of a circuit and the strength of a board, in which case the board should be removed and returned to the manufacturers, since the fault can only be rectified by the application of specialized repair techniques. If tests indicate that circuit electrical characteristics are not affected by blistering, no further action is necessary.

2.4 **Damaged Tracks.** The damage may be any of the following which reduce the cross-sectional area of the track below the tolerance of the original specification: (a) complete break (b) scratches (c) nicks (d) pinholes. A fault which may also occur is lifting or separation of a section of track from the base laminate, leading to fracture under subsequent in-service vibration. Repairs are possible (see paragraphs 3.2 to 3.4) the choice of method depending largely on the size of gap to be bridged, size of damaged area to be covered, and on whether the board is of the single-sided, double-sided or multilayer type. If a damaged track forms part of a coil or a high frequency section of a circuit, a repair is not recommended, since it may produce adverse effects on the electrical characteristics of the circuit.

2.5 **Damaged Lands.** Damage to lands may be either scratches, nicks or lifting from the base laminate, and it is possible for repairs to be carried out (see paragraph 3.5).

NOTE: The term 'land' is used throughout this Leaflet to define the portion of conductive pattern which provides connection or attachment of components. In some repair specifications the alternative term 'pad' may also be used.

2.6 **Edge-contact Damage.** Edge-contacts may be damaged either by scratches, nicks or lifting from the base laminate; in such cases a board should be replaced. If, in service, a board cannot be replaced, a repair should only be sanctioned on the understanding that replacement will be effected at the earliest opportunity.

2.7 **Defective Plated-through Holes.** Holes may become defective as a result of damage to plating, particularly when removing or replacing components. Re-plating of holes is not possible, but repairs may be carried out by by-passing the defective holes (see paragraph 3.6).

2.8 **Defective Eyelets.** Replacement of a defective eyelet, e.g. one having a deformed barrel, should only be carried out when a new eyelet of the same type, and special insertion tool, are available. If an eyelet shows evidence of poor connection at conductor tracks, but is otherwise satisfactory, it may be re-soldered (see paragraph 3.7).

2.9 **Damaged Encapsulant Coatings.** A damaged coating may allow an ingress of moisture causing a subsequent breakdown of the electrical characteristics of the board or failure of a component. It is, therefore, very important to replace a damaged coating as soon as possible after the board has been thoroughly dried out. The replacement method to be adopted depends on the type of board, its application, and type of encapsulant material; reference should, therefore, always be made to the relevant specifications and instructions.

NOTE: In referring to encapsulant coatings, the alternative term 'conformal' may be used in some repair specifications.

3 TYPICAL REPAIR METHODS All repair procedures should comply with those laid down in relevant specifications, or with procedures which are otherwise approved. When repairs are carried out by properly trained personnel repaired boards should continue to meet their performance specifications and have a high standard of reliability. The details given in the following paragraphs relate to typical repair methods which have proved to be practical in operation and acceptable in service. In some cases, alternative methods of repair are possible for the same defect, and these are noted, where appropriate.

NOTE: Information on other procedures associated with repair methods, i.e. encapsulant coating removal, soldering and de-soldering, is given in paragraphs 6, 7 and 8 respectively.

3.1 **General Precautions.** The following general precautions must be observed when carrying out repairs. Additional precautions appropriate to a specific repair process are given in the relevant paragraphs.

(a) A board requiring either removal and replacement of a component, or any form of repair should, where practical, be removed from its associated equipment.

(b) Repairs should only be carried out when the cause of a failure is known, since otherwise the failure may be indicative of latent weaknesses elsewhere in a board.

(c) Handling of boards should be kept to a minimum to avoid changes in electrical characteristics. Boards should be handled by their edges, except at those points where connector contacts are provided.

(d) Contacts formed on the edges of boards should be protected from damage throughout repair operations. This may be done by placing a suitably-cut length of U-shaped PVC extrusion over them. Tubes of the type used for the storage of dual-in-line packages may also provide protection when suitably prepared. Adhesive tapes should not be used, as parts of the adhesive may be left on the contacts and form undesirable dirt traps.

(e) Boards should be firmly held in a suitable jig or holding fixture to prevent shock or damage.

(f) Assembled boards should not be handled by the components, as this may cause breaking of leads and pulling away of conductor tracks.

(g) When a repair method is to be applied to conductor tracks or to the outer layers of a multilayer board, care must be taken to ensure that the method chosen does not include any operation liable to cause damage to plated-through holes, or internal conductors.

(h) When a repair or component installation procedure requires that holes be drilled through printed tracks and base laminate, drilling should be done from the track side. Care should be taken to ensure that the track is not lifted, and that no damage is caused to components or tracks on the other side of the board.

NOTE: Unless programmed drilling machines, or machines of similar capability are available, no attempt should be made to drill a multilayer board.

(j) The repair of defective plated-through holes in multilayer boards should not be carried out other than in accordance with an approved repair scheme.

(k) In cases where bonding of wire by means of a rubber compound is specified, e.g. in broken track repair schemes, the suitability of certain silicon rubber compounds should be verified, particularly where bonding is to be done in the vicinity of precious metal contacts or leads.

(l) Certain semiconductor components are particularly susceptible to thermal shock, and, in some cases, to transient static voltage also. The relevant manufacturer's instructions should be followed without exception. Where any doubt exists, or where instructions are not available, heat sinks and precautions against transient static voltages should be applied. (See also paragraphs 4.4.1 (c) and 7.3.5).

(m) A lead pencil, or other conductive material which can leave a conductive residue, should not be used to trace circuitry, or be allowed to touch any part of a board or component.

(n) Care should always be taken to ensure that a board and its components will not be adversely affected by the use of any of the solvents specified for cleaning purposes and for the removal of particular types of encapsulant coating (see also paragraph 6.1). Chlorinated solvents, for example, should not be used on silicone covered or bonded components, or where there is a risk of component identification markings being removed. In addition, strict attention must be paid to the toxic effects of various solvents, and, therefore, to any special ventilation requirements in the places where repairs are carried out. Solvents commonly used are listed in Appendix 2 to this leaflet for guidance only; reference should always be made to specific approved procedures and instructions.

(o) Conductor widths and spacings should not be reduced below any tolerances associated with the method specified for the repair of damaged or defective conductor tracks.

(p) Boards awaiting repair, or replacement in equipment after repair, should be placed in vertically partitioned racks, so that they are stored supported on their edges and not stacked.

(q) Application of soldering tools to joints should be limited to the time necessary to achieve a successful melt of the solder (see also paragraph 7.3.1). If the correct bit profile is chosen, together with fine gauge solder, a successful joint will normally be achieved in 3 seconds. Excessive heating, or mechanical stress exerted during the application of heat, are common causes of land and conductor track de-bonding.

(r) If it is necessary to apply a sideways force to a component termination, to assist in component removal, it should be done with the minimum of stress applied to the board's conductor track or land. In the event that there is too great a risk of damage being done to a conductor track or land, the component should be removed by cutting its leads and removing the leads separately.

(s) On completion of a repair, flux residue or other debris should be removed using a suitable solvent and brush, and the repair should be visually inspected to ensure that it has been carried out neatly and efficiently, and that no further damage has been caused in effecting the repair. Encapsulant coatings removed prior to the repair procedure, should be made good by applying coatings conforming to the original, or to an approved alternative material specification. The inspection, and the re-coating process, where appropriate, should be followed by tests to establish that electrical characteristics have not been impaired in an unacceptable manner, and also that the board performs its overall function in accordance with the original design requirements.

3.2 **Broken Tracks.** There are several methods which may be adopted for the repair of broken tracks and details of these are given in the following paragraphs. The choice of any one is dependent on such factors as the size of gap to be bridged, width of tracks, position of components relative to tracks, relative positions of tracks on opposing sides of the board, the effects that bridging may have on the vibration characteristics of the board, and whether edge sealing of holes is necessary following drilling. Reference should, therefore, always be made to the design specifications and the approved repair schemes.

NOTE: The reasons why breaks have occurred should always be established in order that remedial action relevant to board design or handling procedures, can subsequently be taken.

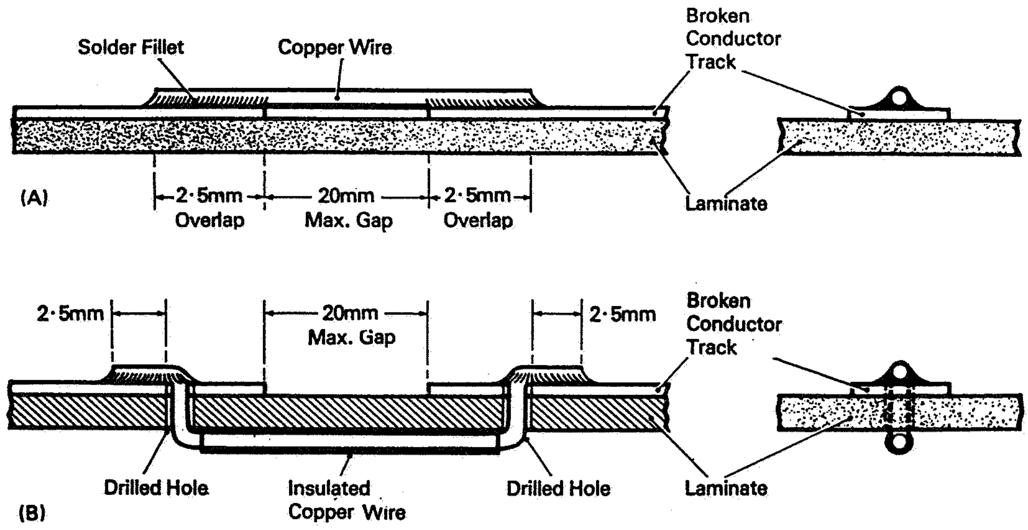


Figure 1 BROKEN TRACK REPAIRS—WIRE METHOD

3.2.1 **Method A.** This method should be used where the gap distance to be bridged is less than 20 mm (0·75 in) the repair being effected by soldering a piece of bare tinned-copper wire to the track either side of the gap as shown in Figure 1 (A).

(a) The track at both sides of the gap should first be cleaned, for at least 6·5 mm (0·25 in), with a rubber eraser and then with a suitable solvent cleaner. The cleaned areas should then be tinned, and a piece of tinned-copper wire, cut long enough to overlap the gap by a nominal 2·5 mm (0·1 in), should be soldered to the track. Care should be taken to ensure that the wire is in contact with the track along its centreline and for the whole length of the overlap, and also that it spans the gap evenly.

NOTE: The size of wire selected depends on the width of the track to be repaired, and as dimensions can vary between types of board, reference should always be made to the approved repair schemes.

(b) Figure 1 (B) shows an alternative method for use when it is necessary for the wire to be run for the major part of its length on the board surface opposite to that of the broken track. In this case, the wire is passed through holes which should be drilled through the track and base laminate, and the ends of leads clinched and soldered to the sections of track each side of the break. The wire should be insulated or sleeved and bonded to the board by means of a suitable epoxy type adhesive or a rubber compound (see also paragraph 3.1 (k)).

NOTE: Drilling of holes should always be done from the track side of the board taking care that no damage is caused to components or tracks on the opposite side.

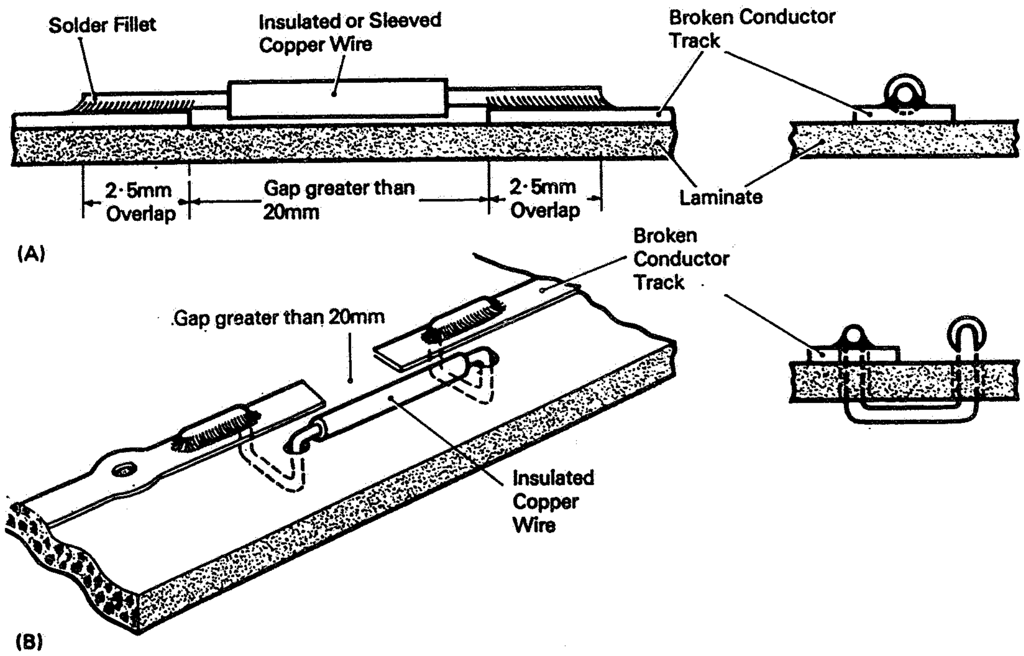


Figure 2 BROKEN TRACK REPAIRS (Gaps greater than 20 mm)

3.2.2 **Method B.** When the gap distance resulting from a break or missing section of track is greater than 20 mm (0·75 in), the wire method described in paragraph 3.2.1 (a) can be used except that the wire should be of the insulated type, or alternatively, bare wire with an appropriate length of sleeving (see Figure 2 (A)). If there is any possibility of the wire lifting, or vibrating to cause lifting of the track to which it is attached, the wire should be bonded to the board at convenient points by means of a suitable epoxy type adhesive or a rubber compound (see also paragraph 3.1 (k)).

(a) Insulated or sleeved wire may also be run on the opposite side of a broken track in a manner similar to that described in paragraph 3.2.1 (b) or on the same side as the track and parallel to it (see Figure 2 (B)). In the latter case, it is necessary

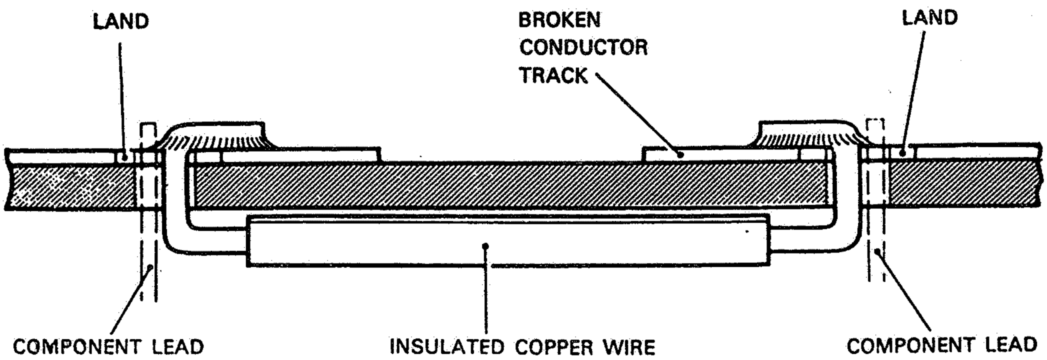


Figure 3 REPAIR OF BREAK BETWEEN LANDS to drill two additional holes in the base laminate. This method may also be used for the repair of a break on the component side of a double-sided board, or to by-pass a component in instances where its removal could cause further damage.

3.2.3 **Method C.** If a break has occurred between lands it may be repaired by soldering the ends of an insulated wire into the lands (see Figure 3). Before adopting this method however, it should be ensured that the wire ends and component leads can share the same land holes. The wire should be run on the side opposite to the track and, before soldering, the ends should be clinched to the track. If there is any possibility of the insulated portion of the wire lifting, or vibrating to cause lifting of

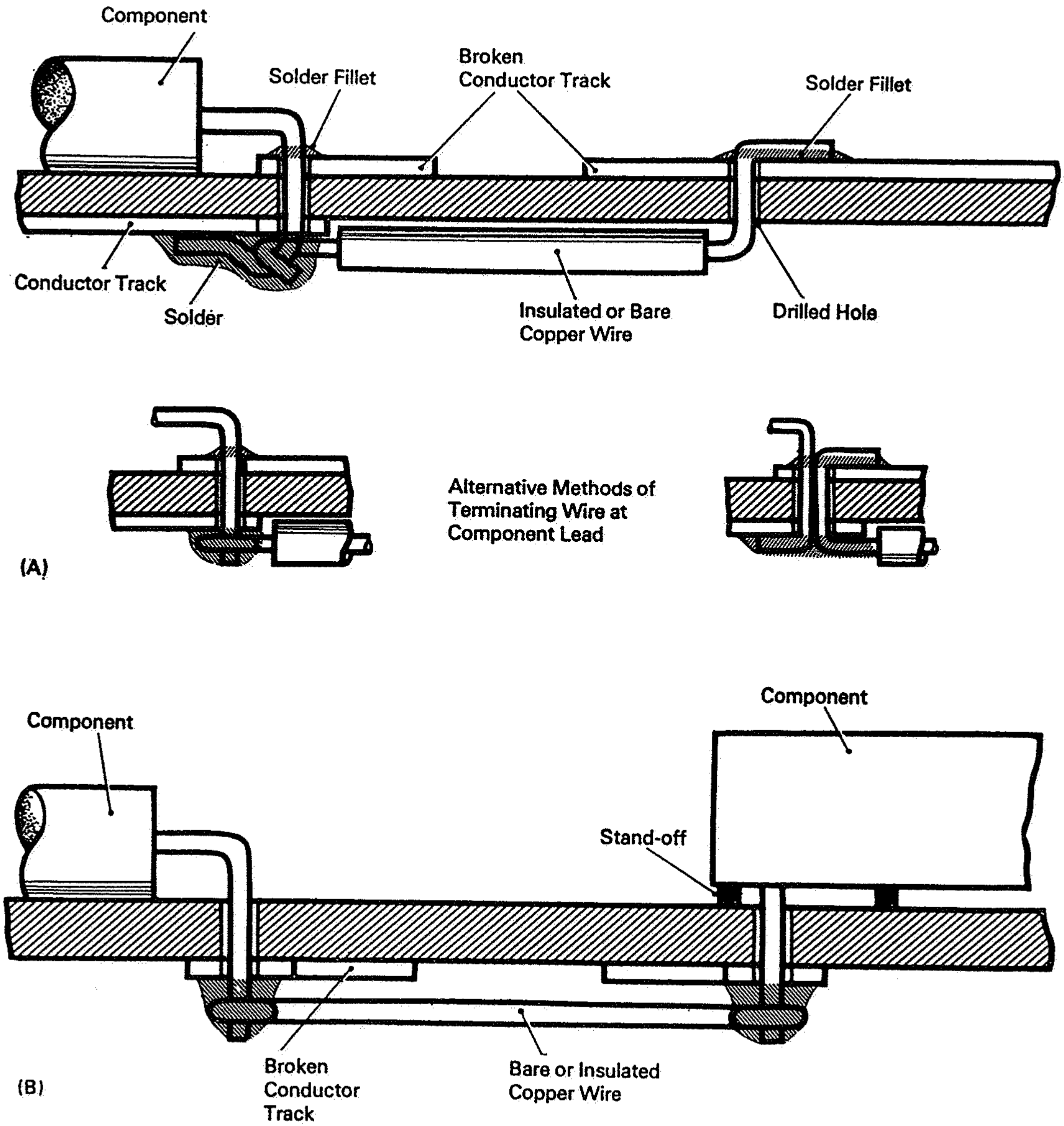


Figure 4 TRACK REPAIRS BETWEEN COMPONENTS the track to which it is attached, the wire should be bonded to the board at convenient points by means of a suitable epoxy type adhesive or a rubber compound (see also paragraph 3.1 (k)).

3.2.4 **Method D.** This method may be adopted for the repair of a broken track between components, particularly in cases where the ends of component leads can serve as connecting points for the repair wire, and also where it is not possible for the repair wire and component leads to share the same land holes (see Figure 4). The wire should be insulated or sleeved if the exposed length is greater than 5 mm (0·2 in).

(a) In the example shown at Figure 4 (A) connection is required between tracks on opposing sides of the board, so that it is necessary to drill a hole through the base laminate to accommodate one end of the wire. Depending on relative positions of tracks and components, the hole may be drilled so that the wire comes up either alongside the track or through it.

(b) The end of the wire is then clinched to the track and soldered. The other end of the wire is looped around and soldered to the component lead, which, depending on the length available, should either be clinched to its appropriate track, or extend from the hole as a short stub.

(c) Where it is possible for the repair wire and component lead to share the same hole, the end of the wire should be clinched to the track and soldered.

(d) The example shown at Figure 4 (B), is one in which the repair wire is connected and soldered to the leads of two components sharing a common track.

3.2.5 **Method E.** By this method (see Figure 5) a repair can be effected by soldering a strip of pre-tinned copper foil to the conductor track, but it should not be used for bridging gap distances greater than 10 mm (0·4 in). It should also be limited to track widths greater than 0·5 mm (0·02 in) to overcome difficulties in handling very narrow strips of foil. The foil should be approximately three-quarters of the track width to permit a well-formed fillet of solder along the overlapping ends, and should be of the same thickness as that of the board foil. Because the strip of copper foil on its own lacks mechanical strength it should be bonded to the board by applying a suitable epoxy adhesive or rubber compound to the area of the gap (see also paragraph 3.1 (k)).

3.3 **Scratched Tracks.** Tracks which are scratched, nicked, or have pinholes in them should be repaired, preferably, by the copper foil strip method referred to in paragraph 3.2.5, with the exception that bonding is not necessary.

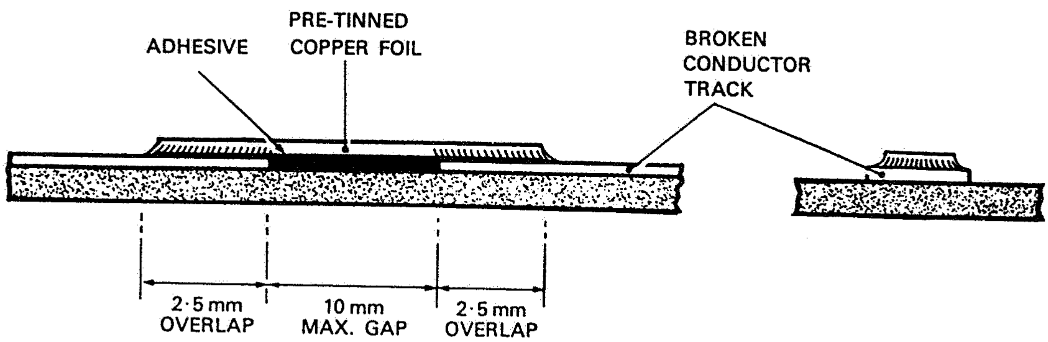


Figure 5 BROKEN TRACK REPAIR—COPPER FOIL METHOD

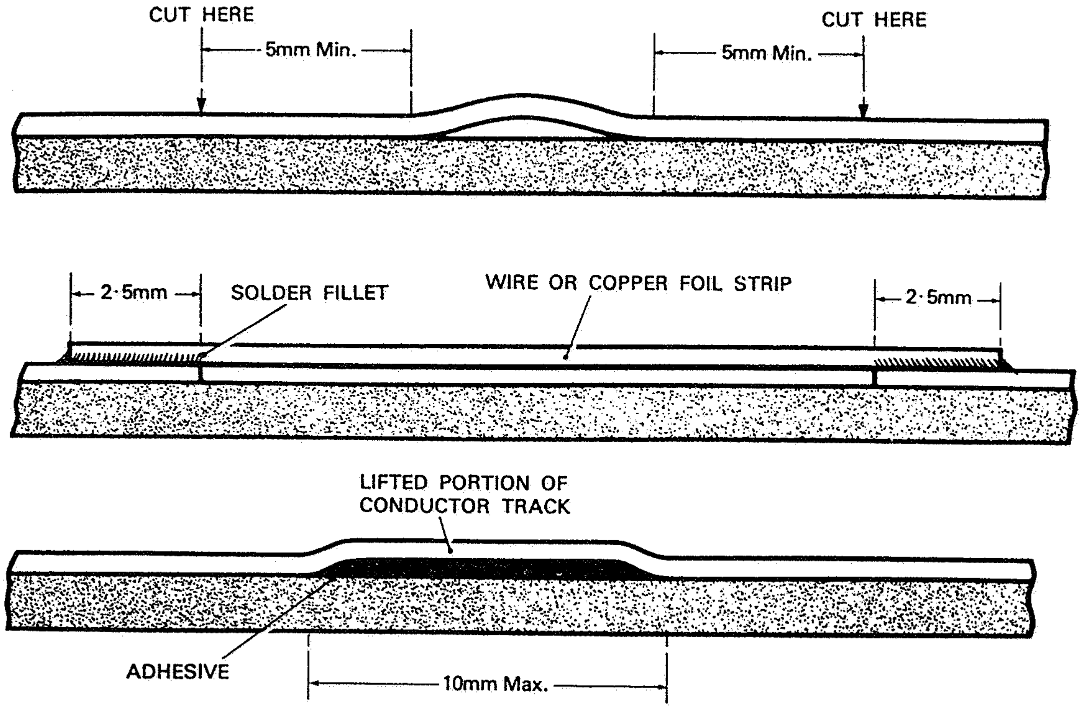


Figure 6 REPAIR OF A LIFTED TRACK

3.4 **Lifted Tracks.** Where a section of track has lifted or separated from the surface of a board (including the outer surfaces of a multilayer board) then, depending on the length of section concerned, and also whether the track is unbroken, it can be repaired either with a length of wire, or by restoring the adhesive bond (see Figure 6).

3.4.1 The wire method is normally used when the length of a lifted section exceeds 10 mm (0·4 in) and the repair procedure is similar to that described in paragraph 3.2.1.

3.4.2 For the adhesive bond method, the encapsulant coating should first be removed from the lifted section (see paragraph 6) and, with a scalpel, the section should be cut at least 5 mm (0·2 in) from each side of the point of lifting and then removed. Care should be taken not to cut the surface of the board. The board surface thus exposed should be cleaned with a solvent to remove all traces of adhesive and fragments of encapsulant coating. The ends of the track sections to be joined should also be cleaned for at least 6·4 mm (0·25 in) by means of a rubber eraser and solvent. After tinning the cleaned areas, a length of the appropriate diameter wire, or a length of copper foil strip, should be soldered to the track ends with a nominal overlap of 2·5 mm (0·1 in).

(a) If the length of a lifted section of track is less than 10 mm (0·4 in) and the track is undamaged, a repair should be effected by restoring the adhesive bond between the lifted section and the board. Following the removal of encapsulant coating, the underside of the lifted section and the exposed area of board should be cleaned with solvent applied by means of a small camel hair brush. Epoxy adhesive, prepared in accordance with the manufacturer's instructions, should then be forced under the entire length of the lifted section by means of a small plastic spatula. Alternatively, a suitably-cut piece of solid-film adhesive may be placed in position.

(b) After application of adhesive, the lifted section should be pressed firmly into contact with the board, excess adhesive removed, and the bonded joint then cured in accordance with the appropriate adhesive specification. Particular attention should be paid to curing temperature requirements, since some components and boards may not withstand the temperature limits that suit adhesives.

(c) If a lifted track has become stretched or otherwise damaged, the most effective repair technique is to cut out the relevant section of track, and to bridge the resulting gap, using either of the methods described in paragraphs 3.4.1 and 3.4.2.

3.5 **Damaged and Lifted Lands.** When tearing, cutting, scoring or lifting of lands has occurred, repairs may be carried out. This also applies to boards with plated-through holes provided that lifting has not damaged the hole plating. Some typical procedures are described in the following paragraphs.

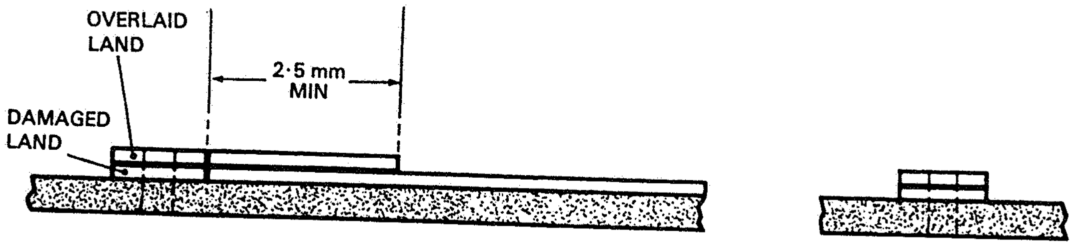


Figure 7 REPAIR OF DAMAGED LAND—OVERLAID LAND

3.5.1 **Damaged Lands.** If a land has been damaged and its adhesion to the board is satisfactory, it may be overlaid with a second land, as shown in Figure 7. The replacement land should be cut so that it overlaps the board conductor track for at least 2·5 mm (0·1 in). Solder should first be extracted from the damaged land, which should then be cleaned with a rubber eraser and solvent cleaner. The adjoining section of conductor track should also be cleaned for a length of approximately 13 to 15 mm (0·5 to 0·6 in). The upper surfaces of the damaged land and cleaned section of track, and the under surface of the replacement land, should be tinned, and, after positioning the land over the damaged area, it should be soldered in position. In order to maintain alignment of the holes during soldering, a non-solderable guide pin should be inserted through them.

NOTE: When soldering a lead or pin of a component into the holes, care must be taken to ensure that the position of the replacement land is not disturbed.

(a) Figure 8 illustrates three different repair methods which involve cutting and removal of a damaged land from the board, and substitution of either a short length of bare tinned-copper wire or a replacement land. Lands should be cut from their tracks at points not greater than 5 mm (0·2 in) from the centres of the land holes. When cutting out lands, care should be taken not to score or cut the surface of the board.

(i) In the wire method shown in Figure 8 (A), the wire is looped around, and soldered to, the component lead, and is also soldered along the centre of the track with at least 10 mm (0·4 in) overlap. Additional support for the wire may be obtained by applying an adhesive fillet in the area of overlap. As in the case of a wire repair to a broken track, the size of wire selected depends on the width of track.

NOTE: This repair should be restricted to cases where the mechanical support achieved is adequate for the particular component, and where a board will not be subject to vibration.

(ii) In the method using a replacement land shown in Figure 8(B), the land should have sufficient conductor track attached to it to enable an overlap of at least 2·5 mm (0·1 in) to be soldered to the existing track. The existing track and the under surface of the replacement land should be cleaned and tinned; tinning of the replacement land should be limited to the overlapping portion only. With the aid of a non-solderable guide pin, the replacement land should then be positioned over the existing hole and soldered to the track. All traces of flux and dirt should be removed from between the under surface of the replacement land and the board, and the land should be lifted sufficiently to permit the smearing of a small quantity of adhesive on the land and board. The land should then be pressed firmly into contact with the board, excess adhesive should be removed and the bonded joint should be cured in accordance with the appropriate adhesive specification.

(iii) In some cases the method shown in Figure 8(C), may be adopted. After removal of the damaged land, a solderable pin should be inserted through the board hole and the component lead looped round and soldered to one end. A piece of bare tinned-copper wire is then soldered to the other end of the pin and to the conductor track in a manner similar to that described in sub-paragraph (i).

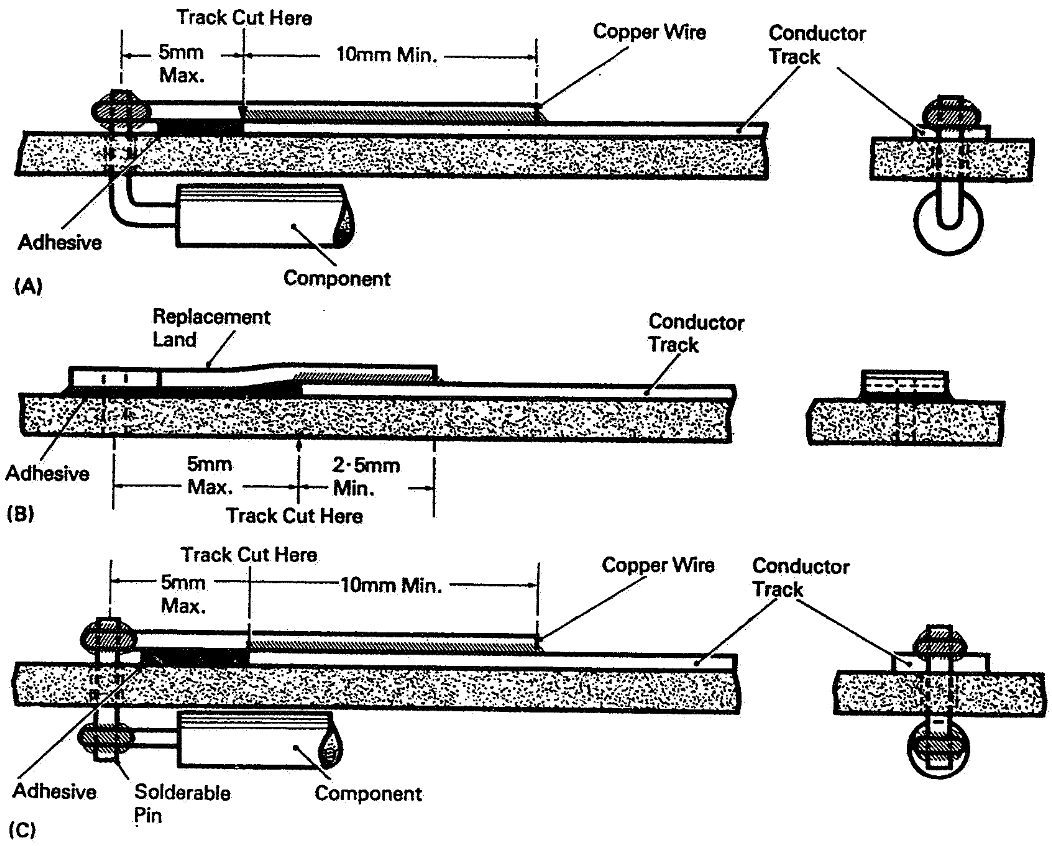


Figure 8 REPAIR OF DAMAGED LANDS

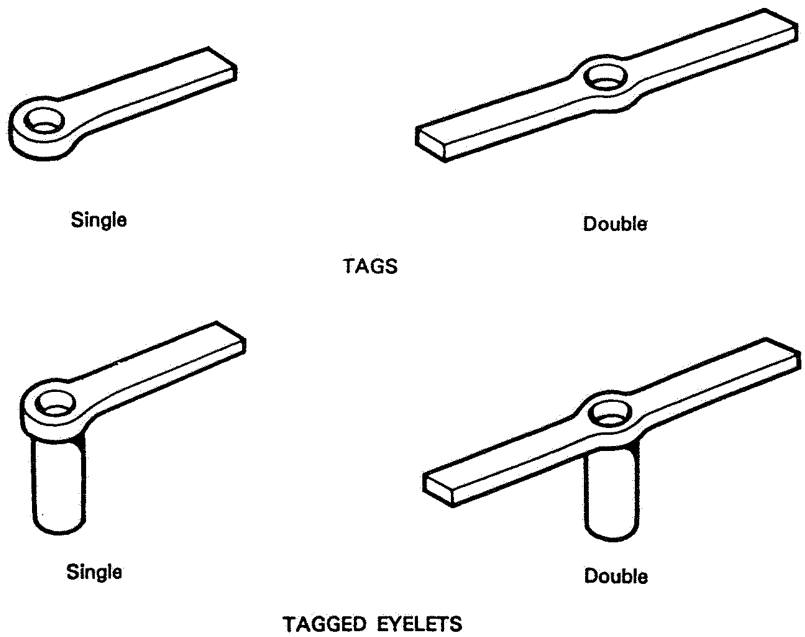


Figure 9 TAGS AND TAGGED EYELETS

(b) Soldered tags and tagged eyelets are commercially available in various forms and sizes, and these can also be used for the repair of damaged lands in the same way as an overlaid land or replacement land (see paragraphs 3.5.1 and 3.5.1 (a) (ii)). Some typical forms are shown in Figure 9. Holes should be drilled out to take eyelets which should then be installed using a commercially available machine or locally-made funnelling tool.

3.5.2 **Lifted Lands.** The procedures to be adopted for the repair of lifted lands depend on whether only partial lifting around a land hole, or complete lifting together with a section of track, has occurred. Before carrying out repairs, solder should be removed from lands and component leads should be disconnected.

(a) If a land has partially lifted, it should be carefully raised further from the board with a scalpel, and the undersurface and board surface should be cleaned free of flux and dirt. After the surfaces have thoroughly dried out, adhesive should be applied, and the joint should be bonded and cured.

NOTE: If a land becomes damaged when raising it from the board, or if lifting is still evident after curing, the land should be removed, and either a replacement land or a soldered tag should be fitted (see paragraphs 3.5.1 (a) (ii) and 3.5.1 (b)).

(b) Lands which have lifted together with a section of conductor track may be repaired by restoring the adhesive bond, or, preferably, by removing the land and track section and soldering on a replacement in the manner described in paragraph 3.5.1 (a) (ii).

(c) If a land has lifted under a mechanical connection, e.g. under the head of an eyelet, then provided that the connection is making adequate electrical contact, adhesive may be applied to the lifted portion and to the area immediately adjacent to it.

(d) In some cases, a land may serve a mechanical function only, i.e. to provide a solderable anchorage point for a component. If such a land is damaged or lifted, it should be removed and, after cleaning the area, an eyelet should be inserted in the hole and swaged to the board.

3.6 **Defective Plated-through Holes.** With the exception of holes in multilayer boards (see paragraph 3.1 (j)) repairs may be carried out, but the methods to be adopted vary, dependent on whether a hole is used solely as an interconnection between conductor tracks, i.e. without a component lead passing through it, or as a lead connecting point.

3.6.1 Three examples of repairs appropriate to defective interconnecting holes, are shown in Figure 10. In each case the hole is 'by-passed' by a short length of wire passing through extra holes drilled in the board laminate, and soldered to each

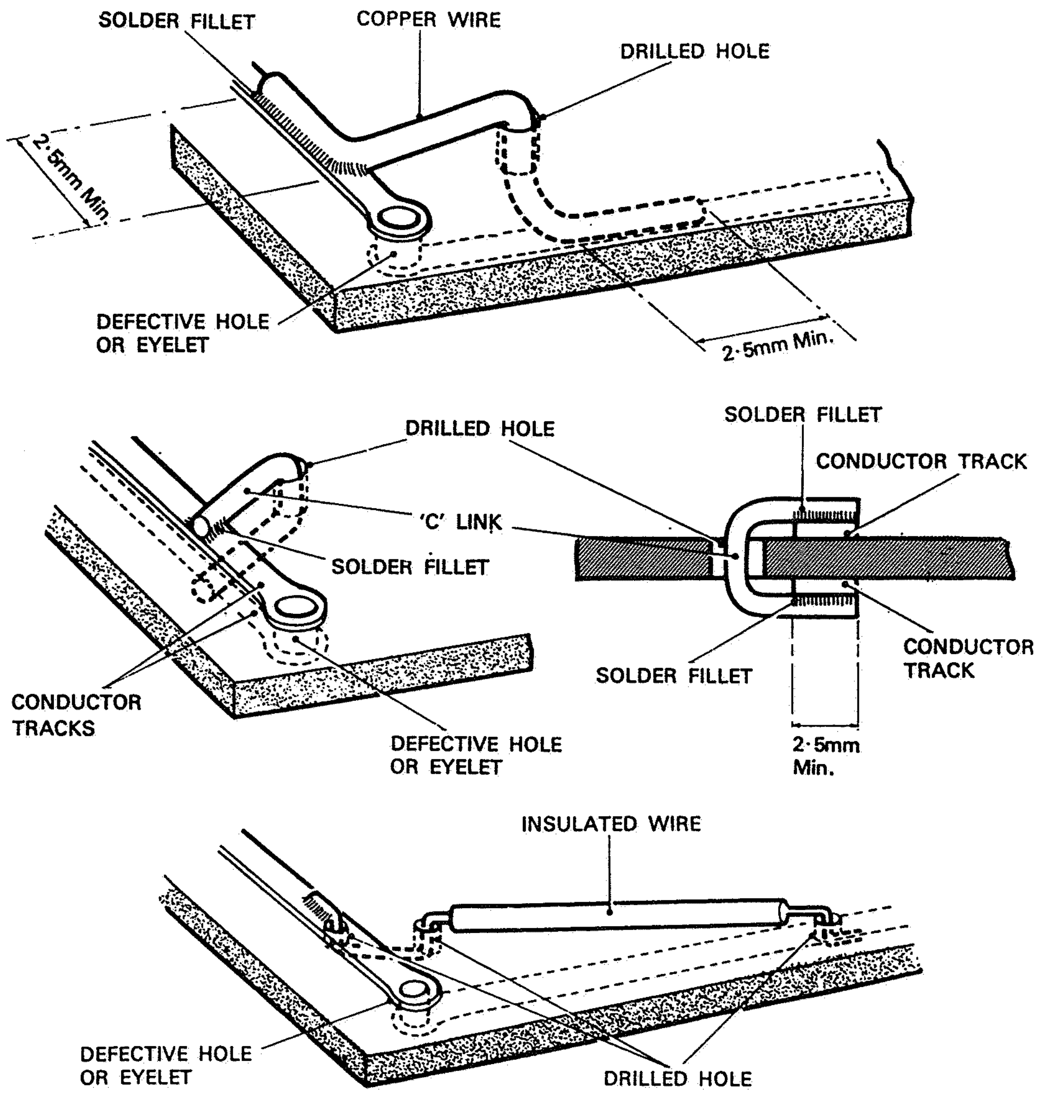


Figure 10 REPAIR OF DEFECTIVE PLATED-THROUGH HOLES AND EYELETS conductor track. In choosing a method, particular attention must be paid to the siting and drilling of holes in relation to the configuration and widths of conductor tracks, and to the position of components. The wire may be bare or insulated depending on the length required.

3.6.2 When a hole serving as a lead connecting point is damaged, and the hole size permits, a repair may be carried out by passing a wire link through it and soldering the ends of the link to the conductor tracks as illustrated in Figure 11. Any encapsulant coating should first be removed from the lands and from at least 2·5 mm (0·1 in) of connected conductor tracks (see paragraph 6). The component lead should then be removed by de-soldering with an extraction iron, ensuring that all excess solder is removed; this being of particular importance where gold plating is present. Following cleaning of the lands they should be re-tinned and the wire link clinched and soldered in place.

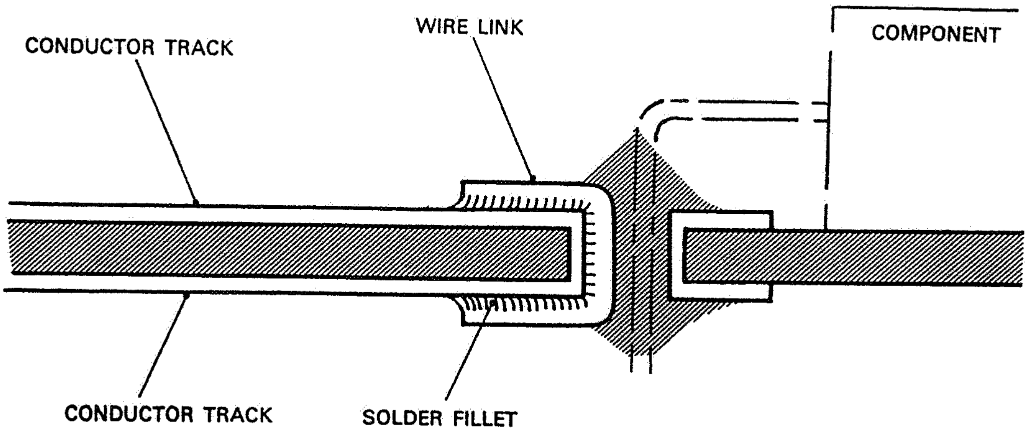


Figure 11 WIRE LINK REPAIR OF DEFECTIVE PLATED-THROUGH HOLE

3.7 **Defective Eyelets.** Eyelets showing evidence of damage, e.g. barrel deformation, may be drilled out using a drill of the same diameter as the hole in the board. Care should be taken to feed the drill slowly so as not to rotate the eyelet in the hole. The flanges should be de-soldered from the conductor tracks, and, after removal, a new eyelet of the same type should be inserted with an eyelet insertion tool, and soldered in place. Alternatively, and if track configurations and component spacing permit, damaged eyelets may be by-passed using either of the repair methods described in paragraph 3.6.1.

3.7.1 Eyelets which show evidence of poor electrical connection between flanges and conductor tracks, but are otherwise satisfactory, may be re-soldered.

4 COMPONENTS The components mounted and soldered to a printed wiring board vary not only functionally, but also in the method of lead termination. Some typical configurations are illustrated in Figure 12.

4.1 Resistors and capacitors are usually cylindrical, rectangular or disc shaped with round terminal wires protruding axially or radially from the body through rubber, plastic or glass seals. The wires are invariably of tin/lead plated copper. In the case of small semi-conductor diodes, which are similar in form to axial lead resistors, the wires are of nickel/iron alloy with a plating of nickel/gold to improve solderability.

4.2 Transistors provide a considerable variety in their mounting patterns. The wire terminations, or pins as in the case of power transistors, are brought out through the

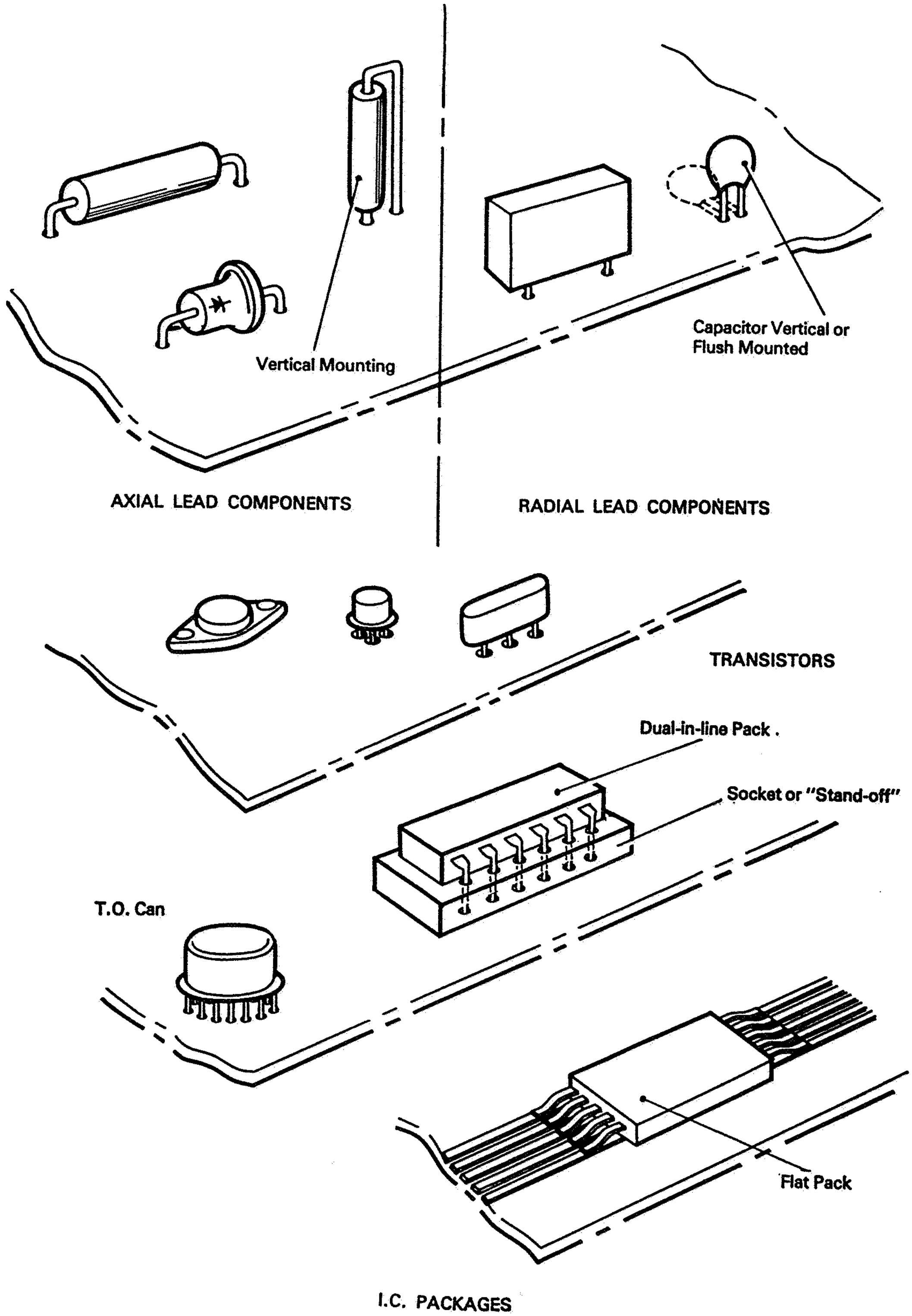


Figure 12 COMPONENT MOUNTING CONFIGURATIONS bases and are plated with either gold or tin/lead to improve solderability. When mounted on a board it is usual for transistors to be spaced a short distance away from the surface of the board by means of a socket (also referred to as a 'stand-off') designed to suit the particular transistor base and board hole spacing configurations. Power transistors are connected to a board via an integral heat sink, or by a separate heat sink specifically profiled for board use.

4.3 Integrated and other forms of microcircuit packages (I.C. packages) are complex components having, in some cases, as many as forty terminations and are often assembled in high density. The mounting patterns for these packages fall into three basic categories: (a) small circular cans (T.O. cans) with a number of wire terminations brought out through the base for connection to board holes, either directly or via a socket or 'stand-off' (b) low profile rectangular packages (known as 'flat packs') with two rows of flat terminations designed for lap solder mounting on conductor tracks, and (c) rectangular packages (known as 'dual-in-line' packages) with two rows of angled tag type terminations designed for through-hole mounting, either directly or by means of a socket. In some cases, dual-in-line packages may also be mounted in a similar manner to 'flat packs'.

4.4 **Installation and Removal.** The procedures for the installation and removal of components vary, depending on such factors as type of component, circuit configuration, and circuit application. Reference should, therefore, always be made to the appropriate manufacturer's repair specifications, modification or overhaul instructions. The details given in the following paragraphs are intended only as a guide to important common aspects of installation and removal.

4.4.1 **General.** When installing or removing components, boards should be firmly held in a suitable jig or holding fixture, and extreme care should be taken to avoid damaging conductor tracks, base laminates, or other components. Damage can be caused by rough handling of boards, improper tool usage, or application of excessive heat during soldering and de-soldering.

(a) Handling of components and assemblies should be kept to a minimum, and should be carried out by means of devices that will not damage leads or component cases.

(b) Unless instructions are given to the contrary, the de-soldering of component leads should be carried out by means of specifically designed tools (see paragraph 4.4.4 and paragraph 8).

(c) I.C. packages require careful handling during installation and removal, and the insertion and extraction tools specifically designed for such purposes should always be used (see paragraph 4.4.4). Certain types of I.C. packages and also certain semiconductor devices (e.g. MOS (metal-oxide-semiconductor) flat packs and FET (field effect transistors)) are particularly sensitive to the generation of static electricity in their unassembled state so that more specialised handling techniques are required. These special techniques include the use of special storage containers, workshop tables with earth-connected tops, lead-shorting clips, earth-connected tweezers, solder pots and lead-forming die presses (see also paragraph 5.6.10). Procedural details are always given in the instructions associated with the relevant packages and devices, and these should, therefore, always be strictly observed.

(d) Components should be installed in such a way that their identification markings, i.e. part numbers, serial numbers, electrical ratings, colour codings and symbols, are visible. If markings are inadvertently removed from a component, or its required location unavoidably obscures the markings, the component should, where practical, be re-marked to agree with the original markings.

(e) Unserviceable components mounted on heat sinks should be removed as a complete unit. In cases where the removal of a heat sink may cause damage to the board, the unserviceable component should be removed separately.

(f) If it is necessary to remove an unserviceable component which is close to other components, these components should first be removed to prevent them being damaged.

(g) Components which, by virtue of their construction, may entrap liquids or moisture, should not be mounted on circuit boards prior to either flow soldering or cleaning operations. This also applies to components which are sensitive to thermal or mechanical shock stresses.

(h) After installing components with pin-type connections, the pins should not be bent against the mounting land, as this makes it impossible to remove the component without damaging the board.

(j) When components, such as electrolytic capacitors, diodes and transistors, are to be mounted on a board, particular attention must be paid to their orientation to ensure correct polarity.

4.4.2 **Component Clearances.** Unless otherwise stated, components should be mounted so that there is adequate clearance between them and the board to permit both the escape of gases generated during soldering and the dissipation of heat generated by components, also to facilitate board cleaning and removal of flux residue. The method of obtaining the required clearance depends on the type of component, and, as will be seen in Figure 13, typical arrangements vary from specifically designed 'stand-offs' to simple spacer strips of nylon or other material. Depending on the requirements of a specification or a repair instruction, spacer strips may either be bonded to the circuit board or temporarily inserted until after a soldering operation has been completed. Strips should neither extend beyond the edges of components nor be too close to the leads of components.

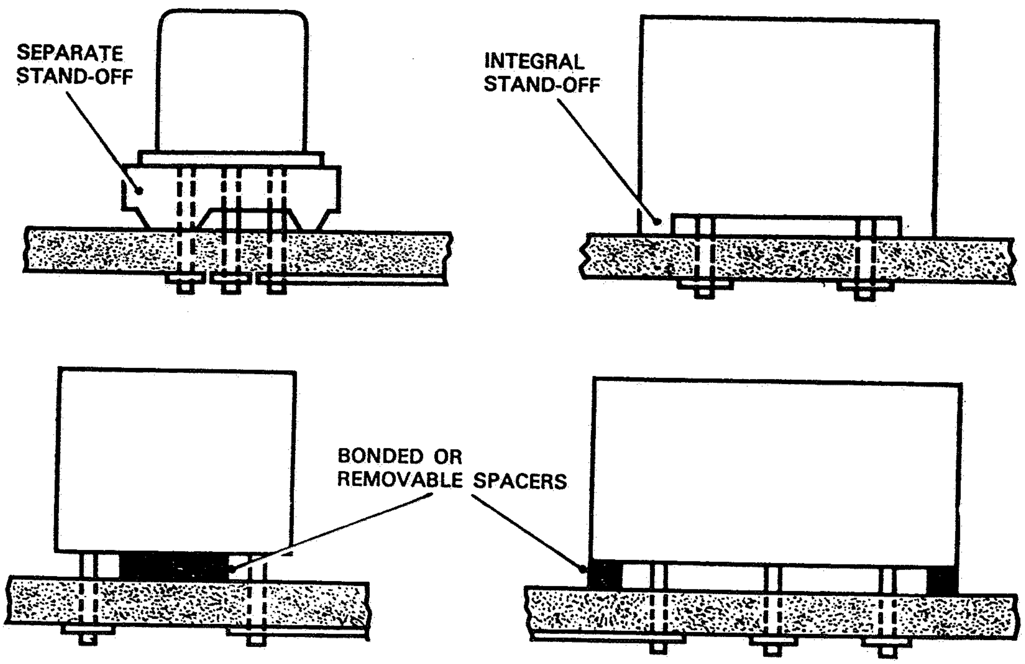


Figure 13 COMPONENT CLEARANCES

4.4.3 **Axial-lead Components.** Components with metal or conductive cases, should be covered with appropriate lengths of transparent insulating sleeving to prevent contact with circuit tracks or other metal parts. This also applies to certain types of diodes and capacitors encased in glass envelopes.

NOTE: Insulation tape should not be used instead of sleeving.

(a) The sleeving should be heated and shrunk on to the component so that it extends beyond the ends of the component body by about 1·5 mm to 3 mm (0·0625 in to 0·125 in).

NOTE: Sleeved components should not be mounted over soldered connections.

(b) Where it is necessary to mount an additional axial lead component on a board, e.g. a resistor or capacitor, it should first be ensured that sufficient space exists on the component side for positioning both the component and the extra jumper leads. Encapsulant coating should be removed from the relevant area of the board (see paragraph 6) and four holes should be drilled in the board to accommodate terminal pins and the jumper leads. The hole sizes and hole configuration should be in accordance with the appropriate installation drawing. An example of a typical mounting is shown in Figure 14.

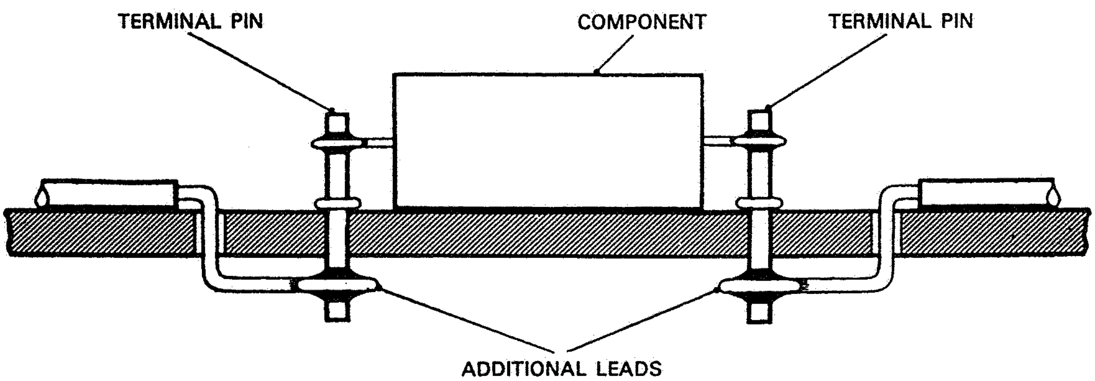


Figure 14 FITTING OF AN ADDITIONAL COMPONENT

(c) If terminal pins are to pass only through the base material of a board, they should be inserted from the component side. If, on the other hand, they must pass through a conductor track, insertion must be from the track side of the board. The methods and procedures for securing pins specified by the manufacturer should always be followed.

(d) If it is necessary to remove a defective axial lead component and replace it with a serviceable one, either of the two methods shown in Figure 15 may be used, the choice being largely dependent on the degree of component accessibility and the amount of soldering required at the board holes.

(i) In the method in Figure 15(A) the leads of the defective component should be cut, and the stubs de-soldered and removed with a solder extraction tool. The holes should be checked to ensure that they are clear of solder, and at the same time lands should be inspected for any signs of lifting. The leads of the serviceable component should then be bent (see paragraph 5.6) and soldered in the board holes.

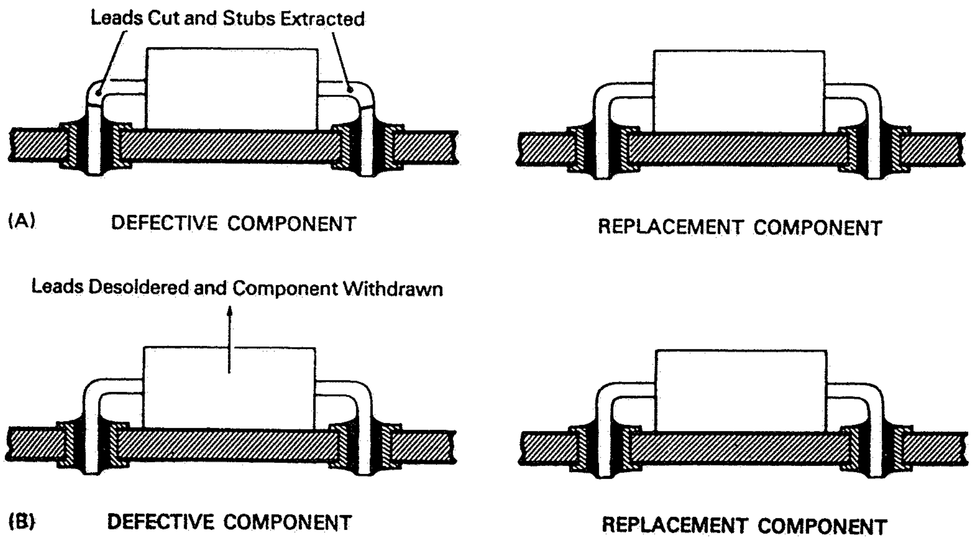


Figure 15 REPLACEMENT OF A DEFECTIVE AXIAL LEAD COMPONENT

(ii) In the method in Figure 15(B) the component is withdrawn from the board after de-soldering the leads. The checks to be carried out and the methods of fitting the serviceable component are the same as those for method (A).

4.4.4 **I.C. Packages.** These packages require careful handling during installation and removal, and reference should always be made to relevant instructions to ascertain any special precautions to be observed (see also paragraph 4.4.1 (c)). Extraction and insertion tools are commercially available and should be employed; two examples of such tools are shown in Figure 16. General procedures associated with installation and removal are given in the following paragraphs.

(a) **Dual-in-line Packs.** If it is necessary to remove a defective pack and replace it with a serviceable one, either of two methods can be used. In each case, encapsulant coating should first be removed from the repair area (see paragraph 6) and the area thoroughly cleaned.

(i) In the first method removal of a defective pack is effected by cutting through all the terminal tags with tip cutting pliers. Each tag stub should then be de-soldered and removed from its hole in the board with a solder extraction tool. After checking that the holes are clear of solder and undamaged, the replacement pack should be correctly orientated and its preformed tags inserted into the holes. The pack should then be pressed firmly down to the waisted portions of the tags and soldered into position.

(ii) In the second method the removal of a defective pack is effected with a heater block (see paragraphs 8.4 and 8.4.2) which permits simultaneous de-soldering of all the terminal tags. Solder should then be extracted from the holes and the replacement pack fitted in the manner already described.

(b) **Flat Packs.** After removal of encapsulant coating and cleaning of the repair area, all the leads along each side of the pack should be individually de-soldered, using a soldering iron with suitably shaped bit, or by one of the methods described in paragraphs 8.2, 8.3, and 8.4. Residual solder should be extracted from the

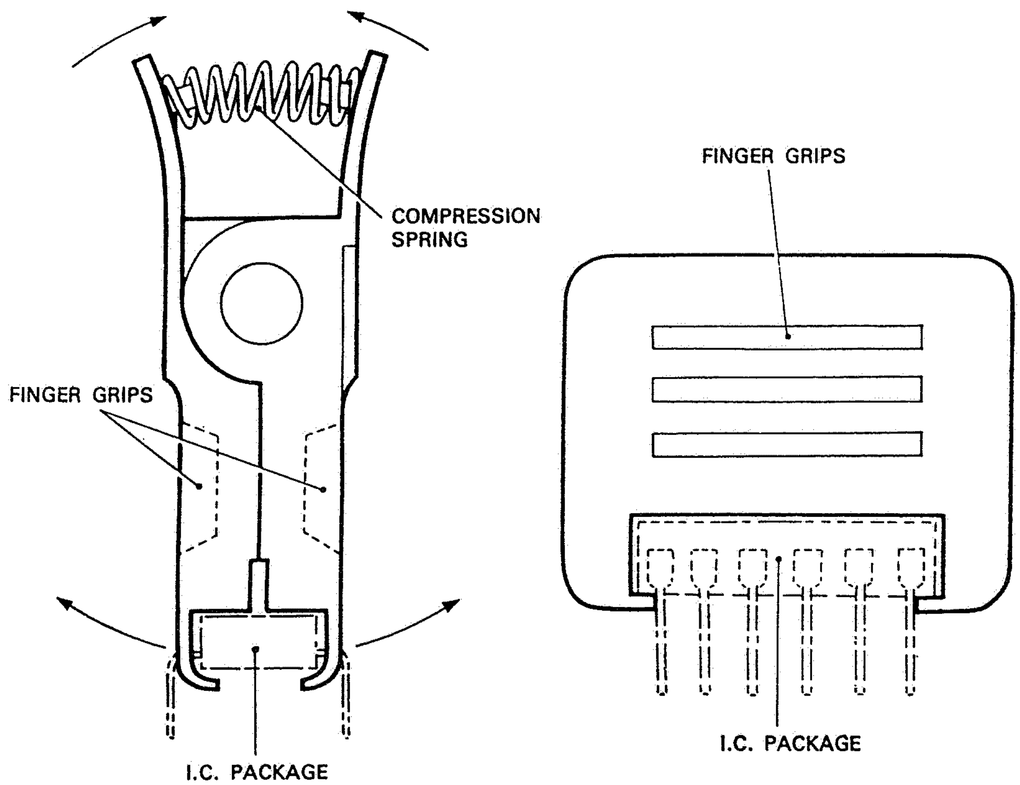


Figure 16 INSERTION AND EXTRACTION TOOLS

associated conductor tracks, which should then be re-tinned. Care should be taken to ensure that solder does not flow over the edges of the conductor tracks on to the board laminates, or cause 'bridging' of the tracks.

(i) The leads of the replacement pack should be cut to a length of 5 mm (0·2 in) and after bending (see paragraph 5.6) and checking for correct orientation, the pack should be positioned so that its leads overlap the portions of the associated conductor tracks equally. The pack should be held firmly in position and the leads attached individually by holding each lead in turn with fine tweezers and soldering it to the track, using an iron fitted with a suitably-shaped bit.

NOTE: Attachment of the leads should be done in the sequence specified in the manufacturer's instructions.

5 LEADS AND CONNECTIONS Leads of such components as transistors, diodes and trimmer capacitors, should be covered with insulation sleeving if displacement of the components from their normal position could cause short-circuiting of the leads.

5.1 Jumper leads should be of the insulated solid type, straight and short as possible, and routed point-to-point alongside component bodies. The leads should be arranged in a neat and orderly fashion, taking care that they are bent slightly to provide stress relief, and set at a safe distance from those components which operate at comparatively high temperatures.

5.1.1 Jumper leads should not be wedged under or between components. Depending on spacing and package density of a board leads may be passed underneath a resistor lead, or similar lead normally positioned off the surface of the board.

5.1.2 The removal of insulation covering should be done with an insulation stripper specifically designed to prevent damage to a conductor. Details of two recommended types of stripper are given in paragraph 7.4.

5.2 If clinching of component leads which pass through plated-through holes or eyelets is specified, the leads should extend through the board by an amount not less than the land radius or more than the land diameter. The leads should then be bent back in the direction of, and parallel to, the conductor tracks as shown in Figure 17. In order to facilitate straightening of the leads during a subsequent component removal operation, the leads should be angled at approximately 15 degrees.

5.3 Unless otherwise specifically authorised, leads should not be spliced.

5.4 The leads of tantulum capacitors usually contain welded joints; they should not, therefore, be subjected to twisting, bending, or undue stressing at the portion of the lead between the welded joint and capacitor body.

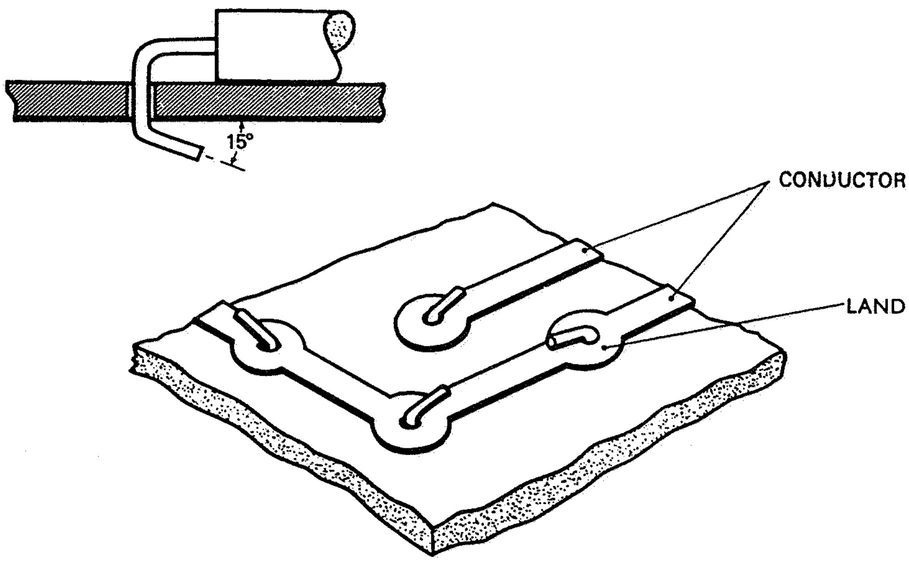
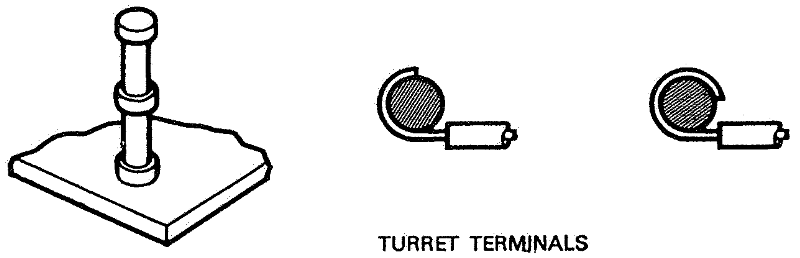


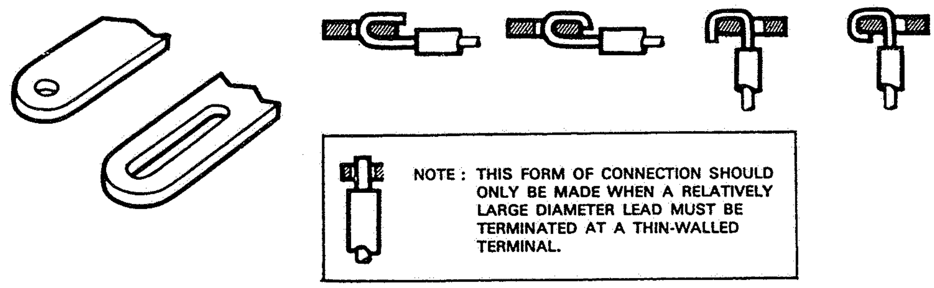
Figure 17 CLINCHING OF COMPONENT LEADS

5.5 Leads which are to be solder-connected to terminals should be firmly clinched to the terminals before soldering to ensure that the mechanical strength of the connection depends on the clinching and not on the solder. Unless otherwise specified, the ends of leads should be wrapped around terminals from between one-half to three-quarters of a turn. Some examples of recommended connections are shown in Figure 18. After wrapping and clinching, any extension of leads should be clipped close to the terminals.

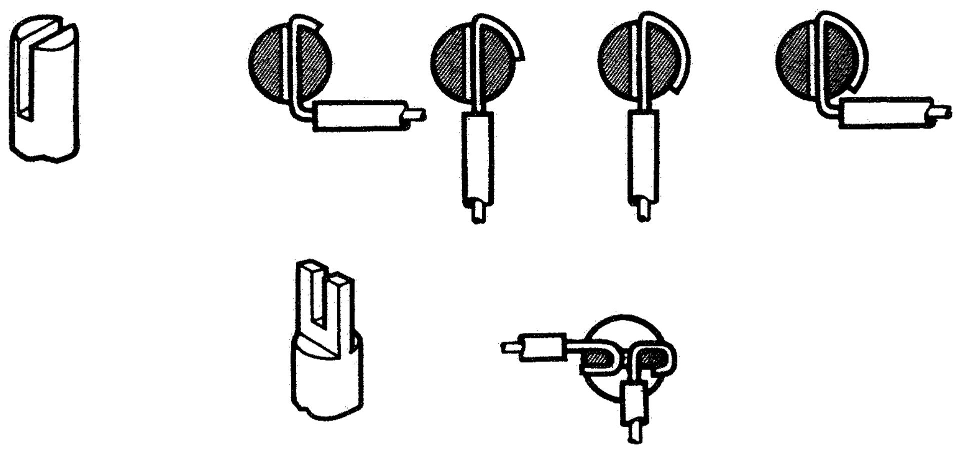
5.5.1 If insulated leads are to be connected, the insulation should be cut-back by such an amount that after connection there is a small clearance between the end of the insulation and the terminal. A typical maximum value for this clearance is equal to the outside diameter of the insulation.



TURRET TERMINALS



EYELET AND SLOTTED TERMINALS



ROUND SLOTTED AND FORKED TERMINALS

Figure 18 EXAMPLES OF TERMINAL/LEAD CONNECTIONS

(a) Where it is necessary to connect several leads to one terminal point, the terminal should be of the turret type with a location for each lead. The ends of the leads should be stacked in sequence from the base of the terminal to the top. They should not be wrapped over one another. If leads are of varying diameter they should be stacked with the largest diameter leads at locations nearest the base of terminals.

5.5.2 When connecting axial lead components to turret terminals, stand-off pins, off-set eyelets or plated-through holes, the leads should also be bent slightly in a horizontal plane to relieve stresses.

5.6 Bending of component and individual conductor leads during installation should be carried out with the utmost care to ensure that specified limits are not exceeded and that no damage is done to the seals of components or leads. Procedures and limits are specified in relevant manufacturer's manuals and specifications; reference should, therefore, always be made to such documents. The following paragraphs are a guide to the points to be generally observed.

NOTE: The dimensions quoted are examples, and as such, do not necessarily apply to all repair and component replacement practices.

5.6.1 The shaping and bending of leads should be done, prior to soldering, with the aid of a smooth metal rod or round-nose wire-forming pliers. Long flat-nose pliers

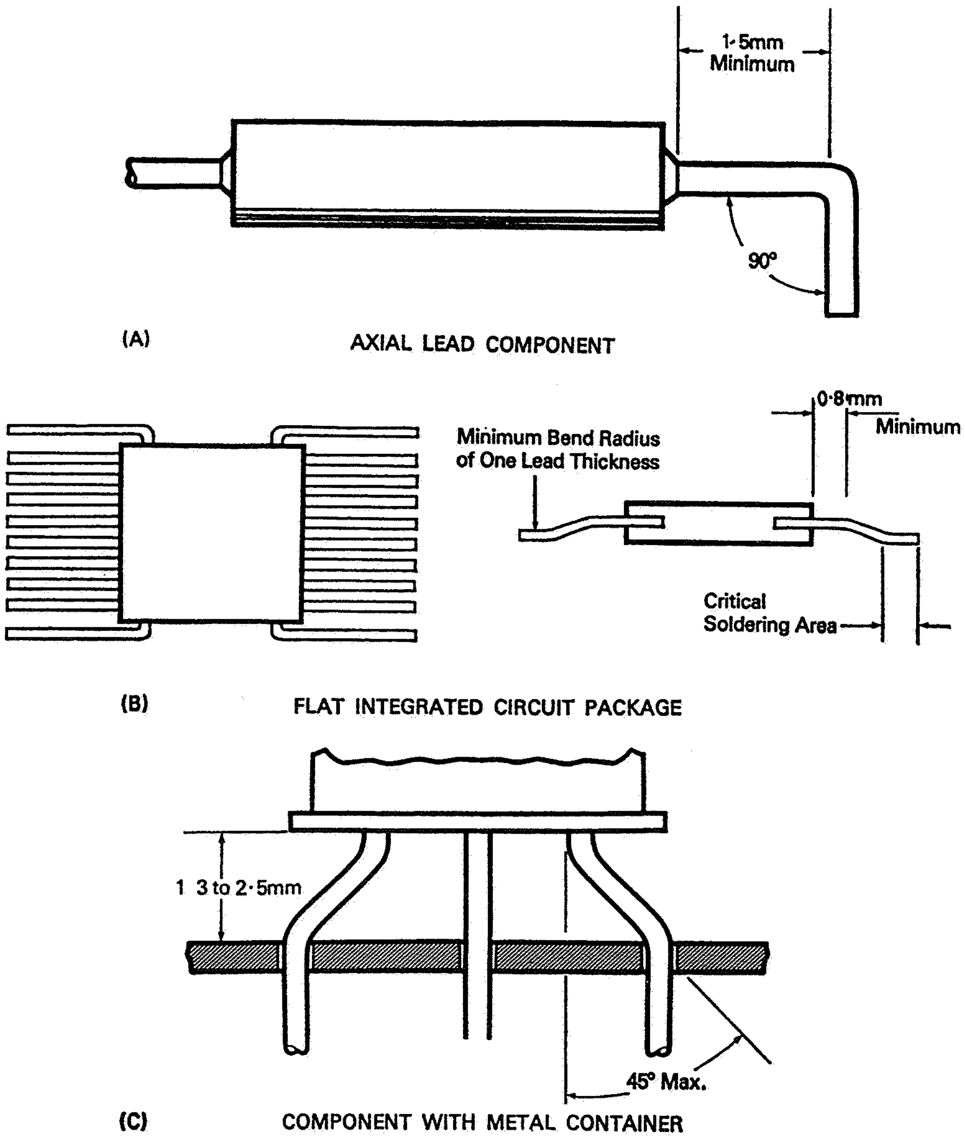


Figure 19 BENDING OF LEADS

are acceptable provided the jaws are smooth and the sharp edges of the jaws are covered with durable plastic tubing or tape.

NOTE: Tools designed solely for the forming and bending of leads, and for accurately gauging the distances between board holes are commercially available and, where possible, their use is recommended.

5.6.2 Solid conductor leads should not be bent with a sharp radius; a minimum of one lead diameter is typical. During the bending process, a component lead should be held at a point between the end of the component and the point of bend. The minimum distance between these two points (see Figure 19 (A)) should correspond to that specified, a typical value for all components except flat packs, being 1·5 mm (0·06 in).

5.6.3 The leads of flat packs should have a minimum bend radius of one lead thickness, and the distance between the end of the pack and point of bend (see Figure 19 (B)) should be a minimum of 0·8 mm (0·03 in). Solder seals, glass bead seals and other protrusions are considered to be included in the component body when measuring this distance. When being formed leads should be supported at a point adjacent to the body in order to avoid stress being applied at the seals.

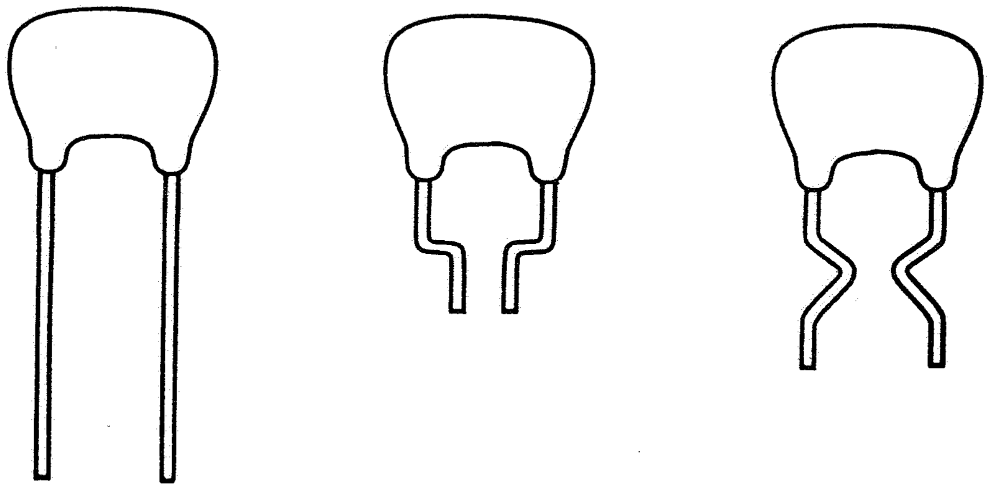


Figure 20 RADIAL LEAD CAPACITORS

5.6.4 In bending and forming leads care should be taken to ensure that they match the spacing of the holes in which they are subsequently to be soldered. Radial lead capacitors are normally designed to cover a range of standard hole spacings, and the leads may either be straight or pre-formed as shown in Figure 20.

5.6.5 If clipping of the leads of a component is required after bending, care must be taken to ensure that the junction between the leads and component body is not stressed and that no shock is transmitted to the junction. A lead should be held securely between the point of clipping and component body during the clipping operation. Clipping tools should be of the side-cutting type with either flush or semi-flush jaws. When in use, the cutting edge faces should be towards the component body and perpendicular to the axis of the leads.

5.6.6 Leads extending from the bottom of components with cylindrical metal containers, referred to as T.O. type cans, may be formed as shown in Figure 19 (C).

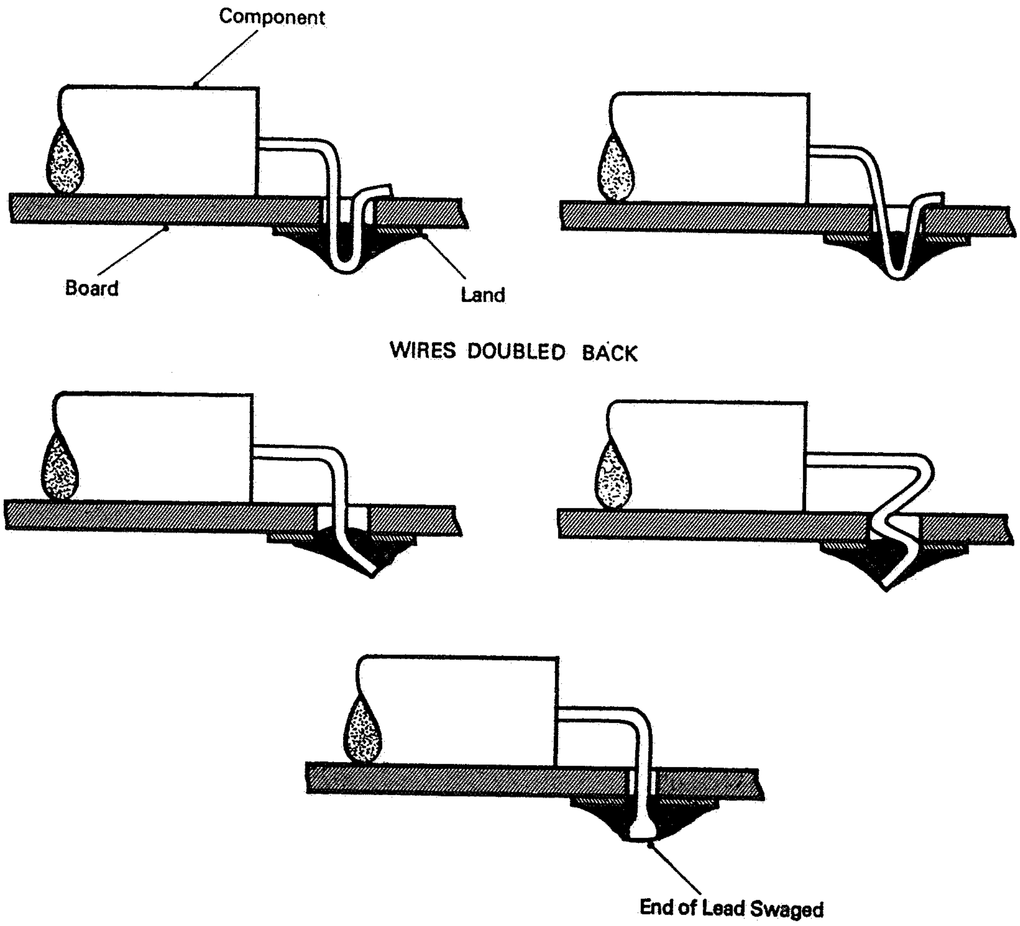


Figure 21 FORMING OF SMALL DIAMETER LEADS

5.6.7 For components with very small diameter leads, difficulty may be experienced in centering them in the board holes. This may be overcome by forming the leads in the manner illustrated in Figure 21.

5.6.8 Before mounting components on boards, the leads should be checked to ensure that any misalignment with the body junction is within specified limits. Provided that the specified limits are not exceeded, straightening of the leads is permitted.

5.6.9 Bending, cutting, straightening or insertion of leads into board holes, should be carried out in a manner which will not cause damage to the leads or the components, or cause changes in electrical ratings. If any of the damage referred to in the following paragraphs has occurred components should be rejected.

(a) Nicks or cuts in excess of 10% of lead diameter in the area between the component body junction and the point at which the lead will be soldered.

(b) Flaking or voids in the plating larger than one-tenth of lead diameter, and of a total area in excess of 10% of lead surface.

(c) Bends which at 2X or 10X magnification show cracks in the base metal. If there is any doubt regarding the presence of cracks, examination of a lead should be made at 30X magnification.

(d) Damaged insulation of connector contacts and of component cases.

(e) Evidence of leakage from components containing liquid dielectric.

5.6.10 If components are not to be mounted on their respective boards immediately after bending their leads, they should be stored in such a way that no damage or disturbance of the lead configuration can occur. It is recommended that the leads of radial lead components, dual-in-line packs, or other I.C. packages with similar lead configurations, be pierced into small sections of thick foam rubber or plastic, and the components then enclosed in dust proof packs. Where semiconductor devices require the use of lead-shorting clips, e.g. MOS (metal-oxide-semiconductor) and FET (field effect transistors) the clips should remain in position and the devices should be stored in their special foil-lined packs. The clips should only be removed after the devices and associated circuitry have been totally assembled on the board.

5.6.11 Bending of leads extending from glass seals should be carried out with the utmost care to avoid cracking or chipping of the seals.

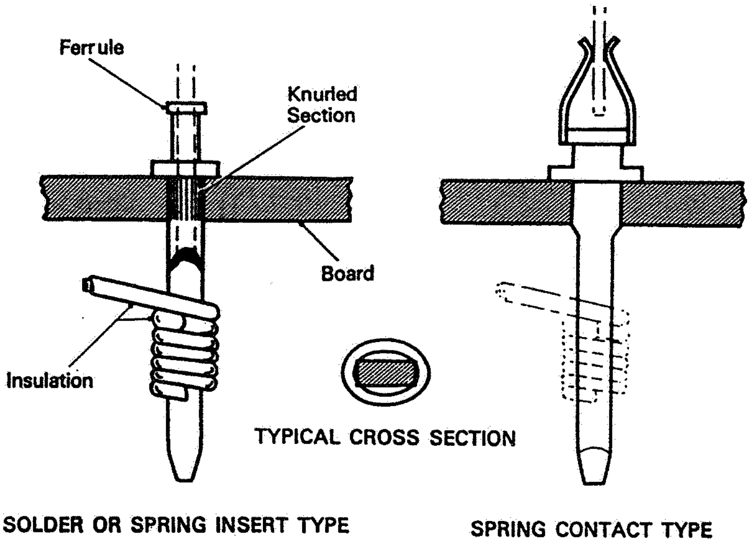


Figure 22 WIRE-WRAP CONNECTIONS

5.7 **Wire-wrap Connections.** These connections are of the solderless type requiring the use of specially designed pins which are pressed through the circuit board (see Figure 22). The pins may be either rectangular, square or V-shaped in cross-section, and provide a spring contact type of connection, or alternatively, a ferrule type of connection to which a lead may be soldered or make contact via a spring insert. In some applications, pins permitting a wire-wrap connection on both sides of a board may also be used. Typical materials used in the manufacture of pins are brass, beryllium copper, copper-nickel alloys, phosphor-bronze and nickel-silver alloys.

5.7.1 The wire, which should be tin- or silver-plated solid annealed copper (e.g. to BS 4109) is wrapped tightly around the pins with a wrapping tool, which ensures a good metal-to-metal contact by deforming the inside of the wire at the edges of the pins. The minimum number of turns required depends on the wire size, e.g. 5 turns minimum for wire size 0·56 to 0·71 mm (0·021 to 0·028 in) and 4 turns minimum for wire size 0·81 to 0·91 mm (0·032 to 0·034 in). Reference should always be made to the instructions specified for a wire wrapping operation. To improve the vibration resistance of a wire-wrapped connection, it is recommended that insulation should be left on the wire for at least one turn as shown in Figure 22.

5.7.2 On completion of a wire-wrapping operation, checks should be made to ensure that each turn of wire is in close contact, that turns have not overlapped, and that plating has not been removed from the wire. If any gaps are present between turns, it should be ensured that they are within specified limits; no attempt should be made to close them.

6 REMOVAL OF ENCAPSULANT COATINGS Prior to the de-soldering and re-soldering of connections, the encapsulant, which is used as an insulating coating, must be removed. In most instances, it is only necessary to remove the encapsulant from a small area in order to effect the required repair. Some typical methods are described in the following paragraphs, and the choice of any one of them is governed principally by the type and condition of the encapsulant and the nature of the printed wiring board and components mounted on it.

NOTE: The thermal parting, abrasion and hot air methods require certain expertise in their application, and it is recommended that they should only be carried out by personnel skilled in the appropriate techniques.

6.1 **Solvent Method.** In choosing the solvent method, any possible adverse effects that a specified solvent might have on a board and its components, should be very carefully considered (see also paragraph 3.1 (n) and Appendix 2). If removal from only a small area is required, the area should be swabbed a number of times with a cotton-tipped applicator dipped in fresh solvent until the area is free from encapsulant. The time required for a given encapsulant to dissolve varies with the type of encapsulant and the solvent used. Rubbing the coated surface carefully with a glass-fibre bristle brush or the end of the solvent applicator will help dislodge the coating. For some encapsulants, particularly those of the polyurethane type, effective removal can be achieved by a solvent applicator having a wedge-shaped tip. After removing the required amount of encapsulant, exposed solder connections should be cleaned.

6.1.1 If it is necessary to remove the entire encapsulant coating from a printed wiring board, the board can be immersed and brushed in a series of tanks containing the appropriate solvent, commencing with a high contamination tank and progressing to a final fresh solvent tank.

6.2 **Thermal Parting Method.** This method utilises a controlled, low-temperature heat source and should be employed for the localised removal of thick coatings of encapsulant from flat surfaces, as well as the softening of bonds between components and boards. Charring or burning of either the encapsulant or circuit board, can be prevented by using temperature-controlled tools designed specifically for thermal parting. The tools can be fitted with a variety of tips shaped to gain proper access to the areas from which encapsulant removal is required.

NOTE: Soldering irons should not be used for encapsulant removal, as their high operating temperatures will cause charring of the encapsulant, as well as possible de-lamination of the board material.

6.2.1 The procedure given in the following paragraphs is based on the use of a special parting tool.

(a) The appropriately shaped tip should be selected and the nominal temperatures set on the parting tool.

(b) The tip should be applied to the encapsulant coating under a light pressure, and the tip temperature regulated to a point where it effectively breaks down the coating without charring or burning. Depending on the type of material, the encapsulant will either soften or granulate, e.g. a polyurethane based material will soften, while an epoxy material will granulate.

(c) Gradually reduce the thickness of the coating without contacting the surface of the board, and remove as much coating as possible from around component leads to allow easy removal of the leads. A stream of dry air at low pressure, or a bristle brush, should be used during the parting process to remove waste material.

(d) If a faulty component is to be removed from a board, the connecting leads of the component should first be cut, thereby permitting its removal separate from the removal of the soldered joints on the board. Once sufficient encapsulant coating has been removed, the component body should be heated with the parting tool so as to weaken the bonded joint between the component body and board, and thereby permit lifting of the component from the board. The remaining encapsulant should then be removed by further thermal parting or by an abrasion method, and the remaining leads and solder joints should be removed by the appropriate solder extraction method (see paragraph 8).

6.3 **Abrasion Method.** The removal of encapsulant coatings by this method requires the use of glass-fibre bristle brushes, or rotary abrasive tools such as end mills, rotary files, or bristle brushes, driven by a miniature type electric motor. The brushes and rotary tools mentioned, as well as others containing abrasive materials, should be carefully selected to suit the various types of coating and configurations of the areas from which a coating is to be removed. The motor should have fingertip control and should be of the high-speed, low-torque type to prevent excessive frictional heating, and to facilitate removal of coatings, particularly those of the soft and pliable type. When in use, great care should always be taken to prevent abrading tools coming into contact with the bare materials of boards and circuit tracks.

6.3.1 The abrasion method is primarily suited to the removal of coating from the circuit side of a board where easier access for rotating abrasive devices is permitted. It can also be applied to the component side of a board provided that there is adequate clearance between components. The method should not be used for removing coatings from components, or for breaking the bond between components and boards. In such cases the thermal parting method (see paragraph 6.2) should be employed.

6.3.2 Rubberized abrasives of the correct grade are ideally suited to removing thin hard coatings from flat surfaces, but not for soft coatings, as these cause the abrasive to 'load' with coating material, and so become ineffective.

6.3.3 Rotary bristle brushes are better suited for use on contoured or irregular shaped surfaces, such as soldered connections, as the bristles easily conform to the contours and surface irregularities. They can be applied to both hard and soft coatings.

6.3.4 Tools should be applied to coatings with varying degrees of pressure to check the rates of coating removal. After getting the feel of these rates the coating can then be removed by applying the degree of pressure best suited to the conditions. Tools should be moved about in a circular motion to minimise localised heating and to avoid inadvertent damage to underlying materials by abrading through the coating too quickly. In some cases it may be necessary to change the tools during coating removal, e.g. removing the bulk of coating with a coarse abrasive tool, and then changing to a finer abrasive tool for final 'clean up' of the area.

6.3.5 Waste coating material should be removed periodically by brushing or by a source of low pressure air, thereby permitting visual inspection of the work surface to ensure that the abrading tool is not causing abrasion of the board's base material or conductor tracks. When all coating has been removed, the area should be cleaned with an appropriate solvent to remove any remaining contaminant particles.

6.4 **Hot Air Jet Method.** In this method there is no direct physical contact between the heating tool and board surfaces, the softening of encapsulant coating being accomplished by a jet of hot air passing through a hollow bit similar to that of a suction type solder-extractor iron. In some commercially available irons the hot air jet may also be selected as a mode of operation for encapsulant coating removal.

6.4.1 The air flow rate and temperature should be selected to achieve softening and breakdown of the specific type of encapsulant coating, without setting up local heating levels which could be of detriment to the board, components (particularly those with glass seals) or insulation of leads and components. When the coating becomes soft it should be removed by means of a small non-metallic spatula (e.g. teflon or nylon). The spatula should be free from sharp edges.

6.5 **Peeling Method.** This method is normally restricted to the removal of certain silicone based encapsulant coatings which require pre-soaking of the coating in a solvent (e.g. freon) and, as this also breaks its bond, the coating can be split by means of a scalpel and then peeled off.

7 SOLDERING In the repair of printed wiring boards, the hand soldering of joints plays a major role, and although it is based on simple and well-established rules, the continuing development of printed wiring boards and associated components, and of soldering equipment, has made it necessary for operatives to develop more specialized skills, both in the actual tasks to be performed and in post-repair inspection. It is most advantageous for operatives to participate in a recommended course on repair and specialised soldering techniques, terminating in selected practical tests, by means of which their capabilities can be demonstrated and finally certified. Re-certification of the operative should be carried out at regularly prescribed intervals, and whenever the results of inspections indicate a downgrading of soldering capability.

7.1 **Types of Soldered Joints.** There are basically five types of joints to be considered in soldering: (a) through-hole unplated, for component lead and jumper lead terminations, (b) through-hole plated, for lead terminations and connection of dual-in-line packs, (c) lap or co-planar, for the connection of flat packs, (d) terminal, for component lead and jumper lead terminations and (e) lead to track connections, as in certain repair methods (examples are shown in Figure 23).

7.2 **Materials.** Solder should be of the wire type, cored with an activated resin flux to a standard complying with BS 441 Grade K 60/40 tin/lead. It is recommended that the solder size be from 22 to 26 swg since this can help significantly to reduce the time required to make good soldered joints. In some cases, wire type solder and flux may be used separately, and should comply respectively with BS 219 and DTD Specification 599. Where small static dip solder baths or pots are used, it is recommended that they should be initially charged and topped up with solder which is commercially available in pellet form.

NOTE: To prevent tin/lead separation, bath or pot solder should be stirred before use and at frequent intervals during a soldering operation. It should also be checked for contamination at a frequency consistent with usage, and changed when necessary. Further information on solders and fluxes is contained in Leaflets **BL/6-1** and **MMC/1-1**.

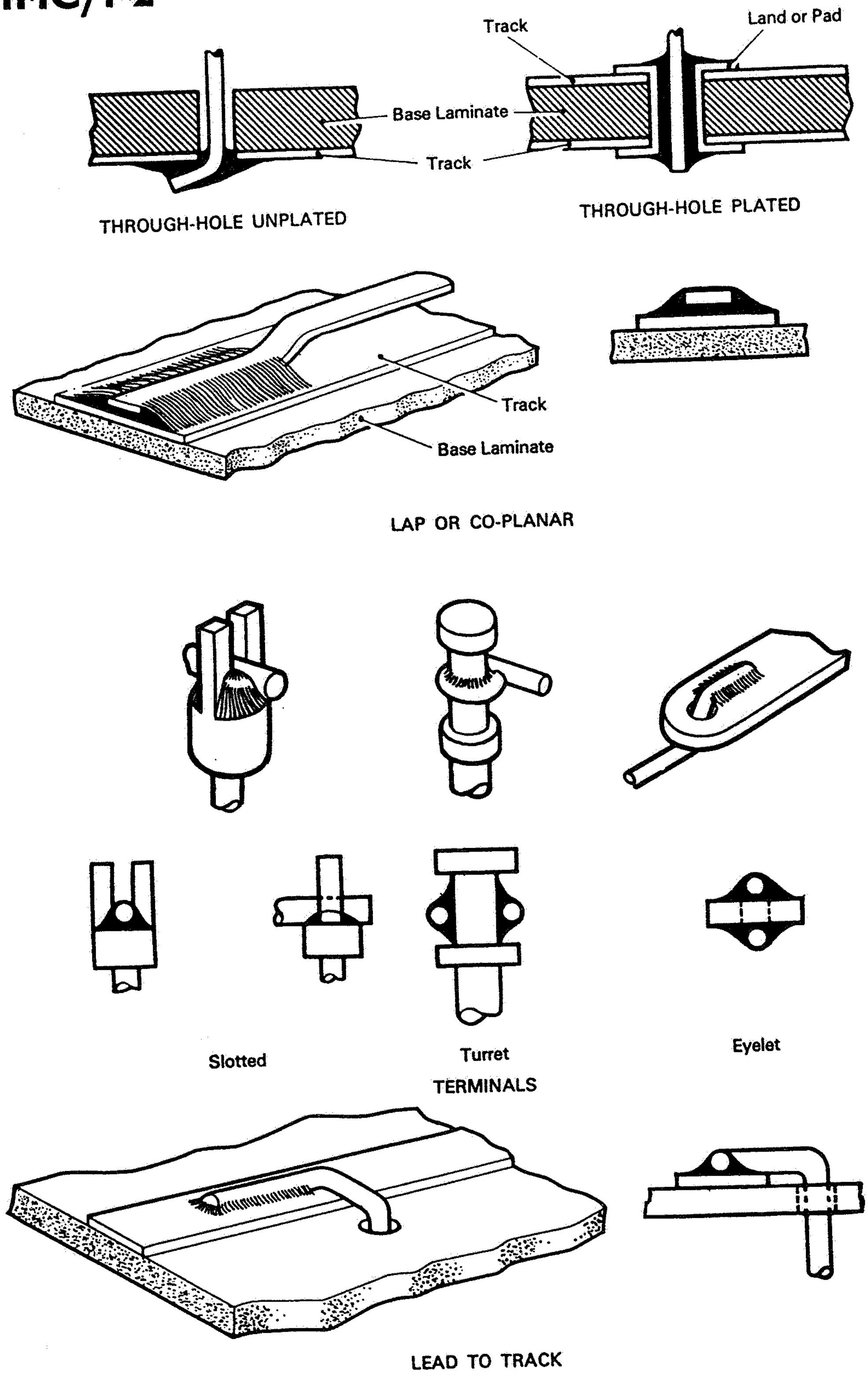


Figure 23 TYPICAL SOLDERED JOINTS

7.3 **Soldering Equipment**

7.3.1 **Soldering Irons.** Soldering irons should be of the light-weight electrically-heated type and should be carefully selected on the bases of such essential requirements as—(i) capability for soldering very small joints, (ii) good temperature/voltage stability, (iii) high rate of thermal recovery after each application to a joint, (iv) prevention of overheating during idling periods, and (v) power consumption related to actual job requirements. The wide variety of irons that are commercially available are of the temperature controlled type; the control being effected by one of the following—(vi) preset power output of the heater element, (vii) thermostatic switching, (viii) electromagnetic switching as in Curie effect irons, and (ix) transistorised power control of pre-selected temperatures. Some irons are designed for direct operation from the normal mains voltage supply, while others are designed for operation at either 6 volts, 12 volts or 24 volts, obtained from mains-connected voltage conversion units.

(a) **Temperature.** Solderability temperature is normally 230°C (446°F) but it is necessary that the bit temperature of an iron be above this value to allow for the thermal load of a joint, and also to avoid a lengthy 'dwell' time. The majority of irons have a bit temperature in the range 260°C to 320°C (500°F to 608°F) under idling conditions. The bit temperature should be periodically checked during soldering operations, such checks being facilitated by means of a bench-mounted pyrometer. A typical pyrometer consists of a thermo-couple against which the soldering iron bit is brought into contact, and a galvanometer calibrated in degrees Celsius.

(b) **Bits.** These are of the detachable type designed in a variety of shapes and sizes thereby permitting a selection best suited to the size and type of joint to be soldered. Bits are manufactured from high-grade copper, and may be unplated, or plated with an iron coating. The shanks are normally chromium-plated as a protection against corrosion, to prevent feed-back of solder, and also to facilitate their removal and replacement. Unplated bits permit satisfactory soldering to be carried out, but they require frequent 'dressing' on account of wear, and this results in considerable variations in heat retention capability. Iron-plated bits, on the other hand, wear less rapidly, and it is therefore recommended that these always be used.

7.3.2 **Soldering Iron Stands.** In between soldering operations, irons should be supported on bench stands designed specifically to permit the irons to idle in free air.

7.3.3 **Cleaning Sponge.** A synthetic or natural fine-textured sponge saturated in water (preferably distilled) should be provided to remove dirt particles and oxide scale from soldering iron bits. In some types of soldering iron stands commercially available, a sponge and water receptacle is incorporated.

7.3.4 **Solder Pots.** For certain soldering operations, e.g. tinning the ends of jumper leads, tags and leads of certain small components, the use of bench-mounted solder pots is generally recommended. A typical pot consists of an electrically-heated crucible and a tube which is tapered so that the end of a lead inserted into it, is guided down and dipped into the molten solder. In some cases a thermostat control and a thermometer are incorporated.

7.3.5 **Heat Sinks.** In some printed wiring board assemblies, components may be employed which are sensitive to the effects of temperature and require the use of a heat sink tool to conduct heat away from the components during soldering and de-soldering (see paragraph 7.6 (e)). In the absence of specially designed heat sink tools

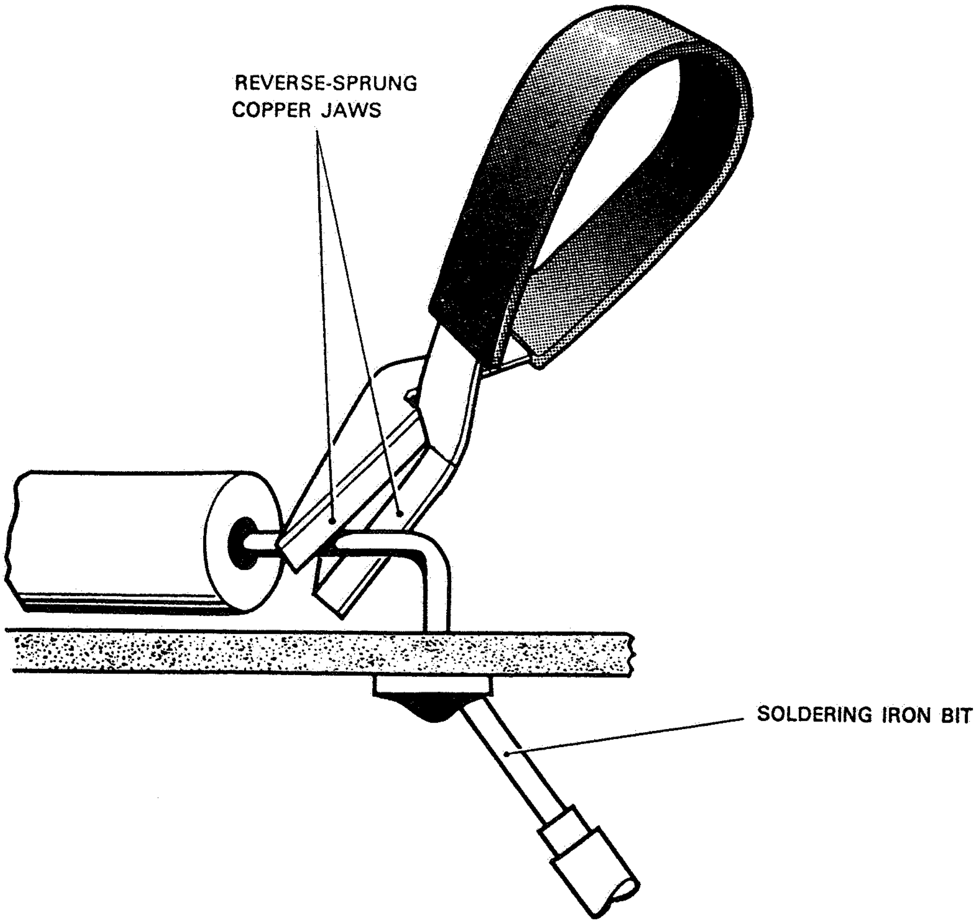


Figure 24 HEAT SINK

of the type shown in Figure 24, small, flat nose, smooth jawed pliers, or miniature type alligator clips with flattened ends and small copper strips soldered to them, may also be used.

7.3.6 **Anti-wicking Tool.** Wicking is a term used in connection with the soldering of leads, and it refers to the seepage of solder along the conductor. Wicking should not be allowed to extend beneath the insulation covering of a lead and it is, therefore, recommended that an anti-wicking tool (see Figure 25) be used. The jaws of the tool are of the reverse-sprung type, and the shape of the tips permits gripping of the lead insulation and the exposed part of the lead, so that during soldering the tips serve as a heat sink.

7.4 **Lead Insulation Strippers.** These should be of either a mechanical cutting or a thermal type.

(a) Mechanical strippers should be of such a design that the cutting blades may be set for the removal of a specific size of insulation without cutting, or nicking of the metal conductor.

(b) Thermal type strippers employ small jaws which are electrically heated, and when closed round the insulation they soften it sufficiently to permit its withdrawal from the conductor. The power ratings of heating elements vary depending on the type of insulation to be removed. Typical ratings of two strippers commercially available are 14 watts for PVC, polythene and similar low-temperature insulation materials and 48 watts for PTFE insulation only. The power supply required is either 12 volts or 24 volts.

NOTE: Extreme care should be exercised when carrying out thermal stripping of insulation, as the fumes given off are highly toxic, particularly from PTFE insulation.

7.5 Preparation for Soldering

7.5.1 **Cleanliness.** Cleanliness is the keynote of all soldering operations and the following points should be observed:—

(a) Work areas should be maintained in a clean and orderly condition. Any dirt, oil, grease, solder splashes, wire clippings, or other foreign matter, should be promptly removed from the immediate soldering area.

(b) All hand tools, supporting jigs, heat sinks and anti-wicking tools should be cleaned frequently, using an appropriate solvent such as aliphatic naptha or isopropyl alcohol.

(c) Components, leads and terminals, should be kept in dust-proof packages until ready for use (see also paragraph 5.6.10).

(d) Hand creams, oils, lotions and similar skin conditioners should not be used by operatives.

(e) Prior to starting soldering operations, hands should be washed and dried with a clean lint-free cloth.

(f) The surface of all types of joints to be soldered should be clean, bright and free from grease, dirt, oxides, or any other foreign substance which may interfere with the action of the flux and prevent proper solder flow. Where the solderability of a component lead is unknown, or doubt exists, a 'tinning' test should be carried out on the wire off-cut after preparing the component for assembly on the board.

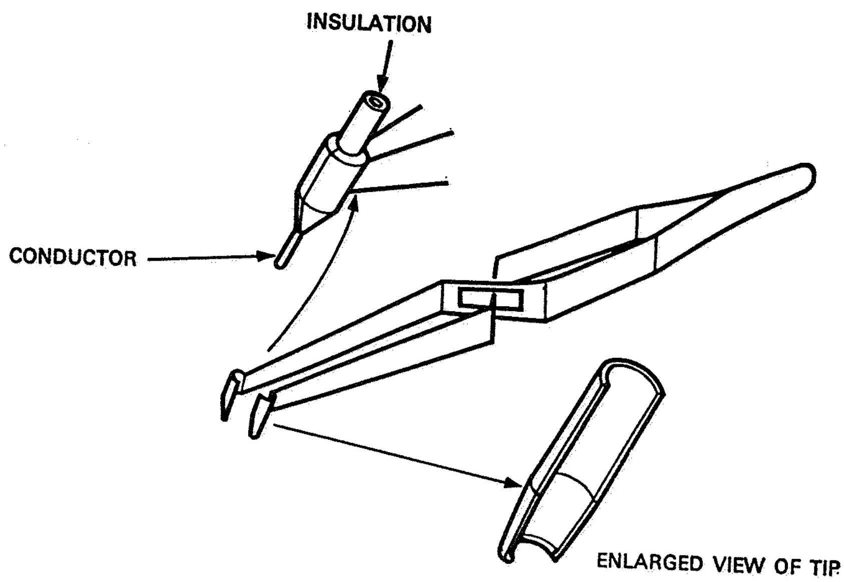


Figure 25 ANTI-WICKING TOOL

7.5.2 **Soldering Iron Maintenance.** Soldering irons should always be maintained in a clean and serviceable condition, particular attention being paid to the condition of the bit, its security of attachment and tinning.

(a) **Cleaning and Tinning.** Before using a soldering iron, it must be ensured that the bit is free of oxides and dross, and that its working surface is bright and tinned to avoid the transfer of impurities to soldered joints.

(i) **Unplated Bits.** When a bit reaches the lowest temperature required to melt the solder, it should be tinned by applying flux and solder to its working surface until a thin film of solder adheres to it. A recommended method of applying the solder for tinning is to wrap a suitable length of it round the bit in order to protect the working surface from oxidation as the bit reaches solder melting temperature. The bit should then be wiped on a damp, fine-textured sponge to remove excess solder and any oxide film that may have formed. As a result of the effects of molten solder, unplated bits become worn and pitted fairly quickly, and frequent dressing is therefore necessary (see also paragraph 7.3.1 (b)). This should be carried out when the bit is cold, by filing the working surface to a smooth finish. After dressing, the bit should be cleaned and re-tinned in the manner already described.

(ii) **Plated Bits.** Plated bits should be tinned in a manner similar to that of unplated bits. If the working surface has an additional protective coating, such as pure tin, nickel, silver, or gold in some cases, the surface should be flooded with molten solder during the initial heating, or these coatings will burn off. A plated bit may idle for a long time without damage, provided that it remains tinned. However, the durability of the tinning depends on the bit temperature. A bit that idles for several minutes between soldering operations will not require frequent tinning if the bit temperature is maintained within the normal idling temperature range i.e. 260°C to 320°C (500°F to 608°F). If the oxides that form on a bit cannot be removed by wiping it on a damp sponge, the bit should be allowed to go cold and all the scale removed by abrasion, by means of a fine grade emery cloth, an abrasive coated stick of polyurethane foam, or a glass-fibre bristle brush. After cleaning, the working surface, which should have a grey metallic appearance, should be re-tinned.

NOTE: A file should not be used since it will remove most, if not all of the plating on the iron, thereby shortening the life of the bit.

7.6 **Soldering Procedure.** The following points should be observed when carrying out the soldering procedure:—

(a) Component terminals and leads, as well as the ends of individual jumper leads, should, unless otherwise specified, be cleaned and tinned prior to making the final soldered joint. Additional tinning is not normally required on those components having pre-tinned leads.

(b) The soldering iron bit should be cleaned by wiping it on a damp sponge, and fresh solder should be applied between each jointing operation.

(c) The soldering iron bit should be applied to the appropriate joint area until the tinning solder reflows to make the joint. The bit should be positioned so as to obtain maximum heat transfer from the bit to the contact area, but at the same time avoiding excessive heat application and consequent damage to surrounding areas.

(d) After a joint has been made by the initial reflow, the soldering iron bit should be held in position and additional solder should be applied to the heated members of the joint (not the soldering iron bit) until it has melted sufficiently to provide a uniform film, or fillet, around the joint members.

(e) If it is necessary to use heat sinks they should not be placed too close to a joint, otherwise they may seriously reduce the rate of heating at the joint itself. Care should also be taken to ensure that they are not inadvertently placed beyond the component to be protected, as this will result in the heat from the joint merely draining through the component. Heat sinks should be removed soon after a soldering operation is completed, or they will act as a heat reservoir which will, itself, heat the component to be protected.

(i) Some components are very often provided with a heat sink device which is intended to remove heat generated while the components are in operation. Such heat sinks do not necessarily give any protection against overheating while soldering operations are being carried out, because, in many cases, the heat from the connection being soldered must pass through the heat-sensitive region before reaching the heat sink.

(f) Joints should be permitted to cool without any relative movement between joint members taking place.

(g) The mechanical strength of a soldered joint should not be checked by twisting, pulling, or pushing a component or lead, as this can result in poor or broken connections (see paragraph 7.7).

(h) Flux residue should be removed from soldered joints and surrounding areas, immediately after a soldering operation, by using the method specified in the appropriate repair instructions. Residue should not be burned off with a soldering iron, since both the bit and the soldered joint will become so contaminated that the solder will merely form a globule over a high resistance joint of dirt and corrosive oxide. Furthermore, there exists the possibility that continued heat application may damage the adhesion of conductor tracks to the base laminate of the board.

7.7 **Inspection of Soldered Joints.** On completion of a soldering operation, joints should be visually inspected, paying particular attention to the aspects given in the following paragraphs. Where necessary, and in particular on high density packaged boards, an optical magnifier of 10X power should be used.

NOTE: Reference should also be made to Leaflet MMC/1-1 which contains additional information on solderability and soldering technique defects.

7.7.1 All soldered joints should present a neat, bright and shiny appearance with well-formed solder films or fillets feathering out to a thin edge, indicating proper 'following and wetting' action by the solder.

7.7.2 The quantity of solder used in making the joint should not be excessive. In general, if the contour of conductors and joint configuration cannot be determined, then there is excessive solder. Other indications of excessive solder are globular formations, and bridging of joints or conductor tracks.

7.7.3 The ends of leads passing through plated or unplated holes, should not extend from their mounting lands by distances greater than those specified in the relevant repair instructions.

7.7.4 There should be no evidence of flux residue at points of contact, or of pitting and holes in the solder. Joints with such defects should be inspected carefully to ensure that no movement of a conductor occurs when the joint is probed with a tool that will not adversely affect the joint. The joint should also be observed under magnification to determine whether or not pitting and holes are only surface imperfections. If movement of a conductor occurs, and pitting and holes extend below the surface, the joint is unacceptable.

7.7.5 There should be no evidence of 'cold' joints, as indicated by a dull, chalky or crystallized flaky surface of the solder. Such a joint is a high resistance, or an insecure joint, caused by insufficient heating, or by movement of a conductor, during soldering. It can also be caused by 'packing', or 'piling' solder on top of a joint which has been improperly prepared or cleaned.

7.7.6 Joints should be free of solder 'icicling', i.e. sharp points of solder, which may cause arcing or corona effects.

7.7.7 Insulated leads should be checked to ensure that their insulation is at the specified distance from the appropriate termination, and that there are no signs of cracking, charring, or decomposition of insulation.

8 DE-SOLDERING METHODS

8.1 **Wicking Method.** This method utilizes a lengh of flux-impregnated braid formed to resemble a lamp wick, which is applied to a solder joint between the solder and the heated bit of the soldering iron (see Figure 26). The combination of heat, molten solder and air spaces in the wick creates a capillary action, which causes the solder to be drawn into the wick. In the absence of commercially available braided wicks, lengths of stranded wire may be used. The wire should be stripped of insulation and dipped in flux prior to de-soldering.

NOTE: The wicking method is rather limited in its application, and in any event, care should be exercised because the long soldering iron 'dwell' time required at a joint could cause overheating of the board and weakening of conductor track adhesion.

8.1.1 The method should be used to remove solder from surface joints only, since the capillary action of the wick can only overcome the surface tension of the molten solder. This is also true for double-sided circuit boards without reinforced holes. Wicking should not be used on through-hole plated joints because the capillary action of this type of joint is, in most cases, stronger than that of the wick and prevents complete removal of solder from the hole.

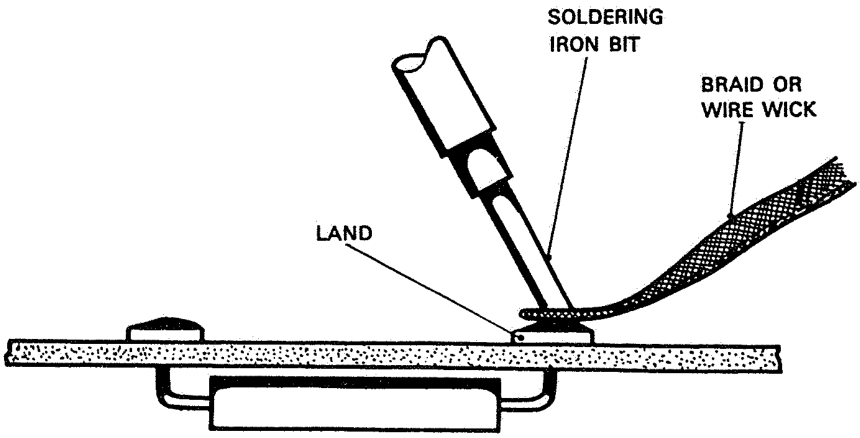


Figure 26 WICKING METHOD

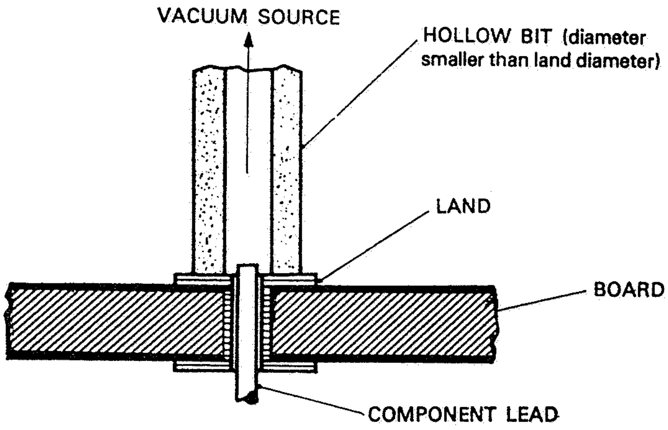


Figure 27 SOLDER SUCTION METHOD

8.1.2 When the ends of braid or wire become saturated with solder, they should be cut off, thereby ensuring proper withdrawal of solder on each application.

8.2 **Solder Suction Method.** In this method de-soldering is carried out by drawing molten solder from a joint through a hollow bit. The hollow bit may form part of a separate suction de-soldering tool which is used in conjunction with a conventional soldering iron, or it may form part of a specially designed suction iron. The principle of the method is shown in Figure 27. In a separate de-soldering tool, the suction is generated by depressing a spring-loaded piston inside the tool body, and then releasing it when the solder at the joint has melted. The solder is drawn into a chamber from which it can be immediately ejected by depressing the piston again. In the simpler types of iron, the suction is generated by a squeeze bulb of stiff rubber connected to the hollow bit via a small collecting chamber. Before the bit is applied to the joint, the bulb is depressed and as soon as the solder melts the bulb is released to draw up the solder into the collecting chamber. The solder remains molten and can be ejected by depressing the bulb again. The use of this type of iron should generally be limited to de-soldering of surface joints only.

8.2.1 Extractor irons designed for operation from a suction pump are also commercially available, and can be more effective than the squeeze bulb type, particularly for the de-soldering of through-hole plated joints. The irons are provided with various sizes of tubular bits to suit joint configurations. The selection of the proper size of bit is based on the minimum inside diameter required to fit over a lead or connector pin, at the same time, permitting molten solder to pass through the bit. The maximum outside diameter of a selected bit should not cover a mounting land completely, should not touch the board laminate itself, and should not extend over the flanges of eyelets. For terminal de-soldering, the outside diameter of the bit should be selected to permit entry into the desired area.

NOTE: Instructions issued by the specific extractor iron manufacturer should always be followed, and the effects the use of the iron may have on board circuit components should also be ascertained. For example, irons with instant-start suction pump motors can generate transient voltages, and it is essential that such voltages are not transmitted via leakage paths into the board circuit; the effects being particularly harmful where MOS (metal-oxide-semiconductor) devices are employed.

(a) The heated bit is applied to the soldered joint, and when melting of the solder is noted, the vacuum should be turned on to withdraw solder into the collector chamber of the iron. When removing a lead from a through-hole type joint, the residual tinning of the lead and hole wall causes re-sweating and the formation of new joints. To overcome this problem, the lead should be gently oscillated with the soldering iron bit while the vacuum is being applied, thereby permitting cool air to flow into the hole and around the lead and wall of the hole.

NOTE: De-soldering iron bits should be kept as clean as possible to avoid contamination of joint surfaces when removing solder.

8.3 **Hot Air Jet Method.** This method uses a controlled flow of hot air, and permits melting of a solder joint without physical contact. The heated air may be supplied through the hollow bit of a specially designed tool, or, in some commercially available solder extractor irons, it may also be selected as a mode of operation. The hot air jet may be applied to very delicate joints, and, in particular, to the de-soldering of lap joints between flat pack integrated circuit leads and conductor tracks. The air flow rate and temperature should be selected to achieve de-soldering without setting-up local heating levels which could be of detriment to the board material, components and their leads, and conductor tracks.

8.3.1 De-soldering should commence on one side of a pack; the hot air jet being progressed from lead to lead along the side. As soon as the solder melts at each joint, the leads should be lifted away from their tracks with the aid of non-metallic tweezers or a small non-metallic spatula. This operation should be repeated on the other side of the pack. When all the leads are free, the pack should be lifted from the board again with the aid of tweezers, or extraction tool (see Figure 16). In cases where a pack is bonded to the board, the bonding material should first be softened by means of the hot air jet (see paragraph 6.4). The conductor tracks should be cleared of residual solder by means of a solder extractor iron.

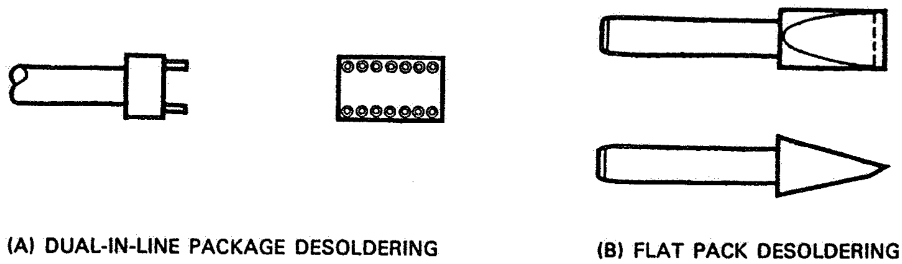


Figure 28 HEATER BLOCKS

8.4 **Heater Block Method.** The heater block method is intended for the simultaneous de-soldering of a number of connections, e.g. the connections of dual-in-line circuit packages. The de-soldering bits take the form of a small copper block which is normally arranged in the manner shown in Figure 28 (A). The pins are of tubular steel and are precision brazed in the block at a spacing which corresponds both to the relevant hole spacing of the board and to the pin configuration of the package. The block should be applied to connections on the circuit side of a board and, with the aid of tweezers, or extraction tool, the package should be gently pulled from the plated-through holes as soon as the solder melts. Residual solder should be removed from the holes by a solder extractor iron before remounting the original package, or mounting its replacement, as appropriate.

8.4.1 For the removal of flat pack integrated circuit packages, a typical de-soldering bit is shaped as shown in Figure 28 (B). In use, the bevelled portion of the bit is held against all the soldered joints at each side of the package, in turn, and as the solder melts, the package is gently pulled away from the board. The de-soldering bit should not come into contact with any adjoining conductor tracks or the base laminate.

8.4.2 Extreme care should be exercised when using heater blocks of all types. They act as heat reservoirs and when applied to a board considerable heat can be transmitted into the base material. In addition tracks connected to circuit packages may, in some cases, be of varied thickness and width, so that blocks can apply different heating levels. Blocks should be kept as clean as possible to avoid contamination of joint surfaces when de-soldering.

APPENDIX 1

TOOLS AND MATERIALS

1 The following tools and materials are required for carrying out repairs and modifications to printed wiring boards.

2 TOOLS

Jig or suitable fixture for supporting boards during repair.

Temperature-controlled soldering iron and interchangeable bits.

Soldering iron stand.

Sponge for cleaning soldering iron bits. This may be a separate item or integral with certain types of soldering iron stand.

Static dip solder bath or pot.

Bench-mounted pyrometer for checking soldering iron bit temperatures.

Solder extractor iron of either the squeeze bulb type or controlled vacuum type.

Cutters with side cutting jaws, with cutting jaws angled at 45°, and with shear cutting jaws

Snipe-nosed and flat-nosed pliers.

Scalpel.

Stainless steel and non-metallic tweezers with pointed and radiused tips.

Dental probe.

Solid carbide drills in a range of diameters to suit conductor track widths, and repair wire sizes.

Rubber eraser, or glass fibre stick, for cleaning conductor tracks after removal of encapsulant coatings.

Small disposable plastic spatulas.

Small stiff-bristle brush.

Small camel hair paint brush.

Heat sinks. In the absence of specially designed tools, small flat nose, smooth jaw pliers or miniature type alligator clips with flattened ends and small copper strips soldered to them may be used.

Anti-wicking tool.

Lead insulation stripper of either the mechanical cutting or thermal type.

Heater blocks for de-soldering of dual-in-line and flat packs.

Polyurethane foam stick with abrasive coating.

Tools for insertion, extraction and general handling of dual-in-line and flat packs.

Optical magnifier. For short term examination of a small area, a watchmakers' eyeglass, or pocket magnifier are satisfactory. For detailed examination and inspection of complete assemblies for long periods, a bench-mounted magnifying viewer is recommended.

3 MATERIALS

Tinned copper wire to BS 4109. The sizes of wire required depend on the width of conductor track to be repaired, and should, therefore be selected in accordance with relevant manufacturer's repair instructions or standards.

Copper foil to BS 2870.

PTFE insulated wire to BSG 210.

PTFE insulating sleeving.

Rosin cored solder of 22-26 SWG and to BS 441 Grade K 60/40 tin/lead.

Terminal pins, turret lugs and eyelets in sizes appropriate to the relevant repair instructions or standards.

Epoxy resin adhesive and hardener appropriate to the relevant repair instructions or standards.

Polyurethane lacquer, hardeners and thinners appropriate to the relevant repair instructions or standards.

APPENDIX 2

CLEANING SOLVENTS

Isopropyl Alcohol Methylated Spirits	Flammable and should be used with caution. Avoid breathing vapours; use in well-ventilated area.
1.1.1 Trichloroethane Chloroethane Trichlorotrifluoroethane	Non-flammable, low-toxicity, chlorinated.
Trichlorotrifluoroethane with isopropanol	Low-toxicity, chlorinated. Under evaporation conditions and towards end of evaporation cycle, a flammable vapour rich in alcohol is produced.

NOTE: Toxic solvent containers should be clearly labelled.

Issue 2.

June, 1981.

AIRCRAFT

MICROMINIATURE CIRCUITS

LIST OF ABBREVIATIONS

1 INTRODUCTION This Leaflet has been introduced in view of the many technical papers and specifications relevant to Printed Circuits, Solid-State and Microminiature Circuit Technology, that have a large number of abbreviated terms, commonly used as a form of shorthand communication. As the meanings of such abbreviations are not always explained in an accompanying text, a number of abbreviations, therefore, have been collected and are set out in this Leaflet.

1.1 As is often the case with abbreviations, many of those given in this Leaflet have different meanings in other disciplines. It is, therefore, recommended that they should not be applied outside the scope of this Leaflet.

ACI	Asynchronous Communications Interface
ACIA	Asynchronous Communications Interface Adapter
a-d	Analogue to Digital
ADC	Analogue—Digital Converter
AFI	Automatic Fault Isolation
AIM	Avalanche Induced Migration
AL-gate MOS	Aluminium-gate Metal-oxide-semiconductor
ALM	Analogue Memory System
ALPS	Advance Logic Processing System
ALRS	Arithmetic-logic Register Stack
ALT	Axial Lead Tubular (ceramic capacitors)
ALU	Arithmetic logic Unit
APD	Average Propagation Display
APG	Automatic Programme Generation
APTE	Automatic Programmable Test Equipment
As	Arsenic
ASCR	Asymmetrical Silicon Controlled Rectifier
ASR	Automated Send/Receive
ATE	Automated Test Equipment
ATG	Automatic Test Generation
ATOL	Automatic Test-orientated Language
ATPG	Automatic Test Pattern Generation
BarITT	Barrier Injection Transit Time
BBD	Bucket Brigade Device
BCD	Binary-coded Decimal
BCSL	Base Current Switch Logic
BeAMOS	Beam Addressed Metal Oxide Semiconductor
BFET	Bipolar Field Effect Transistor
BFL	Buffered Field-effect-transistor Logic
BIGFET	Bipolar Insulated Gate-field Effect Transistor
BIMOS	Bipolar Metal Oxide Semiconductor
bit	Binary Digit
BITS	Backplane Integrated Test System
BML	Bipolar Memory Linear
BOP	Bipolar Operational Power
BORAM	Block Orientated Random-access Memory
BOSS	Binary Option Selection Switch
BPI	Bits Per Inch
BSR	Bit Shift Register
'B' Stage Material	Semi-cured material (Printed Circuit Board Laminates) also called 'Prepreg'
BU	Buffer Unit
BWO	Backward Wave Oscillator
CAD	Computer-aided Design
CAM	Content-Addressable Memory
CAPS	Computer-aided Programming Software (Automatic Testing and Fault-diagnosis)
CASH Circuit	Charge Amplified Sample and Hold Circuit
CATT	Controlled Avalanche Transit Time
CCCL	Complementary Constant Current Logic
CCD	Charge-coupled Device
CCL	Collector-coupled Logic also Constant Current Logic
CCO	Current-controller Oscillator
CCR	Condition Code Register
CCSL	Compatible Current-sinking Logic
CDA	Current-differencing Amplifier
CDI	Collector Diffusion Isolation (Diffused)
Cerdip	Ceramic Dual-in-line Package
CERMET	Ceramic Metallic
CHL	Current-hogging Logic
CMI	Compound Monolithic Integration
CML	Current Mode Logic (differential amplifier)

CMOS (C-MOS)	Complementary Metal-oxide-semiconductor
CMOS/DAC	Complementary Metal-oxide-semiconductor/Digital-Analogue Circuit
CMRR	Common-mode Rejection Ratio
CO	Controlled Oscillator
COM	Computer Output in Microfilm
COS	Complementary Oxide-silicon
COS/MOS	Complementary Oxide-silicon/Metal-oxide-silicon
CPU	Central Processing Unit
CR	Control Register
CRC	Cyclic Redundancy Check
CROM	Control and Read-only Memory
CRT	Cathode Ray Tube
CSL	Current-sinking Logic
'C' Stage Material	Fully-cured Material (Printed Circuit Board Laminates)
CTD	Charge-transfer Device
CTF	Contrast Transfer Function
CTL	Common Transistor Logic also Complementary Transistor Logic
CTR	Current Transfer Ratio
CVM	Correlating Voltmeter
CVT	Constant Voltage Transformer
CWV	Crest Working Voltage
DA	Device Adapter
d-a	Digital to Analogue
DAC	Digital-to-Analogue Converter
DAD	Data Acquisition Display
DAR	Data Access Register
DAS	Data Acquisition Sub-system
DC	Discrete Component
DCC	Discrete Component Circuit
DCD	Differential Correlating Detector
DCFL	Direct-coupled Field-effect-transistor Logic
DCL	Direct Coupled Logic
DCM	Digital Capacitance Meter
DCTL	Direct-coupled Transistor Logic
DDA	Digital Differential Analyser
DDR	Data Direction Register
DDS	Digital Display System
DEB	Data Exchange Bus
DED	Double Error Detection
DEDS	Data Entry and Display Sub-system
DF	Dissipation Factor (capacitors)
DFGA	Distributed Floating-gate Amplifier
D/G	Driver/Gate
DI	Dielectric Isolation also De-ionized Water
DIC	Digital Integrated Circuit also Dust-in-line Ceramic
DIL	Dual-in-line
DILLCD	Dust-in-line Liquid Crystal Display
DIM	Digital Impedance Meter
DIOS	Distributed Input/Output System
DIP	Dual-in-line Package also Dust-in-line Plastic
DL	Data Logging
DLD	Delay Line Decoder
DLDVM	Data Logging Digital Voltmeter
DMA	Direct Memory Access
DMC	Direct Memory Channel
DMM	Digital Multi Meter
DMOS	Double-diffused Metal-oxide-semiconductor
DMOST	Double-diffused Metal-oxide-semiconductor Technology
DMU	Data Management Unit (Computer)
DMUX	De-multiplexer
DOLS	Direct Off-line Switching
DP	Data Processing
DPM	Digital Power Meter
DPP	Delay Power Product
DPS	Data Processing Sub-system
DPVS	Digital Programmed Voltage Source
DR	Data Register
DSB	Double-sided board
DSC	Digital-to-synchro Converter
DSG	Digital Signal Generator
DSM	Dynamic Scattering Mode
DTL	Diode-transistor Logic
DTL/TTL	Diode-transistor Logic/Transistor-transistor Logic
DTL/TTL/CMOS	Diode-transistor Logic/Transistor-transistor Logic/Complementary Metal-oxide-semiconductor
DTL/TTL/MOS	Diode-transistor Logic/Transistor-transistor Logic/Metal-oxide-semiconductor
DTLZC	Diode-transistor Logic Zener Circuit
DUF	Diffusion Under Epitaxial Film
DUT	Device Under Test (Automatic Testing)
DUV	Data Under Voice
DVM	Digital Voltmeter
EAROM	Electrically Alterable Read-only Memory
EBCDIC	Extended Binary-coded Decimal Interchange Code
E beam	Electron Beam
EBES	Electron Beam Exposure System
EBS	Electron-bombarded Semiconductor
ECD	Electro Chromic Display
ECL	Emitter-coupled Logic
ECM	Electronic countermeasure
ECTL	Emitter-coupled Transistor Logic
ED Copper	Electro-deposited Copper (Printed Circuit Boards)
EE-PROM	Electrically Erasable Programmable Read-only Memory
EFL	Emitter-follower Logic
EIDA	Electronic Intelligence Data Acquisition
El-Pc	Electroluminescent-photoconductive
emi	Electro Magnetic Interference
EMP	Electro Magnetic Pulse
EMR	Electro-mechanical Relay
epi	Epitaxial
EPROM	Erasable Programmable Read-only Memory
EPS	Encapsulated Power Supply
EPUT	Events Per Unit Time
ESD	Energy Storage Device (Electro-chemical)
ESS	Electronic Switching System
Famos	Floating-gate Avalanche-injection Metal-oxide-semiconductor
FBG	Feed Back Gate
fdm	Frequency Division Multiplex
FDNR	Frequency Dependent Negative Resistance

FDV Fault Detection Verification
FED Field Effect Device
FET Field Effect Transistor
FF Flip-Flop
FFT Fast Fourier Transform
FIFO First-in First-out
FILU Flag and Interface Logic Unit
FODTS Fibre-optic Data Transmission System
FP Flat Pack
FPLA Field Programme Logic Array
F-PROM Field Programmable Read-only Memory
FSK Frequency-shift Keying
FTU Function Test Units
FVC Frequency-to-voltage Converter

GaAsFET Gallium Arsenic Field Effect Transistor
GDN Ground
GDT Gas Discharge Tube
Ge Germanium
GFET Gate-field Effect Transistor
GFL Guided Fault Location
GPIB General Purpose Interface Bar
GPP Ground Power Plane
GTOSCR Gate and Turn off Silicon Controlled Rectifier

HCMOS High-density Complementary Metal-oxide-semiconductor
HDDT High Density Digital Tape
HIC Hybrid Integrated Circuit
HIIC High Isolation Integrated Circuit
HLTTL High Level Transistor-transistor Logic
HMOS High-performance Metal-oxide-semiconductor
HNIL (HiNil) High Noise Immunity Logic
HOS Higher Order Software
HSLI High Speed Logic Interface
HTFD Hybrid Thick Film Device
HTL High Threshold Logic
HV High voltage
HVPS High Voltage Power Supply

IC Integrated Circuit
ICE In-circuit Emulator
IDDS Incandescent Digital Display System
IEC Infused Emitter coupling
IFU Inter-face Unit
IG-FET Insulated Gate-field Effect Transistor
IHS Integrated Heat Sink
IIL (I^2L) Integrated Injection Logic
ILP Integral Lead Package
IMPATT Impact Avalanche Transit Time
INCITE Instructional Notation for Computer-controlled Inspection and Test Equipment
I/O Input/Output
IOC Input Output Controller
IOI Input Output Interface
IOP Input Output Processor
IPA Integrated Photodetection Assembly
IR Infra-red
I-RLED Infra-red Light Emitting Diode

J-FET Junction-Field Effect Transistor
JI Junction Isolation

KMNR Kodak Micronegative Resist (Semiconductor resist in ICs)

Laput Light-activated Programmable Uni-junction Transistor
LARAM Line Addresses Random-access Memory
LASCR Light-activated Silicon Controlled Rectifier
LCD Liquid Crystal Display
LCS Large Core Store
LCT Logic Circuit Test
LDO Low Distortion Oscillator
LED Light-emitting Diode
LED/IC Light-emitting Diode/Integrated Circuit
LIC Linear Integrated Circuit
LID Leadless Inverted Device
LIFO Last-in First-out
LL Logic Level
LLL Low-Level Logic
LOCMOS Local Oxidation Complementary Metal-oxide-semiconductor
LOCMOS/CMOS Local Oxidation Complementary Metal-oxide-semiconductor/ Complementary Metal-oxide-semiconductor
LOCOS Local Oxidation-of-silicon
LOSOS Local Oxidation Silicon-on-sapphire
LPSTTL Low-power Schottky Transistor-transistor Logic
LRS Linear Reversive Sequence
LS(TTL) Low-power Schottky (Transistor-transistor-logic)
LSA Limited Space-charge Accumulation also Logical Signal Assessor
LSB Least Significant Bit
LSD Least Significant Digit
LSI Large Scale Integration
LSIA Large Scale Integration Array
LSIATE Large Scale Integration Automatic Test Equipment
LSI/MOS Large Scale Integration/Metal-oxide-silicon
LSI/RAM Large Scale Integration/Random-access Memory
LSI/ROM Large Scale Integration/Read-only Memory
LSISi-gate MOS Large Scale Integration Silicon-gate Metal-oxide-semiconductor
LSU Line Switching Unit also Logic Switching Unit
LVDT Linear Variable Displacement Transducer also Linear Variable Differential Transformer

MAR Memory Address Register
MBP Microwave Bonded Package
MC Memory Cycle
MCA Multichip Array
MCC Multichip Carrier
MC MOS Multichip Metal-oxide-semiconductor
MCU Microprocessor Control Unit
mcw Modulated Continuous Wave
MDS Microprogramme Development System also Microcomputer Development System or Microprocessor Development System
MEAL Micro-extended Assembly Language

MECL	Multiple Emitter-coupled Logic also Motorola Emitter-coupled Logic
MEDU	Monitor Equalisation Display Unit
MES FET	Metalised Semiconductor Field-effect-transistor
MIC	Monolithic Integrated Circuit also Microwave Integrated Circuit
MICROM	Micro Instruction Control Read-only Memory
MIR	Memory Information Register
MIS	Metal Insulator Silicon
MLA	Microprocessor Language Assembler
MLE	Microprocessor Language Editor
MM	Micromodule
MMA	Microelectronic Modular Assembly
MMIC	Millimeter-wave Integrated Circuit
MNOS	Metal-nitride-oxide Semiconductor
MOA	Micropower Operational Amplifier
modem	Modulator/Demodulator
MOS	Metal-oxide-silicon
MOSFET	Metal-oxide-silicon Field Effect Transistor
MOS/FIFO	Metal-oxide-silicon/First-in First-out
MOSIC	Metal-oxide-silicon Integrated Circuit
MOS/LSI	Metal-oxide-silicon/Large Scale Integration
MOS/RAM	Metal-oxide-silicon/Random-access Memory
MOST	Metal-oxide-silicon Transistor also Metal-oxide Semiconductor Technique
MOS/TTL	Metal-oxide-silicon/Transistor-transistor Logic
mP	Microprocessor Unit
MPC	Metallised Polycarbonate Capacitor
MPU	Microprocessor Unit
MReq	Memory Request
MRV	Maximum Reverse Voltage
MSB	Most Significant Bit (a/d and d/a Converters)
MSD	Most Significant Digit
MSI	Medium Scale Integration
MST	Monolithic System Technology
MTF	Modulation Transfer Function
MTL	Merged Transistor Logic
MTONS	Metal Thick Oxide-nitride-silicon
MTOS	Metal Thick Oxide-silicon
MU	Microprocessing Unit
MUX	Multiplexer
NDRO	Non-destructive Read-out
NE-PC	Neon-photo Conductive
N-FET	N-type-conduction Field Effect Transistor
N-MOS	N-channel Metal-oxide-silicon
N-MOSLSI	N-channel Metal-oxide-silicon Large Scale Integration
NRZ	None Return to Zero
NRZI	Non-return to Zero Inverted
OBO	On-board Oscillator
OCR	Optical Character Recognition
ODD	Optical Data Digitiser
OEM	Original Equipment Manufacturer
OpAmp	Operational Amplifier
OTA	Operational Transconductance Amplifier
PACE	Processing and Control Element
PAM	Pulse Amplitude Modulation
PAR	Programme-aid Routine
PC	Programme Counter (Microprocessor)
pc	Printed Circuit
P^2C-MOS	Double Polysilicon Complementary Metal-oxide-semiconductor
PCB	Printed Circuit Board
PCCD	Profiled Charge Coupled Device
PCM	Pulse Code Modulation
PDO	Phosphorous-doped Oxide
PDP	Power Delay Product
P-FET	P-type-conduction Field Effect Transistor
PFR	Power Fail Restart
Phot-SCR	Photo-sensitive Silicon Controlled Rectifier
PIA	Programmable Interference Analyser also Programmable Interface Adapter
PIU	Peripheral Interface Unit
P-JFET	P-type-junction Field Effect Transistor
PLA	Programmable Logic Array also Programmed Logic Array
PLL	Phase-locked Loop
Pmma	Polymethylmethacrylate (semiconductor resist in ICs)
P-MOS	P-type Metal-oxide-silicon
P-MOS/FET	P-type Metal-oxide-silicon/Field Effect Transistor
PP	Power Plane
PPM	Pulse Position Modulation
PPP	Potential Power Plane
PPS	Programmable Power Switch
PRACL	Page-replacement Algorithm and Control Logic
PRAM	Programmable Analogue Module
PRBSG	Pseudo-random Binary Sequence Generator
PROM	Programmable Read-only Memory
PRR	Pulse Repetition Rate
PSD	Phase-sensitive Detector
PSK	Phase Shift Key
PSL	Polycrystalline Silicon Layer
PSO	Phase-shift Oscillator
PSU	Power Supply Unit
PTD	Propagation Time Delay
PTH	Plated-through Hole
PTM	Pulse Time Modulation
PTV	Peak Transient Voltage
PUT	Programmable Unijunction Transistor
PW	Printed Wiring
PWB	Printed Wiring Board
RALU	Register and Arithmetic Logic Unit
RAM	Random-access Memory
RAMEn	Random-access Memory Enable
RAS	Random-access Store
RBI	Ripple Blanking Input
RBO	Ripple Blanking Output
RCTL	Resistance-coupled Transistor Logic
RF Cycle	Refresh Cycle
rfi	Radio-frequency Interference
RIM	Read-in Mode
RLC	Radial Lead Capacitor
RMM	Read-mostly (memory) mode
RMOS	Refractory Metal-oxide-semiconductor
ROM	Read-only Memory
ROS	Read-only Store
R Req	Refresh Request
RTD	Resistance-temperature Device
RTL	Resistor Transistor Logic
R/W	Read/Write

SAD	Serial Analogue Delay
SAILS	Soft-ware Adaptable Integrated Logic System
SAW	Surface Acoustic Wave
SBS	Silicon Bilateral Switch
SCDX	Solid State Control Differential Transmitter
SCO	Servo Control Oscillator
SCR	Silicon-controlled Rectifier
SDC	Synchro-to-digital Converter
SDFL	Schottky-diode Field-effect-transistor Logic
SDLC	Synchronous Data-link Control
SEC	Single Error Corrector
SEM	Scanning Electron Microscope
SFL	Substrate Fed Logic
S/H	Sample and Hold (function in electronic control systems)
Si	Silicon
SIC	Silicon integrated circuit
SID	Silicon Imaging Device
Si-gate MOS	Silicon-gate Metal-oxide-semiconductor
SIL	Single-in-line
SIP	Single-in-line Package
SIT	Silicon-intensifier Target
SLF	Straight Line Frequency
SLMS	Selective Level Measuring Set
SLVC	Super Linear Variable Capacitor
SMI	Static Memory Interface
SMO	Stabilised Master Oscillator
SMP	Switched Mode Power
SMPS	Switched Mode Power Supply
SMPSU	Switched Mode Power Supply Unit
SMRR	Senior Mode Rejection Ratio
S/N Ratio	Signal-to-noise Ratio
SOA	Safe Operating Area
SOS	Silicon-on-sapphire
SPAN	Stored Programme Alpha-numeric
SPC	Stored Programme Controlled
SPS	Switching Power Supply
SR	Status Register (Micro Processors)
SRD	Shift Register Decoder
SRT	Shift Register Transistor
SSB	Single-sided Board
SSCT	Solid-state Control Transformer
SSD	Static Sensitive Device
SSI	Small Scale Integration also Super Scale Integration
SSR	Solid State Relay
STT	Special to Type
STTL	Schottky Transistor-transistor Logic
SUS	Silicon Unilateral Switch

T/C/D	Timing/Control/Decoder
TDM	Time Division Multiplexed
TDRM	Time Displaced Ratio Meter
TED	Transferred Electron Device
TEM	Transverse Electromagnetic Mode
TFA	Transfer Function Analyser
TFHC	Thin Film Hybrid Circuit
TFT	Thin Film Transistor
THB	Through-hole Board
THP	Through-hole Plating
THPPCB	Through-hole Plated Printed Circuit Board
TIMOS	Total Implant Metal-oxide-semiconductor
TRAPATT	Trapped-plasma Avalanche Transit Time
TRL	Transistor-resistor Logic
TSDC	Two-speed Digital Converter
TSS	Tangential Signal Sensitivity
TTL	Transistor-transistor Logic
TTL/DTL	Transistor-transistor Logic/Diode-transistor Logic
TTL/DTL/CMOS	Transistor-transistor Logic/Diode-transistor Logic/Complementary Metal-oxide-semiconductor
TTL/ECL	Transistor-transistor Logic/Emitter-coupled Logic
TTY	Teletypewriter
TWT	Travelling-wave Tube

UART	Universal Asynchronous Receiver/Transmitter
UFET	Unipolar Field Effect Transistor
UJT	Unijunction Transistor
ULA	Uncommitted Logic Array
URCLK	Universal Receiver Clock
US/AR/T	Universal Synchronous/Asynchronous Receiver/Transmitter
USRT	Universal Synchronous Receiver/Transmitter
UTCLK	Universal Transmitter Clock
UUT	Unit Under Test

VCGO	Voltage Controlled Gunn Oscillator
VCO	Voltage Controlled Oscillator
VCR	Voltage Controlled Resistor
VDR	Voltage Dependent Resistor
VDU	Visual Display Unit
V-FC(V/FC)	Voltage to frequency Converter
V-FET	Vertical Fixed Effect Transistor
VHSIC	Very High-speed Integrated Circuit
VLED	Visible Light Emitting Diode
VLSI	Very Large-scale Integration
VMOS	Vertical (Structured) Metal-oxide-semiconductor
VOM	Volt-ohm-milliammeter
VSWR	Voltage Standing Wave Ratio
VTL	Variable-threshold Logic

WCS	Writable Control Store
WP	Workspace Pointer (Microprocessors)

XMOS	High-speed Metal-oxide-semiconductor

MMC/1-4

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AIRCRAFT

MICROMINIATURE CIRCUITS

ANTISTATIC PROTECTION

1 INTRODUCTION Certain semi-conductor devices are susceptible to damage from electrostatic charges, and are at risk in any environment where they may come into contact with such charges. The prime risk during maintenance activities is the static charge held on personnel and tools, whilst in storage the risk is from the charge held on personnel and non-conductive packaging materials.

1.1 The metal oxide semi-conductor (MOS) and complementary MOS(CMOS) family of devices is most prone to damage from static electricity. Bi-polar devices which are also susceptible to this type of damage include, but are not limited to, Operational Amplifiers, Emitter-coupled Logic (ECL) devices, and Transistor-transistor Logic (TTL) devices. In addition, there is evidence to show that thick and thin film resistors, multi-metal-layer hybrid substrates, discrete transistors and diodes, Field Effect Transistors (FET) and Schottky TTL devices also suffer damage from electrostatic discharges.

1.2 The information given in this Leaflet, although based on practices which, when carried out by properly trained personnel, are proving to be effective, is intended to serve only as a general guide to the establishment of certain minimum standards of conduct during handling, packaging, storing and testing of these devices.

1.3 Reference should also be made to the following Leaflets which contain information associated with the devices covered by this Leaflet:

MMC/1–1 Printed Wiring Boards

MMC/1–2 Printed Wiring Board Repairs

MMC/1–3 List of Abbreviations

2 MOS DEVICE CONSTRUCTION

2.1 In an electronic circuit, a MOS device functions as a voltage-controlled resistor in which the MOS equivalent resistance between the drain and source is varied by a voltage applied to the gate electrode (see Figure 1). Physically, the gate electrode is a thin layer of metal deposited on a very thin layer of silicon dioxide (SiO_2 (glass)), typically 1000 to 1400 Angstroms thick. This layer of glass effectively insulates the gate electrode from the substrate, in essence, forming a capacitor, the plates of which are the gate electrode and substrate with the dielectric being the layer of glass between the gate electrode and substrate.

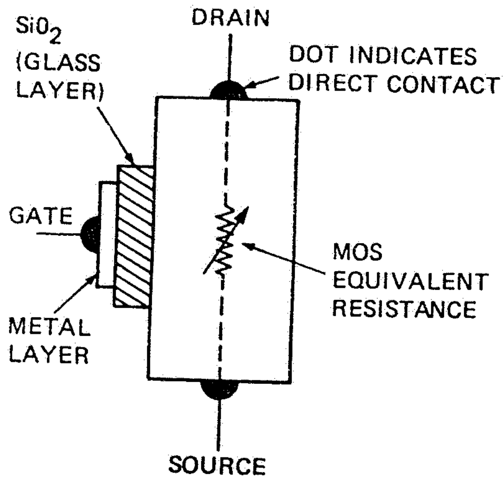


Figure 1 TYPICAL MOS DEVICE SHOWING THE INSULATED GATE

2.2 The dielectric strength of glass is approximately 10^1 V/cm, which means that a voltage in the range of 100 to 140 V can cause a rupturing of the glass, which would result in catastrophic damage to the device, usually as the result of a short circuit of the gate (electrode) to the source, drain or substrate. To avoid damage from overvoltage, manufacturers of MOS/CMOS devices usually incorporate protective circuitry on the gate electrode input pins (usually some type of resistor-diode network) so designed as to provide an alternative path for transient voltage such as electrostatic discharges. It is not the voltage discharge to ground but the potential difference between the pins on the device which causes the damage. With the elimination of such potential difference the damaging effects of an electrostatic discharge can be prevented.

2.2.1 For an unprotected MOS device the resistance at the input pins is approximately 10^{14} ohms. Using this figure it can be calculated that a current of approximately 10^{-12} ampere (10pA) can generate a 100 V potential which can rupture the layer of glass and destroy the device. Since all protective devices require the addition of some P-region the resistance can normally be reduced to approximately 10^{10} ohms. Although the effectiveness of the protective circuitry varies, most provide protection from human body electrostatic discharges only up to several hundred volts. Thus, such circuits can provide only limited protection against electrostatic discharges, which, in uncontrolled areas, can be measured in thousands of volts.

2.2.2 Figure 2 gives a schematic representation of a typical protected MOS device, as indicated by the presence of a built-in zener diode. The source, gate and drain electrodes are the equivalent of the emitter, base and collector electrodes of the typical bi-polar transistor (the substrate lead of the device is normally connected to the source lead). In most cases, the zener diode which protects the MOS device conducts at approximately 50 V. However, selection of a value for the substrate resistance can present a problem to the manufacturer as this resistance value must be great enough to limit current flow to prevent destruction of the zener diode, but must not be so high that the sum of the voltage drop across the zener-resistance combination exceeds the breakthrough voltage of the glass layer.

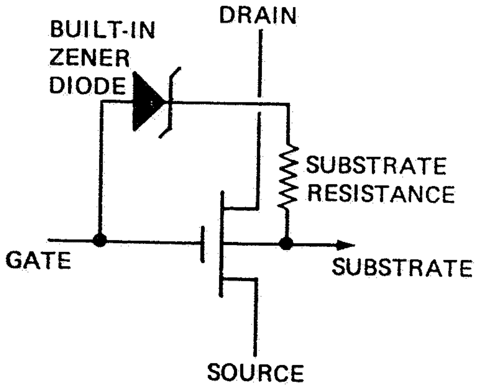


Figure 2 A TYPICAL PROTECTED MOS DEVICE

3 CAUSE OF STATIC ELECTRICITY

3.1 **Positive and Negative Charges.** Whether or not an item becomes subject to 'positive' or 'negative' electrostatic charges stems from the atomic or molecular structure of the materials involved in its construction. Materials which will readily give up electrons become charged positively, whereas others which have an affinity for electrons become charged negatively. Whenever two items are brought into contact and then separated, there is likely to be electron transfer and thus electrostatic charging, and this can result both from rubbing or non-frictional contact/separation. The net charges on the two materials will be equal but the conductivity (or resistivity) of the materials will greatly affect the potential electrostatic charges involved.

3.1.1 The charges tend to dissipate quickly over the entire surface of conductive materials, which not only lowers the electrostatic potential but increases the possibility of further dissipation to other materials which are in contact directly or via an air space.

3.1.2 On non-conductive materials the electrostatic charge can remain in localised areas at high potentials, creating electrical fields between themselves and other materials at different potentials and ground. Materials entering these fields can be charged by induction, which takes place when electrons of the material entering the field are attracted to those areas closest to any one of positive potential, leaving behind positive charged areas and creating negative charged areas. This transfer of electrons and consequent electrostatic charging by contact/separation is known as the 'triboelectric' effect.

3.2 **Prime Electrostatic Generators.** Materials common to electronic maintenance, repair and testing, which can be factors in the generation of electrostatic charges, include the human body, all work surfaces, floors (especially if waxed), furniture, personal clothing (including clean room garments), tools and all non-conductive packaging materials. Some type of motion is required for the generation of electrostatic charges and some non-conductive materials are extremely good generators of such charges. Nylon shirts or smocks, for example, can easily become charged to 20 000 V or higher. However, the human body is, in all likelihood, the most frequent source of damage to sensitive electronic components as a result of electrostatic discharge.

3.2.1 The electrostatic potential of the human body is a function of many variables, such as body capacitance, clothing material and style, body activity, relative humidity of the air, footwear, etc. A widely accepted electrical model for the human body is a capacitor (CHB) and a series resistor (RHB). There must, obviously, be a wide range of published values for both parameters, as many variables can affect them, e.g. body size, muscle tone, skin ruptures (spots, cuts, etc.), skin moistness, contact area, footwear, position in relation to the work piece, etc. However, the consensus of opinion would appear to support 200 pF as a reasonable approximation for CHB and 1000 ohms for RHB (including contact resistance). Table 1 gives representative data under typical industrial conditions.

TABLE 1 TYPICAL MEASURED STATIC CHARGES FOR THE HUMAN BODY

SITUATION	Relative Humidity of Air	
	Low 10-20%	High 65-90%
	Volts	Volts
Walking across a carpet	35 000	1 500
Walking over vinyl floor covering	12 000	250
Worker at bench	6 000	100
Vinyl envelopes containing work instructions	7 000	600
Polythene bag picked up from bench	20 000	1 200
Work chair padded with urethane foam	18 000	1 500

3.2.2 Clothing, floor coverings and furniture are not the only generators of static electricity. So, too, are many of the usual materials which are, unfortunately, still used for the packaging and transportation of electrostatic-sensitive semi-conductors and, in many instances, complete printed circuit board assemblies. Tools which have normally been used in electronic engineering and which have been thought to be safe, are often not. One particularly dangerous tool to use on an electrostatic-sensitive device is the plastics de-soldering tool; the sudden rapid movement of the plastics piston in the piston sleeve of the tool can generate a very high electrostatic potential. Another potentially dangerous tool is the electrical soldering iron which, unless it is 'grounded' at the tip, can also be a dangerous electrostatic carrier.

4 GENERAL HANDLING PROCEDURES FOR ALL SEMI-CONDUCTORS

4.1 It is not possible to lay down a degree of electrostatic protection which would cover all types of semi-conductor. However, there is a strong consensus of opinion that a significant reduction of dangers related to electrostatic charges can be achieved by making personnel aware of possible electrostatic generators and improved general handling techniques, such as:—

(a) Not removing or replacing line replaceable units with electrical power applied.

(b) Not unnecessarily touching the connectors, leads or edge connectors, etc., of printed circuit boards containing such devices.

(c) By using conductive packaging, shorting plugs, bands or wire when provided or prescribed in the relevant aircraft or equipment Maintenance Manual.

(d) By paying particular attention to stores procedures to ensure that protective packaging is not removed during any goods-inwards inspection.

5 ELECTROSTATIC-FREE WORK STATION

5.1 **General.** If, by the nature and volume of work, it is considered necessary to set up an electrostatic-free work station, guidance may be obtained from the following paragraphs which set out the various options which are open.

5.2 **Humidity.** A factor which needs to be considered when working with electrostatic-sensitive devices is the humidity of the working environment. The air in a very low-humidity environment is dry and has a very high resistance, such air will not discharge the static electricity as quickly as a moist air. Therefore, the working environment for an electrostatic-free work station should ideally, have a relative humidity of between 30 and 50%.

5.3 **Working Environment.** There are two basic methods of achieving a safe working environment in which to handle electrostatic-sensitive devices. One is dependent upon the provision of a conductive work surface, which, together with the operator and tools in use, is bonded electrically to a common ground. The other makes use of the conductive properties of an ionised atmosphere to dissipate static electrical charges.

5.3.1 **Conductive Work Surface Technique**

(a) The work surface of a bench is covered with a sheet of conductive material, e.g. plastics, or mat which is secured to the bench to prevent it from moving. The floor area in front of the bench is also covered with conductive material and electrically bonded to the work surface by means of a bonding strap. To be effective the bonding strap should have a resistance of approximately 2000 to 4000 ohms per linear foot, and should be as short as possible. A further bonding strap is used to link a wrist strap, worn by the operator, to the work surface, and this should have a resistance of 200 k ohms to 1 M ohms. To complete the system the work surface is connected to a suitable ground point. In addition the work seat may be covered with a conductive seat cover.

NOTE: Under no circumstances should the work surface of a static-free work station be connected to the electrical power supply ground circuit of the building.

(b) The main disadvantage of the conductive work surface is its conductivity. As each element of the system is bonded to a common ground to which the operator is connected via a wrist strap, immediately the operator is in direct contact with the work surface, which normally has a surface resistivity of approximately 3000 ohms, the wrist strap resistance is rendered ineffective.

5.3.2 **Conductive Atmosphere Technique**

(a) **Electrical Ionisation**

(i) An ozone laden atmosphere can be produced by several electrical methods. The safest and most acceptable method relies upon a capacitive connection between its ozone emitting needles and the conductor. The system for producing ozone consists of a rod made up of three separate elements. The outer element is a tube, made of an insulating material, which has stainless steel needles embedded at right angles at intervals along its length; the blunt ends of these needles protrude through to the second element, which is another tube of the same material coated with rings of a silver compound which are in contact with the needles. The third element which forms the centre of the rod is standard HT conductor cable (motor car ignition type) which is connected to an 8000 V secondary winding of a mains operated transformer. The complete rod is housed in a metal shroud which both protects and supports it. The effective range of this type of electrostatic eliminator is normally 13 cm (5 in) but can be increased to 61 cm (24 in) by providing an air boost, at a pressure of 14 kN/m^2 (2 lbf/in^2).

(ii) The conductive atmosphere technique depends upon ozone which in concentrations exceeding 1·0 parts per million (ppm) causes discomfort. It has been demonstrated that the ozone concentration 50 mm (2 in) from the nozzle of the eliminator is less than the 0·05 ppm which the Institute of Aviation Medicine states is a maximum for long term exposure. Electrically, the eliminator is completely safe despite the high voltage involved, and the emitter rod can be freely handled during operation.

NOTE: Extended periods of working in such an atmosphere may, nevertheless, cause extreme drowsiness.

(b) In special circumstances when the setting up of an electrostatic-free work station is impractical, an air ioniser could be used. A blower projects a stream of air containing both positive and negative ions onto the work surface and onto the operator's hands temporarily neutralising the static charges in the region. These blowers may also be used in conjunction with a conductive work surface when high levels of electrostatic charging are being experienced.

5.4 **General Operating Procedures**

5.4.1 **Conductive-Surface Work Station**

(a) Following the initial setting up the station should be checked for an effective ground and periodically monitored thereafter. In order to establish that wrist straps have not developed any faults, periodic checks should be made on their resistive value.

(b) Under no circumstances should the operator, or anybody else, touch electrostatic-sensitive devices, or assemblies containing such devices, without first having placed a wrist strap in direct contact with his wrist.

(c) When a conductive surface station is equipped with an air-ioniser blower, the normal operating procedure is to allow the blower to operate for approximately two to three minutes before performing any work. The operator should also move his hands into the ionised airstream for a few seconds, to allow for charge dissipation, before handling electrostatic-sensitive devices.

5.4.2 **Conductive Atmosphere Work Station.** Before commencing work it should be ensured that the ionising bars are working properly. This can be done by checking for the smell of ozone, thus establishing the presence of a cloud of ionised air. Satisfactory operation of the eliminator should also be determined by the vibration felt when it is held loosely in the hand, while the flow of boost air can be felt by passing a hand close to the emitter nozzle.

5.4.3 The effectiveness of an electrostatic-free work station can be further checked by the use of an electrostatic-detecting meter. Such meters are normally capable of detecting the presence, and indicating the polarity and level of static electricity, and can be read on various scales, ranging from 30 to 50 000 V at distances of 6·5 to 30 cm (2·5 to 12 in).

6 GROUND CONNECTIONS

6.1 For grounding purposes a copper mat or plate should be sunk into the earth to a depth which will ensure that it will be constantly damp. A typical grounding arrangement is shown in Figure 3. Ideally, electrostatic-free work stations should be connected to the grounding mat with a connecting strip of the shortest possible length, so reducing the possibility of radio frequency pick-up.

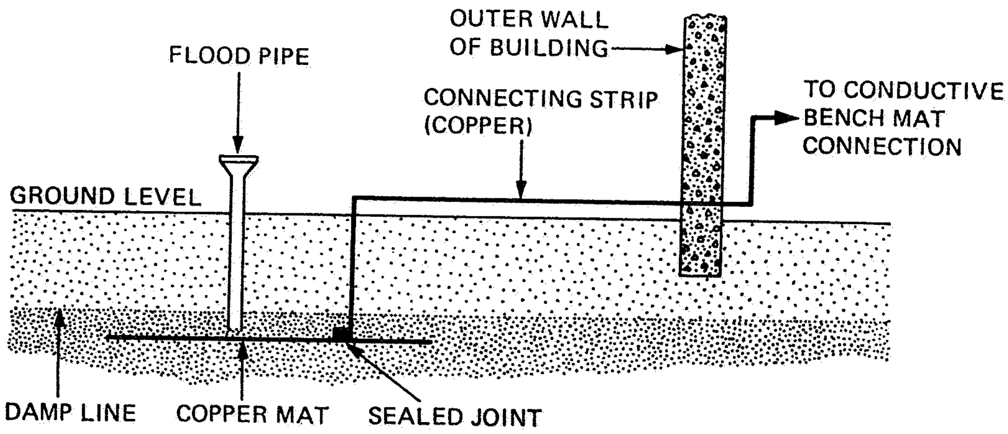


Figure 3 TYPICAL GROUNDING ARRANGEMENT

6.1.1 Care should be taken to use a material for the connecting strip which will not create a potential of more than 0·25 V with the material to which it is joined. If the connections are made by welding or soldering, they should be thoroughly cleaned to remove all traces of flux residue, and should then be completely covered with a sealing compound or other insulating covering.

6.1.2 In well drained locations, it is recommended that a pipe should be sunk over the ground mat to permit occasional flooding of the mat.

6.1.3 Where an outside wall position is not possible, a ground mat should be sited under the floor of the building or, alternatively, the work stations may be connected to grounding spikes.

7 ADDITIONAL PRECAUTIONS

7.1 **General.** Providing an electrostatic-free work station will not, on its own, ensure that no electrostatic-sensitive devices will be damaged or destroyed. Complete protection may only be achieved when certain standard operating and handling procedures are also adhered to. Only then will the complete effectiveness of the work station be realised.

7.1.1 Persons engaged in maintenance or repair work should be electrostatic conscious and should consider the avoidance of damage by electrostatic charges as a normal responsibility. They should also be aware of the necessity for the elimination of electrostatic generation such as plastics envelopes, non-conductive tapes and other commonly used items made from plastics, nylon and rubber.

7.1.2 The effectiveness of an electrostatic-free work station should be regularly checked with a static-detecting meter (see paragraph 5.4.3).

7.1.3 Work which involves the handling of exposed electrostatic-sensitive devices should not normally be undertaken outside the confines of an electrostatic-free work station. Such devices and any modules containing them should always be handled by their cases, and the unnecessary touching of connecting leads, pins or edge connectors, even if grounded, should be avoided. Modules, printed circuit boards or components should never be removed or replaced with electrical power supplies switched on. Devices which are supplied with pin shorting links or wires should only have such links or wires removed after the devices have been fitted into the circuit.

7.1.4 Soldering irons should always be used with a grounded bit, except for those which are normally used in conjunction with an isolation transformer, as grounding of this type of soldering iron may be hazardous to personnel. Any accumulated electrostatic charge on other hand tools should be discharged prior to the tool being used. No attempt should be made to test electrostatic-sensitive devices with a multimeter.

7.1.5 For both serviceable and unserviceable electrostatic-sensitive devices, modules and printed circuit boards the same precautions should be observed. It is, therefore, advisable to retain any conductive or anti-electrostatic packaging material removed from serviceable equipment for re-packaging of the unserviceable items, ensuring that the package is suitably labelled to show that the contents are unserviceable but contain electrostatic-sensitive devices.

8 TESTING

8.1 **General.** All testing of equipment containing electrostatic-sensitive devices should be strictly in accordance with the relevant manufacturer's instructions. The following paragraphs only draw attention to the more general precautions which should be observed during testing of electrostatic-sensitive devices and/or printed circuit boards or modules.

(a) In general, such items should not be inserted or removed from their installed positions unless all electrical power is switched off, as transient voltages may cause permanent damage.

(b) When bench testing, input test signals should not normally be injected into such items without electrical power being applied. All unused input connections should also, normally, be connected to a power source or to ground.

(c) Much of the test equipment used for the testing of such items will also contain electrostatic-sensitive devices. While calibration of this type of test equipment will not normally require the operator to wear a wrist strap, if a repair or replacement has to be made involving an exposed device or module, then a wrist strap should be worn, and the electrostatic damage-prevention measures of this Leaflet should be implemented.

9 STORAGE

9.1 **General.** The creation of a safe storage environment does not depend on the provision of the same kind of facilities which have been outlined. The packaging of equipment precludes the use of a conductive atmosphere technique; therefore, adequate protection is dependent upon the provisioning of a conductive surface. Whilst it is advisable to store electrostatic-sensitive equipment in grounded metal racks and cupboards this alone will not necessarily completely protect such equipment.

9.1.1 It is known that plastics and polymer based packaging materials will retain static charges which produce voltage gradients across the surfaces; accordingly, electrostatic-sensitive equipment must never be stored alongside non-electrostatic-sensitive equipment.

9.1.2 Electrostatic-sensitive equipment should be packed in a conductive material, such as will ensure that the whole of the package is maintained at the same potential, and should then be stored in grounded metal racks or cupboards.

9.2 **General Precautions**

9.2.1 All packages containing goods inward should be checked for the presence of electrostatic-sensitive devices by reference to external markings and reference numbers. Any package not so marked should, if it contains electrostatic-sensitive devices, be labelled accordingly, and should be handled and stored in accordance with the recommendations of this Leaflet.

9.2.2 The conductive packaging of such equipment should never be removed outside the confines of an electrostatic-free work station.

Issue 2.

15*th November*, 1974.

AIRCRAFT

RADIO

ADF LOOP AERIALS

1 INTRODUCTION This Leaflet gives general guidance on the calibration and testing of loop aerials for Automatic Direction Finding (ADF) equipment. Although most aerials in current use are of the fixed loop type, certain aspects of testing appropriate to rotating loop aerials are retained as a guide to the continued serviceability of some existing installations. The Leaflet should be read in conjunction with the relevant aircraft and equipment Maintenance Manuals which contain details of the procedures to be adopted for specific installations. Reference should also be made to the following Leaflets and chapters of British Civil Airworthiness Requirements, which contain information closely associated with the equipment and practices covered by this Leaflet.

AL/10-5	Direct-Reading Magnetic Compasses
EEL/1-6	Bonding and Circuit Testing
RL/2-2	Radio—Aerials
RL/2-3	Screened Rooms for Radio Maintenance
Chapter **R4-5**	Bonding and Lightning Discharge Protection
Chapter **R4-6** App. No. 3	Tests for ADF Systems

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **RL/2-1**, Issue 1 dated 15th March 1955, Leaflet **RL/5-2**, Issue 1 dated 15th June 1960, and Leaflet **RL/5-3**, Issue 1 dated 15th June 1962.

2 LOOP ERRORS When ADF loop aerials are installed in aircraft, errors are introduced which vary with the type of aircraft and the location of the loop. Two types of error may be introduced; (i) Quadrantal and (ii) Loop Alignment. In rotating loop installations a Field Alignment error may also be introduced. The direction and amount of such errors throughout the working range of the equipment must be known to enable corrections to be applied.

NOTE: Information on the correction of loop alignment errors is not included in this Leaflet as such procedures are fully described in the Maintenance Manuals and Overhaul Manuals for the equipment concerned.

2.1 **Quadrantal Error.** When installed, loop aerials are subject to bearing indication errors arising from radio frequency currents circulating in the metal structure of the aircraft. The loop is subjected to induction and re-radiated fields from these currents in addition to the radiation field of the distant transmitter. These errors are classified as quadrantal errors because maximum deviation occurs roughly at the centre of each of the quadrants formed by the horizontal axes of the aircraft (see Figure 1).

2.1.1 After the initial installation of ADF equipment, it is necessary to determine the amount and direction of the errors and also whether or not they remain constant over the full frequency range of the receiver. Any appreciable change of error between one frequency and another indicates that the installation is unreliable.

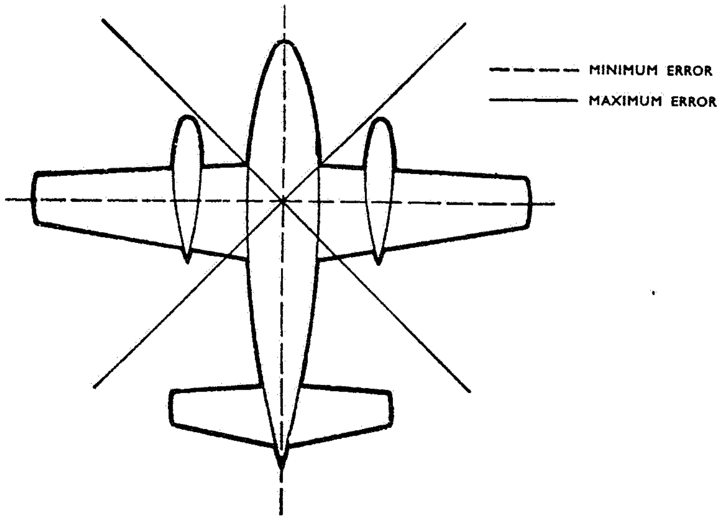


Figure 1 QUADRANTAL ERROR

2.1.2 Allowances for quadrantal errors are made by taking bearings from a transmitter of which the actual bearing is known and making appropriate corrections to the direction finding equipment in the aircraft; the procedure is known as "swinging for quadrantal correction" or, more briefly, "loop swinging".

2.2 **Loop Alignment (Installation) Error.** As it is not always possible to sight the loop for accurate alignment, the CAA recommends that, where applicable, the loop should be jigged at 90° to the loop base whilst the base itself is aligned to within ±0·25° of the longitudinal axis using the lubber lines, fore and aft fixing holes or other means of alignment provided by the aircraft manufacturer.

2.2.1 Systems should be checked by switching to LOOP, under conditions of no signal, and verifying that the remote indicators read ZERO when the plane of the loop is at 90° to the longitudinal axis of the aircraft.

2.2.2 Remaining loop alignment errors will be indicated when the loop is swung and these should be corrected at the same time as the quadrantal errors (see paragraph 3.3.1).

2.3 **Field Alignment Error.** A further error may be revealed on the quadrantal error curve for a rotating loop, should the loop be offset from the aircraft centre-line. In this case it will not be operating at the centre of the re-radiated radio field pattern and a correction should be embodied concurrently with the quadrantal error corrections (see also paragraph 4).

3 LOOP SWINGING The swinging method to be adopted will depend on the position of the loop. A loop mounted on the top of the fuselage can be calibrated on the ground, calibration being facilitated if the aircraft has a nose landing gear and is, therefore, approximately in its flight attitude. A loop mounted on the underside of a fuselage may be appreciably affected by the proximity of the ground, or parts of the aircraft such as the landing gear. If such interference is detected during ground swinging, the loop should be calibrated in the air. In all cases loop installations should be checked by an air test after normal quadrantal errors have been corrected.

NOTE: The highest possible degree of accuracy is essential when calibrating on the ground, or in the air, since observational errors in reading either the ADF bearing or the reference bearing, will cause the calibration curve to differ from the theoretical pure quadrantal curve.

3.1 **Night Effect.** To allow for variations of the ionosphere, no swings should be made at night. In temperate climates "night effect" commences about 2 hours before sunset and continues until 2 hours after sunrise, but in tropical countries the period may be reduced to 1 hour in each case.

3.2 **Ground Calibration.** Before swinging a loop on the ground a site must be selected that is flat and clear of obstructions. The site should be as far as possible from ferro-concrete and steel-mesh runways, hangars, railways and overhead or underground electrical power supplies; it should be remembered that the erection of new buildings may adversely affect the suitability of the site.

3.2.1 Bases specially prepared for magnetic compass swinging should not be assumed to be suitable unless check bearings are taken, e.g. by means of a portable direction finder, although allowances can be made for permanent errors on such sites. Bearings should be taken from a number of transmitters selected to give as wide a check as possible throughout the ADF frequency bands over a 360° range. Radio bearings of the selected transmitters should remain reasonably constant over the whole area which will be covered by the aircraft during the calibration procedure.

3.2.2 A loop can be swung with reference to either True or Magnetic North. The main advantage of referring to True North is that a base can be permanently marked out so that distant station bearings can be ascertained without reference to changes in magnetic variation. If the swing is referred to Magnetic North, the loop should be calibrated by means of a datum compass, such as the medium landing compass, which should be aligned with the aircraft's longitudinal axis and positioned at a specified distance from the aircraft (typical distances can vary between 50 and 150 feet). In order that the longitudinal axis may be accurately determined, aircraft datum points and directions from which they are to be sighted, must be carefully selected.

NOTE: Periodic calibration checks can be referred to the aircraft remote indicating compass system or, if no other method is available, to the aircraft direct-reading magnetic compass. A check should be made that the particular aircraft compass system used has recently been corrected; the correction procedure for direct-reading compasses is given in Leaflet AL/10-5.

3.2.3 Before commencing to swing a loop, a check should be made to ensure that the aircraft contains its full complement of airborne equipment; this is of particular importance if the loop has to be checked against the aircraft compass system. Doors and panels in the vicinity of the loop and the sense aerial, should be closed and secured. Ground equipment such as towing vehicles, towing arms, etc., should not be positioned near the aircraft. Internal power supplies should be used whenever possible. It should also be remembered that the ADF installation may suffer from interference if there are faults in the aircraft bonding or electrical systems, or if additions of aircraft equipment have been made in close proximity to the loop.

3.3 **Swinging By Reference To Magnetic North.** The results obtained by this method of swinging should be recorded on a suitable chart. A specimen chart showing typically essential information and an example calculation is given in paragraph 3.3.1. The swing should be repeated in each frequency band of the ADF receiver.

3.3.1 The aircraft should be turned through a specified number of magnetic headings to enable ADF bearings relative to the selected transmitter bearing (160° in the example considered) to be obtained. For initial swings and for check swings, heading intervals of 15° and 45° respectively, are usually satisfactory. The readings obtained should be entered in column 4 of the correction chart. When aircraft headings are derived from the compass system, the readings in column 4 should be corrected for deviation by taking the algebraic sum of the values entered in columns 2 and 3.

ADF LOOP CALIBRATION

Ref.: ....

Calibrated At: .... Aircraft Type: ....

Radio Station: .... Registration: ....

Frequency: .... ADF Type: ....

Distance: .... Loop Position: ....

Time Calibrated: .... Date: ....

Heading No.	1. Magnetic Bearing of Station from Site: 160					
	2	3	4	5	6	7
	Compass Heading	Compass Deviation	Magnetic Heading (2±3)	Bearing Indicated by ADF	Relative Bearing of Station (4+5) or (4+5−360)	Correction Required (1−6)
1	314	1°E	315	200	155 (i.e. 515–360)	+5

At the same time, the ADF bearing indicated by either the loop or goniometer scale, or other relevant bearing indicator, should be noted and entered in column 5. The relative bearing of the station (column 6) should then be obtained by adding together the magnetic heading and ADF bearing; in the example shown 360° has been subtracted from the total. The difference between the relative and magnetic bearings of the station then gives the amount of quadrantal error correction required and this is entered in column 7.

3.3.2 When completed, entries obtained in columns 5 and 7 should be plotted as shown in Figure 2. This depicts an almost perfect curve which is symmetrically balanced about the base line, and is of regular shape. A well sited loop should give similar results on all bands. For record purposes, the graph should also form part of the calibration chart.

NOTE: Departures from the shape of the curve shown in Figure 2, whether repeated on all frequency bands or not, necessitate elimination of the cause, or, if this cannot readily be done, re-siting of the loop. The most frequent cause of an incorrectly shaped curve is interference from aerials or other equipment in the vicinity of the loop.

3.3.3 Figure 3 shows the results of a swing where vertical shift has occurred from loop alignment error, and where horizontal shift is apparent as a result of field alignment error (see paragraph 2.3). The measurements should be re-checked to ensure that the loop is on the true centre line of the aircraft. In the example shown, repositioning the loop should have the effect of moving the curve 10° to the left, when an adjustment to the bearing indicator of 4° relative to the loop will revert the curve to that of Figure 2.

NOTE: Reference should always be made to the relevant equipment Maintenance Manuals for the methods of correcting loop and field alignment errors. Information of a general nature is given in paragraph 4 of this Leaflet.

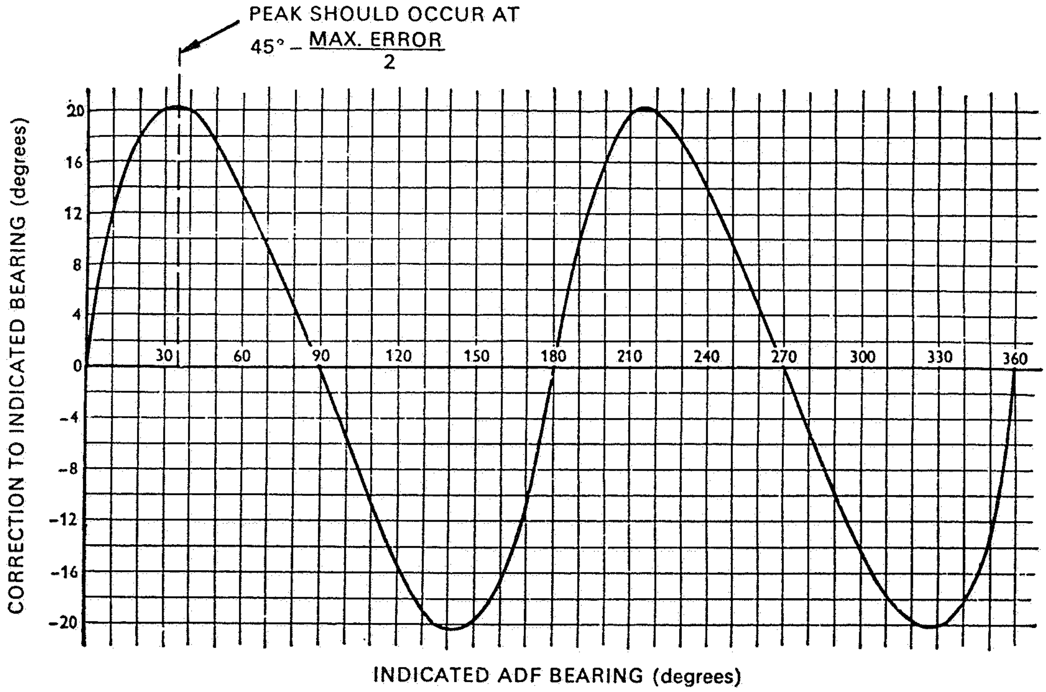


Figure 2 QUADRANTAL ERROR CURVE

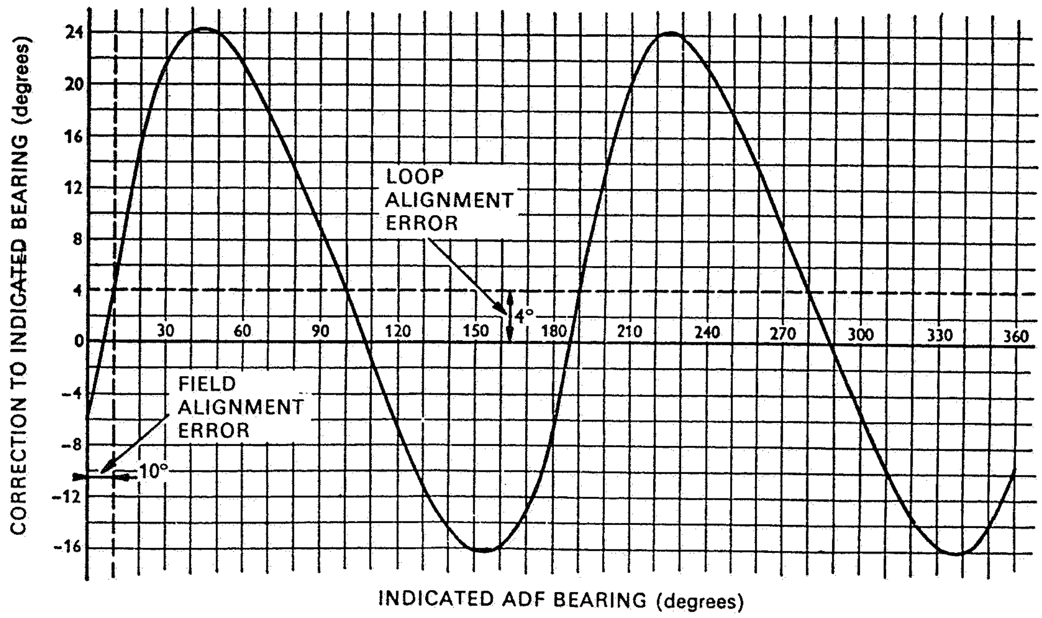


Figure 3 QUADRANTAL ERROR CURVE WITH VERTICAL AND HORIZONTAL SHIFT

3.4 **Air Calibration.** The method of air calibration should be selected according to prevailing circumstances and geographical location. Two methods are given in this Leaflet; Position Line Swinging and Single Point Swinging.

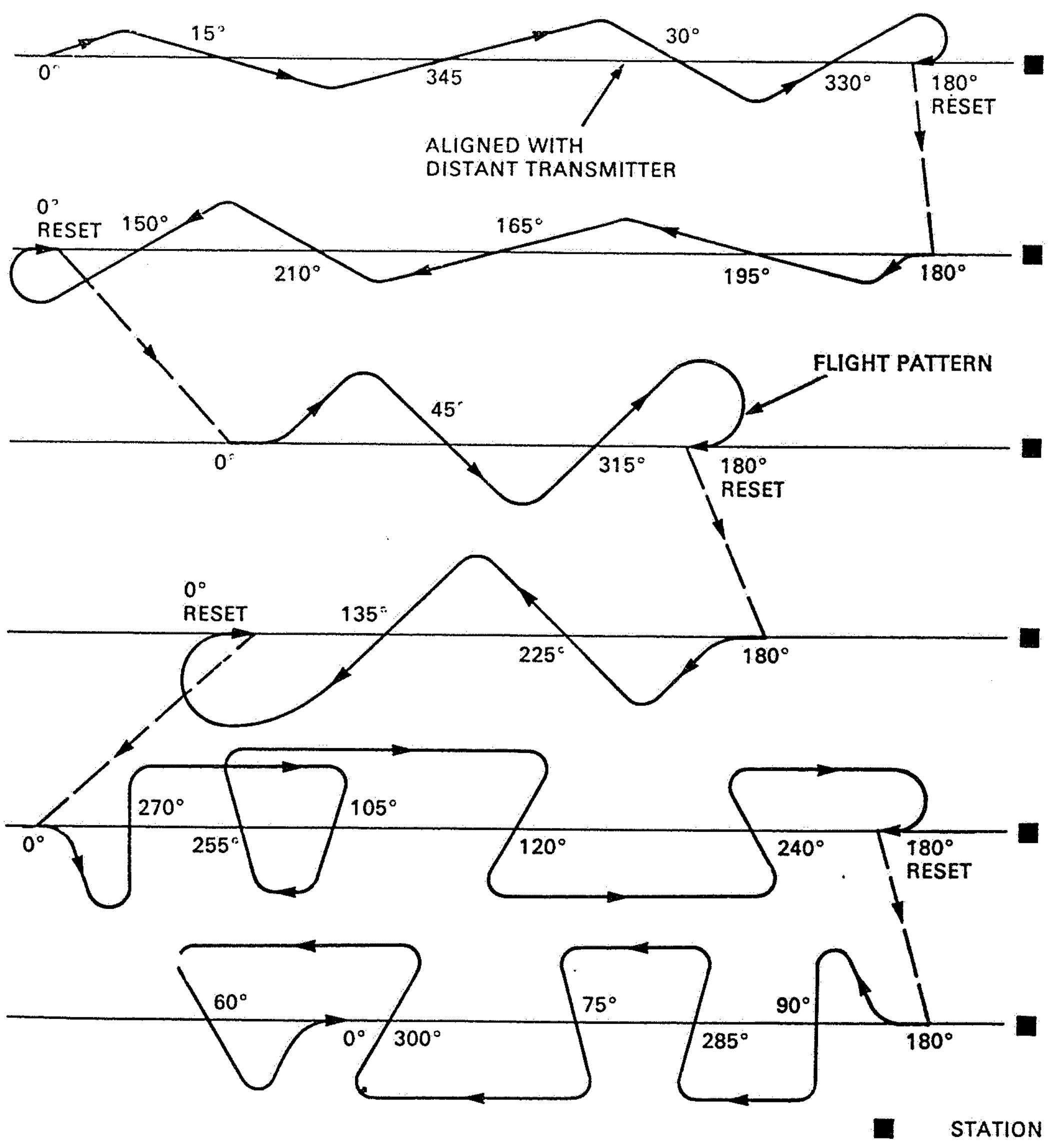


Figure 4 PATTERN OF FLIGHT FOR POSITION LINE SWINGING

3.4.1 **Position Line Swinging.** This method entails flying to a set pattern over such a series of landmarks as will produce a ground reference line aligned with a distant transmitter.

(i) The calibration flight should be made in smooth air conditions, when the wind velocity is negligible, in order to eliminate drift errors. All turns should be gradual and identical.

(ii) The ground reference line should be checked for any distortion of the transmitter radiation pattern. This may be done by flying across the line and observing the bearing indicator for irregularities in indication. If irregularities occur, the flight should be made at another altitude, or another reference line should be selected.

(iii) A pattern of flying similar to that shown in Figure 4 should then be followed, the indicator readings being recorded at each point of intersection with the ground reference line. The aircraft should approach each intersection in level flight and not on the point of a turn.

3.4.2 **Single Point Swinging.** For this method a clearly defined point should be selected which is inland and greater than 40 miles from the transmitter; the true bearing of the point from the transmitter should then be determined from plotting charts. The swing is made by flying a "clover leaf" pattern over the point at an altitude which permits accurate observation; the actual altitude will, of course, depend on the visibility and weather conditions prevailing at the time.

(i) A preliminary check should be made on the aural ADF signal to verify that the minima (null points) are sharp, well defined and in anti-phase.

(ii) The flight pattern should be flown accurately using the remote indicating compass system. The point should be approached on each leg from about 5 miles away with the automatic pilot engaged; after flying about 5 miles past the point the automatic pilot should be disengaged to enable a more rapid turn to be made.

(iii) The flight pattern over the point should consist of twelve even keel runs terminating in 30° turns to port, followed by a 40° turn to port for a second series of twelve runs, and a further 40° turn for a third and final series.

EXAMPLE: If the swing is related to True North, and the selected transmitter is due North of the chosen point, the true headings of the aircraft are as follows:

0	010	020
150	160	170
300	310	320
090	100	110
240	250	260
030	040	050
180	190	200
330	340	350
120	130	140
270	280	290
060	070	080
210	220	230

3.5 **Periodic Calibration Checks.** Periodic checks of the calibration are necessary to ensure that the original pattern of the errors has not changed. Such checks should be made on the following occasions:—

(i) When specified in the approved Maintenance Schedule.

(ii) After the addition, or removal, of aerials, radio equipment, or aircraft equipment in the vicinity of the loop.

(iii) After a lightning strike; in this case a loop calibration check should only be attempted after appropriate measures have been taken to reduce the aircraft's compass system errors to within the permitted tolerances. This is to ensure that the aircraft has been cleared of the effects of the strike.

4 QUADRANTAL ERROR CORRECTION The methods of correcting quadrantal errors vary between types of aerial, and reference to the relevant manufacturer's manuals should always be made for details of the procedure to be adopted. The information given in the following paragraphs is of a general nature, and is intended only as a guide to correction methods.

4.1 For aerials of the rotating loop type, corrections for both quadrantal and field alignment errors are given on a correction chart mounted adjacent to the loop, and the corrections are made by the mechanical adjustment of scales against fixed datums provided on the aerials.

4.1.1 If several aircraft of the same type are concerned, it is possible to replace loops in individual aircraft with loops in which the corrections for quadrantal error have already been incorporated. Since aircraft of the same type with similar ADF installations have very much the same quadrantal errors, a standard correction chart can be prepared for the aircraft on the basis of individual trial calibrations. If this procedure is adopted, a final check should be made for alignment of the loop with the longitudinal axis of the aircraft and for sense reversal. Bearing checks should be made by tuning to suitable transmitters, at the same time referring to previous loop calibration records to check that there are no discrepancies; should there be any, a swing should be made as outlined in paragraph 3.

4.2 Some types of ferrite-cored loops have certain values of quadrantal error correction built-in, by making the fore-and-aft loop more sensitive than the athwartships loop. The preparation of correction charts is, therefore, unnecessary. The correction values required are established on a prototype installation, and are inserted electrically by means of a corrector unit connected in the loop aerial cable.

4.3 In order to supplement a built-in quadrantal error correction, a loop equalizer unit is provided for mounting directly on the loop aerial connector. The unit also compensates for capacitance and inductance changes which occur when loop cables shorter than the standard length of 30 feet are used. Units are designed to suit the cable length and quadrantal errors of individual loop installations; the values being indicated by a suffix to the part number.

5 TESTING OF ADF LOOPS AND RECEIVERS ADF loops and receivers should be tested at the periods specified in the approved Maintenance Schedule. The following tests are normally required and may be carried out either by the Square Loop Method or by the Transmission Line Method, depending on whether an aerial is of the rotating type or the fixed type.

(i) Loop sensitivity; measured in microvolts per metre to give a standard audio output. For the purpose of this test the loop is normally placed in the position of maximum pick-up, and subsequent measurements are then taken a few degrees either side of the null point.

(ii) Compass sensitivity; measured in microvolts per metre.

(iii) Compass accuracy; measured in degrees.

(iv) Speed of loop rotation; measured in degree per second.

(v) Hunting; measured in degrees.

NOTE: The usual measurements for the particular equipment under test are quoted in the relevant manual.

5.1 **Square Loop Method.** This method is the one adopted for testing rotating circular, or flattened, air-cored loops in small screened rooms (or "cages") of the type described in Leaflet **RL/2-3.** In no circumstances should it be used for testing of fixed ferrite-cored loops (see paragraph 5.2).

5.1.1 **Connections to a Square Loop.** The loop under test is closely coupled to a square loop fed from a signal generator. For the purposes of this Leaflet, it is assumed that a self-supporting copper wire or strip is shaped into the form of a square loop the sides of which are 30 cm long, with lower horizontal limbs of from 12 to 14 cm long, fed from the signal generator through 75 ohm co-axial cable, in series with a 925 ohm non-inductive resistor (see Figure 5).

(i) This size of loop is convenient for the types of circular loops and flattened loops generally used in aircraft, but as can be seen from the formula given in paragraph 5.1.1 (iv), the dimensions, and consequently the attenuation figures, can be altered within reasonable limits.

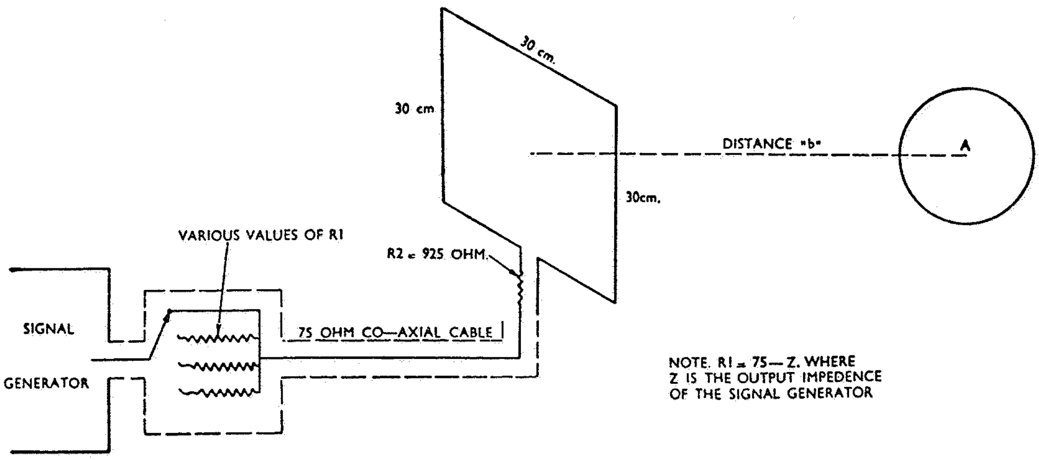


Figure 5 CONNECTIONS TO SQUARE LOOP

(ii) Some signal generators may have output impedances lower than 75 ohms, and these should be connected, as shown in Figure 5, to a 75 ohm co-axial cable, via a non-inductive resistor of a value to provide correct matching. The output impedance of some signal generators also varies at certain settings of output volts, and it may, therefore, be necessary to switch out the extra resistor, or insert one of a new value, depending on the output attenuator setting.

(iii) The current in the loop is determined by the voltage from the signal generator and the total series resistance of the loop circuit (1,000 ohms). No account is taken of the reactance of the loop, which is negligible at the test frequencies used.

(iv) The equivalent field strength produced by the loop at a point "A" on the axis (see Figure 5) is as follows:—

$$\frac{24Ia^2 \times 10^3}{(a^2 + b^2)\sqrt{(2a^2 + b^2)}} = \text{millivolts/metre (mV/m)}$$

where: I = loop current in milliamps,

a = length in centimetres of the side of the loop,

b = distance in centimetres of point "A" from the centre of the square loop.

EXAMPLE: With one volt from the signal generator, the loop current is 1 milliamp (mA) and the equivalent field at point "A", one metre away, is 5·15 mV/m., or +74·3 decibels to 1 microvolt. Attenuation of the applied voltage causes a corresponding attenuation of equivalent field strength, and a signal generator output of +NdB relative to 1 microvolt corresponds to a field strength of N − 45·7 decibels relative to 1 microvolt/metre.

(v) The example given above indicates that to provide a certain voltage at the loop to be tested, the signal generator voltage must be increased by 45·7 (46 to nearest whole number) decibels on this voltage, at which a number of disadvantages accrue, e.g., an abnormally high output from the signal generator is required. This results in a strong induction field from the loop, with consequent distortion of the field by reflection from the adjacent reflecting surfaces of the cage and associated wiring. As indicated in Table 1, distance "b" is required to be one metre, and as both loops have to be positioned so as to avoid the reflection mentioned above, this may result in undue utilisation of space within the cage. It is always advisable to check the complete test layout in a large open space outside the cage, free from obstructions, and these results should be confirmed at the selected position inside the cage. The positions and numbers of instruments, equipment and personnel in the cage at the time of initial testing should be noted, and this layout should be adhered to in all subsequent tests.

NOTE: If one side of the square loop is too near the side of the cage and/or the test equipment, an unbalance would result in the zero heading and the compass speed of rotation.

(vi) Table 1 provides for a number of distances between loop centres, within practical limits, resulting in even number decibel attenuations. A voltage multiplication factor is given, and may be used either where the operator so desires, or where no decibel setting is given on signal generator attenuator controls.

TABLE 1

Distance "b" between Loop Centres (cm)	Signal Generator Setting above Required Voltage (dB)	Voltage Multiplication Factor
100	45·7 (46)	—
80	40	100
74	—	80
67	—	60
58	—	40
53	30	30
42	—	20
33	20	10

NOTE: It is possible to further reduce the distance between loop centres.

5.1.2 **Setting up the Loop for Test.** The loop to be tested is placed at the selected distance from the square loop, with the lower sector of the loop being tested level with the lower horizontal limbs of the square loop. With induction systems, the loop does not "home" on the source of the signal but at 90° to it.

(i) The loop base should be aligned so that its fore and aft axis is parallel with a line drawn horizontally through the vertical limbs of the square loop. In subsequent setting-up with a sense aerial voltage, the loop indicator will initially read either zero or 180°; if the indicator reads 180°, the connections to the square loop should be reversed to obtain a zero reading.

NOTE: It should be borne in mind that it may be necessary to mount the loop base on a calibrated turntable in order to check the accuracy of synchro-system transmission.

5.1.3 **Sense Aerial Requirements.** A sense aerial signal of the correct magnitude and of a phase relative to the loop signal is required. Optimum conditions obtain when the depth of modulation of the locally modulated carrier approaches zero when the loop is receiving no signal. It follows that if the signal generator voltage supplying the square loop is, in addition, to be utilised directly for a sense aerial voltage, it must be severely attenuated. After attenuation, the voltage can be fed directly to the sense aerial input, as at the frequencies used, the required phase shift of 90° between vertical and loop voltage remains unaffected.

(i) **Setting-up for Testing.** The voltage induced in an aerial can be stated as:—

Microvolts/metre × Effective height of aerial in metres = Microvolts induced in the aerial.

An aerial of effective height of 0·25 metres, in a field of 1,000 microvolts per metre, will have induced in it a voltage of 250 microvolts. It is, therefore, necessary to know the effective height of the sense aerial associated with the loop, and this information can be found in the relevant manufacturer's manual. The following setting-up procedure is based on the assumption that the sense aerial effective height is 0·25 metres and that it has an effective capacitance of 50 picofarads (pf).

(a) The ADF receiver should be tuned to 500 kHz or other suitable mid-band frequency, and the function switch should be set to "OMNI". The signal generator should be fed through a 50 pf capacitor to the receiver aerial input, and the signal generator should be set to give 250 microvolts, modulated 30 per cent, at 400 Hz.

NOTE: The modulation percentage and frequency may differ for different equipments, but if so it is usually stated.

(b) The receiver gain controls should be adjusted to give rated audio output in milliwatts. The gain controls should then be left undisturbed whilst the signal generator is disconnected, reconnected to the square loop, adjusted to provide a field of 1,000 microvolts, at the ADF loop, and then connected to the equipment as shown in Figure 6.

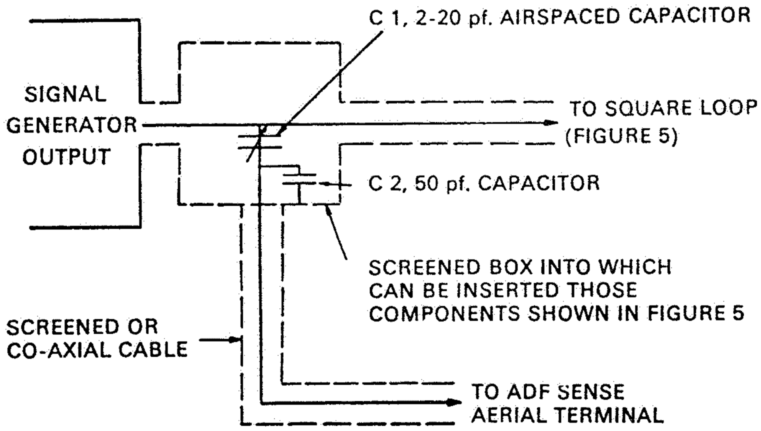


Figure 6 CONNECTIONS TO SENSE AERIAL

(c) The variable capacitor should be adjusted until rated audio output is again registered, taking care that the receiver gain control remains undisturbed. The variable capacitor can now be set in its position permanently, or its value carefully measured, and replaced by a fixed capacitor.

(ii) **Alternative Method of Testing.** If a vertical rod is placed in the field of the square loop as shown in the plan view of Figure 7, it will have a voltage induced in it, the amount being determined by its length and its distance from the square loop.

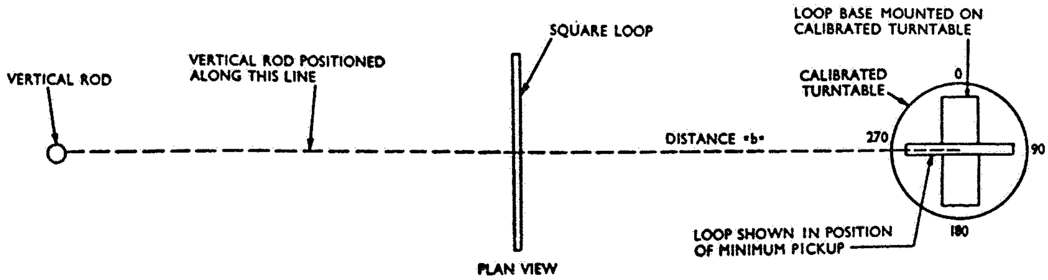


Figure 7 ALTERNATIVE METHOD OF PROVIDING SENSE AERIAL FEED

(a) For testing one particular ADF equipment, the rod length can be made to equal the effective height quoted for the sense aerial; the following formula may be used:—

$$L = \frac{E_h}{0{\cdot}635}$$

Where: L = Length of rod
E_h = Effective height of aerial

(b) For an effective height of 0·25 m, the length of the rod is approximately 40 cm, and this rod should, theoretically, be spaced the same distance away as the loop to be tested. However, as all the rod may not be cut by the square loop field, it should be moved slowly towards the square loop after the adjustments described in paragraph 5.1.3(i) have been made. When rated audio output is registered, the rod can be fixed and left in this position.

(c) Care should be taken to ensure that the rod and its screened feeder cable or co-axial cable equal the capacitance quoted (50 pf in the example given in paragraph 5.1.3(i) (a)) but, if not, a small "padder" capacitor should be added.

(d) Provided the capacitance is correct for the equipment under test, the rod need not equal the effective height for the particular equipment, and a smaller rod (say 30 cm) can be used, and positions determined for any equipment which requires to be tested. The smaller the rod, the nearer it must be positioned to the square loop. Similar results can be obtained by fixing the rod permanently and close up to the square loop, and by feeding the sense aerial through a 2–20 pf airspaced capacitor.

5.2 **Transmission Line Method.** This method is the one approved for testing fixed ferrite-cored loop aerials since it gives improved bearing accuracy and enables more accurate determination of the field strength voltage at the loop.

5.2.1 **Screened Room (Cage) Requirements.** The transmission line must be installed in a screened room of the general construction described in Leaflet **RL/2-3.** The rooms may vary in size, and for convenience they are divided into three groups (see Table 2), to each of which a particular attenuation formula is applicable. The limitations on distances d and d_2 of Figure 8 are also given.

TABLE 2
CAGE INTERNAL DIMENSIONS AND DISTANCE LIMITATIONS

Group	Cage Size	Height (in)	Length (in)	Width (in)	d_2 (not less than) (in)	d (in)
1	Larger than	144	152	108	50	24–50
2	Larger than	90	90	72	12	18–24
3	Less than 2 above				9	12–24
						(all: but less than ½ of d_1)

(i) Dimensions d and d_2 may need slight alteration when determining an attenuation constant, in order to arrive at a whole number. While a whole number constant will make subsequent testing easier, it is not suggested that continuous alterations are made in order to effect this.

(ii) Manufacturers of ADF equipment may give details in their manuals of a transmission line installation quoting cage size and all dimensions necessary to give a whole number attenuation constant. This Leaflet is concerned with the general methods to be adopted where these particular dimensions are not available or cannot be followed.

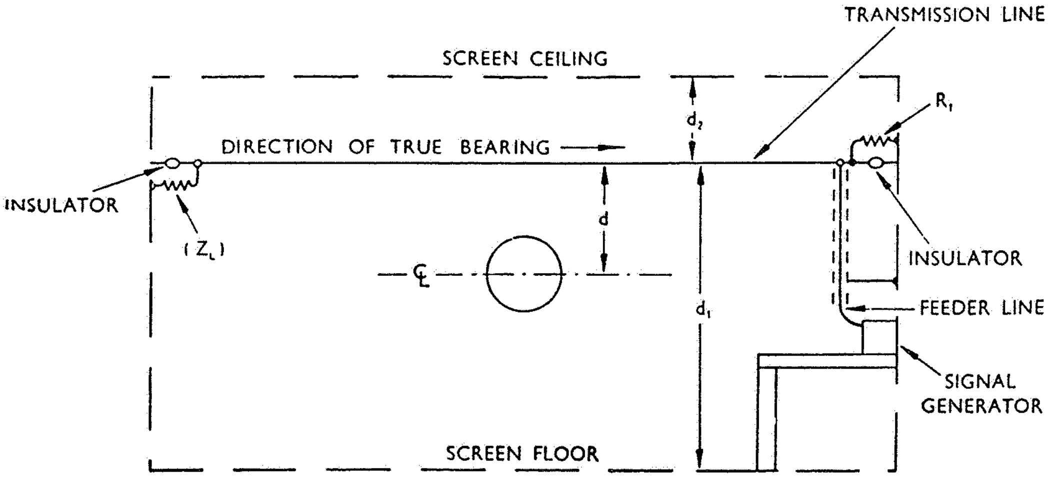


Figure 8 TRANSMISSION LINE SYSTEM GENERAL CONSTRUCTION

5.2.2 **Constructional Details**

(i) **Transmission Line.** The transmission line should be erected centrally along the length of the screened room (see Figure 8). Single-strand copper or tinned-copper wire of 22 s.w.g., or greater, is suitable, and should be secured to the inner wall of the cage by insulators and should be tensioned. The ends of the line (excluding insulators) should reach to within 4 inches of the cage walls.

(ii) **Feeder Line.** A feeder line, sometimes called a "concentric line", should be used to connect the signal generator to the transmission line.

(a) For cages of the sizes defined in Group 1 of Table 2, it is recommended that a copper tube of 1 inch diameter should be mounted vertically under one end of the tranmission line, with a feeder line of 18 s.w.g. copper wire suspended concentrically inside it.

(b) The output terminal of the signal generator should be so arranged that only a very short connector is required to the base of the tube.

(c) Both the signal generator and the concentric tube should be bonded to the cage wall.

(d) For smaller cages it will be found more convenient to use 70 ohm co-axial cable as a feeder line, maintaining an unbroken length from the signal generator to the transmission line. The cable should be kept as short as possible, fixed vertically below the end of the line, and should be bonded to the cage wall.

(iii) **Loop Mounting.** A rigid wooden stand should be mounted on the floor of the cage directly under the centre point of the transmission line.

(a) The top of the stand should consist of a non-metallic turntable, calibrated in degrees, and should be carefully aligned by two plumb bobs suspended from the transmission line and a straight-edge positioned through the 0°–180° points of the turntable. If a 360° cursor is fitted to the turntable it should be numbered in an anti-clockwise direction. If preferred, a normal reading cursor can be fitted to the top of the stand with 0° and 180° marks fixed to the turntable.

(b) The turntable forms the platform for the loop and should be accurately jigged to receive it. The fixed pointer on the loop base should be aligned with 0° of the turntable on that side of the stand nearest the feed line.

(c) For greater flexibility, the turntable can be constructed to move vertically thus ensuring that distance d remains constant for various loop centres, or, preferably, a number of platforms can be constructed to accommodate different loops. The use of nuts and bolts and other metal work should be avoided as far as practicable.

(d) For smaller cages it may be more convenient to mount the loop and turntable on a solidly constructed hinged wooden flap projecting from the workbench.

5.2.3 **Determination of Screened Room Constants.** The following paragraphs indicate the method of determining the screened room constants. These constants may be altered when alterations are made to the layout of the equipment in the screened room, and will need re-calibrating when a signal generator of different output impedance is used. It is important, therefore, that the screened room should not become encumbered with extra equipment, or the layout modified. The output impedance of the signal generator to be used should be displayed adjacent to the feeder connection.

(i) **Termination of Transmission Line (Z_L).** Two valve voltmeters (VV1 and VV2 of Figure 9) should be connected as shown, and the frequency at which the line resonates at ½ wave length should be determined.

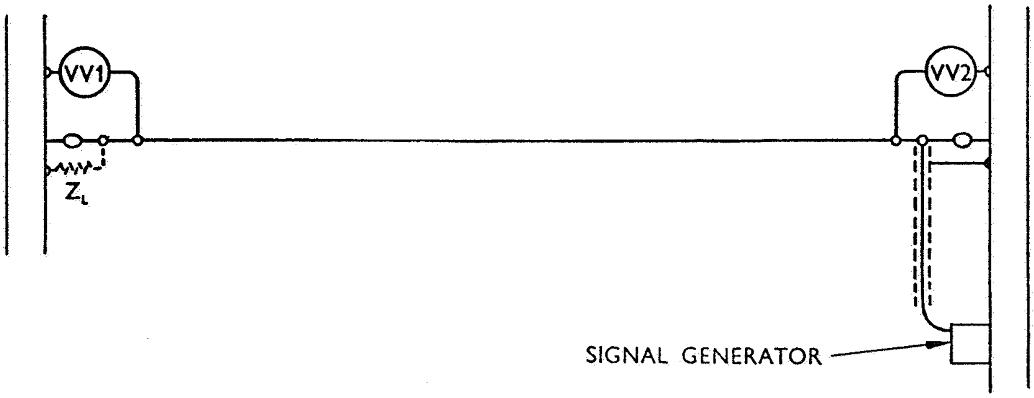


Figure 9 TRANSMISSION LINE CONNECTIONS

(a) With the signal generator connected, tune through the ADF frequency band and upwards until the voltage at the far end of the line reaches a maximum, and voltmeter VV2 shows a dip.

(b) A resistor approximating to the value of Z_L (between 300 and 500 ohms) should be connected as shown by the dotted lines in Figure 9; a 400 ohm non-inductive resistor is suitable.

(c) Both valve voltmeters should be set to zero. With the signal generator also set to zero, the output of the signal generator should then be raised to one or two volts, or to maximum. The voltage readings at both ends will be the same if the termination is correct.

(d) Alterations to the value of the temporary resistor Z_L, may be necessary to effect this condition and it should be noted that if the voltage at the end of the line is higher than that at the feeder, the termination is too high. The final value should be measured and recorded, and a non-inductive resistor placed permanently in the system.

(ii) **Termination of Feeder Line (R_1).** It is now necessary to correctly terminate the feeder line in order to ensure that standing waves are not present in the feeder.

(a) Where a short length of 70 ohm co-axial cable of known characteristic impedance is used, the use of the terminating resistor (R_1) can be dispensed with. Connect the feeder line to the transmission line, and proceed as indicated in paragraph 5.2.3(ii) (e).

(b) Where the cable is of considerable length, or where the impedance value is unknown, it will be necessary to find the frequency at which the feeder acts as a ¼ wave line as follows:—

Disconnect the feeder line from the transmission line, and connect valve voltmeters, VV1 and VV2, as shown in Figure 10.

Proceed as indicated in paragraphs 5.2.3(i) (a) and (i) (c) to find the resonant frequency.

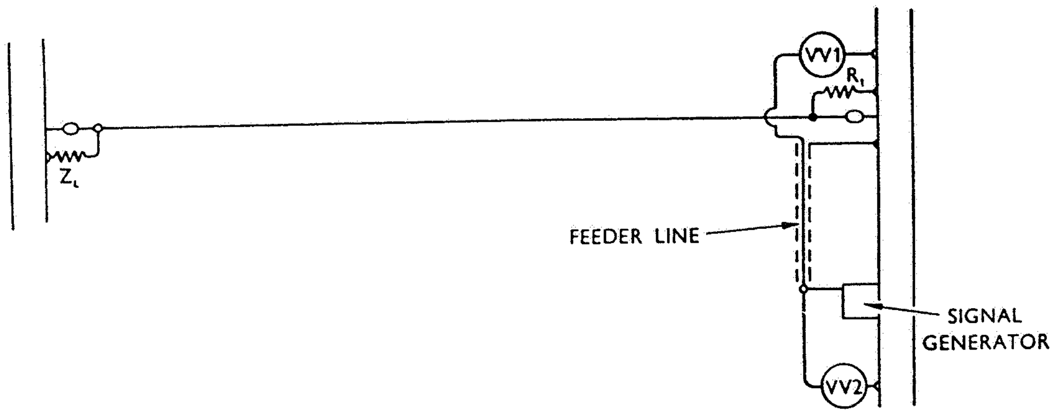


Figure 10 FEEDER LINE CONNECTIONS

(c) Where the feeder line has been constructed as in paragraph 5.2.2(ii), it will be helpful to start with an approximate value of impedance (Z_g). This can be found by application of the formula:—

$$Z_g = 138 \log_{10} \frac{d_2}{d_1}$$

where:

d_2 = inside diameter of tube

d_1 = outside diameter of wire

(d) Using non-inductive resistors, it is necessary to find an accurate value of Z_g which results in equal readings of voltmeters VV1 and VV2. Then:

$$R_1 = \frac{Z_L Z_g}{Z_L - Z_g} \text{ohms}$$

Where a considerable length of 70 ohm cable is used, $Z_g = 70$. Finally the feeder should be reconnected to the line and a permanent value of R_1 inserted.

(e) With VV1 connected across Z_L, and with VV2 connected across the signal generator terminals, the frequency over the entire ADF band should be varied. If the terminations are correct the readings of both voltmeters should remain sensibly equal.

5.2.4 **Calculation of Attenuation Constant.** The attenuation constant $K = \frac{E_L}{E/M}$,

where:

E_L = line voltage (in microvolts) from the signal generator.

E/M = field strength at a known distance in microvolts/metre and calculated from $E_{FS} + E_{FL} - E_C$ ($-E_{FLC}$ $-E_{CFL}$)

The terms E_{FS}, E_{FL} and E_C relate to cage Sizes 1 and 2, and terms E_{FLC} and E_{CFL} to a cage Size 3 (see Table 2) and are calculated from the formulae given in the following paragraphs.

(i) **Cage Size 1**

$$E_{FS} = \frac{2{\cdot}36 \times 10^3}{d} \times \frac{E_L}{Z_L}$$

$$E_{FL} = \frac{2{\cdot}36 \times 10^3}{2d_1 - d} \times \frac{E_L}{Z_L}$$

$$E_L = \frac{2{\cdot}36 \times 10^3}{2d_2 + d} \times \frac{E_L}{Z_L}$$

where: d, d_1 and d_2 are the dimensions (in inches) shown in Figure 8, and Z_L is the characteristic impedance of the line.

The length of the transmission line can be considered as infinite and is not taken into account.

NOTE: The output voltage indicated by the attenuator setting of a signal generator is usually the open circuit voltage, and may need compensating for the effect of loading. Thus, the term E_L given in the formulae for the three sizes of cage, is properly

$$E_L = E_{ind} \times \frac{Z_G}{Z_G + Z_o}$$

where:

E_{ind} = voltage indicated by signal generator (assuming E_L to be 1 millivolt and $Z_G = Z_o$, then E_{ind} is required to be 2 millivolts)

Z_G = characteristic impedance of feeder line.

Z_o = output impedance of signal generator.

(ii) **Cage Size 2**

$$E_{FS} = \frac{2{\cdot}36 \times 10^3}{d} \times \frac{E_L}{Z_L} \cos\theta$$

$$E_{FL} = \frac{2{\cdot}36 \times 10^3}{2d_1 - d} \times \frac{E_L}{Z_L} \cos\theta_1$$

$$E_C = \frac{2{\cdot}36 \times 10^3}{2d_2 + d} \times \frac{E_L}{Z_L} \cos\theta_2$$

where:

$$\theta = \tan^{-1} \frac{2d}{L}$$

$$\theta_1 = \tan^{-1} \frac{2(2d_1 - d)}{L}$$

$$\theta_2 = \tan^{-1} \frac{2(2d_2 + d)}{L}$$

The additional phase angle terms cos θ, cos θ_1 and cos θ_2 are added to take into account the length, in inches, of line L.

(iii) **Cage Size 3.** The forgoing formulae take into account direct voltage reflections from the line to the loop, and also reflections from the floor and ceiling of the appropriate cage. For Size 3 cages however, two further secondary reflections must be included; thus:

$$E_{FLC} = \frac{2{\cdot}36 \times 10^3}{2d_1 + 2d_2 + d} \times \frac{E_L}{Z_L} \cos\theta_3$$

$$E_{CFL} = \frac{2{\cdot}36 \times 10^3}{2d_1 + 2d_2 - d} \times \frac{E_L}{Z_L} \cos\theta_4$$

where:

$$\theta_3 = \tan^{-1} \frac{2(2d_1 + 2d_2 + d)}{L}$$

$$\theta_4 = \tan^{-1} \frac{2(2d_1 + 2d_2 - d)}{L}$$

5.2.5 **Simulated Sense Aerial.** Each item of equipment under test requires an individual sense aerial voltage related to the field strength obtaining at the loop, and dependent on the quoted effective height of the aerial. The quoted aerial capacitance must also be simulated.

(i) Figure 11(a) shows the connection of C_1 and C_{ae} to achieve this. Since several simulated aerials may be required, C_{ae} can be connected permanently to the cage wall, whilst the outer end of C_1 can be fitted with a "crocodile" clip to attach it to the transmission line when required.

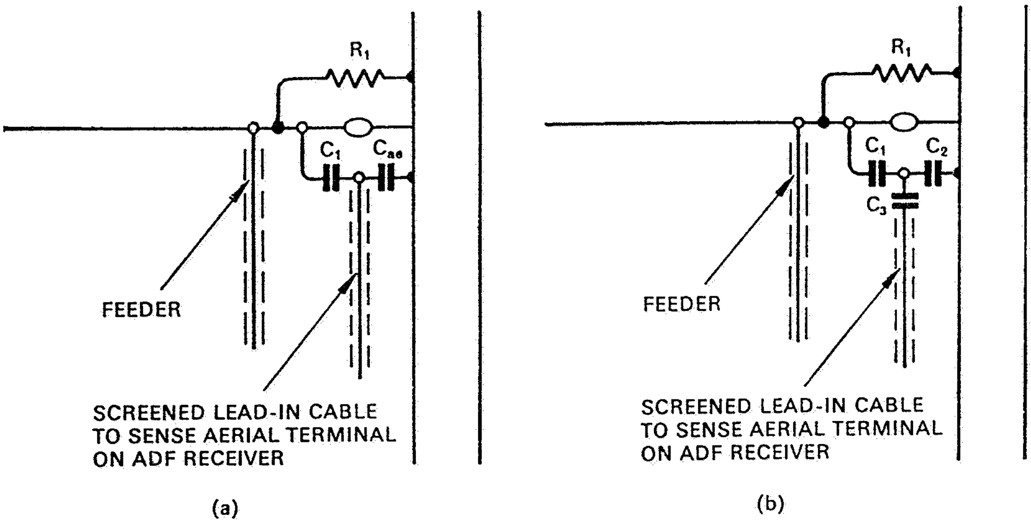


Figure 11 SENSE AERIAL CONNECTIONS

(ii) The values of C_1 and C_{ae} (in picofarads) can be determined by the ratio:—

$$\frac{K}{E_{hs}} = \frac{C_1 + C_{ae}}{C_1}$$

where:

K = the attenuation constant previously determined,

E_{hs} = the effective height of the sense aerial, in metres,

C_{ae} = aerial capacitance;

$$\text{therefore } C_1 = \frac{E_{hs} \times C_{ae}}{K - E_{hs}}$$

(iii) It frequently happens that with certain values of K, E_{hs} and C_{ae}, the value of C_1 becomes too low to achieve in practice. Reference should then be made to Figure 11(b). Choose a low value for C_1 such as not to affect the matching of the line; a value of 10 pf is suitable. Proceed to determine C_2 and C_3 as follows:

$$C_2 = \frac{C_1 (K - E_{hs})}{E_{hs}}$$

$$C_3 = \frac{C_{ae} (C_1 + C_2)}{C_1 + C_2 - C_{ae}}$$

5.2.6 **Loop Signal Simulator.** A loop signal simulator may be used as a substitute for a screened room and calibrated transmission line. It derives simulated loop aerial and sense aerial signals from a standard signal generator. The simulator consists of a metal box containing a transmission line with terminating resistors, a capacitance potentiometer for simulated sense aerial signals, and a rotatable miniature loop aerial. The values of the components used are chosen so as to give an effective attenuation constant of 10. The two coils of the miniature loop aerial are both the same size, so that it is unnecessary to allow for built-in quadrantal error correction. A table of corrections for instrument errors is normally attached to the top of the simulator, adjacent to the loop aerial bearing scale.

(i) When using the simulator, all power supplies should be filtered so as to avoid the introduction of unwanted signals and noise. In areas where severe electrical noise is experienced, it may also be necessary to operate the simulator and the equipment under test, in a screened room.

RL/2-2

Issue 2.

15*th November*, 1974.

AIRCRAFT

RADIO

AERIALS

1 INTRODUCTION This Leaflet gives general guidance on the installation, siting and maintenance of wire, rod, blade and rail type aerials used in conjunction with such equipment as High Frequency (HF) and Very High Frequency (VHF) communications, Automatic Direction Finding (ADF) and Marker Beacon receivers. Guidance is also given on the maintenance and repair of aerial masts manufactured wholly, or in part, of fibreglass-resin laminate. This Leaflet does not include information on aerials designed for use with radar equipment or navigation equipment such as Loran, Doppler, Distance Measuring, etc.

1.1 Full details of the procedures to be adopted for specific installations of the equipment referred to in this Leaflet, are contained in relevant aircraft and equipment Maintenance Manuals; this Leaflet should, therefore, be read in conjunction with these documents. Reference should also be made to the following Leaflets, British Standards and DTD Specifications which contain information closely associated with the equipment and practices covered by this Leaflet.

BL/4-1	Corrosion—Its Nature and Control
BL/4-2	Corrosion—Removal and Rectification
BL/4-3	Corrosion—Methods of Protection
BL/6-24	Cables—Splicing and Swaging
BL/6-26	Doping
EEL/1-6	Bonding and Circuit Testing
BS 2S97	2½ per cent nickel-chromium-molybdenum steel
BS 3S106	3 per cent chromium-molybdenum steel
BS 3X17	Varnish for Aeronautical Purposes
DTD 856A	External finishes for Radomes
DTD 926B	Process Specification for External Finishing of Radomes

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **RL/2-2,** Issue 1 dated 1st April 1958, Leaflet **RL/2-3,** Issue 1 dated 1st April 1958, and Leaflet **RL/2-4,** Issue 2 dated 1st February 1960.

2 WIRE AERIALS Wire aerials may be of the trailing type or of the type which are fixed, e.g. between a mast and the tip of a fin. Guidance on their installation and maintenance is given in the following paragraphs. Since trailing aerials now have only very limited application, the information given is restricted to that necessary to ensure the continued serviceability of existing installations.

2.1 **Trailing Aerials.** A trailing aerial normally consists of a length of stainless steel or tungum cable, usually seven stranded, of approximately 250 lb. breaking load. In some cases phosphor-bronze cable is used. The aerial is wound on a drum, and has its free end weighted for extension purposes, by a number of lead beads or, in some cases, by a drogue. The aerial is so designed that it can be unreeled in flight without fouling the aircraft structure.

2.1.1 **Fairleads.** Trailing aerials are fed through the aircraft skin, via insulated fairleads manufactured either of a non-metallic material or of metal covered with polythene. A clearance must be provided between the fairlead and the skin, the extent of which should be determined by the power of the transmitter and the material of the fairlead. Fairleads should be kept clean at all times, and should be inspected periodically for cracks, as dirt and cracks will not only cause mechanical interference with the reeling of the aerial, but will also provide leakage paths to the aircraft skin. To maintain efficient insulation, fairleads should be re-coated periodically with a suitable varnish, e.g. a varnish containing a phenolic resin.

2.1.2 **Bead Weights.** Bead weights are threaded on to a short length of stranded steel cable, which is attached to the main aerial cable. Two arrangements of bead weights are generally employed; one of which is suitable for power-operated trailing aerials, and the other for manually operated aerials. The arrangement for the former type consists of six lead beads sandwiched between a single brass end bead and a retaining stop. These are threaded on to a stranded 15 cwt. steel cable, making up an assembly having a total weight of about 2½ lb. The lighter assembly used on manual systems consists of fifty lead beads and one brass bead threaded on to a 5 cwt. cable, as shown in Figure 1, the total assembly weighing about 22 oz. In both assemblies, the beads should be secured to the cable in the manner described in the following paragraphs.

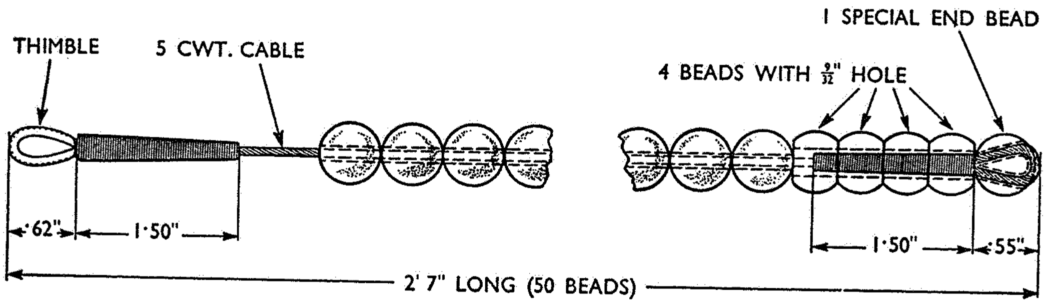


Figure 1 BEAD WEIGHT ASSEMBLY FOR MANUALLY OPERATED TRAILING AERIAL

(i) The cable should first be wrapped around the groove in the brass bead, and then spliced by the method given in Leaflet **BL/6-24.** The splice should be clean and free from projecting ends. It should be covered with two turns of linen fabric, and whipped with two layers of waxed No. 12 linen thread. The holes in the first four of the lead beads should be enlarged to 9/32 inch diameter to slide over this splice, and pulled down hard against the brass bead. The remainder of the beads should then be threaded on, leaving enough cable at the free end to make another splice.

(ii) The free end of the cable should now be looped back on itself, and spliced to provide an attachment point for the aerial wire. The smallest possible loop should be used, and a thimble should be incorporated in the loop as a means of reducing chafing between the aerial cable and the bead cable.

(iii) With the exception of the end bead, and of those containing the enlarged holes, the beads should be free to rotate, but grease should not be used on the beads which enter into the fairlead, since the lead beads will deposit a lead film inside the fairlead which, in due course, will cause insulation failure. The use of grease on bead weights is, however, permissible when the fairlead is of such a type (e.g. one equipped with an automatic electric winch) that the bead weights cannot enter it.

2.1.3 **The Aerial Wire.** Because aerial wires do not lend themselves to splicing by conventional methods, a special splice is used to join the aerial wire to the spliced end of the bead cable. The free end of the aerial wire should first be given two turns around the spliced loop of the bead cable, and then wrapped once around itself. The end should then be unstranded and laid back along the wire. Finally each strand in turn should be wrapped over the wire for a distance of $\frac{3}{8}$ inch, an alternate direction of winding being used for each strand. This wrapping procedure should continue until all the strands are used. The stages and method of the splice are shown in Figure 2. The splice should be finished by whipping the exposed end of strand No. 7 for a distance of $\frac{3}{8}$ inch with waxed twine knotted every half turn. In no circumstances should the joint be soldered.

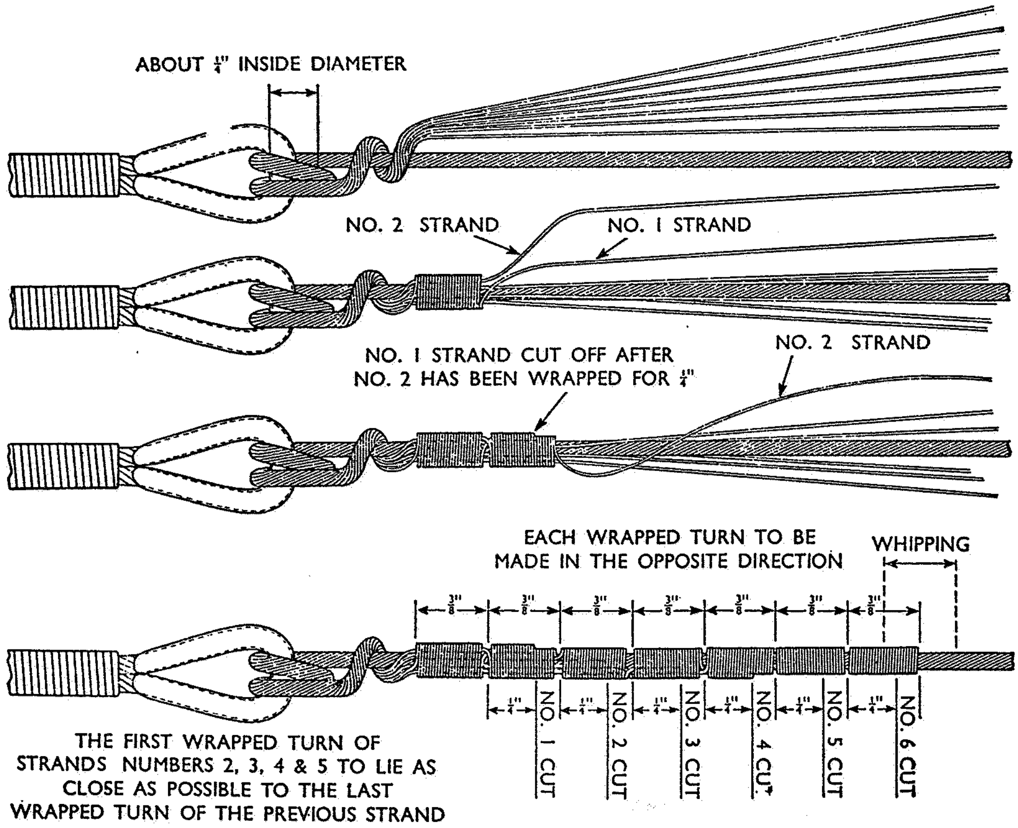


Figure 2 SPLICE FOR ATTACHMENT OF STRANDED AERIAL CABLES

2.2 **Fixed Wire Aerials.** Fixed wire aerials may be manufactured from seven-stranded phosphor-bronze, tungum, or stainless steel cable, but it is more usual to use single strand, copper-plated, high tensile steel wire. In some aircraft, solid drawn aluminium alloy aerials may be used.

2.2.1 **Stranded Cable Aerials.** Of the seven-stranded cables, it should be noted that the ultimate tensile strength of phosphor-bronze is only about three-fifths that of tungum or stainless steel, and it is recommended that phosphor-bronze should not be used where the span of the aerial exceeds 50 feet, calculated on the normal tensioning basis of 1 lbf per foot span. The Radio Frequency (RF) resistance of steel is very high and this results in a loss of radiated power. Table 1 shows the relative RF resistance of various types of aerial wire, and from this the inefficiency of stainless steel is evident. Where aerials of optimum length can be employed, e.g. trailing aerials or aerials of sufficient span, strength considerations may dictate the use of steel, but, in instances where aerials may be severely limited in their effectiveness as a result of their length being restricted by aircraft structural features, the CAA recommends that wire with less RF resistance should be used.

TABLE 1

Frequency	RF Resistance (ohms/ft)		
(MHz)	Stainless Steel	Phosphor Bronze	Tungum
2	0·48	0·118	0·198
4	0·62	0·160	0·275
6	0·85	0·220	0·375
8	1·00	0·270	0·440
10	1·40	0·310	0·550
12	1·40	0·320	0·530
14	1·70	0·370	0·620
16	2·25	0·470	0·740

(i) **Uncovered Stranded Aerials.** These aerials are susceptible to rain static, but are less likely to corrode than aluminium alloy wires (paragraph 2.2.2). They should be inspected along their length for broken strands, corrosion, or other faults which can reduce the mechanical strength of the cable.

(ii) **Covered Stranded Aerials.** The practice of covering stainless steel stranded aerials is adopted as a means of reducing rain static (paragraph 2.2.2) and corona discharge. The cable is covered with a material of high dielectric strength (usually a polythene plastic such as alkathene) along its length, and special terminal insulators are used. These aerials, whilst reducing rain static and corona discharge, only do so while their insulation remains intact; even small punctures will intensify the problem of corona discharge. Usually the first indication of defective insulation is the increased noise level in the receiver; particular attention should be paid to crew reports on this matter. Since there is no satisfactory method of repairing the polythene covering, renewal of the complete cable is the only remedy. The terminal insulators should be renewed whenever cracks are found in them, and should be filled with silicone grease to prevent the ingress of moisture.

(iii) **Covered Single Strand Aerials.** Single-strand, copper-plated, high tensile steel wire covered with opaque polythene offers certain advantages and is used in many types of aircraft. It is officially designated "Electrical Wire WS-25/U, Specification MIL-E-6370," and should not be confused with a similar wire of lower breaking load designated WS-5C/U. Aerials made of this wire should be used in conjunction with chuck-unit tethering (see paragraph 2.2.3 (iii) (c)), and the aerial manufacturer's instructions on tensioning should be followed. A convenient working rule is to tension to 1 lbf per foot of span, thus keeping the ratio dip/span constant. Since this wire has a high ultimate tensile strength, there is no danger of overloading the aerial over any typical aircraft span. Although the wire may be tensioned to a high figure, it is advantageous to use a spring tension unit of the type described in paragraph 2.2.4 (i).

2.2.2 **Solid Drawn Aluminium Alloy Aerials.** These aerials are simple to connect, but care must be taken to avoid contact with dissimilar metals at the terminations. Aerials of this type suffer from three defects: (i) when charged raindrops contact the aerial, the drops transfer their charge to it, giving rise to "rain static", (ii) fatigue may occur when the aerial is out of line with the slipstream, e.g. when it is fitted from a central mast to the fins of double-finned aircraft, and (iii) the aluminium alloy is subject to corrosion. The aerial should be inspected for corrosion at frequent intervals, and if it is found, but is not severe, it should be cleaned off and the wire protected by brushing on a nitro-cellulose lacquer (see Leaflets **BL/4-1, BL/4-2** and **BL/4-3**).

2.2.3 **Fixed Aerials for HF Communication.** For the reasons given in paragraph 2.2.1, fixed wire aerials for HF communication equipment should not be made from stainless steel cable. HF aerials are positioned above the fuselage and usually consist of a single span of wire running parallel to the longitudinal axis of the aircraft. A single span aerial is normally of sufficient length to permit loading throughout the HF band, but there are instances where a longer effective length is required. In such cases it is usual to provide twin forward masts and a common connection on the leading edge of the fin. However, in aircraft having twin fins, a single forward mast may be provided, the aerials being connected to both fins. HF aerials are usually fed from the forward attachment, although occasionally special circumstances necessitate feeding from the fin termination. The following paragraphs deal primarily with the maintenance of single span aerials, but most of the information is also applicable to double span installations.

(i) **Aerial Masts.** To provide adequate stand-off from the fuselage at high voltages, and to improve and maintain insulation, a mast is usually provided for the forward termination of the aerial. Aerial masts may be constructed of a shell of non-hygroscopic, insulating dielectric material surrounding a down-lead rod of brass or cadmium-plated steel. Because of the poor insulating qualities of the rod material, the rod is encased in a tube of polythene or porcelain, suitably terminated at each end for connection to the aerial circuit. The shell material is usually a fibreglass-resin laminate.

(a) The leading edges of masts made from resin impregnated fibreglass cloth tend to suffer severe pitting from rain erosion and should be inspected for this defect at regular intervals. These masts are usually covered with neoprene and are often painted white to reduce the adverse effects of sunlight on the neoprene. Information on the repair of these masts is given in paragraph 8 of this Leaflet.

(b) The interior of some masts is protected against moisture condensation by containers of silica gel crystals. These crystals should be inspected for moisture saturation (indicated by a change of colour from blue to pink or white) and should be renewed when there is evidence of the change. Hollow aerial masts are generally provided with a water drain path through the base which must be kept free from sealant and paint.

(ii) **Deck Insulators.** Sometimes masts are provided purely as tethering posts for aerials, and the aerial down-lead is a separate wire connected to a deck insulator. If a deck insulator of the required insulation value is not available, one of lesser value may be used, provided that it is mounted on a non-conducting plate of acrylic sheet (or similar material) of about 6 inch diameter. The down-lead to the deck insulator should be as direct as possible, and not in tension.

(iii) **Aerial to Mast Connection.** There are several methods by which the aerial can be connected to the mast, e.g. the methods illustrated in Figure 3 and chuck-unit tethering.

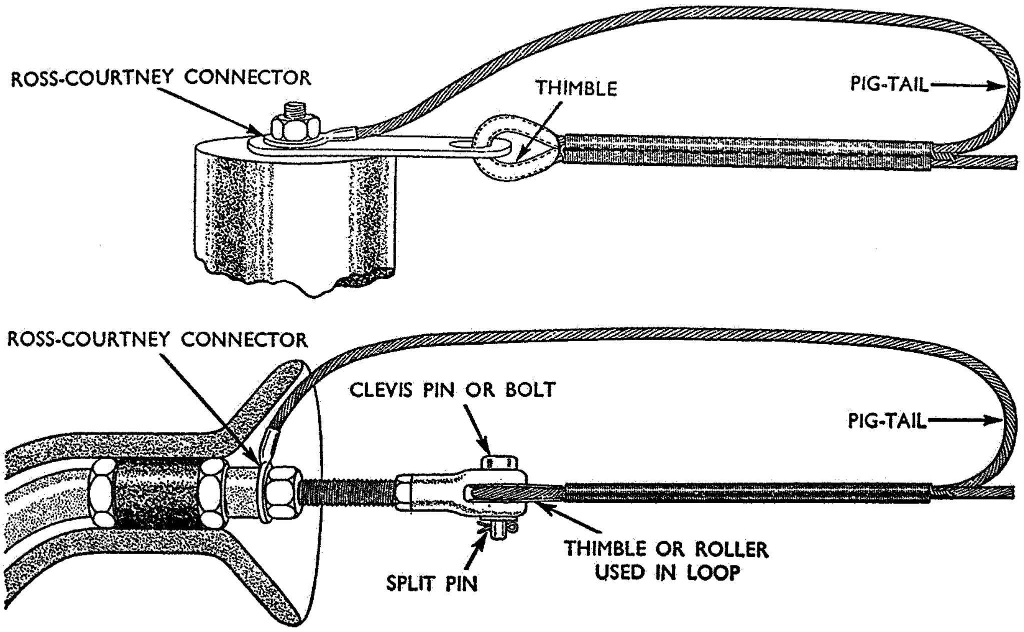


Figure 3 AERIAL TO MAST CONNECTIONS

(a) The connections shown in Figure 3 are made to fittings which function as an extension of the down-lead rod, but because of the risk of poor contact between the thimble and the extension piece, the CAA recommends the use of a continuous type "pigtail".

(b) The typical aerial-to-mast connections shown employ the continuous type of pigtail. The cable is placed around the thimble, and sufficient length is left to provide the pigtail. The cable is secured by at least 2 inches of whipping, the whipping being done with a strand of wire of the same material as the aerial. About 3 inches of the whipping wire should be placed along the cable, then, commencing from the thimble end, the wire should be wrapped over itself as shown, until 2 inches of the cable has been whipped, after which the two ends should be twisted together and cut to a suitable length.

(c) Chuck-unit tethering is used on some types of fixed wire aerials. Chuck units are designed so that it is only necessary to insert the bare end of the wire (either solid or stranded) for the chuck to grip it tightly, the grip increasing with increased tensile load up to the breaking point of the wire. Some units incorporate T- or angled-junctions for down-lead connections. Units should be inspected for cracks, corrosion and accurate fitting of the chuck jaws, and should be lubricated with a silicone grease in accordance with the manufacturer's instructions.

(d) Crimped connections for aerial wire are only acceptable if the method of crimping is strictly in accordance with drawings issued by an approved Organisation. It must be demonstrated that the crimped connection will not fail before the aerial wire, when the wire is loaded under tension.

(e) Where moulded insulators are used along the aerial, the method of connection to and from these is by means of the splice shown in Figure 2.

(f) Aerial wire should be removed from a chuck unit by means of the special extractor tool provided by the wire manufacturer.

2.2.4 **Aerial Tensioning Devices.** The rear tethering point of a fixed wire aerial incorporates a tensioning device to ensure uniform tension of the wire under all conditions of expansion or contraction, or of airframe structural deflections. Tensioning devices may be built-in by the aircraft manufacturer or may consist of separate external tensioning units. Tensioning units may consist of a rubber cord or bungee, which is coupled between the aerial wire and the aircraft structure, or they may be of the spring tension type. Of the two types of unit, the latter is the more widely used, since its tensioning characteristics are more efficient, and its weather-resistant properties are greater.

NOTE: For the maintenance of built-in tensioning devices, reference should be made to the relevant aircraft Maintenance Manual.

(i) **Spring Tension Units.** These units load the aerial wire by means of a metal spring, which may either be exposed, or enclosed in a barrel housing as in the type of unit shown in Figure 4. The spring is located between a plunger and a locking mechanism, the plunger being connected to a serrated tail rod and termination adaptor, via a spring collet and collet housing. The collet grips the tail rod in such a way that the greater the tension of the aerial the firmer is the grip. The tail rod can only be withdrawn by pressing the collet into the plunger, thereby allowing its jaws to spring away from the rod serrations. The forward end of the barrel housing is closed by means of a boss held in position by two grub screws. A small buffer spring is inserted between the boss and the plunger to prevent damage if the aerial tension is suddenly released. An insulator is connected at one end to the barrel boss by means of a spigot and pin, and at the other end provision is made for the attachment of the aerial wire chuck unit. The chuck unit attachment incorporates a copper pin which serves as a weak-link device designed to shear when the tension exceeds 160 to 180 lbf, the object being to ensure that, if a break occurs, it will be at the rear end of the aerial. In some types of tension unit, an overload protection device may also be incorporated to provide two-stage protection against overload, as well as a visual indication that the weak-link pin has sheared.

(a) To install a tension unit, the tail rod should first be freed and removed from the barrel housing by pressing the spring collet into the plunger; it should then be secured to the appropriate tethering point on the aircraft. The tail rod should then be re-inserted in the housing, leaving the serrations exposed

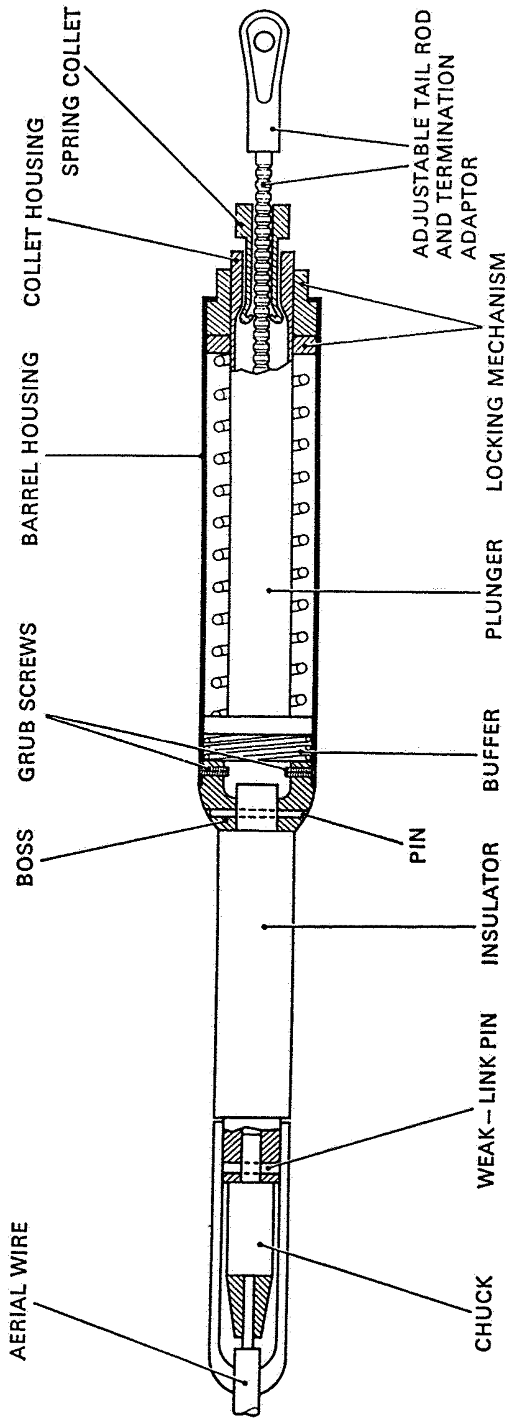


Figure 4 SPRING TENSION UNIT

for a length of 2 to 4 inches, depending on the type of unit. The wire should be cut to the required length and secured in the chuck, then pressed down so as to compress the spring and leave the plunger projecting from the barrel housing by an amount specified for the particular unit. The plunger should then be locked in this position by rotating the locking mechanism a half turn by means of a $\frac{5}{16}$ inch BSF spanner. When pressure on the aerial wire is released, the wire will continue to hang slack, and this slack should be taken up by pushing the tension unit back over its tail rod as far as possible. In order to check that the spring compression provides the required tension, the locking mechanism should be turned to release the plunger and the projection measured. The dimensions obtained should be in accordance with those specified for the type of unit; typical dimensions vary from $\frac{7}{8}$ inch to $1\frac{1}{8}$ inch.

(b) At the periods specified in the approved Maintenance Schedule, tension units should be checked for security of attachment and for signs of damage and corrosion. Tension units should also be checked to ensure that the plunger is free to move. This can be tested by pressing down on the aerial wire at a point about 2 feet away from the tension unit. In installations where the rear end of an aerial is earthed, the appropriate electrical connections should be checked for security, and the resistance, when measured between the aerial wire and earth, must not exceed 0·1 ohm. Where the unit incorporates an overload protection device, this should be inspected to ensure that the yellow warning band is not exposed. An exposed band indicates failure of the tension unit weak-link pin thereby requiring removal of the complete tension unit for overhaul. Such failures should be recorded, and if more than one failure occurs on the same aircraft the cause should be investigated. Should several failures occur it may be necessary to re-site the aerial. Weak-link

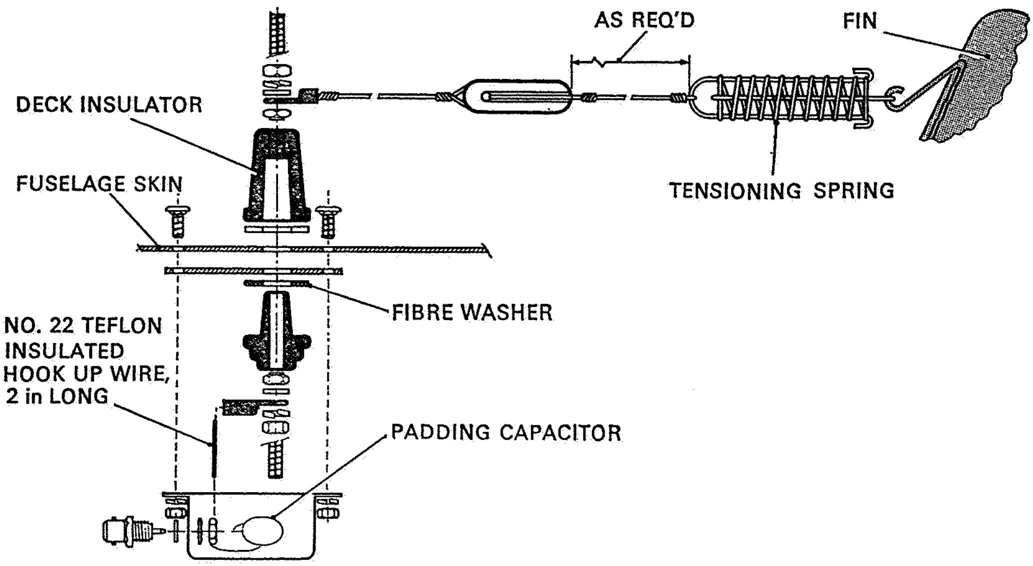


Figure 5 WIRE TYPE ADF SENSE AERIAL

pins should be examined during major inspections for signs of excessive loading and shearing, and should be replaced if necessary.

2.2.5 **ADF Sense Aerials.** Wire ADF sense aerials are designed primarily for use on light aircraft, and consist of a straight wire approximately 12 feet in length, usually end-connected between the fuselage and fin. In some cases, the wire may be connected between stand-off masts beneath the fuselage. A typical assembly using an uncovered single-strand copper wire is shown in Figure 5. No weak-link is provided, but any overload on the wire should result in detachment of the end clip supporting the tensioning spring.

NOTE: The use of this type of aerial is not recommended where reliable ADF performance in all weather conditions is required, as no protection against ice build-up is provided on the deck insulator, and the wire is not insulated against the effects of precipitation static.

(i) During inspection, the wire attachment at the deck insulator should be checked for signs of water and corrosion, and should be dismantled for cleaning if necessary. The wire should be examined for signs of wear at each termination, and for corrosion along its length. To prevent seizure, the tensioning spring should be regularly lubricated.

3 VHF COMMUNICATION AERIALS The external aerials used for VHF communication equipment are either of the rod (whip) or blade type of a length approximately equal to one-quarter-wavelength within the normal frequency band of 118 to 136 MHz.

3.1 **Rod Aerials.** Rod aerials are manufactured of high grade steel, usually having a tensile strength of at least 65 tonf/in², and complying with British Standards 2S97 and 3S106. Aerials vary in length from 22 inches to 38 inches and, depending on the type, the diameter of the rod may be stepped down, or may be uniformly tapered, so as to reduce the incidence of breakages. Protection against corrosion is usually provided by either a heavy coating of cadmium or a plastic sheath. Some types of aerial have the rod enclosed in a fibreglass sheath which is reinforced with resin.

3.1.1 **Rod Aerial Mountings.** The method of mounting varies between aerials and the type of aircraft in which they are to be installed; reference should, therefore, always be made to the relevant Maintenance Manuals. In general, aerial rods extend through a hole in the fuselage skin which is locally reinforced, and are clamped between a base or mounting bollard by means of a coupling nut or a bolted securing ring. The base or bollard of an aerial also provides for the attachment of the aerial co-axial cable. Figure 6 illustrates a typical rod aerial and mounting. The rake of the aerial can be adjusted by fitting spacers which are machined to the appropriate angular dimensions; typical angles are 15°, 20° and 30°.

(i) In some instances it may be necessary for a rod aerial to be flexibly mounted in order to obviate the effects of aerodynamic vibration or flutter. Figure 7 illustrates an anti-flutter installation which permits the aerial to move in a lateral direction, its movement being controlled by a rubber damper. The mounting is suitable for installation in all aircraft where the maximum cabin pressure differential does not exceed 6·5 lbf/in². If guards are to be fitted to prevent the build-up of ice on the aerial, care should be taken to ensure that the movement of the weather-proofing grommet is not restricted.

(ii) For the mounting of rod aerials on wooden or fabric covered aircraft, the siting considerations referred to in paragraph 3.3.1 may be used as a guide, but do not necessarily apply. Variations in construction and layout are so great that individual consideration of each type is essential.

(a) The radiation efficiency of the aerial is somewhat impaired with wooden and fabric covered types of aircraft. This condition can be improved by presenting a ground plane to the aerial, and, in order to do this, a counterpoise mat or strip, centrally disposed under the rod, is required (see Figure 8). The counterpoise should consist of a circle of copper gauze of 24 inch radius, or of 4 to 8 radiating members of copper strip, which should be attached to the underside of the covering by a suitable method. The connection of the counterpoise to the bollard should be through the mounting bolts, ensuring a good connection to the aerial base.

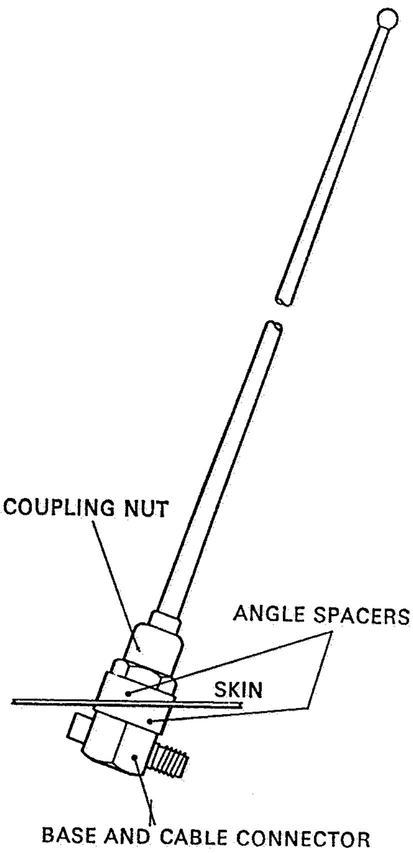


Figure 6 TYPICAL ROD AERIAL

3.2 **Blade Aerials.** Blade aerials cover a broader frequency range than rod aerials and are designed to provide a more acceptable Voltage Standing Wave Ratio (VSWR). When mounted on either the top or bottom of the fuselage, a vertically polarised, omni-directional radiation pattern is obtained. The construction of aerials varies between manufacturers' designs, but in general, the radiating elements are embedded in polyurethane foam and encased in a resin-bonded fibreglass shell, the external surface of which is protected by a polyurethane or epoxy resin paint. The shell is raked rearwards and has a drilled flange at the base which carries the appropriate cable connector, and provides for attachment of the aerial to the fuselage skin. Leading edge protection is provided in the form of a plastic or stainless steel strip.

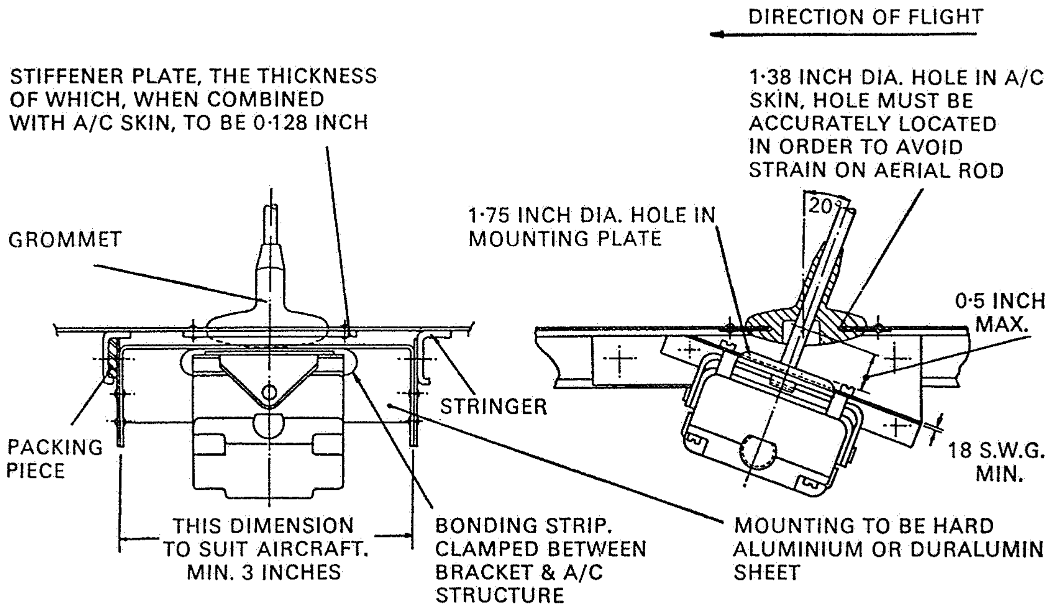


Figure 7 FLEXIBLE MOUNTING

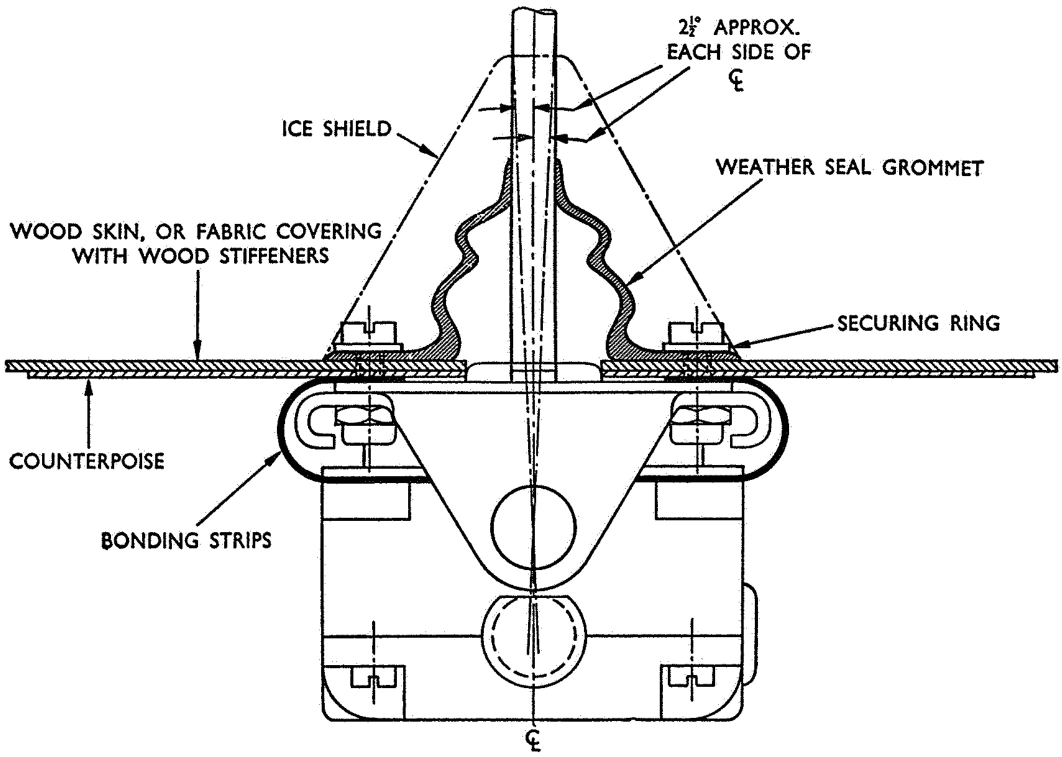


Figure 8 AERIAL MOUNTING WITH COUNTERPOISE

3.2.1 Aerials should be installed in a suitably reinforced skin area, in accordance with the relevant installation drawings. The mating surfaces must be perfectly clean, and, in order to prevent moisture or water from entering the aircraft, and to guard against the loss of air from pressurised structures, a special sealing gasket should be inserted between the aerial mounting base and fuselage skin. To ensure efficient electrical bonding at radio frequencies, some gasket materials either consist of metal gauze, or are impregnated with carbon or metal particles. Effective RF bonding can also be ensured by fitting spring contacts to the base of the aerial. The procedure to be adopted when applying seals varies between installations and, as full details are normally given in the relevant Maintenance Manuals, reference should always be made to such documents.

3.2.2 At the periods specified in the approved Maintenance Schedule, a blade aerial should be inspected for security of attachment, cracks around fixing holes, and corrosion or other damage to the protective finish of the shell.

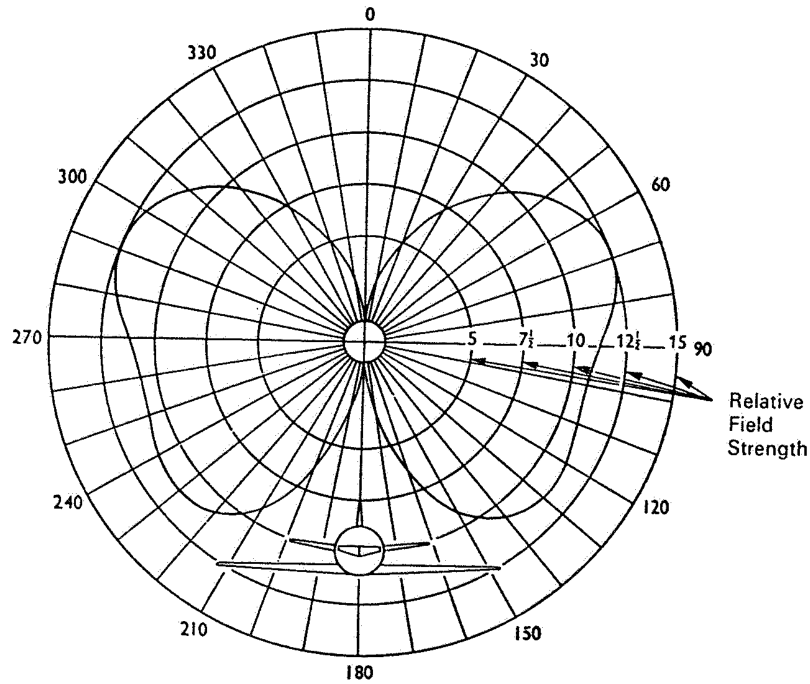
3.3 **Radiation Patterns and Siting of VHF Aerials.** In assessing the performance of an aerial it is usual to measure the field strength in three mutually perpendicular planes, known as the principal radiation planes. Although absolute field strengths could be measured, it is easier, and more usual, to obtain field strengths relative to the field strength in one fixed direction, usually the line of flight of the aircraft. The absolute standard of reference for field strength is based on an aerial giving an equal pattern of radiated energy at all points on the surface of a sphere at the centre of which the aerial is situated. Although such an aerial cannot be achieved in practice, its relation to certain existing aerials can be calculated. Figure 9(a) shows the transverse elevation radiation pattern of a quarter-wavelength rod aerial mounted on the top of a half-wavelength diameter cylinder representing an aircraft fuselage. The radiation pattern in the fore-and-aft elevation plane is dependent on the distance of the aerial from the ends of the cylinder, and will show more shielding as the length increases. With a cylinder tending to infinite length, no radiation is experienced on the shadow side. The azimuth radiation pattern is the most important and when this has been determined a fair approximation of an aerial's radiating properties can be obtained. A typical azimuth pattern is shown in Figure 9(b).

3.3.1 **Siting Considerations.** Considerable modification to both elevation and azimuth patterns is experienced in practice, mainly as a result of the screening effect of the wings. In general, the screening effect is most marked where the VHF aerial is mounted within the planform of the wings, and adjacent to it, e.g. a high wing aircraft with a top fuselage mounted aerial.

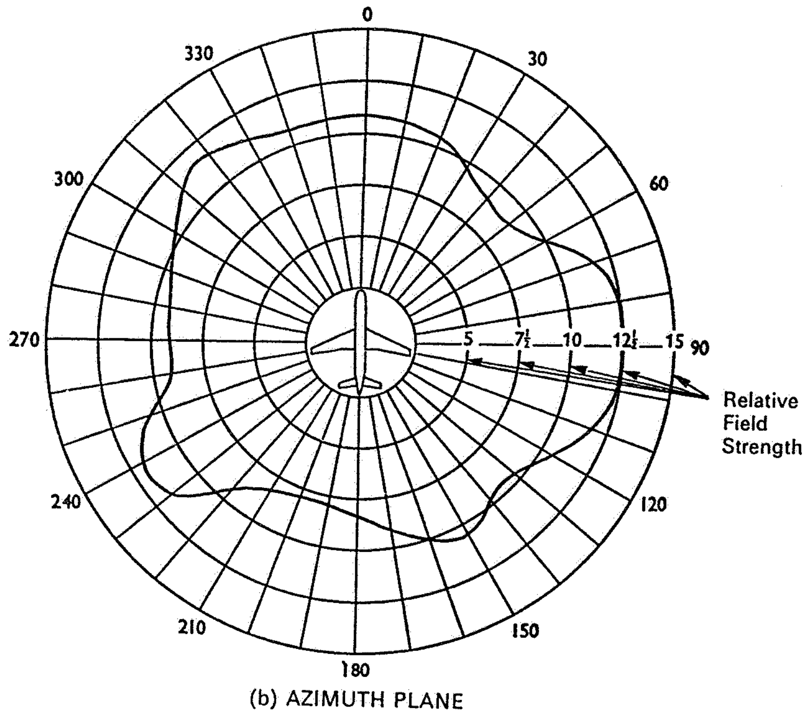
(i) Although a ventrally mounted aerial shows a theoretical improvement in range and distribution over a top mounted aerial, in practice a suitable position is difficult to achieve, and the CAA recommends a top mounted aerial. Aerials should preferably be mounted on the centre line of the fuselage, at or near right angles to the aircraft skin laterally, and within an arc extending from the vertical to 20° aft longitudinally.

3.3.2 **High Wing Aircraft.** For low aspect ratio wings, the fuselage area between leading and trailing edges should, where possible, be avoided, thus limiting the available effective area to between leading edge and cockpit roof, and from trailing edge to within two or three wavelengths of the fin.

(i) With these types of aircraft, ground clearance is usually small, and a large number of aerials may require to be top mounted. The minimum distance between aerials, and between aerials and other protuberances of a similar nature, should be greater than one wavelength. VHF aerials should be mounted aft of essentially forward looking aerials mounted in the same plane.



(a) TRANSVERSE ELEVATION PLANE



(b) AZIMUTH PLANE

Figure 9 RADIATION PATTERNS

(ii) Propeller modulation may adversely modify radiation patterns, and suitable wavelength clearance should therefore be allowed between aerials and propellers.

NOTE: Propeller modulation is caused by a variation in the high frequency currents induced in the propeller blades each time they reach a vertical position, causing the radiation pattern to vary in synchronism. The effect is most marked when the length of the blades is comparable to the wavelength.

3.3.3 **Low Wing Aircraft.** Top mounted aerials should be positioned between the cockpit roof and to within two or three wavelengths of the fin, subject to the limitation imposed by propeller modulation. The minimum interference distance between aerials and protuberances is as quoted in para. 3.3.2(i).

3.3.4 **General.** When assessing the proposed location for an aerial, consideration should be given to the potential screening which may arise from the close proximity to the aerial of the undercarriage, flaps, etc., and of the fuselage itself in certain aircraft attitudes. Attention should also be given to potential mutual interference between aerials.

(i) The area aft of effluxes of waste products should be avoided. Aerials should be mounted clear of loading bays, inspection panels, and areas where they might be damaged by aircraft steps, refuelling tankers, etc.

(ii) When twin VHF equipment is installed in an aircraft, a separate blade or rod aerial should be provided for each installation but, if preferred, a single blade aerial incorporating a co-axial changeover relay may be utilised.

NOTE: The use of a single rod aerial is not recommended, because of the possibility of losing the aerial through ice accretion or fatigue.

(iii) Some degree of "mis-match" is inevitable between an aerial and its feeder and the transmitter aerial circuit, but choice of the correct type of aerial, and careful design of the installation can result in a VSWR down to 2½ to 1, or better.

3.3.5 **Drag Load.** The approximate drag load of an aerial can be determined by the following formula:—

$$D = \cdot000327\ AV^2$$

(The formula includes a 90% reduction factor for the streamline shape of an aerial)

Where D is the drag load on the aerial in lbf.

A is the frontal area of the aerial in ft^2, and

V is the V_{NE} of the aircraft in mph.

Example: An aerial having a frontal area of 0·135 ft^2, at 250 mph

$$D = \cdot000327 \times 0{\cdot}135 \times (250)^2$$
$$= \cdot000327 \times 0{\cdot}135 \times 62{,}500$$
$$= 2{\cdot}75 \text{ lbf.}$$

4 RAIL OR TUBE AERIALS Horizontal rail or tube aerials are principally intended for airborne reception of ADF sense signals, but are equally suitable for any other application requiring a capacitance-type aerial. The aerials are generally fitted under the fuselage, using either two or three fibreglass moulded stand-off masts. The aerials should be located in such positions that they will not be damaged by, or interfere with, loading steps, doors, or inspection panels, and where they will not be in the path of ejected waste fluids, e.g. from toilet or galley drains. The lead-in mast can be positioned forward, aft, or intermediate, according to convenience of mounting. Care must also be taken to site these aerials so that, ideally, the ADF "turn round" occurs when the aircraft is directly over the beacon. It should be borne in mind that, whereas a slightly early turn round is acceptable, a late one is not.

NOTE: The position of such aerials may be critical, and guidance on siting should be sought from the manufacturers of the equipment.

4.1 In order to determine aerial requirements in terms of height and length, it is usual for manufacturers to quote the minimum performance of their equipment in picofarad metres or "hicaps" as these units are more commonly called. The hicap is a sensitivity factor equal to the product of the effective height of the aerial in metres and its capacity in picofarads. The factor is of particular use in the design of these aerials where the stand-off distance from the fuselage is sensibly constant along its length. Table 2 gives values in hicaps per foot for typical sense aerials mounted on flat metal sheet.

TABLE 2

	Hicaps per Foot of Aerial		
Height (in.)	Wire 0·05 in. dia.	Rod 0·375 in. dia.	Rod 0·5 in. dia.
4	0·295	0·450	0·490
5	0·365	0·540	0·575
6	0·420	0·615	0·660
8	0·530	0·760	0·820
10	0·640	0·910	0·965
15	0·920	1·280	1·360
20	1·175	1·600	1·690
30	1·640	2·150	2·280

4.2 **Curvature Factor.** The pick-up of an aerial mounted on a curved fuselage will be greater than that of an aerial mounted on a flat sheet and some correction must be made to the values in Table 2 which will increase the effective hicap value per foot.

4.2.1 Formulae are available from which this factor can be computed with a fair degree of accuracy, but it is recommended that installation designers should consult the equipment manufacturer before applying such formulae, since they have a limited use and can be modified by a number of factors. Aerials mounted vertically on rectangular fuselages can be displaced either side of the centre line without decreasing the curvature factor, but displacement of aerials away from the centre line of circular section fuselages reduces the factor proportionally as the cosine of the angle.

4.2.2 For a medium-sized aircraft an aerial with 10 inch masts on the centre line would have a factor of 1·86 reducing to 1·75, displaced 20° either side of the centre line. Aerials mounted close to the wing root on low wing aircraft can, however, reduce the factor to as low as unity. In the absence of specialised information, a maximum factor of 1·5 is recommended.

4.3 **Aerial Capacitance.** The capacitance of an aerial can be determined by the following formula:—

$$C_a = \frac{L}{4{\cdot}144 \log_{10} \frac{4H}{D}}$$

where, C_a = capacitance in picofarads (pfs)
L = length of aerial
H = height of aerial above metal skin
D = diameter of aerial

Small additions (5 to 10 pfs) should be made to allow for the capacitance of lead-in masts and dead-end masts.

4.3.1 Manufacturers of ADF equipment for General Purpose Category aircraft normally specify the aerial length required, or make provision for the installation of additional capacitance. Separate aerial and feeder capacitance, or a combined figure, may be specified but no height requirements are stated since most aerials are assumed to be located between fuselage and fin.

4.3.2 When measuring aerial and feeder capacitance for ADF purposes, the use of a capacitance bridge with an operating frequency of 200 kHz is recommended.

5 VOR AND ILS AERIALS VOR (VHF Omni-Range) navigational systems utilise unipole aerials which are required to receive horizontally polarised waves and are therefore mounted horizontally. They operate in the frequency band 112–118 MHz and basically consist of a steel blade or rod. The ILS (Instrument Landing System) utilises two aerials which are also horizontally polarised but operate in different frequency bands. One aerial receives localiser signals in the band 108–112 MHz, while the other receives glide slope signals in the band 328–336 MHz.

5.1 As the requirements of both VOR and ILS localiser equipments are similar, and particularly since they have adjoining frequency bands, it is usual to combine them into either a V- or U-shaped horizontal dipole for mounting on the top or bottom of a fuselage, or as a plate-type unit for flush-mounting. In some cases, the arms of the dipole may be separate so as to be mounted one each side of a fin; the two are connected to a single cable by suitable phasing links. Glide slope aerials are separate units, and are mounted in the fuselage nose section.

5.1.1 The position of combined VOR/LOC aerials is governed mainly by the radiation pattern of the glide slope aerial, and also by the location of the VHF communication aerials. In general, a position as far forward as possible must be made available, taking into account such factors as degree of curvature of the fuselage nose, screening effect of the wings, and propeller modulation.

6 MARKER BEACON AERIALS A marker beacon aerial may be a simple wire or horizontal rod, an encapsulated tuned circuit, or a suppressed plate. It is located under the fuselage and may be connected to either one or two receivers.

6.1 The dimensions for a 75 MHz Fan Marker aerial are standardised at 75·5 inches total length with the lead-in tapped at 35·5 inches. This is suitable for matching to 50 ohm co-axial cable. However, these aerials have been found to be not critical in regard to length, in fact the pick-up may be excessive and result in artificial broadening of the marker beacon cone. Often an end-fed quarter wave aerial gives satisfactory results. The installation of a fixed-wire marker aerial may utilise two stub masts for the end supports, with a further stub mast for the lead-in, or, alternatively, two stub masts with a spliced pigtail lead-in to a deck insulator (see paragraph 2.2.3 (ii)).

6.2 Encapsulated aerials consist of a circuit, pre-tuned to 75 MHz, which is tightly sealed in a plastic foam-filled shell. When installing this type of aerial, good contact must be made between the aerial and the fuselage skin. Provision is made for matching an aerial to the feeder by means of a trimming control on the aerial and, after installation, the control must be adjusted for maximum signal at the receiver.

6.3 For the reception of marker beacon signals in high speed aircraft, a plate type aerial recessed into a cavity underneath the fuselage is usually employed. The aerial is insulated from the surrounding structure, and a fibreglass cover is fitted over the cavity. A trimming capacitor is normally provided for matching the aerial to the feeder in a similar manner to that adopted for an encapsulated aerial. The fibreglass cover should be removed at intervals to check that the sealing is adequate, and that moisture has not entered. A check should also be made on the condition of the protective coating applied to the cover and, if necessary, the coating should be renewed in the manner prescribed in the aircraft Maintenance Manual.

7 AERIAL EARTHING AND STATIC DISCHARGE DEVICES These devices are provided to minimise the damaging effects of lightning strikes, and also to dissipate accumulations of static charges in aerials most commonly used for high-power HF Communications equipment. These devices may either be incorporated within radio equipment or mounted at the lead-in terminal locations of aerials. They may be of three principal types: (i) electrically operated earthing switches, or relays, (ii) gas filled spark gaps and (iii) static discharge resistors.

7.1 **Electrically Operated Earthing Switches or Relays.** These should be of an approved type and should always be mounted at the base of the lead-in insulator or mast. With the open type of switch, a rigid mounting is required for the associated relay unit and the aerial contact assembly should be bolted to the base of the lead-in rod. It is essential to ensure that twisting of the lead-in rod, which may result in the rotation of the aerial contact, cannot take place.

7.2 **Gas-Filled Spark Gaps.** Gas-filled spark gaps may be fitted instead of aerial earthing switches or relays; they are automatic in operation, and have no moving parts. It should be noted that the maximum transmitter voltage must not be sufficient to operate the spark gap under the conditions defined in Chapter R4-5 of British Civil Airworthiness Requirements.

7.2.1 The unit should be mounted as closely as possible to the aerial lead-in terminal, whilst the earthing terminal should be secured to a suitable rib or stringer, and not directly to the skin, unless the latter is suitably reinforced. The location of a spark gap should be such that it provides a more direct path to earth for a lightning strike on the protected aerial, than any path through the associated equipment.

NOTE: Open spark gaps must not be fitted in any part of the aircraft where they would constitute a fire hazard.

7.2.2 Brackets and clips made locally to receive spark gap dischargers should be manufactured of silver-plated copper wire and should have a minimum cross-sectional area of 0·009 square inches, this figure normally being exceeded in practice to impart stiffness to the mounting. Prominent edges and corners of all fittings should be radiused and adequately spaced from any earthed metal or component, to avoid both high-voltage arcing within the aircraft during transmission and the possibility of lightning discharging directly to the structure.

7.2.3 In some types of aircraft, particularly those using a suppressed type of HF aerial located at the top of a fin, a spark gap type of lightning arrester is installed at the aerial location. A window is normally provided at the side of the fin to permit inspection of the arrester.

7.3 **Static Discharge Resistors.** In order to dissipate an accumulation of static charge in aerials, a conducting path from aerial to earth must be provided in installations where the following conditions apply:

(i) The equipment to which the aerial is connected does not provide a path to earth.

(ii) An arrangement of earthing switches leaves an aerial isolated from an equipment which would normally provide the path.

NOTE: The practice of designing a relay to revert to "Receive" when the equipment is switched off is by no means universal, and the point should be checked during the installation of the system.

7.3.1 Static discharge resistors are designed to provide a permanent conducting path, and are normally incorporated within the radio equipment. The prescribed value and rating of resistors is given in Chapter R4-5 of British Civil Airworthiness Requirements.

7.3.2 The general guidance given in paragraphs 7.2.1 and 7.2.2 regarding the mounting of spark gaps, is equally applicable to the mounting of resistors. However, when resistors having a thick soldered ring at each end are used, it is recommended that these should be mounted in spring clips designed to accommodate the end rings.

8 REPAIR OF RESIN-BONDED FIBREGLASS MASTS Aerial masts manufactured from resin-bonded fibreglass have excellent insulating qualities and high tensile and compressive strength, but the material is prone to damage by the erosive action of raindrops, sand and dust, which may be driven at high velocities into the surfaces of the mast which are normal to the line of flight. These elements gradually penetrate the layers of glass-cloth, causing peeling of the laminates or, after prolonged exposure, complete disintegration.

8.1 **Neoprene Protective.** Deterioration of the fibreglass laminate as a result of erosion can be considerably retarded by the use of a neoprene protective which complies with Material Specification DTD 856A, and which should be applied to the surface of the laminate as detailed in Process Specification DTD 926B.

8.1.1 When masts protected with neoprene are exposed to sunlight, the matt-black finish of the neoprene absorbs heat to such an extent that the strength of the underlying glass-resin laminate may be impaired; to prevent this the mast can be further protected with a white paint finish.

8.1.2 A suitable painting scheme consists of two undercoats of flat paint and a top coat of oil-bound high-gloss paint. Care should be taken to ensure that both paints are produced by the same manufacturer, and are in fact suitable for use together. Paints having a cellulose base should not be used, since cellulose has a detrimental effect on neoprene.

8.2 **Repair of Neoprene Protective.** Should the neoprene become damaged to such an extent that the surface of the glass fibre laminate is exposed, the mast should be removed from the aircraft at the earliest opportunity for repair. Because of the extent of control which is necessary over the neoprening process, i.e. temperature, humidity, method of application and subsequent curing, it is strongly recommended that aerial masts rendered unserviceable by eroded, or otherwise damaged, neoprene or fibreglass laminate, should be returned to the manufacturer of the mast for repair. Where such action is impractical for small repairs, the repair procedure given in the following paragraphs should be employed. Integral lead-in components cannot be repaired.

8.2.1 Figure 10 illustrates a typical area of damage and the type of repair permissible. The erosion of the neoprene is most likely to occur on the aerial mast leading edge, where this is within an included angle of 60° to the line of flight; the repair should be made beyond this area to ensure that the weaker mating edges of the old and new neoprene are not exposed to the full erosive action.

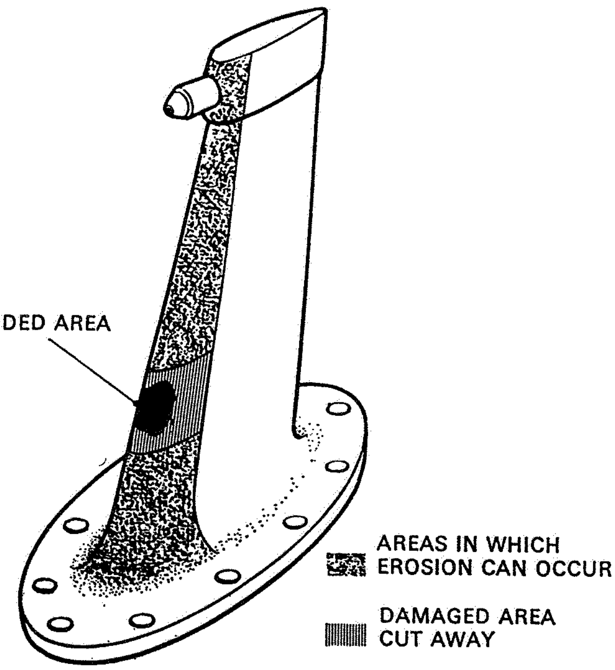


Figure 10 AREAS OF DAMAGE

8.2.2 The white paint should be removed from, and at least 0·5 inch beyond, the area to be repaired, by rubbing down with wet carborundum waterproof paper No. 220C. Any resistant paint should be cleaned off with methylated spirit.

NOTE: Methylated spirit is a safe solvent, but cellulose or highly volatile cleaning agents will damage the neoprene.

8.2.3 One hour should be allowed for the methylated spirit to dry out thoroughly, after which the square of damaged neoprene should be cut out, ensuring that the edges do not lift. If the cut edge does not adhere to the underlying laminate, more neoprene should be cut away until this condition is achieved.

8.2.4 The exposed surface of the laminate should be cleaned with toluene, but care must be taken to ensure that the toluene does not come into contact with the neoprene. This can be prevented by masking the edges of the neoprene.

8.2.5 A neoprene primer of the type recommended in DTD 926B should be applied to the laminate, using only enough thinners to permit ease of working, and taking special care to ensure that the primer does not come into contact with the edges of the neoprene. One hour should be allowed for the primer to dry before the neoprene is applied.

8.2.6 The neoprene should be applied with a fine camel hair brush, allowing one hour between each coat, until the desired thickness is achieved. Approximately 20 coats each of about 0·001 inch thickness, will be required, and each coat should overlap the cut-away area by about 0·25 inch.

NOTE: Thinners must not be mixed with neoprene.

8.2.7 The neoprene has an accelerator added which produces a cured film at room temperature, but curing can be accelerated with heat, the time taken to effect the curing depending on the temperature. About seven days is necessary to produce a completely cured coating, and, until this period has elapsed, the mast should not be repainted.

8.3 **Renovating White Paint.** It is necessary to renew the white paint only when more than 25 per cent has been lost or when appearance is of importance. Prior to repainting, the whole mast should be rubbed down with No. 220C carborundum waterproof paper, wetted to remove the gloss paint. The mast should then be dried and repainted as recommended in paragraph 8.1.2.

8.4 **Insulation Tests.** On completion of the repair the insulation of the mast should be checked as detailed in the relevant Maintenance Manual.

RL/2-3

Issue 1.

15*th November*, 1974.

AIRCRAFT

RADIO

SCREENED ROOMS FOR RADIO MAINTENANCE

1 INTRODUCTION This Leaflet gives general guidance on the purpose, design and construction of screened rooms for radio workshops. The purpose of screened rooms, or "cages" as they are more often called, is to prevent undue radiation of radio frequency signals from equipment operated inside the room, since such radiation may be unlawful, and may cause interference to radio users in the locality. In addition, the screening is an attenuator of interfering signals and noise from outside the room, and thus provides an interference-free region for delicate adjustment and measurements.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet RL/5-1, Issue 1 dated 15th February 1961.

2 ATTENUATION The degree of attenuation obtained is usually referred to as "Insertion Loss" and is measured in decibels (db).

NOTE: The term "decibel" is used throughout this Leaflet to express a voltage ratio and is not a reference to any particular level of voltage.

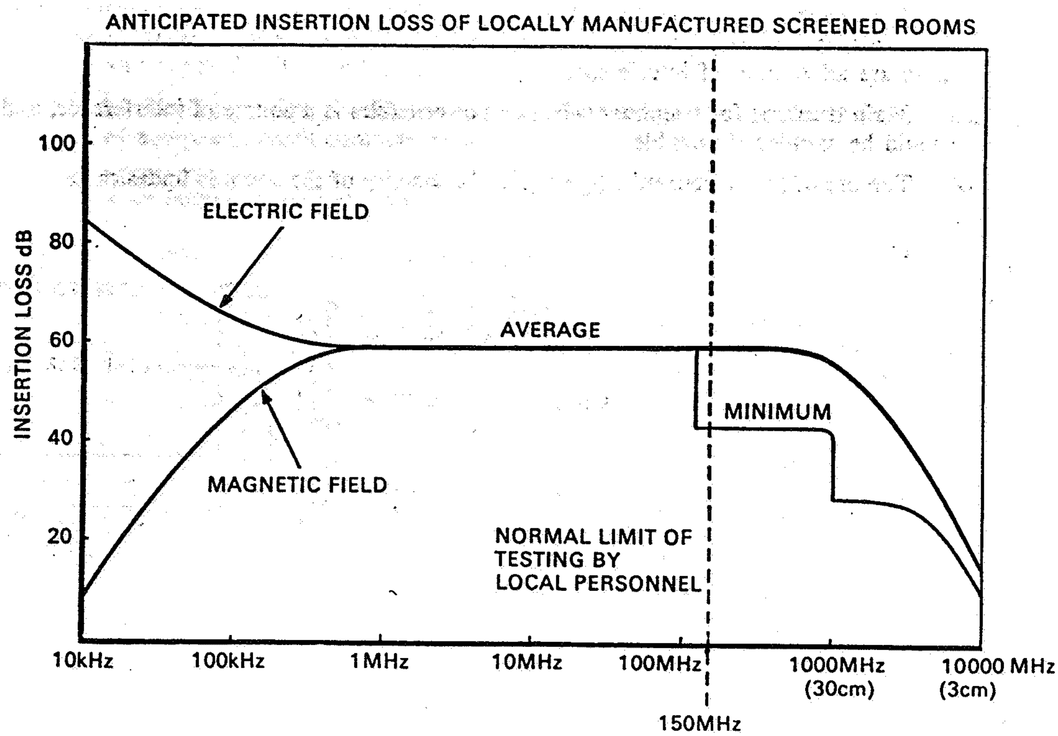


Figure 1 GRAPH OF INSERTION LOSS OF A DOUBLE-SCREENED ROOM

2.1 An insertion loss of 60 db gives a voltage reduction equivalent to a ratio of 1,000:1. This is usually adequate for the suppression of radiation from within the cage, and for the calibration of equipment having sensitivities of the order generally encountered in aircraft radio, even in localities of high "man-made" interference.

2.2 The portion of the radio frequency spectrum over which attenuation is usually required is between 10 kHz and 400 MHz. For a one-man cage of 6 feet 6 inches cube, direct measurements can be made below 150 MHz using suitable field strength meters, or by receivers similar to the type under test. Above this frequency measurement becomes more difficult, since the screened room will resonate as a cavity resonator. The resonant frequency will depend on the size of the room, its contents and the space between the inner and outer screens. To determine such resonances it would be necessary to sweep the entire band instead of relying on spot checks. With large cages the resonance frequency may be as low as 10 to 15 MHz, and more careful testing will be necessary.

2.3 Figure 1 shows the insertion loss expected of a typical double-screened room, the internal measurements of which are in the form of a 6 feet 6 inches cube. This is a suitable size for most overhaul Organisations. The figures given relate to an empty room in which power supplies, heating and compressed air pipes have not been installed.

3 SITING CONSIDERATIONS The site of the screened room may have to be related to the position of a previously erected radio workshop, but in any case the factors outlined in the following paragraphs should be borne in mind.

3.1 The efficiency of the room will be reduced if it is situated in a region of high "man-made" static.

3.2 The screened room should not be positioned adjacent to spark-plug testing equipment, battery-charging petrol-electric equipment, or an electrical overhaul shop, since these are all sources of interference.

3.3 Main trunking for telephone wires or power cables is a source of interference, and should be avoided if possible.

3.4 The use of fluorescent tube lighting in the vicinity of the room is undesirable.

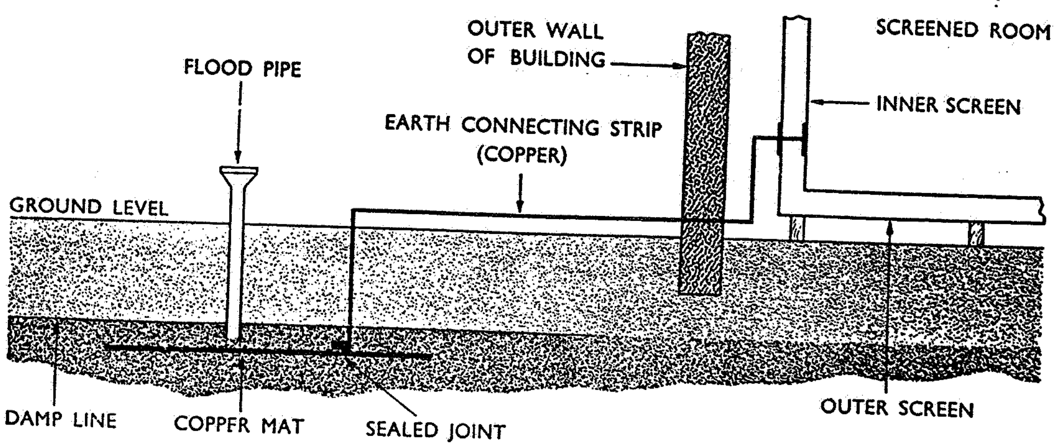


Figure 2 TYPICAL EARTHING ARRANGEMENT

3.5 The room should, where possible, be on the ground floor and adjacent to an outer wall, so that the earth strip bonding the screened room to the main earth is as short as possible (see paragraph 4).

4 EARTHING For earthing purposes a copper mat or plate should be sunk into the earth to a depth which will ensure consistent damping; a typical earthing arrangement is shown in Figure 2. After the test described in paragraph 6 has been conducted, the screens should be connected to the earthing mat by an earth strip of the shortest possible length.

4.1 Care should be taken to use a material for the earth strip that will not create a potential of more than 0·25 V with the material to which it is joined. If the connections are made by welding or soldering, they should be thoroughly cleaned to remove all traces of flux residue, and should then be covered completely with a sealing compound or other insulating covering.

4.2 In well-drained locations, it is recommended that a pipe should be sunk over the earth mat to permit occasional flooding of the mat.

4.3 In instances where an outside wall position is not available, an earth mat should be positioned under the floor of the main building or, alternatively, the room may be connected to earthing spikes.

4.4 Care must be taken to ensure that both screens are bonded together at the same point and over a good contact area. Suitable methods are welding, soldering or by bolting to the plates welded to the screen. The bonding of the screens at one point may cause some difficulty in aligning the earth strip with the mains input point (paragraph 7) since normally the lead-through filter will bond the screens together. Local requirements or Government regulations may preclude the feeding of a.c. mains supply below a certain height, in which case the earth strip should be run up the outer screen and bonded to it from top to bottom.

4.5 Bonding points should be provided in the room at bench height for the connection of equipment earth contacts or cases.

NOTE: Test equipment may require an earthing connection from its case to the inner screen in addition to the earthed mains supply plug.

5 CONSTRUCTION OF SCREENED ROOM In theory, a single-walled screened room constructed of copper or aluminium sheet is suitable, and would meet most requirements, but in practice there are a number of factors which may make its use undesirable, e.g. the possibility of the occupant suffering from claustrophobia, the necessity of individual heating and lighting and, possibly, the installation of an extractor fan, and the fact that communication with the occupant would be difficult.

5.1 In view of the above, the use of a double-walled room constructed of well-seasoned timber, using wooden dowels instead of nails or screws where possible, and having screens manufactured of close-mesh copper, expanded aluminium or galvanised expanded steel, is recommended. The mixing of these various materials is not recommended, since any electrolytic action between them will cause noise. In such a structure, the inner and outer screens should be spaced 3 inches apart.

NOTE: Rooms have been constructed of ½ inch mesh steel wire but, in general, such a structure has no inherent strength and tends to warp and sag. In addition, it is difficult to bond the structure satisfactorily. Electrically, this material gives poor insertion loss figures, and its use is not recommended.

5.2 The room should be raised from the floor of the main building by wooden beams, or other insulating media, and all screened joints should be bonded by welding or soldering, for preference, although clamping is quite satisfactory if sufficient care is taken.

5.3 If steel staples are used to attach the screen material to the frame, it should be ensured that the staples are galvanised, as any rusting may cause noise.

5.4 **Doors.** Special care should be taken when fitting doors of screened rooms, as a good fit at all points is essential for good attenuation. Hinged doors may be employed, and they should consist of a 3 inch deep wooden frame, covered on both sides with screening material, and bonded to the walls of the room by any suitable method, e.g. by using the hinge as one bond, and spring copper or bronze draught excluder strip as the remaining bond, or by using the method illustrated in Figure 3. It should, however, be borne in mind that such doors occupy space in a possibly restricted workshop, are clumsy, and are difficult to construct with a locking mechanism which can be operated from both sides. Sliding doors are generally found to be more convenient.

NOTE: Where screened rooms of proprietary design are installed, the manufacturer's recommendations regarding methods of erection and testing should be followed.

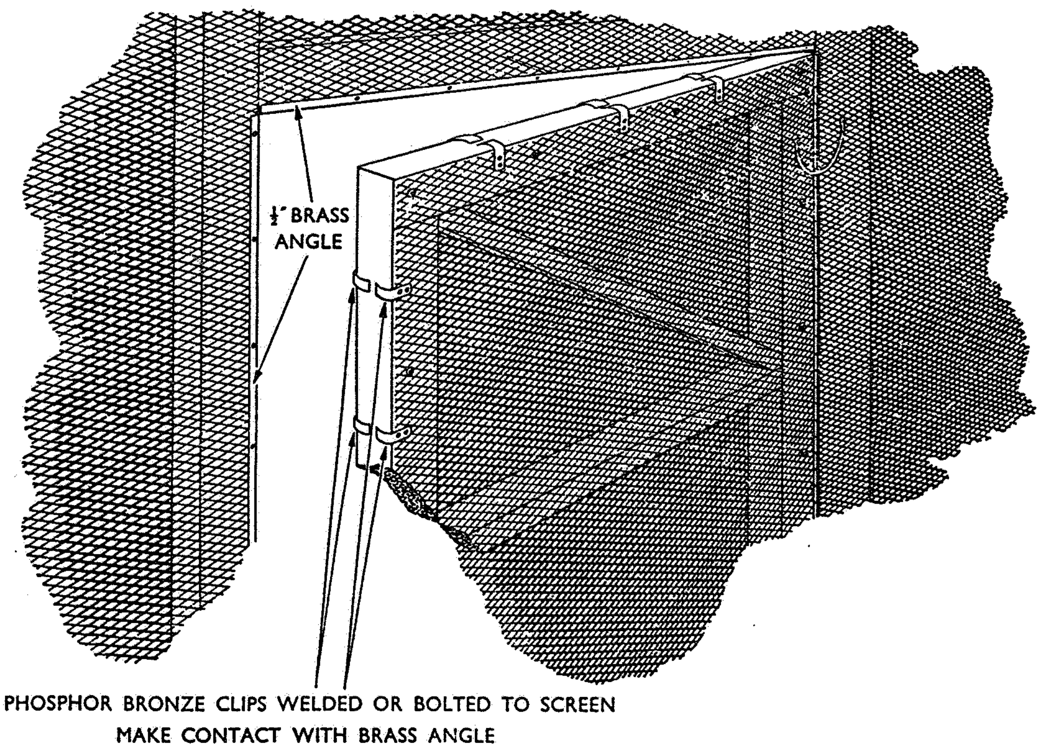


Figure 3 METHOD OF BONDING DOOR

6 INITIAL TESTING At this stage in the construction of the screened room, i.e. before any equipment or services are fitted, it will be of advantage to obtain a rough estimate of insertion loss. However, before commencing the test, and before connecting the main earth strip to the cage, a careful check should be made on the efficiency of all bonded joints and on the operation of the door and its bonding. With the door closed, the insulation of the inner and outer screens should be checked with a 500 V insulation-resistance tester, and a reading of more than 10 megohms should be obtained. On completion of the check, the earth should be connected to the screens.

6.1 The test should be made as follows:—

(i) Select a suitable battery-driven communications receiver and connect it to a horizontal wire aerial 6 feet in length.

(ii) With the automatic gain control switches off, and the receiver connected to an output power meter, tune in a number of powerful transmitters, either continuous wave or tone modulated, and adjust gain for a high output.

(iii) Transfer the set-up into the screened room and check the resulting attenuation.

The range of attenuation will be limited by the field strength of the transmitters, and by the output power capabilities of the receiver, but figures of 25 to 35 db should be reached, and complete suppression of signals should be obtained.

6.2 A cage in this initial state should easily be capable of attenuation figures double those given in paragraph 6.1 and therefore incomplete suppression is most likely as a result of leaks in the screening. It is important to bear in mind that filtered power supplies and other services fed to the cage will considerably reduce its attenuation efficiency.

7 SERVICES The electrical supplies normally required inside a screened room consist of a single-phase, 230 V a.c. supply, heavy duty 24 V d.c. supplies, and either a single phase or a three-phase supply of 115 V, 400 Hz. Services such as compressed air, water and gas heating may be required, but their installation presents no major problems provided that they are introduced at the main earth point and are securely bonded to both screens. All power supplies fed into the cage should be filtered by interference suppressors (see paragraph 8).

7.1 **A.C. Mains Supply.** A 200–250 V, 50 Hz a.c. supply is required to operate test instruments, and for individual bench lighting and heating. All supplies should be run in seamless conduits to three-pin sockets, and, where required, to fully-screened angle-poise lamps. All sockets and conduits should be bonded to the inner screen. Heating in the cage should be of the metal-clad strip type, wall-mounted below bench level. All power supplies should be run at or below bench level, and, if roof lighting is required, this should be provided outside the cage. Ring main connection of a.c. supplies is not recommended.

7.2 **Battery Supply.** Heavy-duty cables for a 24 V d.c. supply with a common negative may be run unscreened from a large storage battery situated outside the screened room. The feed-through point, consisting of co-axial capacitor filters, should be adjacent to the other feeds and the earth point. A ring main connection is inadvisable, and is, in any case, difficult to achieve unless a loop is introduced at the door.

7.2.1 The cables should be run, unscreened, inside the cage, at bench level to avoid long "spurs" off the main cable and consequent voltage drop.

7.2.2 Where noise is still evident inside the screened room, it is possible, where the storage batteries are large enough, to take all measurements with the charging supply switched off; alternatively, the batteries may be brought into the room.

7.3 **Alternator Supply.** Single-phase and three-phase alternator supplies are normally obtained from a motor-driven alternator situated at a distance from the screened room. If the alternator is in close proximity to the room, it is generally boxed in to suppress whine. Cables from externally situated alternators should be run into the room by the most direct route; loops made by running cables round walls or along ceilings should be avoided. Interference-free alternators may be operated inside the screened room, but it should be borne in mind that it is not possible to run the motor without creating a strong interference field. The motor may be positioned outside the screened room and connected to the alternator by an insulated connecting shaft through the screens. If this is done care should be taken to shield rotating parts, and to prevent earthing of the screens.

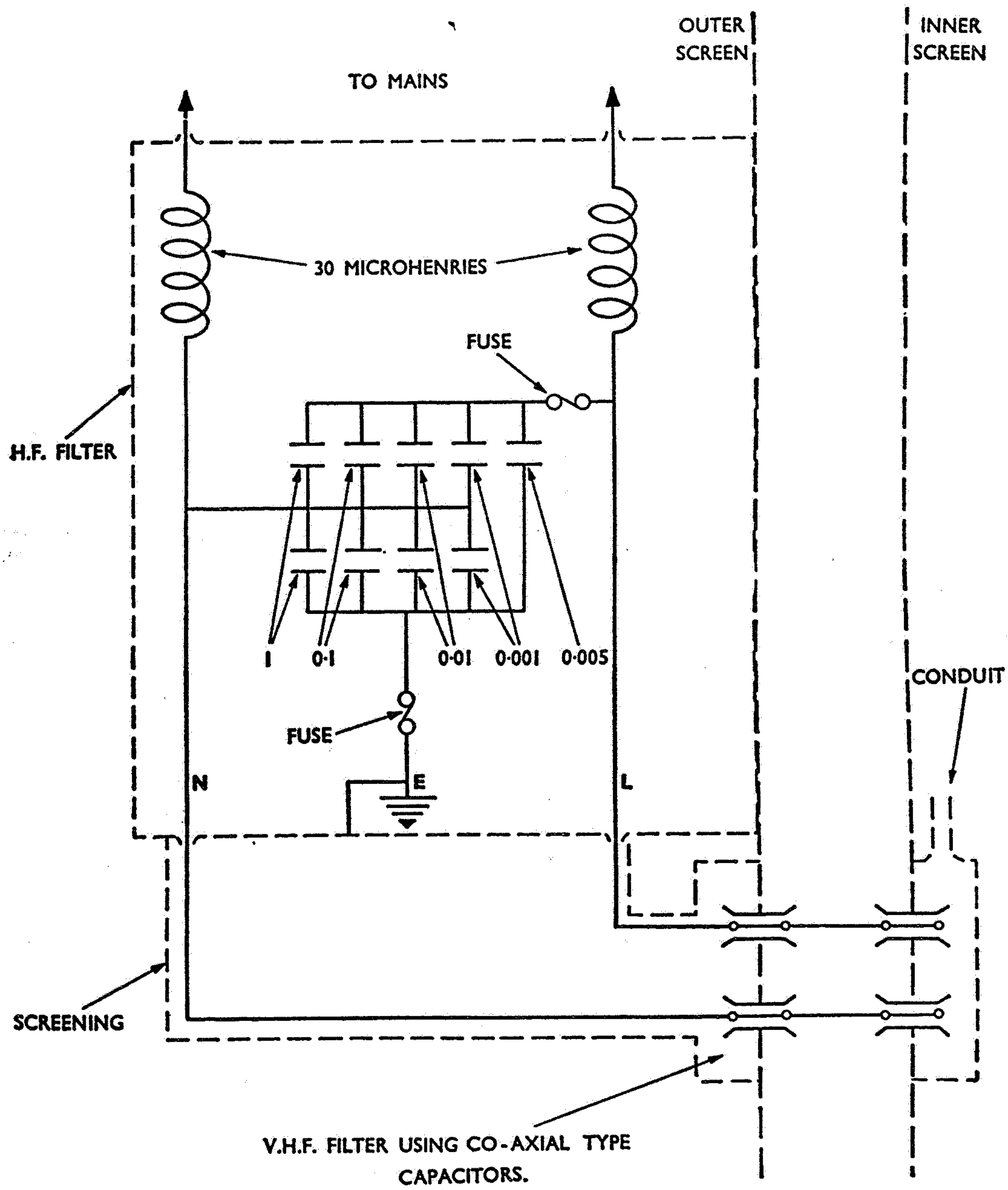


Figure 4 STANDARD FILTERING METHOD

7.4 **Alternator Power Sources.** A.C. mains-operated power supply units can often be made locally or obtained from specialist manufacturers. In addition, a range of transistor power units, which can be operated from 24 V sources from inside the screened room, is available. These units should be well filtered at both the input and output sources, and should be enclosed in metal boxes bonded to the inner screen of the room.

8 RADIO INTERFERENCE SUPPRESSION The efficiency of the room, as a suppressor of radio noise, depends to a very large extent on the efficiency of the suppressors or filters which must be fitted to all electrical supplies at their point of entry into the room.

8.1 The by-passing of the interference voltage is achieved by providing a low impedance path to earth, the magnitude of the impedance being dependent on the frequency. The ratio output noise volts/input noise current is known as "Transfer Impedance" and the value must be kept in the region of 1 ohm or less at all frequencies.

8.2 Practical two-terminal foil capacitors have appreciable self-inductance, and standard suppressors utilize a series of capacitors in conjunction with an inductor to cover the frequency range specified. These suppressors are designed to cover the medium and high frequency range, and must be used in conjunction with a very high frequency suppressor, using co-axial type capacitors.

8.3 Figure 4 indicates the standard method of filtering a single-phase mains supply into a screened room with proprietary suppressors. Three-phase 400 Hz supplies and d.c. supplies can be treated similarly, having regard to supply current requirements.

8.4 Co-axial type capacitors (see Figure 5) simplify suppressor design, and suppressors which give good transfer impedance characteristics between 150 kHz to 150 MHz can be made locally.

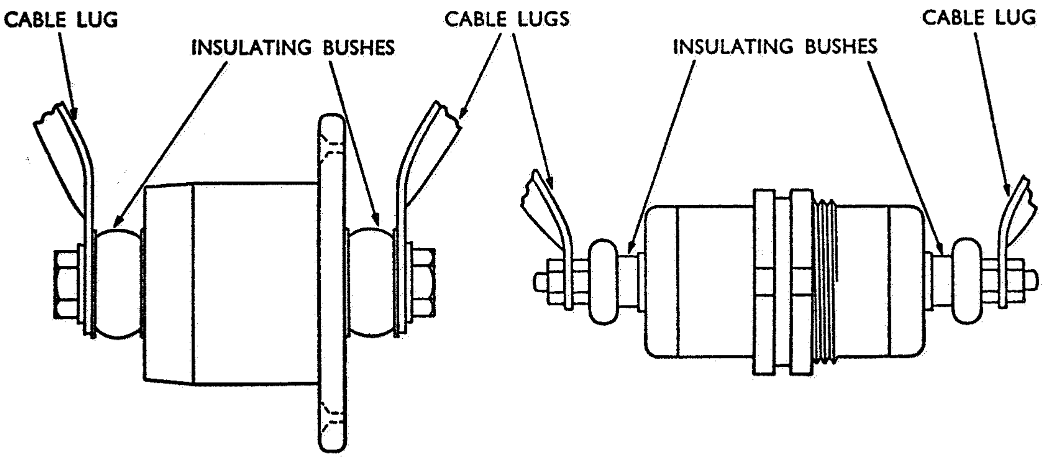


Figure 5 TYPICAL CO-AXIAL TYPE SUPPRESSOR CAPACITORS

8.5 All power supplies into the screened room should be fed through separate two or three element filters (Figure 6). Capacitors can be obtained having current ratings of up to 60 amps, but, for currents greater than this, two capacitors may be connected in parallel at each end, and large copper straps should be used to avoid heating of the end caps. Filter boxes should be constructed from a metal which will not create excessive contact potential with the cage screening material, and the seams of filter boxes should be welded.

8.6 The capacitor mounting screens should be bonded to the main structure of the box. The box length is dependent on the size of the capacitors and of the inductor, and on the distance between the inner and outer screens of the room. The width and depth of each section can be the same, but must be twice the diameter of the inductor to minimise short circuit turn effect.

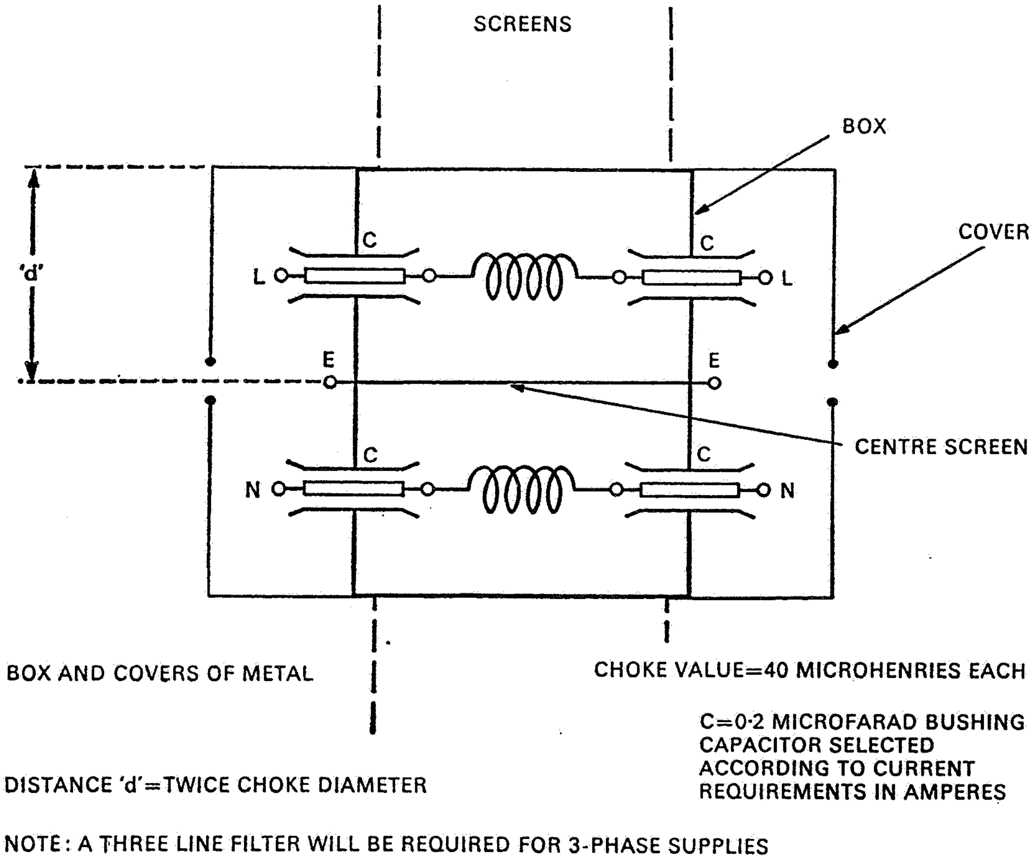


Figure 6 TWO-LINE FILTER FOR A.C. MAINS OR D.C. SUPPLIES

8.7 The separate assemblies, consisting of two-element filters for a.c. mains and l.t. supplies, or of a three-element filter for a three-phase supply can, if necessary, be mounted through a screened room at one point (see Figure 6). The main earth strap (see Figure 2) is then brought to the same point. Alternatively, each filter box can be mounted on the outer wall of the screened room, and the supplies can be fed through the screens inside metal conduits. The conduits should both make good electrical contact with the filter boxes and both screens, and have a very much reduced area for the earthing of the screens. Further filtering can be achieved by the use of an electro-statically screened transformer in the a.c. mains input.

NOTE: The wiring and testing of a.c. mains circuits should be in accordance with Government requirements.

9 TESTING THE SCREENED ROOM From Figure 1, it will be noted that at about 1 MHz the magnetic field becomes important and, because of this, testing below this frequency is performed with a loop aerial. Above this frequency it is more usual to measure the electric field, and this is done with a simple vertical or horizontal rod, or wire, aerial. The method of testing involves the use of two identical aerials, one inside the room and the other outside, a comparison being made between them.

9.1 To perform the test, identical aerials of the inverted "L" type should be constructed, the vertical members of which should be at least 4 feet long. The aerials should be erected in the same plane, about 8 to 10 feet apart, one in the room and the other outside. A similar aerial should then be erected midway between the two, also outside the room, and this aerial should be connected to the output terminal of a signal generator.

9.2 A suitable receiver and output meter should be arranged in the screened room, and the outside aerial should be connected to the receiver by means of a double-screened co-axial cable which should be fed into the room at floor level, if possible. The automatic gain control should be switched off.

9.3 The test should be commenced at the high frequency end of the receiver, and the output attenuator of the signal generator should be adjusted until a reasonable output is obtained on the receiver output meter (say 10 milliwatts). The attenuator setting should then be noted.

9.4 The co-axial cable should be withdrawn from the screened room, and the internal aerial should then be connected to the receiver, also using co-axial cable. The output attenuator should be increased until 10 milliwatts is again recorded on the receiver output meter, and the attenuator setting should be noted. The difference in the reading gives a measure of the insertion loss, in decibels.

NOTE: Unless the external aerial feeder cable is withdrawn from the room when testing the internal aerial, erroneous readings will be obtained.

9.5 The foregoing process should be repeated at intervals throughout the frequency range of the receiver, and the results should be recorded. For work-shops having a limited amount of apparatus, accurate testing throughout the radio band will not be possible, but for a room of the size recommended, the insertion loss between 1 MHz and 20 MHz will give a good guide to the efficiency of the room.

9.6 Local leaks can be explored by the use of a small hand-held loop aerial on a wander lead which is connected to a receiver, which in turn is tuned to a powerful local signal. The loop should be held close to the inner screen and moved along the screening seams, around the door frame and at the point of entry of power supplies.

NOTE: Where rooms are used for testing VHF or radar equipment, they must be checked at the particular frequencies used in such equipment, in order to determine room resonances. The normal method of testing cannot be followed at these frequencies, but any resonance will be self-evident when operating receiving equipment, similar to that under test, from outside the room.

RL/2-4

Issue 1.

18*th May*, 1977

AIRCRAFT

RADIO

STATIC DISCHARGERS

1 INTRODUCTION This Leaflet gives information on types of dischargers and general guidance on their installation, siting and maintenance. Full details of the procedures to be adopted for specific installations of dischargers referred to in this Leaflet are contained in relevant aircraft and equipment Maintenance Manuals and, therefore, this Leaflet should be read in conjunction with these documents. Information on the discharge of static from aerials is given in Leaflet **RL/2-2.**

NOTE: **RL/2-4** was previously used for a Leaflet entitled 'External Blade, Rod and Rail Aerials—Installation and Maintenance', the information for which is now included in Leaflet **RL/2-2.**

2 STATIC

2.1 The effects of static electricity are of considerable importance in the design, operation and maintenance of aircraft. Static electricity will cause noise interference in radio communications equipment and can also cause disturbance in other electronic systems.

2.2 During flight, an aircraft picks up static charges because of contact with particles such as rain, snow, ice and dust. The charge results mainly from the high-speed impact or frictional passage of these airborne particles and the charge rate is particularly high when, for example, ice crystals precipitate out from a cold-moist atmosphere (hence the expression 'precipitation static'). Precipitation is termed as 'hard' to distinguish relatively dry particles such as snow, ice, hail and sand, from the wet particles of 'soft' precipitation such as rain and sleet.

2.3 If the surface area of an aircraft was shaped like a sphere possessing a very smooth surface, the surface charge would be uniform and the sphere could be charged to an extremely high potential with respect to the surrounding atmosphere. The field intensity just off the surface would be the same over any part of the sphere. However, an aircraft of practical configuration does not possess a smooth spherical surface and there are in fact numerous protuberances. These protuberances cause a redistribution of the electric field and the field is concentrated at the tip of the protuberance, with a consequent higher field intensity in the atmosphere immediately at the tip. As a result, this portion of the atmosphere could reach such excessive voltage gradients that charge leakage could start and, after ionization, a complete breakdown could occur.

2.4 When an aircraft is struck by hard precipitation, the particles carry away a charge and the aircraft is left with a charge of opposite sign with respect to the surrounding atmosphere. During the charging time the smaller exposed radii of the aircraft extremities and protuberances will reach the corona starting potentials (see Note to paragraph 2.5) and will begin to discharge. If the aircraft is large and fast, and the precipitation is dense and fairly dry, the charging will continue and if the charging rate exceeds the discharge rate the larger radii and/or the less-exposed protuberances will reach their corona starting potential. The discharge currents involved may begin as fractions of a microamp but in some conditions they may reach the order of a milliamp. The charging mechanisms result in a discharge of pulsed radio frequency (RF) energy by corona which, for example, will be heard in the earphones of an automatic direction finder (ADF) receiver as a slow 'popping' noise rising to a crescendo of 'screaming and crying'.

2.5 The energy released by the discharge can be observed in light form. Although visible corona appears as a continuous light, in fact, the release of electrical energy from all corona is in pulse form. The energy is spread over the radio spectrum and is, in the main, contained in the lower frequencies.

NOTE: Corona is accumulative ionization of a small part of the atmosphere surrounding a point and should not be confused with sparking which represents heavier discharge of a more intermittent nature and has its own interference characteristics.

2.6 If the charging mechanism could be removed, the problem of interference from static would be relieved, but this is not possible. However, it is possible to bring about a reduction of the charge and to provide means of discharging the aircraft in a regulated and electrically-quiet manner.

3 TYPES AND FUNCTION OF DISCHARGERS The following paragraphs give details of the types of dischargers and the manner in which they function.

3.1 Older types of static dischargers comprise a stranded cotton wick, chemically impregnated with metallic silver, covered with a protective plastics sheath leaving a short tail exposed. An aluminium anchor plate is fitted to the sheath for attachment to the aircraft. During service, the wick is eroded and thus the discharge efficiency is reduced. To maintain the discharge efficiency, the plastics sheath is progressively trimmed to expose fresh wick fibres. Normally, the sheath is marked with a LIMIT OF TRIM. Figure 1 shows a typical example of a wick discharger.

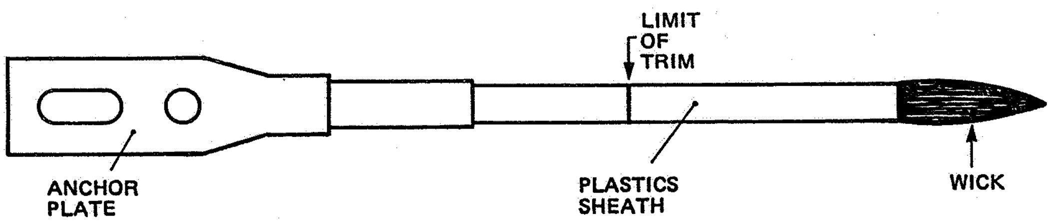


Figure 1 WICK DISCHARGER

3.1.1 This type of discharger is no longer readily available and has been replaced by a discharger of flexible design. The flexible discharger is similar to the rigid discharger described in paragraph 3.2 except that in order to obtain flexibility the glass-fibre rod is replaced by a nylon cord. Flexible dischargers are suitable for use on light aircraft or larger aircraft of moderate speeds where mounting circumstances do not produce unduly severe turbulence.

3.2 Many modern dischargers consist of a tapered glass-fibre rod for mechanical support which is rendered conductive by a coating of material having high electrical resistivity to provide the path back from a discharge tip assembly. The conductive coating is protected by baked-on synthetic finish and in some types is further protected by a heat-shrunk sheath of Skydrol-resistant plastics. Three types of discharger tips are normally used; (a) a minute brush of extremely fine 80/20 nichrome wires, (b) solid carbon which is machined to a 90 degree point, and (c) tungsten needles. The glass-fibre rod is terminated at its thicker end by one of various attachment fittings, assembled together with a conducting cement. Figure 2 shows a typical example of a rod discharger.

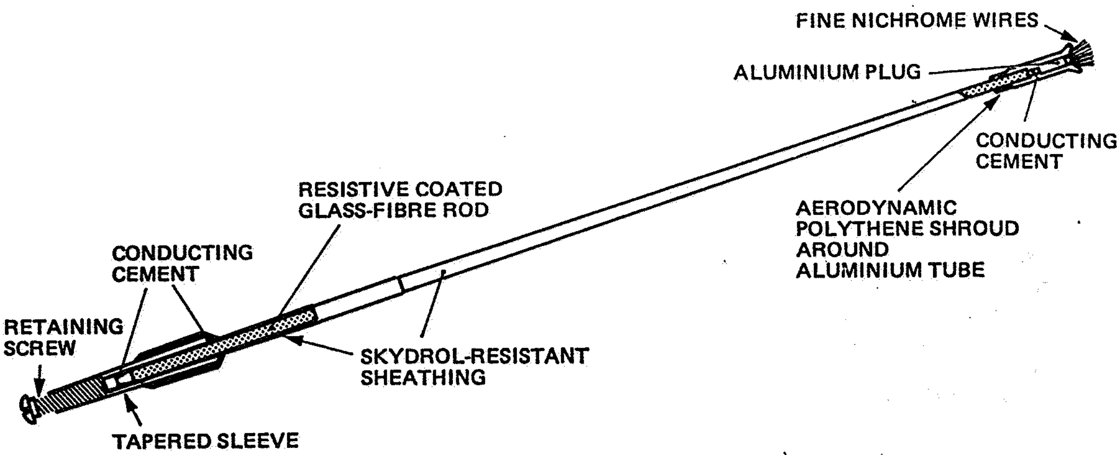


Figure 2 ROD DISCHARGER

3.3 The lightning diverter spike fitted at the apex of nose radomes on some aircraft can be particularly prone to noisy discharge. To minimize the noise from this source, a discharger assembly which can be screwed into the lightning diverter is fitted. This discharger comprises four wire-brush dischargers mounted at the forward end of a rigid dielectric support, and critically angled back so that each wire brush remains well exposed to high electric field intensity while remaining protected by its polythene shroud against bunching of the wires under air pressure. A high-resistance spiral track provides the current path back to the airframe. Figure 3 shows the general arrangement of the dischargers.

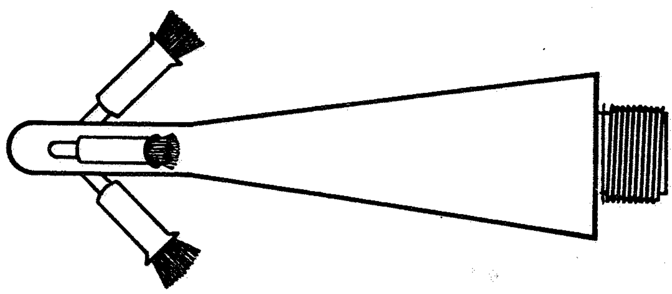


Figure 3 RADOME-MOUNTED DISCHARGER

3.4 Static dischargers are intended to prevent or reduce the radio noise experienced when an aircraft, which has acquired a high electric charge relative to its immediate surroundings, releases this charge by corona breakdown directly from one or more of the aircraft extremities or protuberances. The dischargers provide the means for shifting this discharge point aft of the trailing edge where the RF coupling is at a minimum. The charge travels along the resistive coating over the glass-fibre material to the discharger tip positioned away from the wing or tail surface. Since the dischargers act as low-impedance discharge points, the voltage required to cause and sustain discharging is minimized. The result is a high pulse rate with much lower pulse peaks. Recorded test results have shown a 70,000 volts discharge threshold to have been reduced to 7,800 volts by the use of static dischargers. Dischargers need to be fitted in sufficient numbers to ensure that their total discharge current holds the aircraft potential below the threshold of direct discharge at the higher charge accumulation rates anticipated.

4 SITING It is important that sufficient numbers of static dischargers are fitted and are sited in positions where they can efficiently discharge the static with the minimum of interference being induced into radio aerials. Optimum siting of dischargers can only be determined by a thorough investigation of the characteristics of the particular aircraft type. However, in general, the wing, tail and fin tips, particularly at the trailing edges, are the locations of the greatest potential gradient. Dischargers positioned at these points, with additional units at spacings of 9 inches around these regions will generally give satisfactory results. Dischargers should not be located near to radio aerials unless they are specifically designed to be so located. Table 1 gives details of the number and location of static dischargers on various aircraft.

TABLE 1

Aircraft	Wing Trailing Edge	Wing Tip	Horizontal Stabilizer (Tailplane) Trailing Edge	Horizontal Stabilizer (Tailplane) Tip	Vertical Fin Trailing Edge	Vertical Fin Tip	Tailplane Bullet
Trident 3B	8 on each wing	2 on each tip	3 on each stabilizer	2 on each tip	Nil	N/A	2
BAC 1–11	3 on each wing	1 on each tip	3 on each stabilizer	2 on each tip	Nil	N/A	2
Boeing 707	6 on each wing	2 on each tip	4 on each stabilizer	2 on each tip	4	2	N/A
Boeing 747	12 on each wing	3 on each tip	9 on each stabilizer	4 on each tip	8	4	N/A

5 INSTALLATION

5.1 The discharger units are attached to the aircraft by means of bases machined from high-purity aluminium to obviate problems of electro-mechanical corrosion where there is direct contact with the aircraft skin. The base may be fixed permanently to the aircraft by screws, rivets, a conducting cement, or any combination of these. Where a conducting cement is used, this should be of the type recommended by the manufacturer. A tapered sleeve on the end of the discharger rod plugs into the base and is locked by means of a round-head screw. Where the discharger is to be fitted to wing or horizontal stabilizer tips, an angled sleeve is provided. The base flanges are sufficiently ductile to enable shaping to the aircraft skin contour. Figure 4 shows the general arrangement of a discharger and its base.

NOTE: On certain types of aircraft, e.g. BAC 1-11, the wing tips are made of reinforced plastics and it is important to ensure that the bonding inside the plastics is of sound construction so that where dischargers are fitted to the wing tips there is good bonding between the discharger and the main structure.

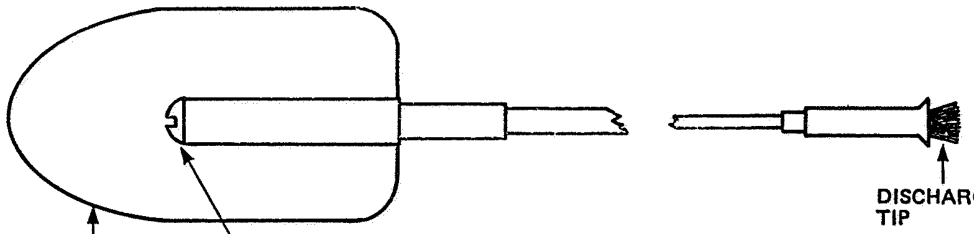


Figure 4 DISCHARGER AND BASE

5.2 Various types of discharger exist which are interchangeable. However, where dischargers are installed on the trailing edge of control surfaces it is important to ensure that replacement of a discharger with a different type does not alter the control-surface balance. This is particularly important on smaller aircraft employing stabilizers where both primary controls and tabs are balanced to fine limits.

6 MAINTENANCE The dischargers should be checked in accordance with procedures detailed in the relevant Maintenance Manual at the periods prescribed in the approved Maintenance Schedule for the particular aircraft. As a general guide the following points should be observed.

6.1 Periodically, a general check should be made to determine that all dischargers are securely mounted, and are not broken or missing.

6.2 The efficient operation of the dischargers is dependent on good electrical contact between the base and the aircraft. The resistance between the base and the aircraft should, in general, not exceed 0·05 ohm. However, provided there is no static interference with the radio systems, a resistance not exceeding 0·1 ohm may be acceptable. If the resistance exceeds the acceptable limit, the discharger should be removed and the contact surfaces cleaned.

6.3 Where dischargers of the tapered glass-fibre rod type are fitted, the condition of the resistive coating between the base and tip, and of the Skydrol-resistant plastics, should be checked for physical continuity particularly at the base and tip joints. The electrical resistance between the base and tip should be within the limits specified by the manufacturer for the type of discharger. Typically, values between 8 and 100 megohms are acceptable for trailing-edge dischargers and 5 to 60 megohms for tip-mounted dischargers.

6.4 Particular attention should be paid to the condition of the discharger tip. In the case of carbon or tungsten tips, if these show signs of damage or erosion the discharger should be renewed. Where the tips comprise nichrome wire brushes, these should be clean and the wires should not be matted together. If the brush is corroded, or clogged with fuel, oil, polish or any other foreign matter, the discharger should be renewed.

6.5 Impregnated cotton-fibre dischargers will erode in service and when this occurs the plastic sheath should be cut back to expose fresh fibres such that a wick length of 1½ inches is obtained. The cotton fibres must not be cut with scissors in order to obtain the desired tip shape as this would compress the silver into comparatively large metallic areas resulting in noisy discharge. A sharp knife or similar tool is suitable for trimming the tip to shape. Generally, this type of discharger is marked with a 'limit of trim' indicating when a new unit should be fitted.

6.6 Dischargers should be checked for lightning damage, which is generally indicated by a burning and roughening of the conductive coating and pitting of the metal base plate. In extreme cases, as a result of lightning, part of the discharger may be burnt away. Any discharger damaged by lightning should be replaced with a new unit.

RL/2-5

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AIRCRAFT

RADIO

RADOMES—REPAIR AND ELECTRICAL TESTS

1 INTRODUCTION

1.1 The function of a radome is to provide protection for an antenna and it must also be capable of providing a clear, undistorted, antenna view, with minimum reflection. In addition a radome must be structurally sound, since structural failure can result in aircraft damage. Although radomes are generally thought of as curved structures (e.g. a nose radome for protecting a weather radar antenna), they can also be flat or slightly curved coverings such as those used for the protection of doppler equipment.

1.2 This leaflet gives general guidance on the repair and electrical testing of radomes. Information is also included on measures taken to minimize the damage resulting from the effects of lightning strikes and of erosion resulting from rain and hail. Methods of minimizing the risks associated with lightning strikes on aerials are dealt with in Leaflet **RL/2-2.** Full details of repair and testing procedures referred to in this leaflet are contained in the relevant aircraft and equipment manuals which must, therefore, be read in conjunction with this Leaflet. Leaflet **AL/7-6** also provides information on repair techniques for glass-fibre panels.

2 CONSTRUCTION In general, the radomes used on aircraft may be classified as either 'sandwich' or 'thin wall', and can be regarded as 'tuned' or 'untuned' respectively. To minimize power losses the thickness of a sandwich (tuned) radome is proportional to the frequency of the associated radar system, whereas a thin wall radome, being untuned, is made as thin as structural limitations permit.

2.1 The sandwich type of radome consists of a dielectric core of glass-fibre honeycomb, expanded nitrile ebonite, expanded PVC or polyurethane foam, which is supported on each side by a skin comprising three or more layers of glass-fibre cloth impregnated and bonded with resin. The thin wall type of radome is manufactured from a number of layers of resin-impregnated, glass-fibre cloth. Nose-mounted radomes are generally protected from erosion by covering the nose with a neoprene overshoe, or by a polyurethane coating.

2.2 The thickness, number of layers, and type of glass-fibre cloth used in a radome is determined during the original design. Generally radomes manufactured in the UK employ a plain weave cloth of 0·006 in (0·15 mm) thickness, whereas radomes manufactured in the USA often use a satin weave cloth of 0·008 to 0·011 in (0·2 to 0·28 mm) thickness.

3 INSPECTION FOR DAMAGE

3.1 Damage to radomes can result from rain erosion, lightning strikes, static discharges, impact with ground handling equipment, and other accidental causes. If, for any reason, the outer skin is perforated, differential pressure may result in the ingress of water or moist air. Water or condensed moisture in the cells of a honeycomb structure may freeze as the aircraft ascends, and in freezing could expand and rupture the bond between adjacent cells or skin. As this process continues, further cells could become contaminated by water, and eventually large areas of the radome could be affected. Thus, although the damage may appear superficial over a relatively small area, internal damage may be extensive because of moisture penetration. It is, therefore, important to establish the full extent of any damage. A moisture meter should normally be used to check the extent of moisture penetration, but radiographic techniques could also be used to check the quantity of water present. Before using a moisture meter the surface of the radome should be thoroughly dried, and the probe should be traversed across the inner skin, care being taken to avoid denting, scratching or pitting the surface.

3.1.1 In addition to the effects of damage on structural integrity, any consequent deviation from the design dimensions or dielectric properties of the structure will result in a degradation in microwave performance.

3.2 Where moisture is detected outside the known damaged area, a check should be made to ensure the structural integrity of the skin laminations. This can often be determined by tapping the skin with a small metallic object, which should produce a live resonant tone if the structure is sound but if delamination has occurred, a flat, dead response will be obtained; the results should, however, be treated with caution, and should be compared with a part having a known defect. Any moisture must be thoroughly dried out before making repairs.

3.3 In addition to moisture penetration, delamination can result from fatigue or accidental damage. Where a hole or dent exists there may be delamination. Since certain radomes are relatively flexible, they will often spring back to their original shape after impact; thus any area showing signs of greasy smudges or scratches is suspect and should be investigated. Impact damage can be detected by applying finger pressure over the radome surface. A soft area is an indication of internal damage, a greasy smudge could be evidence of a bird strike, and scratches or abrasions indicate possible impact with such things as hangar doors, refuelling vehicles, etc.

3.4 Radomes can also be damaged by lightning, such damage falling into three basic categories:

(a) **Surface Damage.** This is indicated by scorching of the outer surface as a result of heat transfer.

(b) **Puncture.** If a lightning strike does not track to external metal, the radome will be punctured and the strike may connect to internal hardware, e.g. the radar scanner. As a result of dielectric breakdown, a hole may be burnt through the complete structure, and multiple discharges may leave a distinctive trail of pin holes. Typically, holes with diameters of 3 to 100 mm (0·125 to 4·0 in) may result.

(c) **Internal Damage.** This commonly results from punctures caused by lightning strikes and takes the form of delamination of the internal surface. The damage can extend over areas up to 0·5 m (1·5 ft) away from the location of the hole.

3.4.1 Overall, the type of damage caused by lightning has the effect of weakening the structure and degrading the radar performance. Structural weakening is particularly serious since radome break-up can subsequently occur which, in turn, will affect aerodynamic performance and also possibly lead to engine damage and jamming of control surfaces. A discharge which punctures the radome could also cause serious damage to the radar equipment it houses.

3.4.2 To minimize the damage to radomes resulting from lightning strikes, lightning diverter strips may be fitted. In order that these remain effective it is important to ensure that the electrical bonding to the airframe is sound. Bonding should therefore be regularly checked (paragraph 5.2.3), and in particular, after any major repairs are carried out (see Leaflet **EEL/1-6**).

3.5 Radomes are protected from rain erosion by either neoprene overshoes fitted over the nose area, or by coating the nose area with neoprene or a polyurethane elastomer. In addition, an anti-static coating may be provided to prevent the build-up of static charges, which can lead to discharge damage and radio interference. The condition of overshoes, and protective or anti-static coatings should be regularly checked.

4 REPAIR

4.1 Repairs may be classified as either minor or major depending on the nature and extent of the damage. Minor repairs may be made by suitably qualified line maintenance personnel whereas major repairs will necessitate the return of a radome to an organization approved for the major repair and electrical testing of radomes.

4.1.1 **Minor Repairs.** These apply to nicks, pits, scratches and breaks of the outside protective coating which do not penetrate the radome skins by more than the specified number of layers of glass-fibre, and no moisture penetration is revealed on checking with a moisture meter.

4.1.2 **Major Repairs.** These apply to damage consisting of punctures, delaminations and contamination which exceed minor repair limitations, and burned areas resulting from static discharge or lightning strikes. Major repairs also apply to separation or loss of laminations, and penetration of outer skins, with resultant core damage or inner skin damage, including holes completely through the radome. On completion of major repairs, tests should be carried out to ensure that the electrical performance remains within the acceptable limits (see paragraph 5).

4.2 **Temporary Repairs.** Although all repairs must ultimately be of a permanent nature, temporary repairs may sometimes be permitted to enable the aircraft to proceed to a base where permanent repairs can be carried out. Temporary repairs will, in most cases, degrade the radar performance and are only intended to permit continued use of a radome until a permanent repair can be made. Temporary repairs are usually restricted to cases where, after cleaning out, the hole does not exceed 19 mm (0·75 in) diameter (depending on the location), and if several holes exist, their centres are separated by at least four times the diameter of the largest adjacent hole. A general procedure for making temporary repairs is given in paragraph 4.4.1.

4.3 **Permanent Repairs.** When making permanent repairs to radomes, it is important that the proper materials and tools are used in accordance with the specified repair procedures. A repair should return the radome to a satisfactory condition, both electrically and structurally. Improper repairs can affect such factors as transmissivity, reflection and diffraction, with a resultant degradation of microwave performance. As the design thicknesses of the radome wall may be directly related to the wavelength of the radar energy which passes through it, it is important when making repairs that the design dimensions and contour, including any protective finishes, are maintained.

NOTE: Refer to Leaflet **AL/7-6** for the health hazards associated with the use of resins and glass-fibre materials.

4.4 **Repair Procedures.** The repair procedures to be followed will be dependent on the classification applicable to the damage. General guidance is given in the following paragraphs on the procedures to be followed by suitably qualified personnel when making temporary, minor and major repairs.

4.4.1 **Temporary Repairs**

(a) The damaged area should be thoroughly cleaned and in the case of a hole it should be finished with a slight inward taper.

(b) To provide structural strength, holes should be plugged. For small holes a polysulphide sealant may be used, but larger holes will require a plug made from wood, rubber or other suitable material, as specified in the appropriate Repair Manual.

(c) The repair should be completed by sticking a neoprene patch, approximately 1·6 mm (0·0625 in) thick, on the outer surface, so that it overlaps the damage by 12·5 mm (0·5 in). An adhesive compatible with the repair material should be applied, and should be used as sparingly as possible, consistent with achieving a good bond.

4.4.2 **Minor Repairs**

(a) Prior to undertaking a minor repair, a thorough inspection should be made to check the full extent of the damage. A small hole could be the external indication of a lightning strike or static discharge, and inspection of the inner surface may reveal a burn mark.

(b) The area to be repaired must be thoroughly cleaned prior to undertaking the repair.

(c) If the damage is such that it requires more than paint touch-up to restore the radome to its original condition, then prior to filling with a recommended patching paste or filler putty, all paint should be removed from the surface area concerned, using an approved solvent or by sanding. Extreme care must be taken when sanding to ensure that the glass-fibre laminates are not penetrated and that the structure is not overheated.

NOTE: Paint stripper should not be used unless specifically approved by the manufacturer.

(d) After removal of the paint, the area under repair should be wiped clean with a cloth soaked in methyl ethyl ketone (MEK), or equivalent, and thoroughly dried. Filler paste sufficient for the repair should be prepared in accordance with the manufacturer's instructions. The filler must be of a non-metallic type.

(e) Filler paste should be applied using a plastic scraper, or other suitable tool, and any excess paste should be scraped away to leave the repair flush with the surrounding surface.

(f) When the filler has thoroughly dried, any excess should be sanded smooth to conform with the contour of the radome, and the repair should be completed by re-applying the paint or anti-static coating in accordance with the appropriate specification.

4.4.3 **Major Repairs.** For making major repairs reference should be made to the relevant aircraft maintenance and structural repair manuals and to the general repair procedures given in Leaflet **AL/7-6.** The following paragraphs give general information and guidance on procedures associated with major repairs.

(a) Superficially, the area to be repaired may appear to be relatively small, but damage such as delamination may have occurred beyond the visible area. Checks for delamination should therefore be made and the full extent of the damage should be determined. Where delamination has occurred, it will be necessary to cut out an area of sufficient size to ensure that the repair will extend into a sound portion of the radome.

(b) As a result of skin punctures, holes or other damage, moisture may have entered the structure. Moisture can cause extensive damage beyond the apparent damaged area and, in particular, will often result in delamination. The extent to which moisture has become entrapped should be checked using a recommended type of moisture meter. It should be noted that misleading results can sometimes be obtained where an anti-static coating is applied, and if there is doubt concerning the results, a further check should be made with the coating removed.

(c) Repairs must only be made using materials of the same type, or an approved equivalent, as was used in the original construction. To ensure that the radar performance is not degraded as a result of the repair, it is important that the design dimensions and original contour of the radome are maintained. Paragraphs (i) to (xx) give examples of improper repairs which could result in degradation of radar performance or weakening of the structure.

(i) Use of materials which are not compatible with the original radome materials.
(ii) Patches of different thickness.
(iii) Poor fabrication techniques.
(iv) Too high a content of air in the lay-up of the patches.
(v) Repairs overlapping.
(vi) Holes plugged with resin, screws, metal, wood and plastic plugs.
(vii) Cuts or cracks simply coated with resin.
(viii) Tape (including electrical tape) over hole or crack and covered with resin.
(ix) Oversize patches.
(x) Too much or too little resin.
(xi) Exterior coatings too thick, or uneven, or use of metallic base paints.
(xii) Filled honeycomb cells.
(xiii) Repairs made without removing moisture or moisture contamination from inside of radome wall.
(xiv) Abrupt changes in cross-section.
(xv) Patches projecting above outside contour.
(xvi) Improper cure.
(xvii) Wrong size cells or density of honeycomb.
(xviii) Excessive overlap in honeycomb joints.
(xix) Poor bonding of skin to core.
(xx) Gaps in honeycomb core.

(d) The method used for cutting away damage, and for making repairs, will depend on the size of the repair. Generally, it is recommended that where the damage requires removal of an area in excess of 75 mm (3 in) in diameter the 'stepped joint' method be used. For repairs of damage smaller than 75 mm (3 in) in diameter the 'scarf' method may be used. Both of these repair methods are described in Leaflet **AL/7-6**. If the damage necessitates repair to both the inner and outer skins, it is important that the repair to one side is completed before removal of the plies from the opposite side. In addition, the repairs should be made so that the new plies on one side overlap those on the other side, i.e. joints to sound material on one side are positioned away from joints on the opposite side.

4.5 **Overshoes and Protective Coatings.** The following paragraphs give general guidance on the renewal or repair, as appropriate, of overshoes and protective coatings.

4.5.1 **Overshoes.** Although the only satisfactory procedure when an overshoe becomes damaged is to fit a new one, a temporary repair may be made when the circumstances do not permit complete renewal. Such a repair may be achieved by sticking a neoprene patch, approximately 1·6 mm (0·0625 in) thick on the outer face, to overlap the damage by 12·5 mm (0·5 in) using a suitable adhesive as recommended in the appropriate maintenance manual. The extent to which a temporary patch may be used will depend on the contour of the radome in the damaged area, since the patch must take up the radome shape with satisfactory adhesion and freedom from wrinkles. At the earliest opportunity the overshoe must be renewed. The procedures for the removal of an overshoe and the fitting of a new one are given in the appropriate Structural Repair Manual.

4.5.2 **Protective Coatings.** Close inspection of protective coatings may reveal damage in the form of pin-holes. If these are 'touched-in', further damage, e.g. water ingress, may be prevented.

5 ELECTRICAL TESTS Electrical testing of radomes must be carried out in accordance with the manufacturer's instructions, after making major repairs, and whenever the associated radar performance falls below an acceptable level and the radome is suspected of being the cause. Paragraphs (a) to (d) give examples of the types of degradation in radar performance which can result from a poor radome.

(a) **Excessive Ground Clutter.** This may appear as half-moon shaped returns extending across wide angles in the forward portion of the display. As a result the radar capability is reduced when the aircraft is flying at low altitude. Ground clutter is caused by the radome deforming the antenna pattern and increasing the level of side lobe radiation towards the ground. Increased ground clutter can also occur when an aircraft is banked, as a result of beam distortion in areas of the radome other than those normally scanned in level flight.

(b) **Loss of Range.** If the antenna is tilted up to reduce the effects of ground clutter, this may raise the centreline of the radar beam above the level of any distant storms in the path of the aircraft, and thus produce an apparent reduction in range. As much as 25% of one-way power may also be lost through a poor portion of radome.

(c) **Loss of Resolution and Beam Refraction.** As a result of distortion of the radar beam in the azimuth plane, reduced target resolution may occur, and similarly, refraction of the beam may introduce target bearing errors.

(d) **System Problems.** As a result of excessive radar reflections, frequency pulling of the magnetron can occur, the rapid frequency changes causing the local oscillator automatic frequency control to unlock as the antenna rotates. This is seen as intermittent returns on the radar display.

5.1 **Test Requirements**

5.1.1 The area in which the tests are to be made must be free from such objects as servicing stands, vehicles and buildings likely to cause nuisance radar reflections.

5.1.2 The radome stand should be capable of rigidly supporting the radome, and of permitting the radome to be moved a short distance towards and away from the receiving antenna. It should also permit the radome to be rotated in azimuth and elevation, through the angles over which it is required to function when fitted to the aircraft. The stand should present a minimum of interference with the energy received.

5.1.3 The microwave signal source should provide a suitable output signal (typically 100 mW) at the frequency required.

5.1.4 The transmitting and receiving antennae should be separated from one another by a distance calculated in accordance with the formula:

$$\frac{2D^2}{\lambda}$$

where D = Aperture of the larger antenna
λ = Free space wavelength.

NOTE: For a simple parabolic reflector the aperture D may be obtained by measuring the diameter of the reflecting dish.

5.1.5 The antenna receiving system should be the same as the antenna system which the radome houses when fitted to the aircraft. A horn should be used as the transmitting antenna, and the distance between the two antennae should be adjusted to align the first null of the horn radiation pattern along the ground reflection path (see Figure 1). Data showing the position of the null is obtainable from the horn manufacturers.

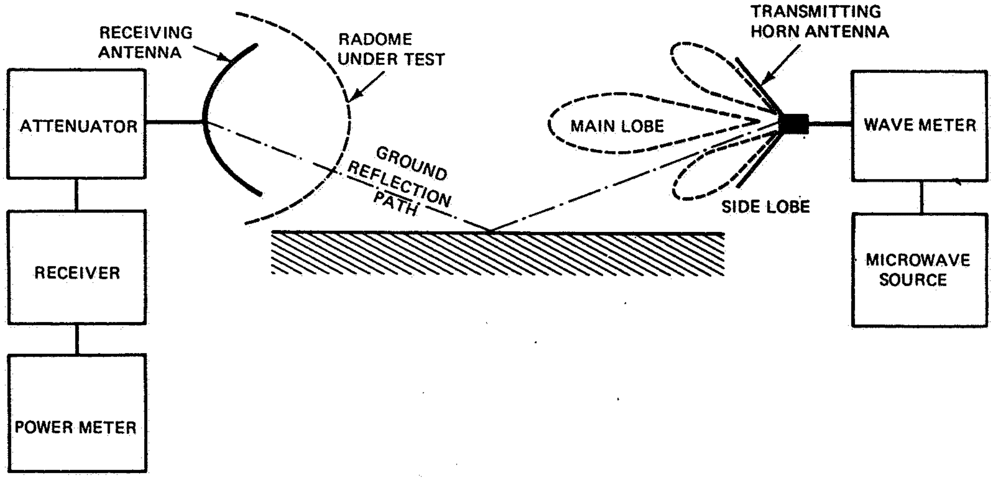

Figure 1 ATTENUATION TEST ARRANGEMENT

5.2 **Test Procedure.** The following paragraphs give general procedures for carrying out attenuation, VSWR and bonding checks on a radome.

NOTE: Microwave energy may damage body tissues, and test personnel should avoid standing in the path of the beam.

5.2.1 **Attenuation.** A typical test arrangement is shown in Figure 1.

(a) With the equipment arranged as shown, the power should be switched on and the equipment should be allowed to warm up, to ensure that it attains a stable operating temperature before carrying out the required tests.

(b) The microwave source should be adjusted to the correct operating frequency at the required power output.

(c) With the radome removed, the two antennae should be aligned in pitch and azimuth, for maximum received power. The attenuator should be adjusted to give an indicated received power of 0 dB.

(d) The radome should be mounted on the stand in the same relative position it would have in the aircraft. The radome should then be moved forwards and backwards slightly, and the maximum and minimum readings on the power meter should be noted. The average of the two readings should not differ from the reference level set in (c) by more than the figure quoted in the relevant Maintenance Manual. The figure obtained may vary depending on whether the radome is stripped or completely finished, i.e. the protective coating and, if applicable, the paint finish have been applied. Typical readings to be obtained should not exceed 0·7 dB for a stripped radome, and 1·0 dB for a completely finished radome. For radomes fitted with a lightning protection spike, typical figures are 1·0 dB and 1·5 dB respectively.

(e) Measurements should also be taken with the antenna turned about its axis to the extreme azimuth and elevation positions at which the radome is required to pass energy when fitted to the aircraft. The results obtained should be within the limits quoted in paragraph (d).

5.2.2 **VSWR** There are several methods which may be used to measure VSWR, including (a) comparison of forward and reflected power levels, detected by a directional coupler, (b) measurement of the standing wave ratio by means of a slotted line, and (c) measurement of standing wave ratio by means of a high directivity bridge. Procedures for measuring the standing wave ratio in the waveguide feed are described in Leaflet **RL/2-7.** Method (a) requires a laboratory standard directional coupler able to discriminate accurately between the forward and reflected signals; this method is liable to error and is not recommended for field measurements. Method (b) is more reliable, and a suitable test arrangement is shown in Figure 2.

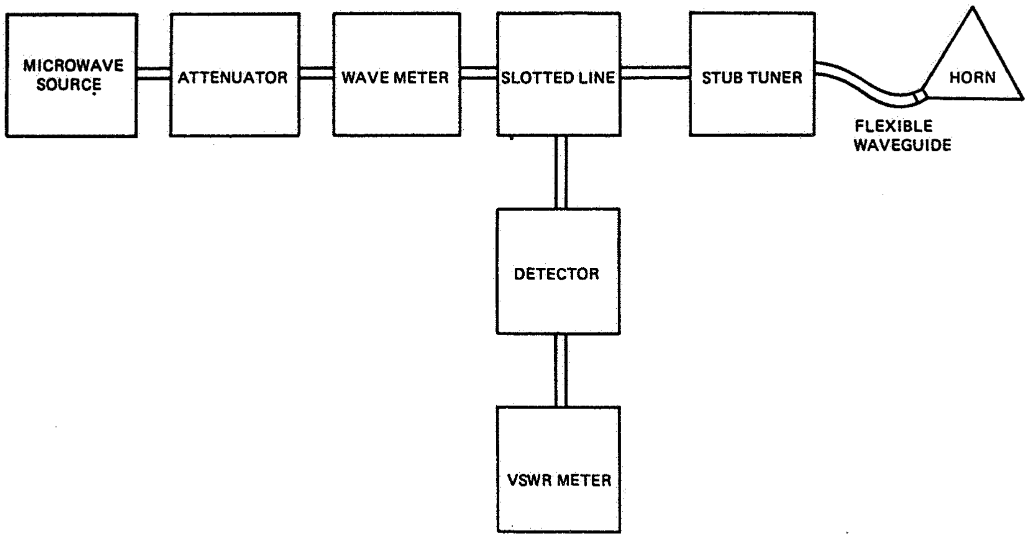

Figure 2 VSWR TEST ARRANGEMENT

(a) Two methods of scanning the radome inner surface are possible. The first requires that the VSWR measuring assembly be connected via a section of flexible waveguide to a horn antenna. The horn is held firmly against the radome inner surface and the measurement is taken. The measurement is repeated at different locations, until a VSWR map of the radome surface is obtained. This method is suitable for 'in situ' checks to detect areas of unacceptably high reflections, but, due to a variation of reflection levels caused by movement of the flexible waveguide, accurate measurement of low VSWRs is not possible. To obtain accurate measurements it is necessary to reduce all unwanted reflections to a minimum before scanning the radome surface. To achieve this objective the second method must be used, in which the VSWR measuring assembly, including the horn antenna, must be rigidly mounted. A VSWR map of the radome surface is then possible by rotating the radome around and in close proximity to the horn antenna.

(b) Typically, for a stripped radome the VSWR in any area should not exceed 1·3:1, and for a completely finished radome should not exceed 1·6:1.

5.2.3 **Bonding Test.** The following checks should be carried out to ensure that the electrical bonding is satisfactory.

(a) Check that the resistance between the aft end of the diverter strip and the bonding plate on the inside surface of the radome does not exceed 0·008 ohm.

(b) Check that between the rear end of the diverter strip and the aircraft skin immediately aft of the radome hinge line the resistance does not exceed 0·01 ohm.

(c) Check that between the forward end of the diverter strip and the aircraft skin aft of the radome hinge line the resistance does not exceed 0·05 ohm.

NOTE: When using a bonding tester, care must be taken not to damage the diverter strips with the point of the probe. Contact should be made by pressing the flat surface of the probe against the strip.

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AIRCRAFT

RADIO

TRANSMISSION LINES AND WAVEGUIDES

1 INTRODUCTION Transmission lines and waveguides are the means by which radio frequency (RF) energy is guided from one point to another. A typical application is the transfer of energy from a transmitter to its associated aerial. Although transmission lines and waveguides serve the same purpose, the choice of which to use is dependent on the frequency of the energy and the power to be transmitted. Generally, in aircraft applications transmission lines are used for frequencies below 5000 MHz and waveguides for higher frequencies. It should be noted that for dimensional reasons the use of waveguides is impractical at frequencies lower than about 3000 MHz. At frequencies above 5000 MHz, waveguides are preferred because of their lower circuit losses (paragraph 3.4).

2 TRANSMISSION LINES A transmission line consists of two wires, of any length, suitably insulated from each other. A particular case of a two-wire transmission line is a coaxial cable (paragraph 2.4).

2.1 **Two-Wire Line.** Associated with each line there is inductance and resistance which is evenly distributed throughout the entire length of line and, similarly, there is distributed capacitance and conductance between opposite lines. At high frequencies the inductance (L) and capacitance (C) have a much greater effect than the resistive and conductive components which may be ignored and the impedance of the line is equal to $\sqrt{L/C}$ which is known as the characteristic impedance (Zo) and is purely resistive. If the line is terminated in a load impedance equal to Zo all energy is absorbed in the load. For any other value of load a mismatch will exist and the load will not dissipate all the energy and all or part of the energy will be reflected. Figure 1 shows the effect when the line is open circuit at the receiving end. The result of the incident and reflected wave on the line is that standing waves are set up and, in the open circuit case, the voltage standing wave is a maximum and the current standing wave is zero at the end of the line. There would also be a 90° phase difference between the voltage and current standing waves. The voltage standing wave will also be a maximum at half-wavelength intervals from the receiving end. In respect of a transmission line, a wavelength (λ) is defined as that length in which the signal phase changes through 360° and is determined by the physical characteristics of the line. Similarly the voltage standing wave will be zero at odd quarter-wavelength intervals from the receiving end. The current standing wave maximum and zero values are displaced by a quarter wavelength from the voltage standing wave. If a short circuit exists at the receiving end (Figure 2), standing waves are again produced but the voltage and current maximum and zero values are reversed from the open circuit positions. For a load impedance not equal to Zo reflected waves are produced (Figure 3) and the maximum and minimum values of the resultant standing wave will depend on the load (Z_L) which can be a complex quantity; the phase difference at the receiving end between the incident and reflected waves will be determined by the reactive component of Z_L.

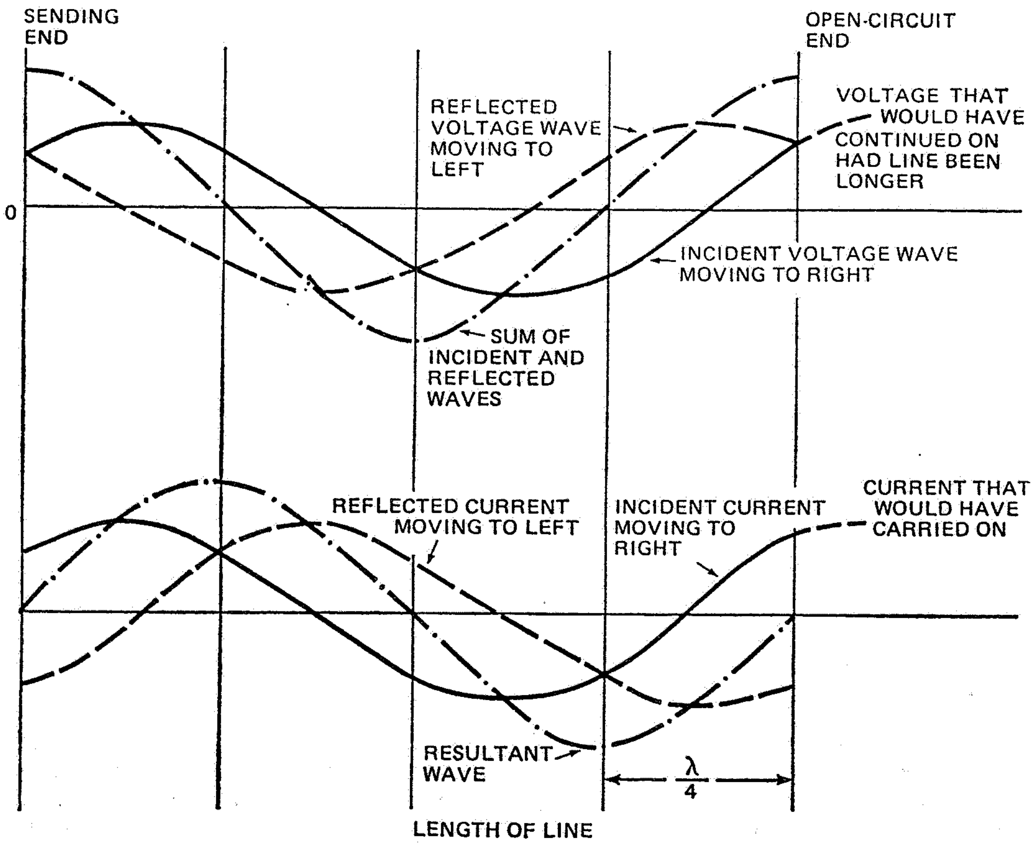


Figure 1 FORMATION OF STANDING WAVES ON OPEN CIRCUIT LINE

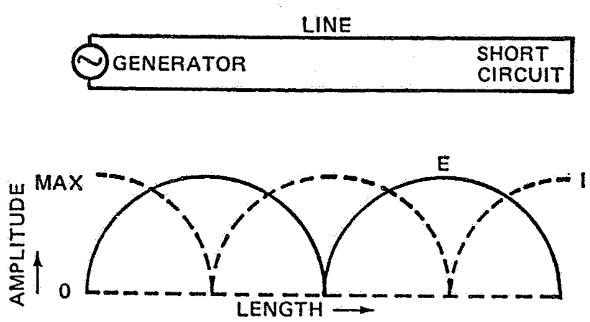


Figure 2 STANDING WAVES ON SHORTED LINE

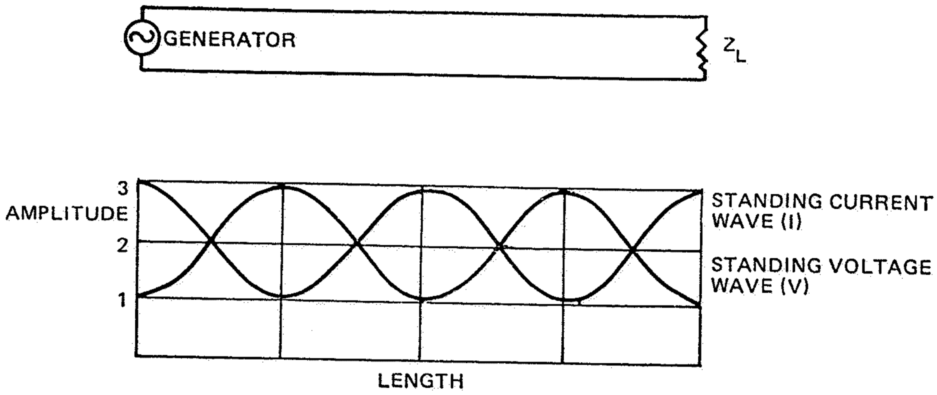


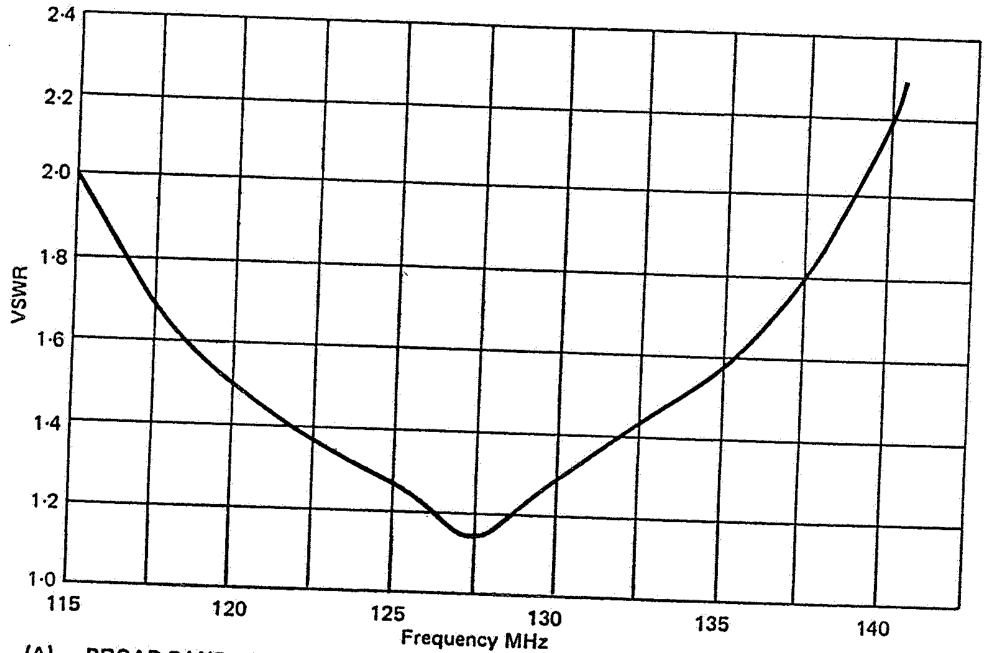
Figure 3 STANDING WAVES ON MISMATCHED LINE. VSWR=3:1

2.2 **Standing Wave Ratio (SWR)**

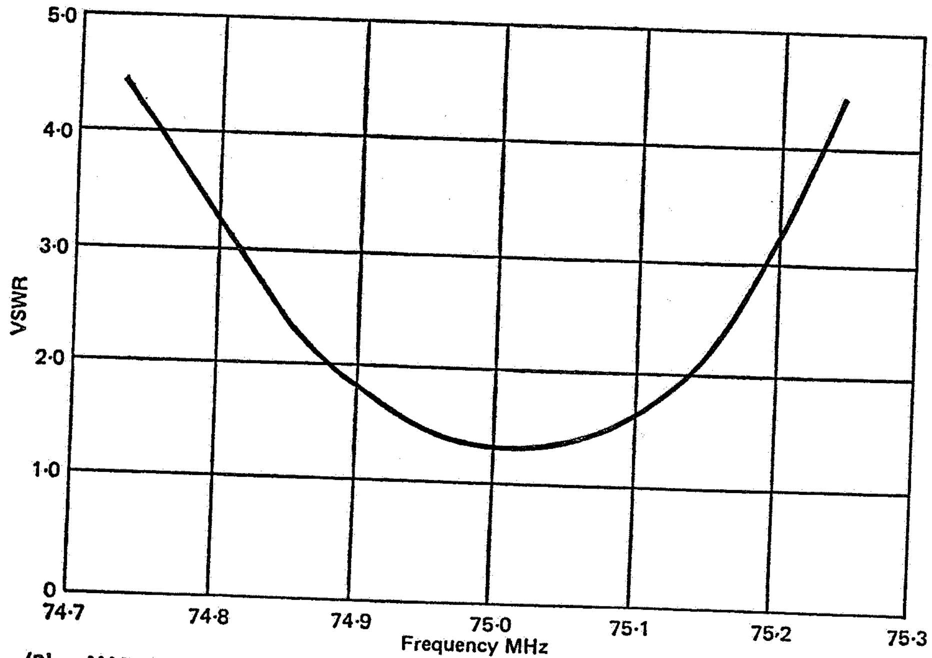
2.2.1 Distribution of the voltage (or current) along a transmission line can usefully be defined in terms of the ratio of the standing voltage maximum (standing current maximum) to the standing voltage minimum (standing current minimum). This quantity is termed the Standing Wave Ratio and, more generally, since voltages are considered, the Voltage Standing Wave Ratio (VSWR). The standing wave ratio $S = \frac{\text{Standing V max}}{\text{Standing V min}}$ where standing V max is the sum of the incident (V_I) and the reflected (V_R) voltages and standing V min is the difference between V_I and V_R and thus the VSWR $= \frac{V_I + V_R}{V_I - V_R}$. From this equation it is seen that a VSWR = 1 indicates that there is no reflection whilst a very high VSWR indicates that the reflected voltage almost equals the incident voltage. Assuming zero attenuation along the line, the VSWR will be infinite when the line is terminated in either an open or short circuit. The example in Figure 3 shows that the ratio $\frac{\text{standing wave voltage max}}{\text{standing wave voltage min}} = \frac{3}{1}$ thus producing a VSWR of 3 : 1. Measurement of VSWR will indicate the existence of reflected waves on the line which, in turn, will indicate the degree of mismatch between the transmitter and load.

2.2.2 Losses along the transmission line will attenuate the incident and reflected signals thus the VSWR will vary along the line. If, as an extreme example, the incident signal is completely attenuated along the line, there can be no reflection from the load. In this example even though a complete mismatch may exist at the load, the VSWR measured at the sending end will be 1, i.e. a perfect match. Methods of measuring VSWR are described in paragraph 5.

2.2.3 In practice, a VSWR of 1 cannot be achieved and in carrying out tests and adjustments on aerials, the lowest practical VSWR is sought. If an aerial is to operate over a band of frequencies, e.g. 118 MHz to 136 MHz, it is preferable to obtain a VSWR which is acceptable throughout the frequency band even though this may not be the minimum obtainable value at certain frequencies. The VSWR curves for two typical aerials used over a band of frequencies are shown in Figure 4.



(A) BROAD-BAND VHF COMMUNICATIONS AERIAL



(B) MARKER BEACON RECEIVER AERIAL

Figure 4 TYPICAL VSWR CURVES

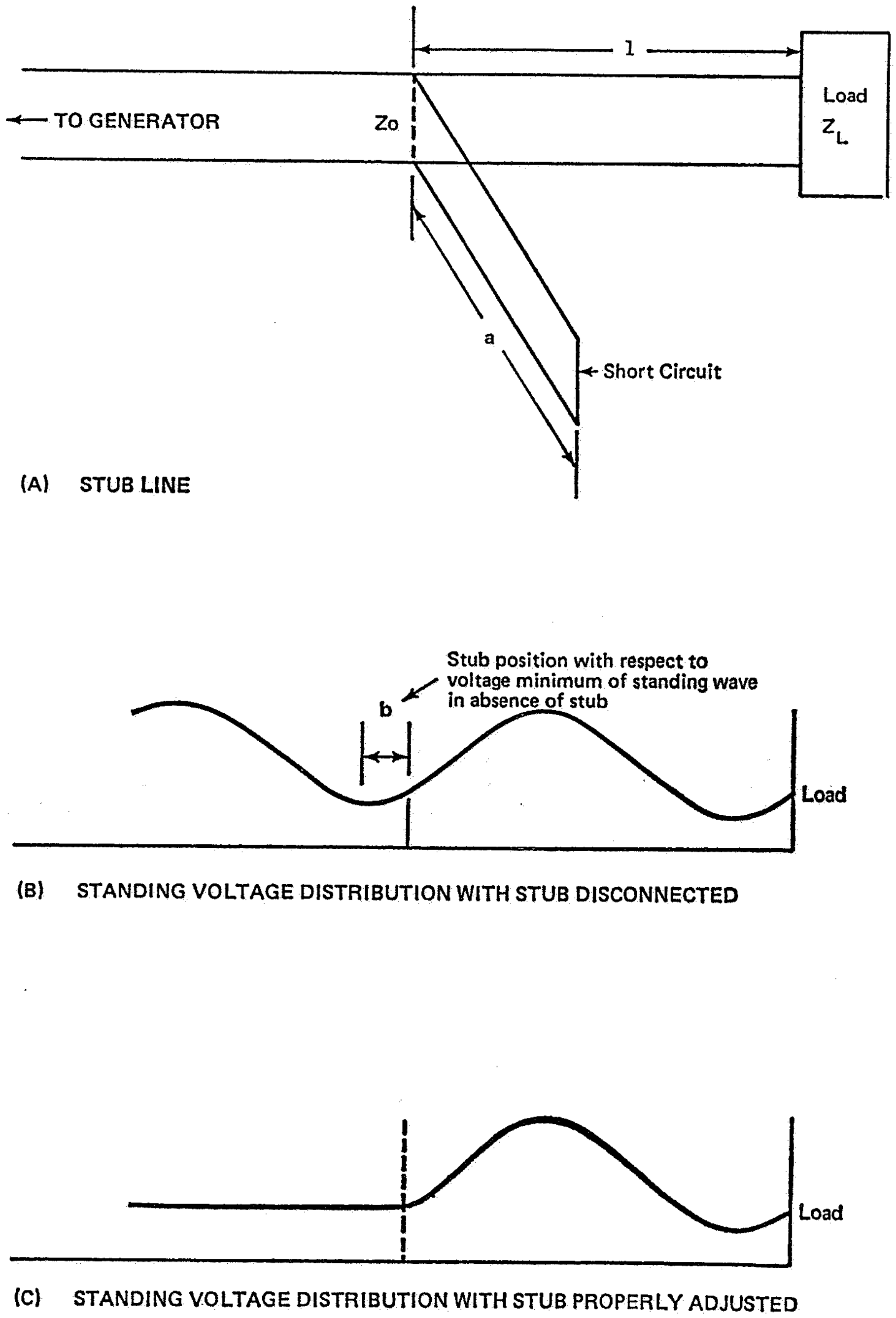


Figure 5 MATCHING BY MEANS OF A SHORT-CIRCUIT STUB

2.3 **Impedance Matching.** Energy is transmitted most efficiently by a transmission line when no reflected wave is present. Generally, the load impedance will not have a resistive value which is exactly equal to the characteristic impedance of the line, thus it is necessary to provide means of matching the load to the characteristic impedance of the line. It should be noted that features which, for matching purposes, are used to increase the bandwidth of an aerial, often reduce the efficiency of the aerial itself. Thus the improved efficiency obtained by correctly matching the line may not lead to an equivalent improvement in overall system performance.

(a) In Figure 5 use is made of the 'stub' and here a short section of short-circuited transmission line is connected in shunt with the transmission line. The stub position and length are so chosen that the input impedance of line 'l', shunted by the input impedance of stub line 'a' will equal the characteristic impedance Zo. Therefore, although the line 'l' and stub 'a' both produce reflected waves they are in anti-phase and cancel so that there is no reflected wave on the generator side of the stub. Any load impedance may be matched in this way provided it is not an open-circuit, a short-circuit or pure reactance.

(b) A method often used to match the unbalanced (coaxial) feeder to a balanced system is the arrangement shown in Figure 6. The arrangement is known as a 'balun', a contraction for 'balanced to unbalanced'. The balun is formed by folding the end of the feeder, one quarter of a wave in length, with the outer (screen) broken at the fold and connected to each aerial element (load Z_L). The inner is continuous and unconnected whilst the screens are shorted together at the extreme end of the stub. Since the outers form a short circuit quarter wave stub, the short at point X is reflected to give a high impedance at points A and B effectively isolating the outer conductor from earth and maintaining the balanced characteristics of the aerial. Similarly, the inner conductor being an open circuit to its outer, effectively at the quarter wavelength point, will be reflected as a short circuit at A thus connecting the feeder cable to the aerial system.

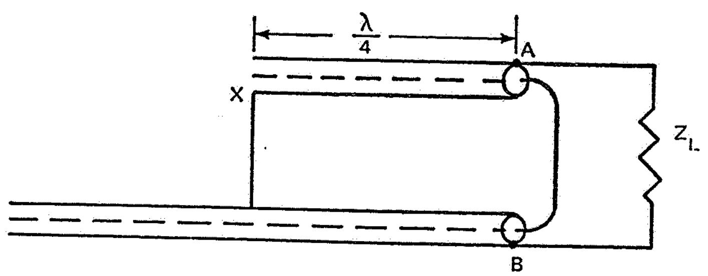


Figure 6 BALUN IMPEDANCE MATCHING

(c) If the load impedance is resistive, or can easily be made resistive by tuning, the matching problem is simplified since all that is required is to transform the actual resistance present to a value that is equal to the characteristic impedance of the line. Techniques which can be used to achieve this include the use of the quarter-wave transformer. A quarter-wave section will always invert any impedance at its receiving end. The section is reactive to frequencies at which it is not a quarter wavelength and is electrically similar to a parallel resonant circuit which, theoretically, has a high impedance at resonance. An open-circuit will present zero impedance at the sending end of the section and a short-circuit will present a very high impedance at the sending end, i.e. open-circuit becomes a short-circuit and short-circuit becomes an open circuit. When a quarter-wave section is terminated in a resistance, inversion still takes place and the resistance seen at the sending end can be calculated from the equation:—

$$Z_S = \frac{Z_O^2}{Z_R}$$

where Z_R is impedance at receiving end
Z_O is characteristic impedance of line.

2.4 **Coaxial Line.** This is the most commonly used type of line for RF transmission. The line may be either rigid (Figure 7) or flexible (Figure 8). At frequencies of the order of 5000 MHz, use is made of the rigid coaxial cable having air dielectric which has a low loss. In this cable the centre conductor is supported with metallic insulators which are quarter-wave sections of coaxial line. Since there is air in the interior, the interior of the line is usually pressurized to keep moisture out. Flexible coaxial cables usually employ polyethylene as the dielectric material. Polyethylene is unaffected by such fluids as acids, alkalis, aviation gasoline, oil, hydraulic brake fluid or sea water. At the lower radar frequencies (of the order of 2000 MHz) the cable losses are low.

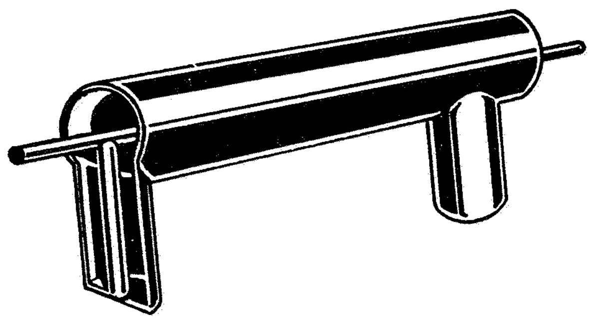


Figure 7 RIGID COAXIAL CABLE WITH METALLIC INSULATORS

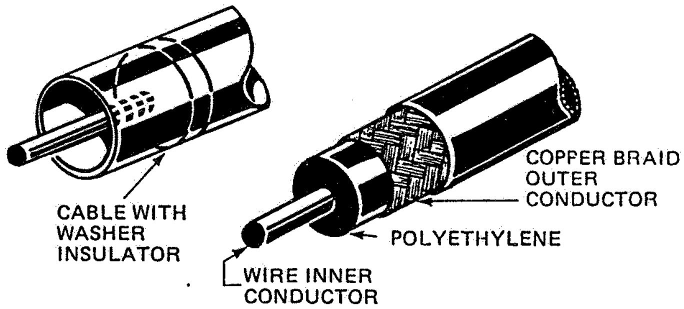


Figure 8 FLEXIBLE COAXIAL CABLES

2.5 **Losses.** In transmission lines, losses may be of three types—copper, dielectric and radiation or induction losses.

2.5.1 **Copper Loss.** One form of copper loss is power loss resulting from I^2R since the resistance of the conductor is never zero. A further loss results from skin effect. Skin effect is the tendency for alternating currents to flow near the surface of a conductor. Since the resistance of a conductor varies inversely with the cross-section, the effective cross-section is less and consequently the resistance is greater. As the frequency is increased this effect becomes more marked. The conductivity of an RF line can be increased by plating it with silver. The majority of the current will flow in the silver layer and the copper will serve mainly for mechanical support.

2.5.2 **Dielectric Loss.** This loss results from heating of the dielectric material (insulation) between conductors. The heating is caused by disturbance of the orbits of the electrons as a result of a potential difference between the conductors. The change in the paths of the electrons requires work (power) which is supplied by the RF power for the line. The losses can be reduced by selecting materials whose atom structure is readily distorted. Such a material is polyethylene which is used extensively in coaxial cables.

2.5.3 **Radiation and Induction Loss.** These losses are similar, both resulting from the fields surrounding conductors. When the field about the conductor is cut by a nearby metallic object, a current is induced in the object with the result that power is dissipated by the object. The power lost is supplied by transformer action from the RF source for the line. Radiation losses result from the fact that some lines of force about the conductor do not return to it when the frequency cycle changes. These lines of force are projected into space as radiation and, as they do not return, the energy they use must be supplied by the RF source. In coaxial lines there is minimal radiation loss since both the electrostatic and magnetic fields are effectively confined within the cable.

WAVEGUIDES A waveguide may be considered to be a two-wire transmission line supported by numerous quarter-wave sections extending above and below the line with each section making contact with the next to form an open-ended rectangular box (see Figure 9). The waveguide will operate over a range of frequencies but there is a lower frequency limit (or cut-off) below which the guide will greatly attenuate energy. The rectangular waveguide width at this cut-off frequency is equal to one half wavelength. In practice, most waveguides are made 0·7 wavelength in the wide dimension. The other dimension is governed by the voltage breakdown potential of the dielectric, which is usually air; common widths are 0·2 to 0·5 wavelength.

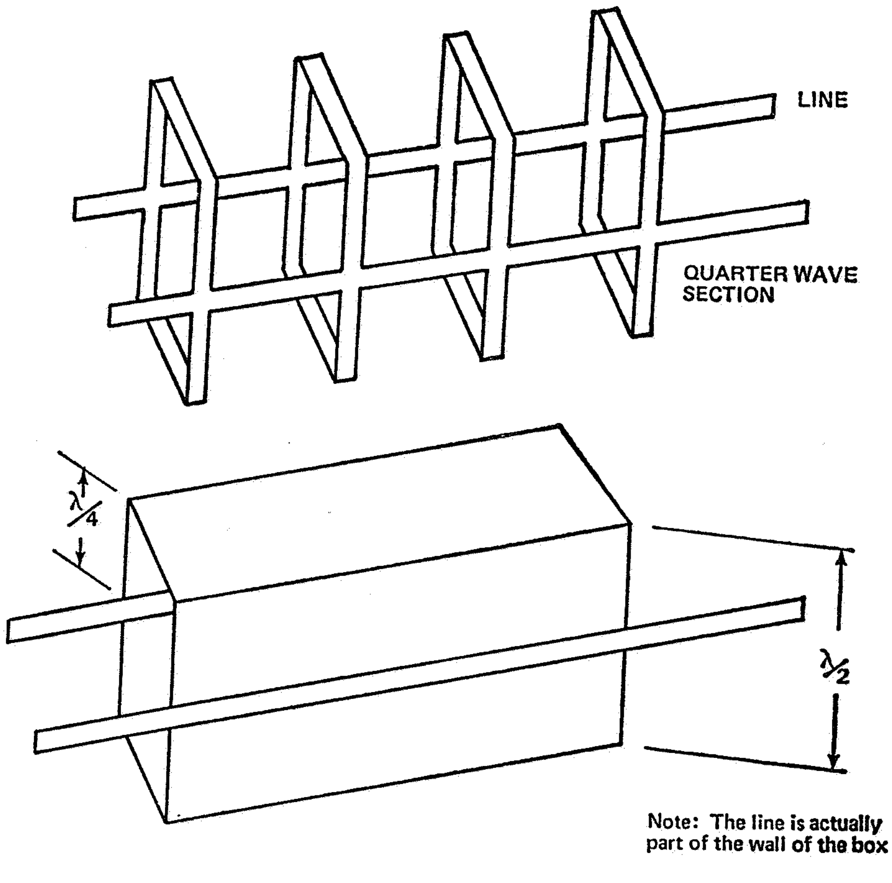


Figure 9 DEVELOPMENT OF WAVEGUIDE BY ADDING QUARTER WAVE SECTIONS

3.1 **Transfer of Energy.** Two fields, the electromagnetic ('h') and the electrostatic ('e'), are always present in a waveguide. Energy is propagated along a waveguide as a series of reflections of the 'e' and 'h' fields from the narrow walls of the guide. For transfer of energy to take place, certain boundary conditions must be satisfied and these are that there must be no electric field tangential to the walls of the guide and that there be no perpendicular component of the magnetic field at the guide surface. These conditions are satisfied by the 'e' field being a maximum at the centre of the guide and falling to zero intensity at the sides and the 'h' field lines being parallel to the guide surface as shown in Figure 10. The number of 'e'-lines in a given area indicates the electrostatic field strength while the number of 'h'-lines in any given cross-section indicates the magnetic field strength. The configuration of the fields is known as a Mode of Operation. For that shown, the configuration is known as the Dominant Mode since it is the easiest to produce.

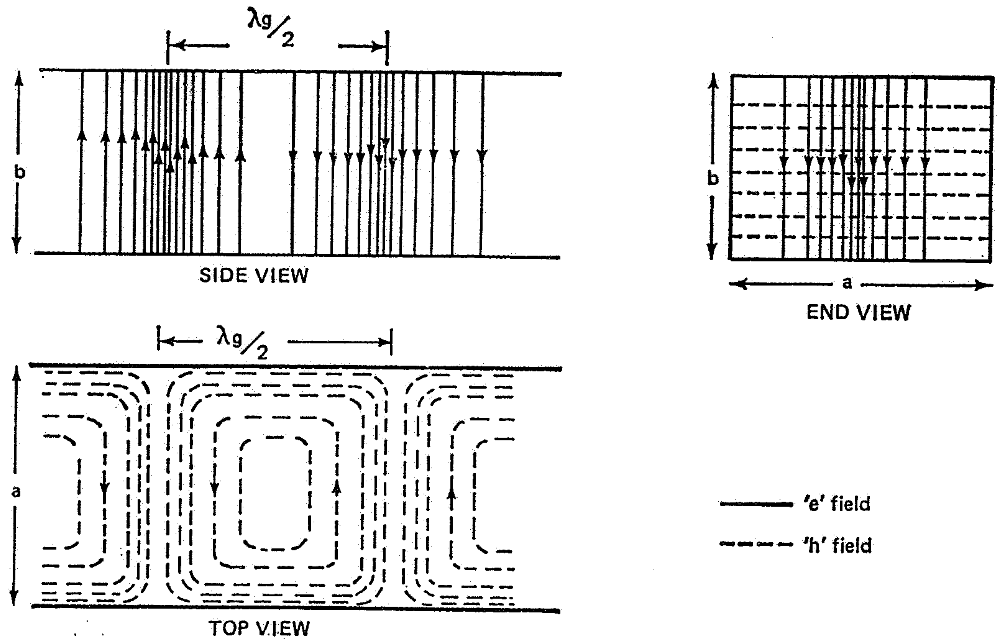
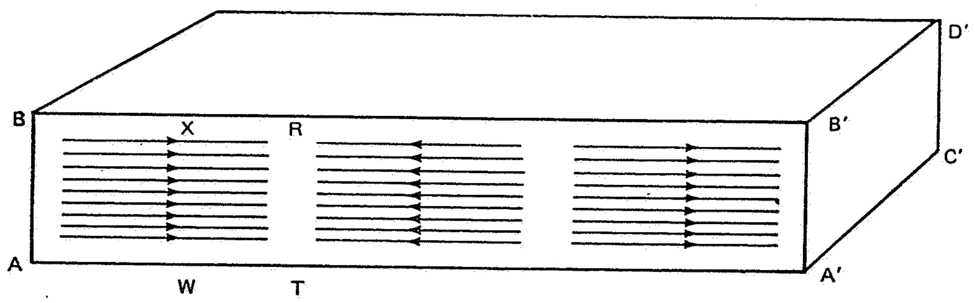
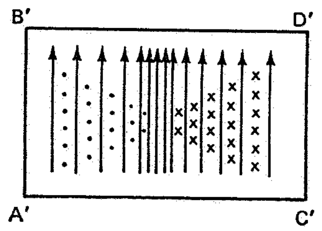


Figure 10 FIELDS IN WAVEGUIDE

3.1.1 Modes are classified as either transverse electric (TE) or transverse magnetic (TM). In a TE mode, all parts of the electric field are perpendicular to the length of the guide and no 'e'-line is parallel to the direction of propagation. The TE mode is sometimes referred to as the H-mode. In a TM mode, the plane of the 'h'-field is perpendicular to the length of the waveguide and no 'h'-line is parallel to the direction of propagation. The TM mode is sometimes referred to as the E-mode. The mode is further defined by the use of two numbers, the first indicating the number of half-wave patterns of the transverse lines which exist parallel to the short dimension of the guide and the second indicating the number of transverse half-wave patterns parallel to the long dimension of the guide. If no change in field intensity occurs, a zero is used. Thus TE_{01} indicates that the magnetic field lies partly along the length of the guide and the electric field is transverse (see Figure 11). The dominant mode is variously described as TE_{01}, TE_{10}, H_{10} or H_{01} since the first figure is sometimes taken to refer to the short side and sometimes to the long side, e.g. TE_{10} is widely used in the USA to specify the dominant mode.



(A) SHORT SIDE OF WAVEGUIDE LOOKING IN H COMPONENT IN DIRECTION OF PROPAGATION



(B) END VIEW

From X to W in (A) the field is uniform and from R to T it is uniform, being zero all along this line. In (A), from A to B there is no concentration as may be encountered in (B) when going from A'B' to C'D'. On this path (A'B' to C'D') there is one definite maximum encountered and thus TE_{01} describes the mode.

Figure 11 TE_{01} MODE

3.2 **Standing Wave Ratio.** The field configuration in a waveguide behaves in the same way as a wave on a transmission line. The magnetic and electric fields travel down the guide and at the end of the guide, if the load is not a matched termination, a reflection is produced which creates a similar field configuration travelling in the opposite direction. The electric and magnetic fields of the guide can be considered as the equivalent of the voltage and current of the transmission line. The super-position of the incident and reflected wave gives rise to amplitude distributions along the guide. A short-circuit at the end of the guide gives a distribution in which the resultant electric field is maximum at distances from the load corresponding to an odd number of quarter wavelengths based on λg, the guide wavelength (the wavelength in the guide is defined as the distance along the axis of the guide between similar field patterns at any instant). The guide wavelength λg, is always longer than the free space wavelength. At the same time, the magnetic field is a maximum at the end and at distances corresponding to an even number of quarter wavelengths. Any resistive load which is not of the correct value to absorb completely the incident wave will produce reflections the amplitude of which will differ from the short circuit case but the maxima and minima will occur at the same places along the guide if the resistive load is less than Zo. If the load is greater than Zo, the 'e' and 'h' maxima and minima will be reversed, since the load is tending towards an open circuit. Loan impedances which have a reactive component will have the minima displaced as in a transmission line. The extent to which a reflected wave is present in a waveguide can be expressed in terms of a standing wave ratio.

3.3 **Attenuation.** In a rectangular waveguide of given dimensions, the attenuation (losses) increases as the wavelength approaches the cut-off value. These losses are skin losses in the guide walls. Generally, wavelengths much shorter than the optimum wavelength attenuate rapidly as a result of increased skin effect per reflection.

3.4 **Losses.** The losses which occur in waveguides are much less than in transmission lines.

3.4.1 **Copper Loss.** In a waveguide there is no centre conductor and the surface area is large, hence when current flows the copper loss is low compared with transmission lines and coaxial cables.

3.4.2 **Dielectric Loss.** Since a waveguide has no centre conductor to support, there is only air inside the guide and as the dielectric loss of air is negligible it follows that the dielectric loss of the waveguide is low.

3.4.3 **Radiation Loss.** The fields are contained wholly within the waveguide just as in a coaxial cable and therefore only a negligible amount of energy is radiated.

3.5 **Impedance.** There are several different ways in which a characteristic impedance can be defined for a waveguide. Each definition gives a different numerical result. For a given guide, the impedance will be a function of frequency irrespective of how it is defined and its value varies with frequency. One definition of impedance is given as the ratio of the strength of the electric field to the strength of the magnetic field:

$$Zg = \frac{\text{Strength of 'e' field}}{\text{Strength of 'h' field}}$$

Another definition of the impedance of a waveguide is the ratio of the maximum value of the transverse voltage to the total longitudinal current flowing in the guide walls for a travelling wave when no reflected wave is present.

3.6 Bends and Joints

3.6.1 **Bends.** Waveguides may be bent in several ways to avoid reflections. One method is to make the bend gradual with the radius of bend greater than 2 wavelengths. Bends may be 90° or less depending upon system requirements. In a sharp 90° bend, normally reflections will occur and to avoid this, the guide is bent twice at 45°, one quarter-wave apart. The combination of the direct reflection at one bend and the inverted reflection from the other bend will cancel and leave the fields as though no reflection had occurred. To cater for special bends, flexible sections of waveguides are often used. These sections can be bent or twisted in any desired direction and they consist of a spiral-wound ribbon of brass with the outside covered in rubber to give it flexibility and to make it both air- and water-tight.

3.6.2 **Joints.** It is not possible to mould an entire waveguide system into one piece for a radar set and thus it is constructed in sections which are connected together by joints. There are three main types of joints; permanent, semi-permanent and rotating.

(a) **Permanent.** This joint is made during manufacture and, when used, the waveguide sections are machined within a few thousandths of an inch and then welded together. The result is a hermetically-sealed and mirror-smooth joint.

(b) **Semi-Permanent.** Where it is necessary for sections to be taken apart for routine maintenance or repair, a semi-permanent joint is used and the most common type is the choke joint. A cross sectional view of a choke joint is shown in Figure 12. It consists of two flanges which are connected to the waveguide at the centre. The right-hand flange is flat, and the one at the left is slotted a quarter wave deep at a distance a quarter wave from the point where the walls of the guide are joined. The quarter-wave slot is shorted at the end and the two quarter waves together become a half wave which reflects a short circuit at the place where the walls are joined together. Electrically, a short circuit exists at the junction of the two waveguides. The two guides can be separated by as much as a tenth of a wavelength without appreciable energy loss and this permits sealing of the interior of the waveguide with a rubber gasket for pressurization.

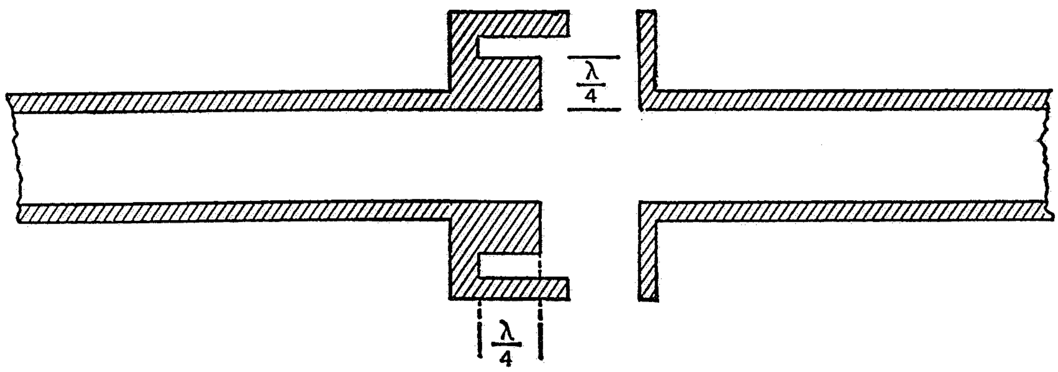


Figure 12 CROSS SECTION OF CHOKE JOINT

(c) **Rotating Joint.** Since the radar antenna rotates, a rotating joint is required for connecting the waveguide to the antenna. A simple method for rotating part of a waveguide system is by using a mode of operation that is symmetrical about the axis as shown in Figure 13. This requirement is met by using a circular waveguide and a TM_{01} mode. In this method a choke joint may be used to separate the sections mechanically and to join them electrically. Airborne radar systems employ rectangular waveguides and hence a different method is required for connecting sections of the waveguide which need to rotate. Two short lengths of circular waveguide can be butted together to form a rotating joint, with transformation to the normal rectangular waveguide at each end. A cross section of such a joint, with a TM_{01} wave in the circular portion and a TE_{01} in the rectangular guide is shown in Figure 14(A). The TE_{01} in the input rectangular guide is transformed into the TM_{01} circular mode as shown. Similarly, the axial 'e' field in the circular section launches a TE_{01} mode into the rectangular output guide. Because of the axial symmetry, the TM_{01} circular mode will present the same field pattern to the output rectangular guide in whatever direction it may be turned The arrangement gives a reasonably pure TM_{01} mode but a certain amount of TE_{11} wave is however set up in the circular guide which is transferred to the output guide and the amount varies with angle of rotation thus giving rise to variation in output. To suppress the unwanted TE_{11} circular mode, two ring filters are mounted as shown in Figure 14(A). These rings act as resonant rejector circuits, rejecting the TE_{11} mode while the TM_{01} mode is almost unaffected since its electric field is always perpendicular to the ring. To prevent radiation from the gap between the two circular guides a choke groove is machined as shown. Another form of rotating joint involves the use of a coaxial cable which provides axial symmetry of the fields and circular cross-section for rotation. In the rotating joint, a probe forms the end of the centre conductor and takes energy from one waveguide and delivers it through the cable to another probe in the other waveguide. The centre conductor remains stationary with respect to one waveguide and rotates with respect to the other. To make the rotating electrical connection, the outer conductor is fitted with tubing having a half wave slot which is shorted at the end and reflects a short at the junction of the outer conductors. No mechanical contact is required between the two sections of the outer conductor. The inner conductor is supported by insulating washers. Figure 14(B) shows a cross-sectional view of the arrangement.

3.7 **Pressurization.** Since airborne equipment is flown at high altitudes, temperature changes will cause moisture condensation inside the waveguide. As water causes extremely high losses, the interior of the waveguide must be maintained at a higher pressure than the outside to drive the moisture out and keep it out. To maintain this pressure, all joints must be airtight.

4 LOSS CHECKS There are various methods for performing loss checks on transmission lines and waveguides. The method used will depend on such factors as frequency and accessibility if checks are to be carried out with the system in situ in the aircraft. The following paragraphs describe some of the methods which may be employed.

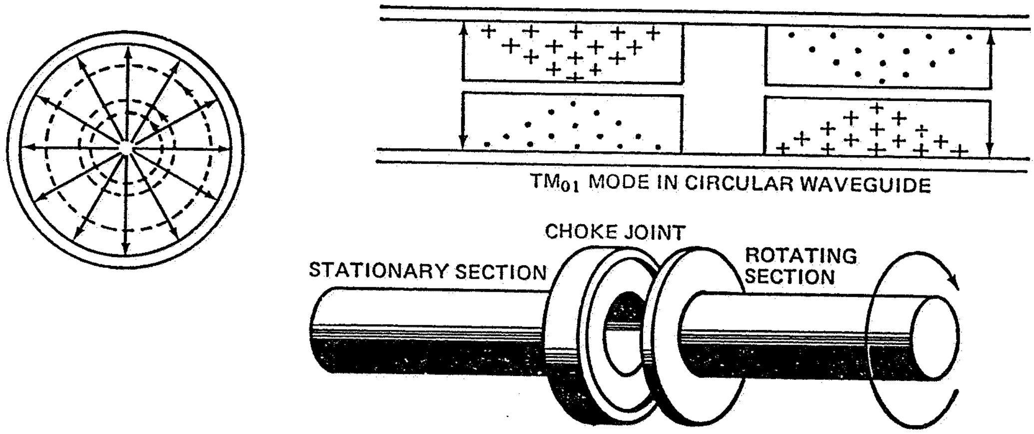


Figure 13 ROTATING JOINT AND TM_{01} MODE IN CIRCULAR WAVEGUIDE

4.1 Transmission Lines

4.1.1 In-Line Wattmeter

(a) The in-line wattmeter should be compatible with the Zo of the line and be capable of covering the frequency range and the RF power of the system to be tested. Any additional lengths of test line used should have the correct characteristic impedance and be as short as possible, preferably a length which produces a total test section insertion of one half-wavelength or multiples thereof at the frequency used.

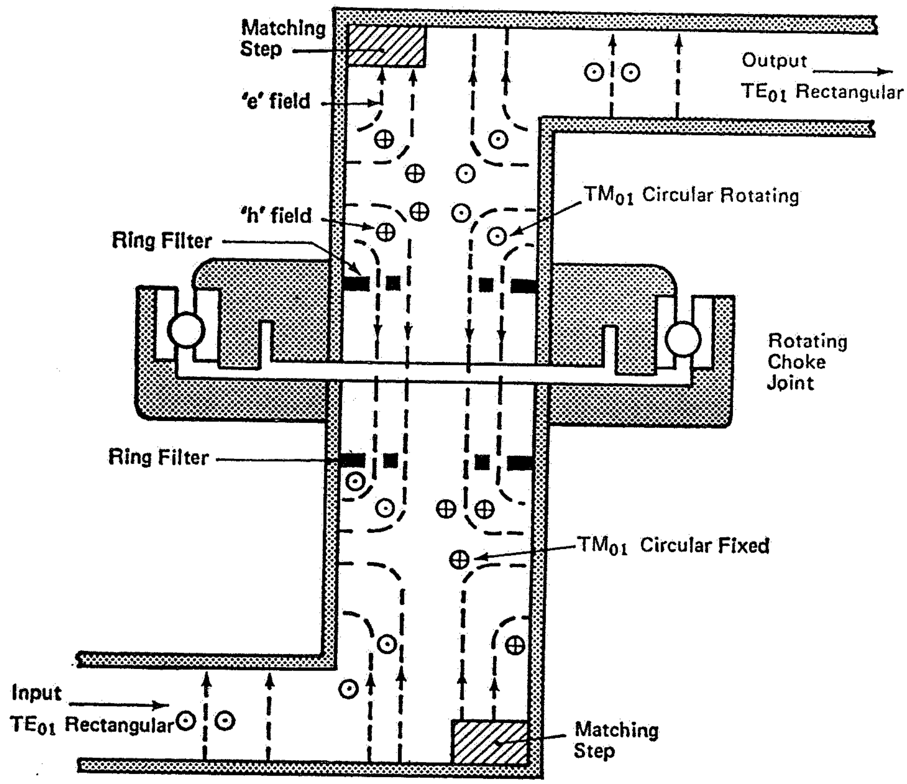
(b) Initially the equipment should be connected with the wattmeter adjacent to the transmitter. With the system transmitting, the forward power should be noted.

(c) The aerial feeder should be re-connected to the transmitter and the wattmeter should now be connected adjacent to the aerial, or adjacent to the aerial tuning unit for HF systems, and the forward power should again be noted with the transmitter on (CW or AM mode for HF systems).

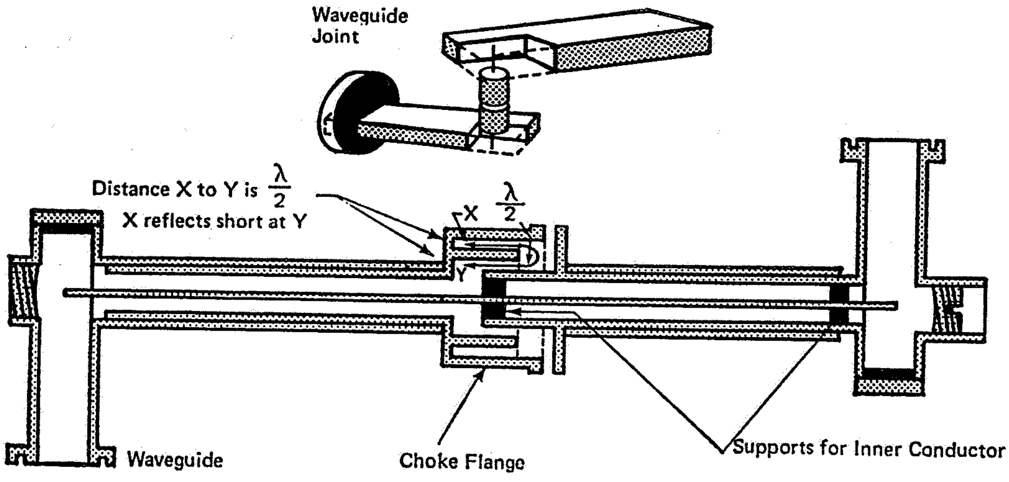
(d) The cable loss may be calculated from the formula:

$$10 \log_{10} \frac{\text{Forward Power at Transmitter}}{\text{Forward Power at Aerial}}$$

(e) Cable loss measurements should be carried out at the centre and ends of the frequency band at which the system operates. Attenuation of aerial feeders may be slightly more than quoted by manufacturers for a given frequency and length as a result of connectors, relays, etc., in the system. It is normal for the attenuation to rise with frequency because of the increase in capacitance loss.



(A) ROTATING JOINT USING CIRCULAR WAVEGUIDE



(B) ROTATING JOINT USING COAXIAL PROBES

Figure 14 ROTATING JOINTS WITH RECTANGULAR WAVEGUIDE

(f) Table 1 gives typical cable loss figures in decibels per 100 feet.

TABLE 1

Frequency	Cable UR 43	Cable UR 67
118 MHz	4·6	2·2
200 MHz	6·5	2·8
300 MHz	8·4	3·7

4.1.2 **Swept Frequency.** Where the system is required to operate over a range of frequencies, use of swept frequency technique is more convenient for checking loss rather than setting an oscillator to various frequencies throughout the band and checking the loss at each frequency. This method uses a sweep generator capable of producing an RF output over the required frequency range. A typical test set-up is shown in Figure 15. Initially the oscilloscope is calibrated with the detector connected directly to the output of the isolator. This adjustment provides a reference point for the test. The section under test is then connected between the output of the isolator and the detector. The oscilloscope controls are now re-adjusted to bring the trace back to the reference line established during calibration. The difference between the new setting and the reference setting is a measure of the loss (or gain) of the section under test.

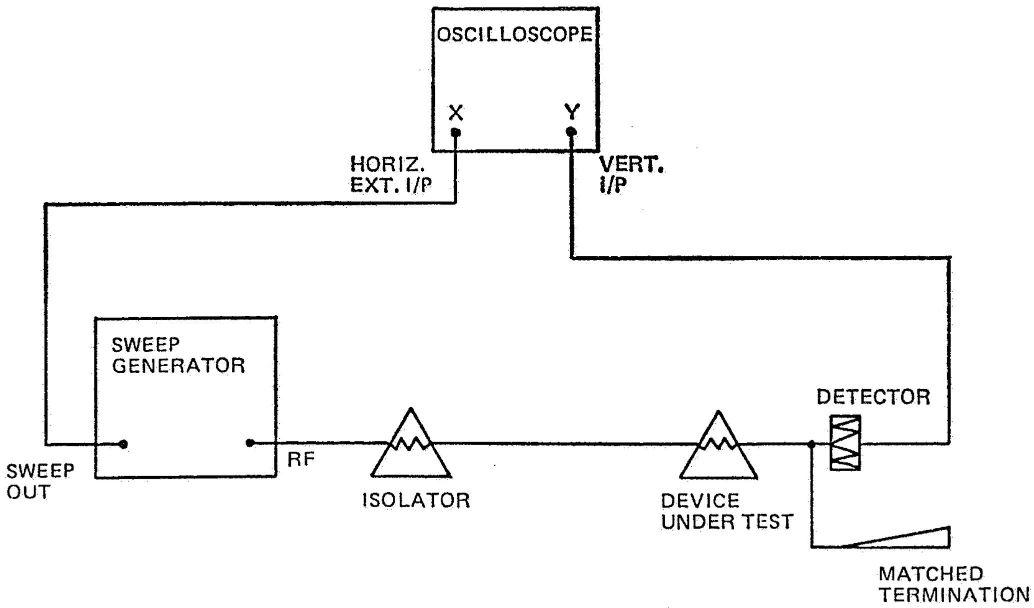


Figure 15 LOSS MEASUREMENT USING SWEPT FREQUENCY TECHNIQUE

4.1.3 If cable loss is required to be measured at a particular frequency or a number of spot frequencies, a simple method employing only a signal generator and a broadband voltmeter may be used. In this method the following procedure is used.

(a) Initially, connect the output of the signal generator to the input of the broadband voltmeter and set up a reference level (V_1) on the meter.

(b) Connect the item to be tested between the output of the signal generator and the input to the voltmeter and note the voltage (V_2) displayed on the meter. The cable loss can then be calculated in dB from the formula:

$$\text{Loss} = 20 \log_{10} \frac{V_1}{V_2}$$

4.1.4 **Time Domain Reflectometry (TDR).** This method is particularly useful where it is required to match a feeder cable to an aerial or where analysis of a feeder performance is required.

(a) The system operates on the principle that any impedance discontinuity along the transmission line will produce a reflection. The method consists of applying a very fast rise-time step voltage to the input of the system under test and monitoring the applied (incident) and reflected voltages on an oscilloscope. This technique shows the characteristic impedance of the line, the position and nature (resistive, inductive or capacitive) of each discontinuity along the line and also whether line losses are series or shunt. The advantage of the system over simple VSWR measurement is that it provides a detailed examination of the line whereas VSWR only gives an overall figure from which, in effect, a figure of merit is established for the transmission system. Figure 16 shows the arrangement for TDR measurements.

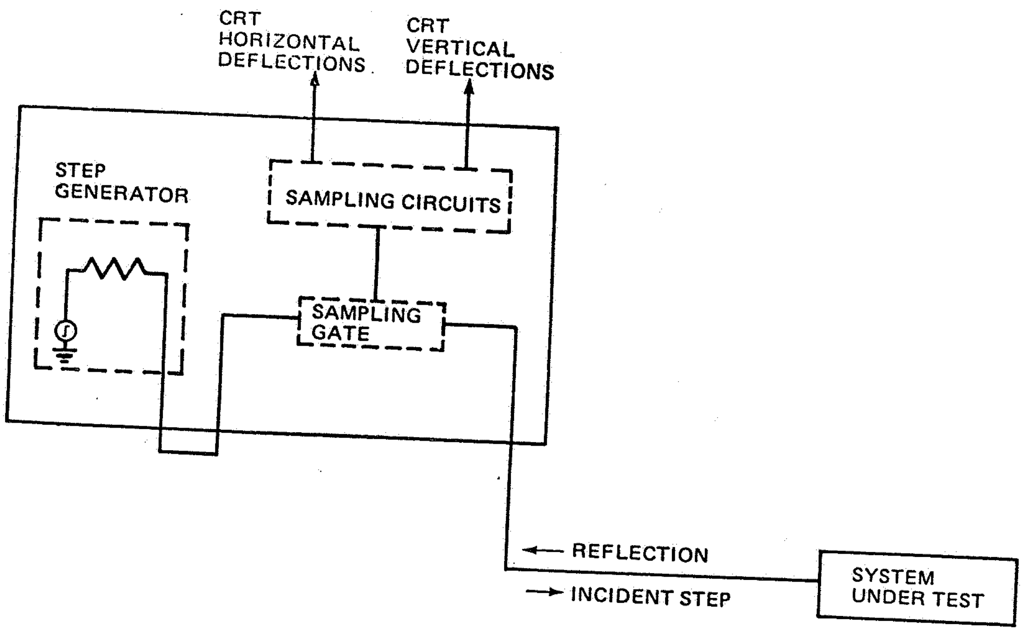


Figure 16 TIME DOMAIN REFLECTOMETRY TEST ARRANGEMENT

(b) The step generator produces a positive-going incident wave which is fed into the system under test. The step travels down the transmission line at the velocity of propagation of the line. If the load is equal to the characteristic impedance of the line, no wave is reflected and all that is seen on the oscilloscope is the incident voltage step. If a mismatch exists, part, or all, of the incident step is reflected. This reflected voltage will be seen on the oscilloscope display algebraically added to the incident step. If the line is terminated in an open circuit, the reflected step will be equal in amplitude to the incident step and will be positive going. If the termination is a short circuit the reflection will again be equal in amplitude to the incident step but will be negative going. Figure 17 shows the oscilloscope display for values of load corresponding to open circuit, short circuit and Z_L not equal to Zo.

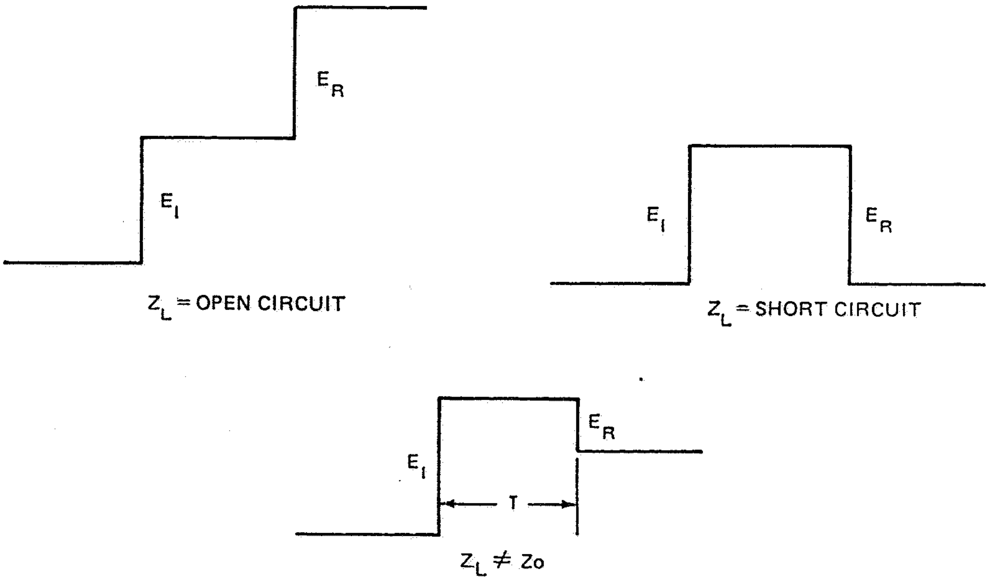


Figure 17 TDR DISPLAYS FOR VARIOUS VALUES OF LOAD

(c) The reflected wave is readily identified since it is separated in time from the incident wave. This time is valuable in determining the position along a line where a mismatch exists. If D is the distance to the fault from the start of a line then,

$$D = V_P \times \frac{T}{2}$$

where V_P = velocity of propagation
T = transit time from start of line to mismatch and back again.

(d) **Interpreting Time Domain Reflections.** Discontinuities, which for the purpose of TDR is the title given to any localized fault which gives rise to a reflection, may be shown as small peaks or bumps (Figure 18). A positive peak or bump indicates a rise in Zo over a short length of line or that there is a series inductance at that point on the line, similarly a negative dip shows a lowering of impedance or a shunt capacitance.

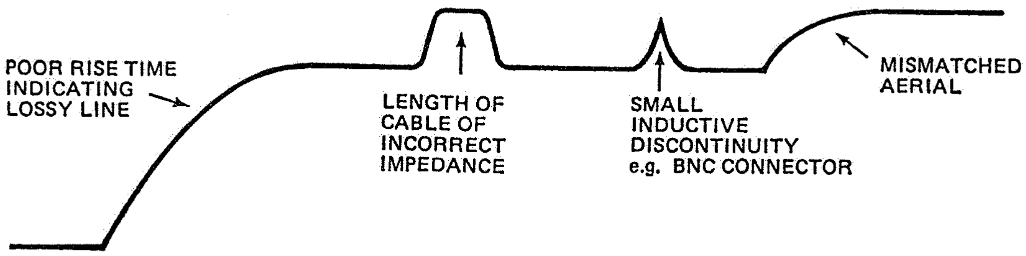


Figure 18 TDR DISPLAY OF VARIOUS FAULTS IN A TRANSMISSION SYSTEM

(i) Experience in the use of TDR is a most valuable asset in the interpretation of reflections. Display wave forms may be affected by several factors such as line attenuation, velocity of propagation for the line, multiple reflections, complex load impedances. Comparison of displays with those for known serviceable aerial systems can be useful in determining the location and magnitude of mismatches or discontinuities.

(ii) Accuracy in distance measuring is dependent on a fast rise-time incident step and long lossy lines can severely degrade rise-time so that both amplitude and shape of reflections are changed. Each discontinuity affects those which follow it, later reflections in a line may be mixed in with re-reflections of earlier discontinuities. Time domain reflectometry is however a recommended method of transmission line or aerial system evaluation. Its use can result in improvement to aerial systems and the speedy diagnosis and rectification of faults.

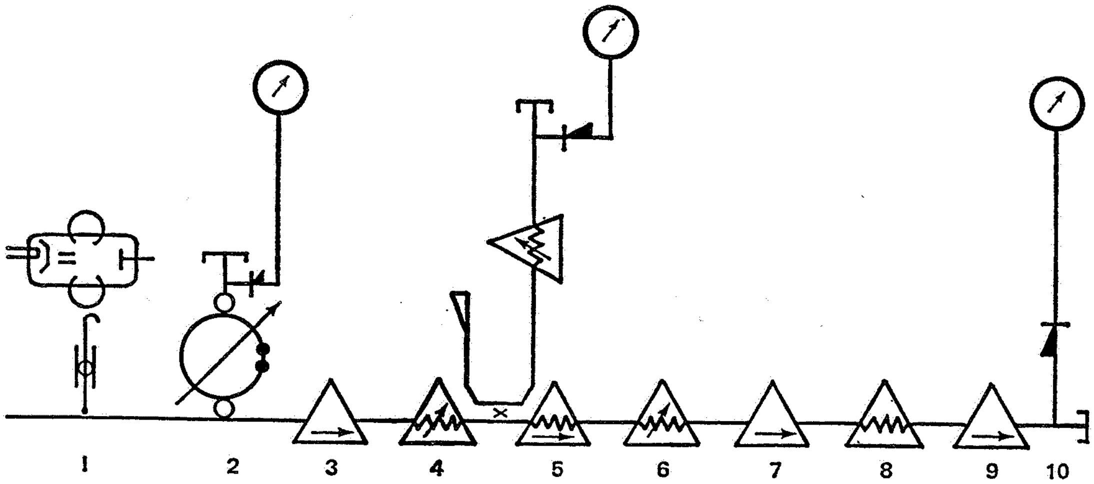


Figure 19 WAVEGUIDE ATTENUATION—TEST ARRANGEMENT

4.2 Waveguides

4.2.1 Attenuation Check

(a) The attenuation (loss) of a length of waveguide or a waveguide system can be measured by substitution. The section to be checked is inserted in the test arrangement shown in Figure 19, and a measurement taken. Removal of the unknown section will result in a changed overall attenuation which can be measured. The difference between the two measurements is the insertion loss of the section.

(b) **Test Arrangement (Figure 19).** Each of the items required in the test arrangement shown has been numbered for the purpose of describing their function and explaining the test method (paragraph (c)).

1. Klystron Oscillator for providing RF power. A stabilized power supply will be required for the Klystron.
2. Frequency measurement and monitor.

3, 5, 7, 9. Isolators. Isolator 3 is used to prevent any mismatch at the end of the line from affecting the frequency or power output of the oscillator; the isolator should be at least 12 dB. Isolator 5 is only necessary if the precision attenuator (6) reflects an appreciable amount of power, which is unlikely with most waveguide attenuators. Isolator 7 is necessary if the unknown section reflects an appreciable amount of power. If it is a bad mis-match the isolator is necessary because any large standing wave pattern in the precision attenuator will give a non-uniform distribution of electric field strength through the attenuator which may alter its calibration. Isolator 9 may be necessary if the crystal receiver is not a good match.

4. Power level setting and monitor by precision attenuator with directional coupler, variable attenuator and crystal receiver.
6. Precision Attenuator.
8. Unknown section of waveguide.
10. Crystal receiver and matched termination.

(c) **Test Method**

(i) Initially, a reference level is set up on the crystal receiver (10) with the unknown section of waveguide (8) connected in the test arrangement and the precision attenuator (6) set to zero.

(ii) The unknown section (8) is removed from the test arrangement and the level on the crystal receiver (10) will rise as some attenuation has been removed. The precision attenuator (6) is adjusted to bring the crystal receiver reading back to the reference level set up in (i). The reading on the calibrated attenuator is then the insertion loss of the unknown section of waveguide. Since the attenuation measurement involves bringing the output of the test arrangement to the same level on the output crystal receiver meter, the measurements are independent of the detector crystal calibration.

(d) **Alternative Test Arrangement**

(i) Figure 20 shows an alternative set-up in which the Klystron signal source is replaced by a sweep generator and the attenuation is displayed on an oscilloscope. With the waveguide section or system connected in the test arrangement the display will represent the attenuation throughout the sweep range.

(ii) To measure the attenuation, a note is first made of the display pattern on the oscilloscope to establish a reference. The unknown section is removed and the rotary attenuator is adjusted to bring the display pattern back to the reference level. The attenuation of the unknown section can be read directly from the rotary attenuator. Typical loss figures for WG 16 waveguide are 0·1 dB/foot for rigid waveguide and 0·15 dB/foot for flexible waveguide.

(iii) As shown in Figure 20 a Bolometer can be used to detect the RF power. The Bolometer is a resistive element which when heated changes its resistance. The change in resistance is measured by a Wheatstone bridge circuit. In its most accurate form, the bridge allows a considerable direct-current flow through the element. Initially it is balanced with no microwave power incident on the device. When measuring power, the element will warm-up, unbalancing the bridge, which can be brought back to balance by reducing the direct current flowing through the element. The power represented by the reduction in current is the same as the microwave power being absorbed by the device. In the circuit of Figure 20 the device is used to provide a deflection source for the oscilloscope 'Y' amplifier. Care must be taken to limit the current through the Bolometer to that recommended by the manufacturer.

(iv) The circuit of Figure 20 can be used with various means of measuring the waveguide attenuation. In one such method the waveguide under test is terminated in a matched load and the output of a crystal detector is fed to the Y input of an X–Y Recorder. Initially the recorder is calibrated with the unknown waveguide out of circuit by plotting calibration lines with the rotary attenuator set to various dB settings over the range of expected attenuation. A plot is then made with the unknown waveguide in circuit and the rotary attenuator set to zero. For WG 16 waveguide, calibration lines would typically be plotted over the range 0·5 dB to 3 dB every 0·5 dB.

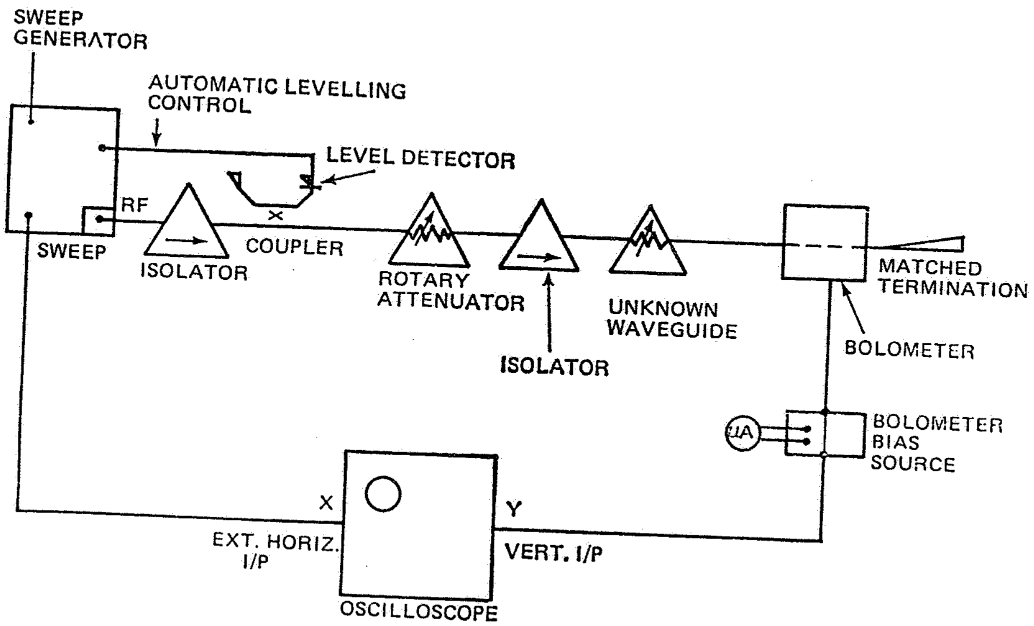


Figure 20 WAVEGUIDE ATTENUATION—ALTERNATIVE TEST ARRANGEMENT

5 VSWR CHECKS As with transmission-line loss checks, the method used to check the VSWR of a transmission line or waveguide will depend on the frequency and accessibility if the system is to be checked in situ in the aircraft. Some of the methods which can be used are given in the following paragraphs.

5.1 **In-Line Wattmeter**

5.1.1 The in-line wattmeter should have performance characteristics appropriate to the measurement being made. Particular attention should be given to the wattmeter's ability to discriminate between forward power and reflected power, its accuracy at high forward powers and low reflected powers, its impedance and frequency range. Servo-driven peak-reading wattmeters are necessary for pulsed systems.

5.1.2 The in-line wattmeter should be connected adjacent to the transmitter and, with the system transmitting on a free channel (HF systems in the CW or AM mode), the forward power should be noted. Any additional lengths of test cable used must have the correct characteristic impedance and be as short as possible, preferably a length which produces a total test section insertion of one half-wavelength or multiples thereof at the frequency used.

5.1.3 The coupling element should be reversed and, with the transmitter on, the reverse power should be noted. From the nomograph (see Figure 21) provided with the wattmeter the VSWR can be found. If a nomograph is not available the VSWR can be calculated from the formula:

$$\text{VSWR} = \frac{\sqrt{\dfrac{\text{P FORWARD}}{\text{P REFLECTED}}}+1}{\sqrt{\dfrac{\text{P FORWARD}}{\text{P REFLECTED}}}-1}$$

The measurement should be repeated to obtain the VSWR at a minimum of three frequencies spaced across the band of the system under test.

5.1.4 The measurement of VSWR described in paragraphs 5.1.2 and 5.1.3 does not represent the true VSWR at the aerial because attenuation in the aerial feeder will reduce the forward power, and the reflected power. It will however show if there is an unacceptable amount of reverse power at the transmitter. An important point is to use, as criteria, the measured VSWR known to be satisfactory for the installed system rather than the published figure for the aerial alone.

5.1.5 To establish the VSWR of the installed aerial, the wattmeter should be connected adjacent to the aerial, or adjacent to the aerial tuning unit for HF systems, and the procedure of paragraphs 5.1.2 and 5.1.3 should be repeated. An important point to note is that any reflecting surface near the aerial, e.g. air scoops, landing gear, hangar equipment, etc., can reflect power back into an aerial and along the transmission line feeder. The power level can be significantly higher than the reflection caused by normal aerial mismatch, thus misleading readings may be obtained. The possibility of such reflections from metal reinforced glass-fibre components should not be overlooked.

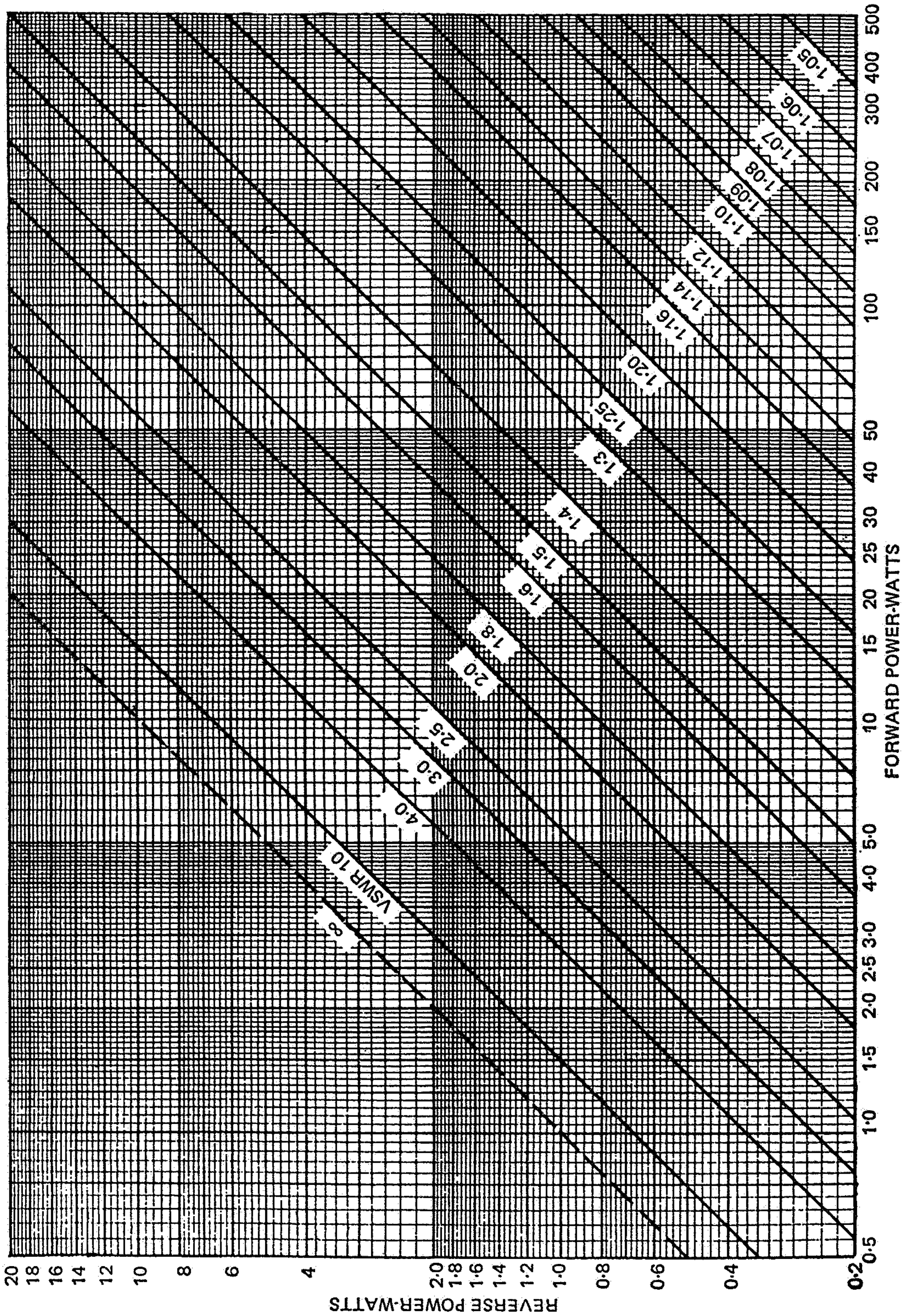


Figure 21 VSWR NOMOGRAPH—POWER VALUES vs VSWR

5.2 **VSWR Bridge.** This method uses an RF version of the Wheatstone bridge circuit to compare the unknown impedance seen at the input end of the system under test with a standard impedance (50 ohms). RF voltage at the appropriate frequency is applied across the bridge and adjusted to maintain constant level during the test. For this constant applied voltage, the out-of-balance voltage of the bridge is a function of the VSWR of the unknown impedance relative to the internal standard impedance. The out-of-balance resultant is rectified and displayed on a meter calibrated directly in VSWR. Measurement does not require adjustment of ratio arms to bring the bridge into balance. The basis of measurement therefore uses the off-balance meter to provide direct reference against an internal standard. The accuracy of the bridge is of the order of 10%. The effect of a standing wave on the line causes the magnitude of the impedance to vary along the line with the maximum value being equal to Zo × SWR and the minimum value equal to $\frac{Zo}{SWR}$. Thus the indicated SWR will vary depending on the length of the feeder. For the most accurate results, it is therefore necessary to connect the bridge directly to the aerial connector when measuring aerial VSWR. Feeders should be checked with a compatible load termination such that any measured VSWR is known to be as a result of the feeder itself.

5.2.1 **Description**

(a) The bridge (Figure 22) consists of two fixed arms R1 and R2 of equal impedance which are high-stability 50 ohm resistors. The third arm is a preselected standard resistance (normally 50 ohms) incorporated within the instrument, and the fourth arm is the system under test. The standard resistance may be replaced by others of different values to permit tests on systems having a non-standard characteristic impedance. Some additional error sources may, however, arise from the ratio arms and connector sockets being no longer optimized.

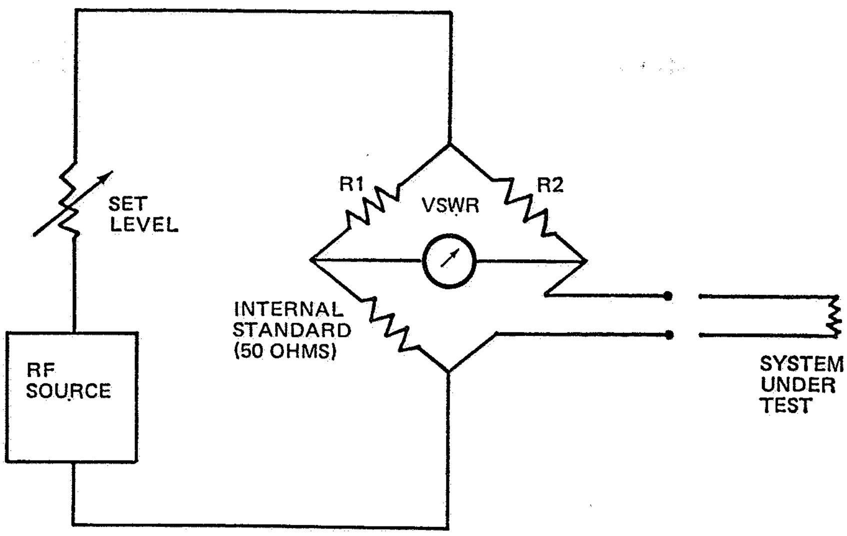


Figure 22 SCHEMATIC OF VSWR BRIDGE CIRCUIT

(b) The calibration of the instrument may be checked and adjusted by connecting an external standard resistance to the test socket. For an instrument having a 50 ohm bridge standard, an external standard resistance of 25 ohms simulates a VSWR of 2:1 and may be used for calibration purposes.

(c) The SET LEVEL control permits adjustment of the RF voltage which the oscillator applies across the bridge, after allowing for the loading produced by connection of the system under test. Adjustment of this control should therefore be made with the system under test connected.

(d) By virtue of its internally-generated RF voltage, the bridge is particularly useful for measurement of receiving aerials and feeders where the absence of a transmitter precludes the use of an in-line wattmeter, e.g. VOR, ILS, Marker. Tests should only be carried out with the aerials in their fully assembled state and with all adjacent structures in position. On aircraft where the rudder mass balance is in close proximity to the VOR–ILS aerial, the rudder should be centralized during the test.

5.3 **Alternative VSWR Bridge Method.** A more elaborate bridge technique employs a sweep signal generator and an oscilloscope to permit display of aerial matching over the complete frequency range in which it is required to operate.

5.3.1 **Description**

(a) In the arrangement shown in Figure 23 the RF comparator bridge is enclosed in a separate unit. Half of the bridge is built-in, while known impedance Z_1 and unknown loads (system under test) are applied to make up the remainder. A standard mismatch is available for calibration and the system incorporates an automatic levelling control (ALC) signal from the bridge which is used to eliminate any error that could be caused by variation in signal level, comparator detector input or feeder discontinuities. A VSWR meter may be incorporated for precise spot frequency measurements.

(b) As in other bridge methods, the detected output signal from the RF bridge represents the degree of mismatch between the reference impedance (Z_1) and the load impedance (Z_2).

(c) This technique may be used to check the VSWR of an aerial or aerial system in-situ but frequently finds application in areas where aerials are being tested during production or prior to fitting to an aircraft. When testing aerials it is essential that they should be well bonded to a large ground plane. Where possible similar methods of attachment should be employed as are used in the aerial's aircraft installation.

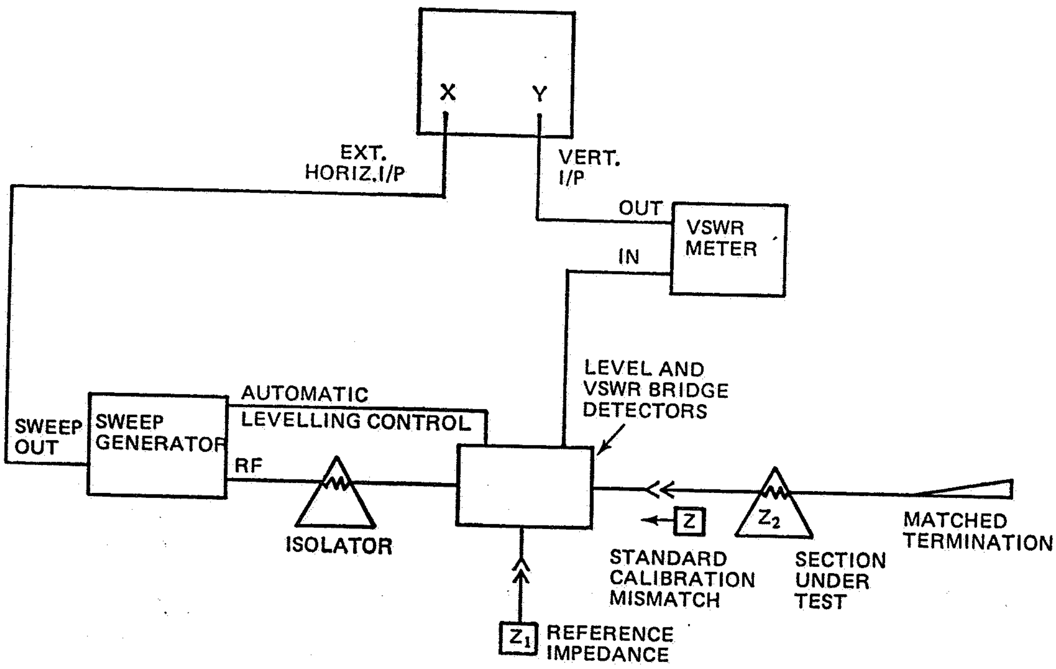


Figure 23 VSWR BRIDGE—SWEPT FREQUENCY TECHNIQUE

5.4 Swept frequency techniques can be used for measurement of VSWR using various methods of display. One such method which makes use of a slotted line with a storage oscilloscope as the display medium is shown in Figure 24. The sweep generator is set to the required sweep range and with RF power on, the slotted line tuning probes are adjusted for as flat a trace as possible. On the oscilloscope, 'write' facility is selected and the intensity and persistence controls are adjusted so that when the carriage of the slotted line is slowly moved from one end of the line to the other a picture is built up as shown in Figure 25. The VSWR at any point is obtained by measuring the dB difference between maximum 'a' and minimum 'b' and converting to VSWR by reference to a conversion table. The VSWR for a particular value of dB can be calculated from the formula:

$$dB = 20 \log_{10} \frac{V_1}{V_2}$$

where $\frac{V_1}{V_2}$ is the voltage standing wave ratio

$$\text{hence, } \frac{V_1}{V_2} = \text{antilog} \frac{dB}{20}$$

for example, if the difference was 1 dB:

$$\frac{V_1}{V_2} = \text{antilog} \frac{1}{20} = \text{antilog } 0{\cdot}0500$$

thus VSWR = 1·122

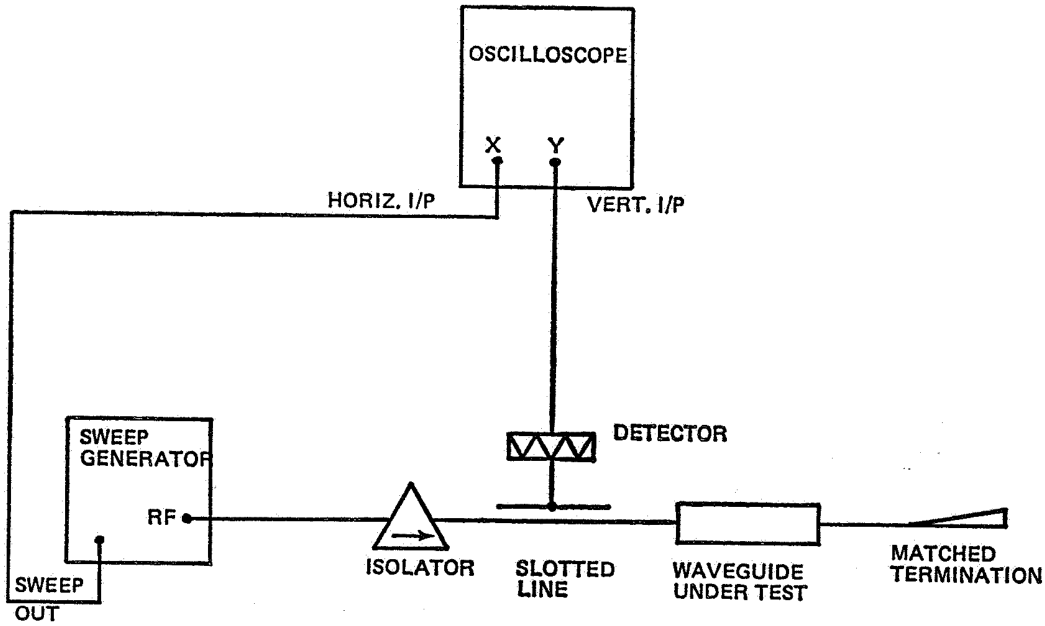


Figure 24 VSWR MEASUREMENT USING SLOTTED LINE

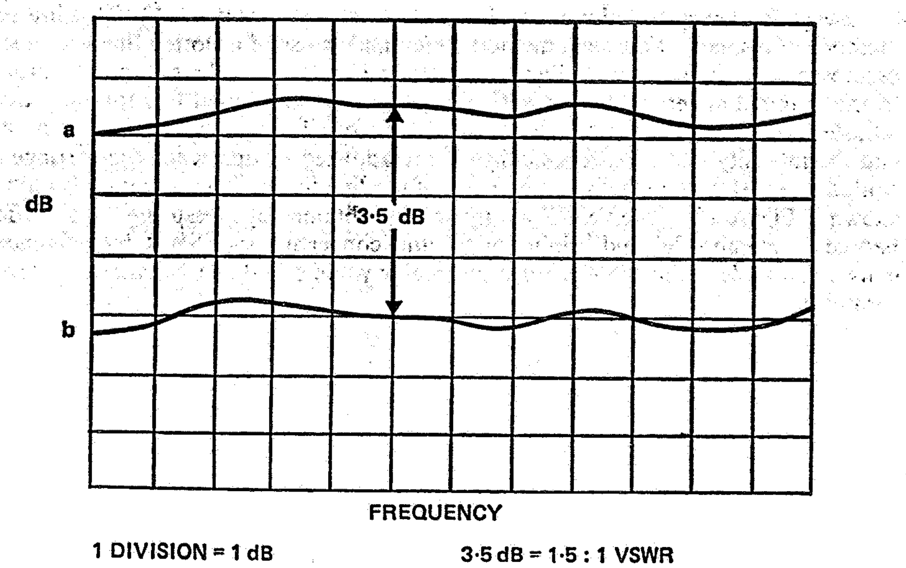


Figure 25 OSCILLOSCOPE DISPLAY USING SLOTTED LINE MEASUREMENT OF VSWR

5.5 By substituting a directional coupler in place of the slotted line in Figure 24, VSWR can be measured using reflectometer technique. Initially, the oscilloscope is calibrated with a short connected to the mainline output of the directional coupler. The device under test is then connected to the output of the coupler and the oscilloscope controls are adjusted to bring the trace as close as possible to the reference line established during calibration. The difference is read directly by adding the setting of the controls to the trace position below the reference line (if the trace is above the reference line subtract that amount from the dB setting). The dB difference figure can be converted to VSWR by reference to a conversion table for the particular coupler or can be calculated from the formula:

$$\text{VSWR} = \frac{\left(\text{antilog}\frac{\text{dB}}{20}\right)+1}{\left(\text{antilog}\frac{\text{dB}}{20}\right)-1}$$

6 WAVEGUIDE PRESSURIZATION CHECK

6.1 A typical set-up for checking leakage of an antenna and waveguide is shown in Figure 26. If the leakage is found to be excessive this may be corrected by renewal of the seal at the suspect joint. If this does not cure the fault, renewal of the part is necessary.

6.2 When checking the waveguide in isolation it is necessary to seal it at one end. Initially, open valve V1, close valve V2 and adjust the pressure source for the appropriate indication on the pressure gauge (typically 15 lbf/in^2). Maintain this pressure in the waveguide.

6.3 Close valve V1 and open valve V2. Observe the flowmeter and check that the air leakage rate does not exceed the value quoted in the relevant Maintenance Manual or manufacturer's instructions (typically not greater than 2 in^3/min).

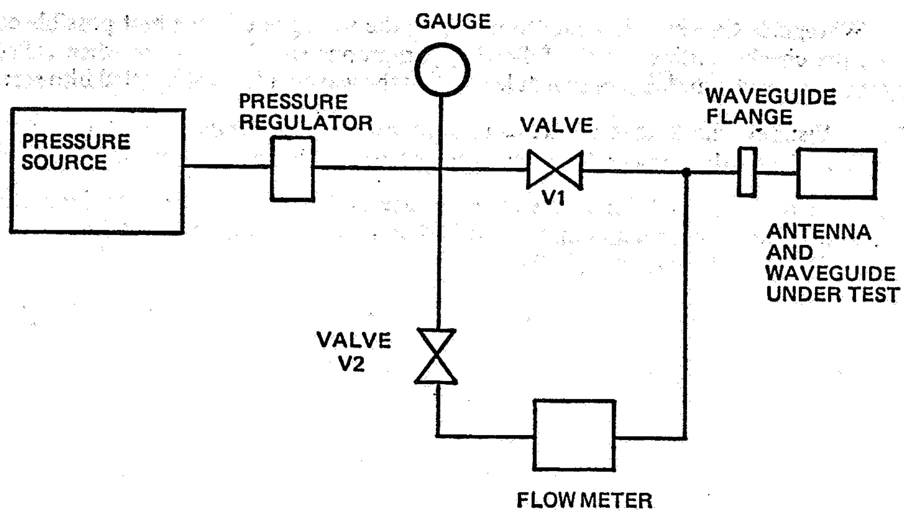


Figure 26 WAVEGUIDE PRESSURIZATION TEST ARRANGEMENT

7 WAVEGUIDE MAINTENANCE

7.1 The necessity to maintain the waveguide in an efficient condition cannot be over emphasized. It is the transmission line between the T/R unit and the aerial and should any losses occur then the efficiency of the radar system is impaired, e.g. maximum range reduced, storm cells not identified. Attenuation in the waveguide reduces the pulse power transmitted from the aerial and also reduces any echo signal between the aerial and receiver.

7.2 There are many points which should be considered when examining the waveguide sections. Any damage or deterioration that changes the impedance or increases the attenuation of the waveguide will affect radar performance. Since the RF current only travels on the thin conducting film of material on the inside surface of the waveguide and choke-joint flange surfaces these should present the best possible conducting properties. Corrosion of the surfaces will increase the I^2R losses thus reducing radiation. Moisture in a waveguide is particularly serious since water causes heavy attenuation and if the moisture is allowed to persist, corrosion will occur. Corrosion is extremely difficult to remove and generally necessitates renewal of affected sections of the waveguide. Maintenance practices should be aimed at preventing moisture from entering the waveguide by sealing it up using rubber sealing rings and by reducing the effect of moisture in the atmosphere in the guide. To absorb moisture content in the atmosphere in the guide, a dehydrator unit containing silica gel crystals may be fitted. The silica gel crystals should be inspected periodically to ensure they are in good condition (blue colour) and if not the dehydrator unit should be renewed. Sometimes a water drain trap is fitted to the waveguide run at a low point to collect any condensation, in which case it should be inspected periodically and emptied if necessary and should also be checked that it is not blocked. Dirt or other foreign matter on the inside surface of the waveguide will also cause attenuation and, to prevent any substance entering the guide when removing units, it is good practice to place plastic covers or bungs over the end of any open guide. Care should be taken in the handling of the waveguide since if the cross sectional dimension of the guide is altered by denting, bending, etc., a mismatch will occur causing energy to be reflected.

7.3 **Waveguide Checks.** In order to maintain the waveguide in the best possible condition, the checks outlined in the following paragraphs should be made when called for by the approved maintenance schedule or when the waveguide is dismantled into sections.

7.3.1 Visually check that no damage such as dents, cracking, distortion, etc., has occurred and that no cracking has occurred where the flanges join the waveguide.

7.3.2 Inspect the condition of the inner surface and flange surfaces, checking that no corrosion has occurred and that all the surfaces are clean, that no scratches are evident and that a good conducting surface exists.

7.3.3 For a flexible waveguide, in addition to the checks of 7.3.1 and 7.3.2, a check should be made to ensure that no perishing or cracking of the outer rubber bonding material has occurred and that the bonding of the rubber to the flanges is satisfactory. A check should be made to ensure that there are no internal breaks by gently flexing the guide and at the same time checking for even flexing along its length. Care must be taken not to overstrain the guide when making flexing checks. Some types of flexible waveguide must not be twisted. If the guide is of a twistable type it should be gently twisted to check that there are no internal breaks.

7.3.4 All rubber sealing rings should be checked to ensure that there is no perishing, hardening or cracking. Any bulkhead coupling seals should be checked for cleanliness and to ensure that there are no cracks, holes or other forms of damage.

7.4 **Waveguide Installation.** The precautions detailed in the following paragraphs should be observed with respect to the waveguide installation.

7.4.1 In general, the waveguide run should be as short as possible to reduce attenuation and it should be properly supported throughout its length; it is usually recommended that the maximum permissible length should not exceed 30 feet. The waveguide must not be installed so that it is suffering any stress or strain. Special clamps will normally be specified to minimize the risk of guide distortion.

7.4.2 Use of flexible waveguide should be kept to a minimum as it has greater attenuation than rigid guide. It must not be installed so that it is overstrained, i.e. bent or twisted too much, and it must not rub against the structure of the aircraft. Flexible guide is normally specified where relative movement between items of equipment occurs: a check should be made to ensure that the required degree of freedom of the moving parts is not restricted by the guide.

7.4.3 Dehydrator units are sometimes fitted to waveguide runs and in such cases a serviceable unit must be fitted on completion of the installation.

7.4.4 If for any reason the waveguide is opened, plastic covers should be placed over the flanges to prevent the ingress of foreign matter, e.g. dirt, sand, oil. Before trying to re-install the waveguide, a check should be made to ensure that any plastic covers have been removed, otherwise damage may result.

RL/3-1

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AIRCRAFT

RADIO

RADIO WORKSHOPS—BASIC FACILITIES

1 INTRODUCTION

1.1 An organisation may be approved to certify that overhauls, repairs, modifications, replacements, inspections and tests to aircraft, engines, items of equipment or components thereof have been carried out in conformity with acceptable standards/specifications and CAA Requirements, subject to compliance with the procedures in Section A, Chapter A8-3 of British Civil Airworthiness Requirements.

1.2 This Leaflet gives guidance on the basic facilities necessary for radio workshops which are established for the overhaul, repair, modification and inspection of airborne radio and radar equipment, also for the manufacture of interfacing cable harnesses, racking, junction boxes and switch boxes forming complete installations in aircraft. Information is also included on documentation and records used in workshops.

2 GENERAL

2.1 Radio workshops can be categorised into two groups, namely those which are established as an adjunct to an approved Maintenance Organisation of an airline solely to maintain that company's equipment and those which are set up independently by Organisations other than an airline, and which, generally, are more extensive and have a much wider scope especially in respect of overhaul facilities.

2.2 It follows that in an airline radio workshop there will be a high degree of standardisation and specialisation. In addition, the resources of the company may include approved electrical and instrument workshops capable of handling such items as rotary transformers, blower motors, synchro and servo-mechanisms, and delicate instruments for which the radio workshop may not be equipped.

2.3 It frequently happens that where workshops are established as part of an airline maintenance organisation, they become encumbered with equipment, racks, cables and other items all requiring technical attention but which could properly be dealt with in a separate workshop within the maintenance area. It is, therefore, recommended that a separate radio workshop should be set up to handle such items as:—

(a) Operating checks on equipment prior to installation in aircraft.

(b) Verification of reported defects.

(c) Storage of serviceable equipment removed from aircraft undergoing extensive servicing checks.

(d) Servicing of racks, cable harnesses, aerials and other associated items during the general course of maintenance.

2.4 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to these as appropriate.

BL/1-7	Storage Conditions for Aeronautical Supplies
BL/1-8	Maintenance and Certification of Aircraft
RL/3-2	Workshops—Test Equipment
MMC/1-1	Printed Wiring Boards
MMC/1-2	Printed Wiring Board Repairs

3 ELECTRICAL AND RADIO INTERFERENCE Radio workshops situated on airports and close to hangars, air traffic control buildings, ground radio stations and electrical installations will inevitably be subjected to a considerable amount of radio and/or electrical interference, sufficient at times to seriously affect the testing of sensitive receivers. In addition, the tuning and testing of transmitters into watt-meters and artificial aerials may result in the generation of further interference. It should, therefore, be determined at an early stage whether incoming or outgoing interference is being experienced and suitable suppression and screening should be provided.

3.1 Incoming interference can be dealt with by adequate filtering of all power supplies and by the provision of screened cages. Further information may be obtained from Leaflet **RL/2-3.**

3.2 Outgoing interference can be suppressed by the adequate screening of aerial cables and made-up artificial aerials, or by operation of transmitters inside screened cages. Further information may be obtained from Leaflet **RL/2-3.**

3.3 Engineers must listen out on the transmitter frequency before switching-on and announce the identity of the workshop.

4 PREMISES The premises selected for a radio workshop should provide a stable environment appropriate to aircraft radio equipment maintenance. Corrugated type roofing should be avoided; if, however, this is not possible consideration must be given to sealing and the fitting of false ceilings. There should be no pollution of the air by dust caused, for example, by aircraft engines running-up, by dope or paint spraying operations or by corrosive agents caused by battery charging. In areas where dust-laden air is frequently encountered or in areas of habitual high humidity, air conditioning plant should be installed, particularly in the stores area and assembly and test bay areas. The radio workshop should also be sited such that no unacceptable electrical interference is present in the radio test area (see paragraph 3).

4.1 The overall lighting intensity should be commensurate with the work to be done, particularly so in the region of the detailed inspection areas. Except for positions where exposed rotating machinery will be operating, the lighting may be of the fluorescent type, provided that it is correctly installed and maintained.

4.2 The building should not be prone to dampness and should be heated, preferably by electricity or steam/hot water central heating. The use of solid fuel or oil heaters is not recommended.

4.3 The workshop and its furnishings should be constructed of materials which assist the maintenance of a clean environment. Concrete and unpolished wood floors should be covered or sealed and painted so as to minimise dust.

4.4 Accommodation separate from the radio workshop should normally be provided for the following:—

(a) Quarantine and bonded stores.

NOTE: Special precautions are necessary for the storage and handling of magnetrons and radioactive valves. Magnetrons should be stored in cupboards remote from any equipment, instruments and components, which may be affected by a strong magnetic field.

(b) A store for items of equipment, test panels, instruments, etc., not immediately required.

(c) Battery compartment (when required).

(d) Office equipment, including record system.

(e) Stripping and cleaning bay.

4.5 In addition to the provision of adequate storage space, the main workshop should be segregated on the following lines.

(a) A zone for racks or cupboards for unserviceable equipment. Two classes of unserviceable equipment need to be catered for, firstly items which are awaiting initial inspection prior to being fed into the workshop, and secondly those items on which some work has been completed but which are held up for lack of spares or information. Unserviceable equipment of either class may, in fact, be stored in the quarantine store and, where workshop space is limited, such an arrangement may be preferable. The use of cupboards or anti-static covers for each class of equipment is essential.

(b) A zone for benches suitable for working, inspection and testing.

(c) A zone for covered dust-free benches for instrument assembly.

(d) A zone for technical manuals, bulletins, specifications, modification leaflets and drawings.

(e) A storage zone for fluids, lubricants, pastes, varnishes and general stores.

(f) A zone for staff personal possessions.

5 TEST BENCHES Where several benches are to be provided with common power supplies, each bench should have an independent control of the d.c. supply with a voltmeter and ammeter of sufficient accuracy permanently connected to the supply. An earth rail of substantial cross section and having a very low resistance to earth should be provided in addition to the 240-volt main supply earth. All mains wiring should be run through metal conduits and provided with 3-pin outlets. Individual power supplies, from a central source, to each bench should be protected by circuit breakers or fuses but power supplies other than the a.c. mains supply may be protected at the test installations, thus avoiding very large main fuses or circuit breakers.

5.1 Test benches may be designed for working on one type of equipment or of a composite type covering several types of equipment. In the latter case it is usual to provide storage space on or near the bench for the different types of connecting harness. Test installations may also be attached to removable panels of a standard size, thus allowing benches to be adapted to suit different requirements.

5.2 Test instruments should either be placed on raised shelves on the benches to permit ease of adjustment and viewing, or they may be carried on portable trolleys. Depth of worktops should be compatible with the size of equipment to be worked on. Additional space should be provided where installations require the use of back plates with edge connectors or separate plugs and sockets at the rear of the equipment under test.

6 POWER SUPPLIES

6.1 **General.** Where the different supplies terminate in sockets, the use of dissimilar sockets is recommended, with each being clearly identified. It is recommended that, where possible, specialised precision power be supplied by individual bench-mounted supply units. Where this is not possible it should be provided as detailed in the following paragraphs, and should be distributed through the workshop with minimal mutual interference. Monitoring of voltage, frequency and current should be provided at the test benches.

6.2 The power supplies described in (a) to (d) should be made available in most radio workshops.

(a) A 240-volt 50 Hz, single-phase a.c. supply for lighting, heating, mains rectifiers, test instruments, soldering irons and other equipment. This supply should be wired throughout in screened conduit.

(b) A 15-volt and a 30-volt d.c. supply regulated at source under varying loads, the current capacity of the cables being determined by the size of the workshop. These supplies may be obtained from a series of secondary batteries of sufficient capacity and may be charged by mains rectifiers. The output should be ripple free and should be filtered to exclude noise and to reduce transient voltage peaks liable to damage the most sensitive equipment, e.g. transistors, integrated circuits and equipment wiring. It is possible to dispense with the use of batteries by utilising a suitable ripple-free stabilised d.c. power supply unit. To minimise voltage loss along the supply lines the d.c. supply should be run in a heavy duty cable. It should also be possible to vary the voltage at the bench positions so as to enable high/low voltage tests to be carried out to the prescribed limits.

NOTES: (1) A common negative cable may be used for the 15-volt and 30-volt supplies.

(2) Cognisance should be taken of prevailing wind direction relative to the workshop and stores, and the battery room ventilation system, to prevent contaminated air gaining access if battery supplies are to be used.

(c) A 19-volt d.c. stabilised supply for the testing of certain equipment; this is best supplied by individual precision supply units.

(d) A 200-volt 400 Hz, three-phase regulated supply, wired to the benches in screened cable, to provide the following precision a.c. bench supplies:—

(i) 115-volt, 400 Hz, single-phase,

(ii) 115-volt, 400 Hz, three-phase,

(iii) 26-volt, 400 Hz, single-phase.

A frequency meter is necessary where the frequency has to be monitored to within ±3 Hz. As an alternative method of supply, individual static invertors can be wired to benches as required.

7 ANCILLARY SUPPLIES

7.1 **Compressed Air.** A low pressure air supply should be provided for blowing out inaccessible dust from the more robust equipment and components and for use in connection with the assembly of instruments (paragraph 9.1.1). The compressed air may be derived from an extension of a main air supply, but must be filtered and dry.

7.2 **Vacuum Supply.** A vacuum cleaner with a small flexible nozzle should be provided for removing dust from delicate equipment and sub-assemblies in the workshop.

7.3 **Test Installations.** Installations specially designed for the operation of certain items of equipment during fault finding and final tests should be provided. Such installations normally include connectors and cable harnesses made up into a back-plate or connected to the rear of the equipment under test by edge-connectors or individual plugs and sockets. No side members or mounting trays should normally be used unless it is impractical to do without; for example, where the connectors are of the sprung-ball-and-socket type, which require a continual pressure to be exerted to maintain electrical contact. Instruments used as part of the test installation should be of a proven accuracy, certified and marked accordingly, together with the period of validity.

7.4 **Power-Unit Test Rigs.** Special rigs should be provided for measurement of power-units, blower motors, switch drives and step-by-step motors. The rigs will also be required for testing on prolonged running and for bedding-in of brushes.

7.4.1 The essential equipment to be fitted to such test rigs are a.c. and d.c. voltmeters and ammeters, frequency-measuring indicators, tachometers and equipment for applying resistive loads. An oscilloscope or similar device may be necessary where ripple voltage needs to be measured.

7.4.2 Where it is necessary to load power-units by means of switched fixed-resistors, continuously-variable rheostats or by controlling the grid circuit of a suitable power-output valve, the high-tension supply should be derived from the unit under test.

7.4.3 Where certain units, such as switch drives, require a torque test, testers should be provided.

NOTE: Testers made locally should be calibrated using an accurate spring balance.

8 SPECIALISED EQUIPMENT TESTING

Airborne equipment of a specialised nature, such as VOR/ILS, DME, Transponders, Doppler and weather radar may need to be tested only at specially equipped bench positions. Careful planning of these positions in relation to the total working area is necessary and careful siting of such benches may be necessary to avoid radio interference with other equipment being tested at other positions.

8.1 **Certification of Radio Equipment.** To enable certification of radio equipment following workshop repair, modification and test, it will be necessary to provide the following:—

(a) Test installations with the necessary harness incorporating the required test points, switches, jacks, etc., as specified in the equipment Overhaul Manual.

(b) Certified test equipment as specified in the equipment Overhaul Manual. Appropriate technical manuals for this test equipment will also be required. For further information on test equipment see Leaflet **RL/3-2.**

(c) Tools, lubricants, solvents and accessories, as specified in the equipment Overhaul Manual.

8.1.1 Procedures should be introduced to control the use of lubricants, solvents, etc. other than those specified in the equipment Maintenance and Overhaul Manuals. The use of such products should only be authorised after appropriate expert advice has been sought.

8.2 Where repair work to be undertaken includes printed circuit boards, a selection of suitable tools should be provided. For information on the repair of printed circuit boards see Leaflet **MMC/1-2.**

9 RADIO INSTRUMENTS The term "radio instruments" is taken, in general, to mean those instruments which operate independently of non-radio aids and flight systems but may include instruments such as radio magnetic indicators where arrangements are made for an approved instrument shop to carry out and certify work on the compass card synchro.

9.1 **Instrument Overhaul**

9.1.1 A small work bench should be provided for the dismantling, inspection, re-assembly and testing of radio instruments. The bench should be fitted with a dust-proof enclosure in the form of a detachable or hinged cover of laminated glass with a gap at the front sufficient for the operator to insert his hands for assembly and sealing work.

(a) A filtered and dried compressed air supply should be available to be brought in at the back of the enclosure to operate at a pressure slightly higher than ambient, and thus provide a means of sealing the cabinet from the ingress of foreign matter. A mirror held up to the air nozzle will show whether or not condensation takes place, and thus determine if the air is dry enough.

9.1.2 Covered trays should be provided for storage of exposed parts of equipment awaiting inspection.

9.1.3 Where instruments are required to be hermetically sealed, the process must be carried out in accordance with the manufacturer's specification.

10 DOCUMENTATION AND RECORDS The minimum documentation and records which is normally required to be provided is described below:—

(a) Worksheets on which the work to be carried out during inspection, modification, overhaul or repair is detailed. For overhauls, a separate sheet may be provided in which the standard overhaul work involved on a particular unit is itemised, the worksheet then being used to call up any additional work found necessary on initial inspection.

(b) Performance sheets on which results obtained during electrical and electronic testing is recorded. Such sheets are also used to record the specification number to which the unit has been tested.

(c) Modification records on which are listed all modifications which have been embodied and those required on the worksheet to be embodied.

(d) Certificates of Compliance which are required to be issued in accordance with Section A Chapter **A4-3** of British Civil Airworthiness Requirements (BCAR). This certification can, in particular organisations, be part of the worksheet and/or performance sheet described above.

(e) Status identification tags or labels for attachment to equipment during storage and transit. These tags or labels normally give details of the equipment including part numbers, serial number, modification status, life used since overhaul, workshop job reference number, related approved certificate number and brief details of work carried out.

(f) Records of all tests and calibrations made on test equipment. Such equipment is normally returned to approved test houses annually and calibration certificates obtained.

(g) The retention of documents is covered in section A, Chapter **A4-3** of BCAR.

(h) **Technical Publications.** Technical publications for workshops are covered in the approval procedures. The following are normally provided for use in radio workshops:—

- (i) British Civil Airworthiness Requirements, Sections A and R.
- (ii) Civil Aircraft Inspection Procedures.
- (iii) Technical descriptive literature and operating manuals of test equipment.
- (iv) Maintenance, overhaul and repair manuals.
- (v) Spare parts catalogues.
- (vi) Modification leaflets and bulletins.
- (vii) Servicing leaflets or bulletins, where applicable.
- (viii) Such mechanical and electrical specifications as are not included in radio equipment manuals and which may be required for overhaul of specialised components and accessories.

The publications have to be supported by an amendment service and periodical checks also have to be made to ensure that all literature in the library is, in fact, up to date.

Issue 1.

18*th November*, 1977.

AIRCRAFT

GROUND OPERATIONS

AIRCRAFT HANDLING

1 INTRODUCTION This Leaflet describes the ground handling tasks which may be necessary during the normal day-to-day operation of an aircraft, and details the procedures and precautions which are generally specified. These tasks vary considerably according to the size and type of aircraft concerned and the layout of the aircraft systems; this Leaflet should, therefore, be read in conjunction with the appropriate Maintenance Manual, where information relating to the particular aircraft will be found.

1.1 A number of Leaflets concerned with various aircraft systems and components, and which also contain information on aircraft ground handling, will be found in Part II of CAIP; these Leaflets should be referred to as necessary.

2 GENERAL The tasks which may be required to be carried out on an aircraft between flights, apart from routine maintenance, cover a variety of subjects, and these are dealt with separately in paragraphs 3 to 8 in this Leaflet. Special ground equipment is often required to enable these tasks to be carried out satisfactorily; in the case of light-aircraft operations this equipment may be of a very rudimentary nature, but when dealing with large transport aircraft more sophisticated equipment may be necessary. Reference to ground equipment will be made in this Leaflet, but the operation and maintenance of the equipment will be dealt with in leaflet **GOL/1-2** when this is issued.

2.1 Preparations for the reception of an aircraft should be made in advance of its arrival. The positioning of aircraft in the reception area should be arranged so that access paths to the aircraft are available for all replenishing vehicles and for the loading and unloading of passengers or cargo as applicable. All equipment likely to be required for the servicing of an aircraft should be readily available and should be in a fully serviceable condition.

2.2 When an aircraft has to be moved into a hangar in order to allow servicing operations or maintenance to be carried out, it should be positioned so as to avoid obstructing access to other working space or necessitating disturbance before the work is complete. Account should also be taken of the location of all necessary facilities such as weighing platforms, electric and pneumatic power sources, and lighting, and of the necessity for providing docks or platforms to enable the work to be carried out.

3 TOWING It is often necessary to move an aircraft without starting the engines, in order to position it for servicing or to enable passengers or cargo to be loaded, and if this operation is not carried out properly, severe damage can be caused to the aircraft. Should it be necessary to call upon the assistance of untrained or inexperienced persons to move the aircraft, the person taking charge should instruct them adequately before starting and ensure that they fully appreciate what they are required to do. Paragraphs 3.1 and 3.2 contain general information on the towing of aircraft and the precautions to be observed, but detailed information relating to the movement of a particular aircraft will be found in the manufacturer's Maintenance Manual for the aircraft concerned.

3.1 **Light Aircraft.** Great care should be exercised when manhandling light aircraft, particularly those constructed from wood and fabric.

3.1.1 On aircraft having a nose-wheel landing gear, a steering arm should be fitted to the nose wheel to guide the aircraft, and force should be applied only to those parts of the structure which are designed to accept it. Force should not be applied to trailing edges of wings or control surfaces, to streamlined wires, or to areas which are marked to prohibit the application of force; an engine should always be regarded as 'live', and, therefore, a propeller should not be used to push or pull the aircraft.

3.1.2 Generally speaking it is better to push an aircraft backwards rather than forwards, since the leading edges of the wings and tailplane are stronger than the trailing edges, but the struts and undercarriages on some aircraft are suitable for pushing the aircraft forwards. The flat of the hands should be used when pushing, so as to spread the load over the largest area, and when pushing on struts or undercarriages the force should be applied as near to the end fittings as possible.

3.1.3 On aircraft with a steerable nose wheel connected to the rudder pedals, care must be taken not to exceed the turning limits, which are normally marked on the nose undercarriage leg. On this type of aircraft it is also important that the rudder controls are not locked during towing operations.

3.1.4 On aircraft which are fitted with a tail skid instead of a tail wheel it is customary to raise the tail by lifting on the tailplane struts near to the fuselage fittings, so that the aircraft is balanced at the main wheels; the aircraft may then be pushed backwards as required. On some aircraft it may also be advisable to place the propeller in a horizontal position, to prevent it striking the ground when the tail is lifted.

3.1.5 When towing a light aircraft by means of a tractor, the correct tow-bar should be connected between the towing attachment at the base of the nose undercarriage leg and the tractor, and a person familiar with the aircraft brake system should be seated in the cockpit/cabin to operate the brakes in an emergency; the brakes should not normally be applied unless the aircraft is stationary. Once the tow-bar is connected, the brakes, and where fitted the rudder lock, may be released, and the aircraft towed forwards at a safe speed, depending on conditions in the vicinity. A close watch should be kept on the wing tips and tail, particularly in confined spaces, to ensure that they do not come into contact with other stationary or moving objects. Care should be taken when negotiating bends, to prevent the limits of nose-wheel movement being exceeded.

3.1.6 In circumstances where the ground over which the aircraft has to be towed is either boggy or very uneven, the strain imposed on the nose undercarriage may be excessive, and it may be necessary to tow the aircraft by means of bridles attached to each main undercarriage. If towing attachments are not provided on the main undercarriage legs, ropes should be passed carefully around the legs as near to the top as possible, and avoiding fouling on adjacent pipes or structure. A separate tractor should be connected to each main undercarriage, and steering should be carried out by means of a steering arm attached to the nose wheel rather than by differential movement of the tractors.

3.2 **Large Aircraft.** Large multi-engined aircraft are usually moved by towing with a tow-bar attached to the nose undercarriage leg, a special tug often being required to provide sufficient tractive effort. The tow-bar is fitted with a shear-pin or bolt, which will shear at a predetermined load to prevent excessive force being applied to the nose undercarriage.

3.2.1 The centre of gravity (C of G) of the aircraft must be determined before towing, to ensure that there is sufficient weight on the nose wheel. Adverse fuel distribution, and the aircraft being in a non-standard condition (e.g. with an engine removed), could affect the C of G position, and a maximum aft limit is generally specified in the relevant Maintenance Manual. Ballast may sometimes be required to achieve a safe C of G position, but the maximum towing weight must not be exceeded.

3.2.2 Before towing is commenced the undercarriage ground locks should be installed, the steering should, if applicable, be disconnected or disabled (usually by removing a steering disconnection pin, by inserting a lock-out pin, or by tripping the associated circuit breaker), and the nose undercarriage shock absorber should be checked for normal extension. In addition, the brake pressure should be checked and, if necessary, built up to the minimum safe pressure (this is often accomplished by operation of an electrically-driven hydraulic pump, which must be used sparingly to prevent the motor overheating). If it is likely to be necessary to turn the nose wheel through a greater angle than the prescribed steering limits, the nose wheel is usually freed by removing the apex pin from the torque links, thus allowing the nose wheel complete freedom of movement, but particular attention must be paid to any limits imposed on aircraft having bogie undercarriages.

3.2.3 When towing the aircraft, two qualified pilots or suitably trained and authorized members of the towing crew should be stationed in the cabin, to operate the brakes and any other aircraft systems which may be required, and to keep a look-out and monitor progress. These persons should be in telephonic communication with the outside ground crew and with the tractor driver. Ground crew should be located at the wing tips and tail to guide the aircraft past any obstructions, and one person should be in overall control of the operation.

3.2.4 The aircraft brakes should be released before the tractor moves off, and towing-speed should be kept down to a safe speed. The radii of turns should be kept as large as possible, to minimize tyre scrubbing and twisting loads on the main undercarriage legs, and care should be taken not to exceed any towing-force limits which may be specified in the relevant Maintenance Manual for various nose-wheel steering angles. Before stopping, the aircraft should be towed in a straight line for a short distance in order to remove any tyre stresses imposed by turning. Once stationary the aircraft brakes may be re-applied, the tractor and tow-bar may be removed, and the nose-wheel steering links refitted and safety locked.

3.2.5 In circumstances where the towing load exceeds the nose-wheel limitations, towing bridles should be attached to the main undercarriage legs and the aircraft should be towed using two tractors, one connected to each main undercarriage leg. A steering arm attached to the nose wheel should be used for steering purposes. Where no special towing attachments are provided, it will often be necessary to remove the fixed doors from the main undercarriage legs to permit attachment of the towing bridles.

3.2.6 In an emergency it may be necessary to move an aircraft from a runway while it has one or more deflated tyres. Provided that there is one sound tyre on an axle the aircraft may be towed to the maintenance area, but sharp turns should be avoided, towing speed should be kept to an absolute minimum, and brakes should be applied very carefully. If an axle is not supported by a sound tyre, however, the aircraft may only be moved the shortest distance necessary to clear the active runway and the wheels with deflated tyres must be removed and serviceable components fitted before towing is continued. After any tyre failure the associated wheel must be inspected (see Leaflet **AL/3-19**), and it may also be necessary to inspect the wheels and tyres which have not failed if the aircraft has landed or been towed with a deflated tyre.

4 PARKING AND PICKETING When an aircraft is out of service and in the open, it should be secured against inadvertent movement and protected against adverse weather conditions. The operations which are recommended in the relevant Maintenance Manual depend on the type of aircraft, the length of time it will be out of service, and the prevailing or forecast weather conditions.

4.1 Between flights it is usually sufficient to apply the parking brakes, lock the control surfaces, and chock the wheels, but in a strong wind light aircraft should be headed into wind. Light aircraft without wheel brakes should be headed into wind and their wheels should be chocked front and rear.

4.1.1 Flying controls on many aircraft are locked by movement of a lever in the cockpit/cabin, which is connected to locking pins at convenient positions in the control runs or at the control surfaces. When this type of lock is not fitted, locking attachments may have to be fitted to the control column and rudder pedals, but a more positive method which is frequently used on older or elementary aircraft, is the fitting of external control surface locks, which prevent control surface movement and thus prevent strain on the control system. All external locks should have suitable streamers attached, to make it visually obvious that the locks are fitted.

4.2 If an aircraft has to be parked overnight or for longer periods in the open, then additional precautions should be taken to guard against the effects of adverse weather. The undercarriage ground locks should be fitted, all openings such as static vents, engine intakes and cooling air intakes should be blanked to prevent the ingress of dirt, birds, insects and precipitation, and all fittings such as pitot heads and incidence indicators should be covered. When severe weather is expected it is recommended that cockpit/cabin covers and wheel covers are also fitted. Blanks and covers for all these components are specially designed for the particular aircraft and, if not visually obvious, are fitted with streamers to guard against their being left in position when the aircraft is prepared for service; servicing instructions should, however, include a pre-flight check to ensure that all covers and locks have been removed.

4.3 Light aircraft should normally be tied down when parked overnight or longer, but this is not usually necessary with large aircraft unless particularly strong winds are expected.

4.3.1 Light aircraft are fitted with picketing rings (or positions for the attachment of picketing rings) at the wings and tail and, on some aircraft, adjacent to the main undercarriage legs. The aircraft should be parked into wind and secured from the picketing points to suitable anchorage points on the ground (heavy concrete blocks or screw pickets). Cable or nylon rope of adequate strength should be used if possible, but if rope made from natural fibres is used, sufficient slack must be left to allow for shrinkage in damp conditions. Additional picketing from the undercarriage legs may be recommended in strong wind conditions and, if so, care should be taken not to damage any pipelines or equipment attached to the legs or wheels.

4.3.2 Large aircraft only require picketing in very strong wind conditions. The aircraft should be headed into wind, the parking brakes should be applied (unless pre-loaded main-wheel chocks are recommended) and cables should be attached from the aircraft picketing points to prepared anchorages. In some cases the picketing cables are special components, and include a tension meter which is used when applying a pre-load to the cable.

4.4 For helicopters, in addition to the actions outlined in paragraphs 4.1 to 4.3, the rotor blades should be tethered whenever possible, since even light gusting winds can cause damage to blades which are free to flap. The collective pitch lever should normally be locked in the fully fine position, and the rotor brake applied. Rotor head and blade covers should also be fitted if the helicopter is parked overnight, and if high winds are expected it should be hangared or the rotor blades should be folded.

4.4.1 On many helicopters the main rotor blades are tethered by aligning one blade along the tail cone, locking the collective pitch lever in fine pitch, and applying the tip covers to each blade, pulling them against the damper stops. Each blade may then be lashed to its respective picketing point, but care must be taken not to pull the blades down excessively; the relevant Maintenance Manual will generally stipulate a maximum distance from the normal drooped position, and this must not be exceeded. The tail rotor is generally tethered by fitting the blade covers and securing them to the associated picketing point or tail skid.

4.4.2 The method of folding the main rotor blades depends on the method of attachment to the rotor head and on the position of each blade; the procedure for a particular helicopter should, therefore, be obtained from the relevant Maintenance Manual. In the folded position the blade tips are generally secured by means of support cradles, which are attached to the tail cone structure.

5 JACKING An aircraft may have to be jacked up for a variety of reasons, including servicing, weighing, changing wheels, and retraction tests, and care is necessary to avoid damaging the aircraft. Jacking points are provided in the wings and fuselage to enable the whole aircraft to be lifted, and, usually, at the nose and main undercarriages to enable individual wheels to be changed. Some aircraft require a jacking pad to be fitted to each jacking point in the wings and fuselage, and adapters to be fitted to the jacks, while in other cases special stirrups or beams may be required to lift individual axles.

5.1 Because of the position of the jacking points, the centre of gravity of some aircraft may, although satisfactory for flight, fall behind the main jacking points and thus be unsatisfactory for jacking purposes. In these cases it may be necessary to add ballast forward of the main jacking points to bring the centre of gravity within limits specified in the relevant Maintenance Manual. In addition, each jacking or steadying point may have a load limit which, if exceeded, could result in structural damage. To avoid exceeding the limiting load at the jacking points it is sometimes necessary to fit hydraulic or electrical load cells (see Leaflet **BL/1-11**) to the jacks, while ballast may have to be used to avoid exceeding the loading limit at a steadying point.

5.2 Micro-switches fitted to the undercarriage legs and operated by the extension or contraction of the shock absorbers, are used to arm or disarm various electrical circuits on an aircraft. If the aircraft is jacked up these circuits will operate as required during flight, and this may not be desirable. These circuits should, therefore, be isolated by tripping the appropriate circuit-breakers or by removing the associated fuses, as necessary.

5.3 As a safety precaution, light aircraft should normally be jacked inside a hangar, but large aircraft may be jacked in the open provided that they are headed into wind and that the surface is level and strong enough to support the weight of the aircraft at the jacking points. A maximum safe windspeed for jacking is generally specified in the relevant Maintenance Manual.

5.4 The following procedure will generally ensure the satisfactory jacking of most aircraft, but account should also be taken of any additional precautions or actions specified in the Maintenance Manual for a particular aircraft. One person should be located at each jacking position and a co-ordinator should supervise the operation. On large aircraft the levelling station (paragraph 6) should also be manned, and all ground crew concerned should be in communication with the co-ordinator, headphones being used when necessary.

(a) Check that the aircraft weight, fuel state and centre of gravity are within the limits specified in the aircraft Maintenance Manual.

(b) Head the aircraft into wind if it is to be jacked in the open, chock the main wheels front and rear, and release the brakes.

(c) If jacking an aircraft in a restricted space, ensure that there is adequate clearance above every part of the aircraft to allow for its being raised, and adequate access and lifting space for cranes or other equipment which may be required.

(d) Connect earthing cables to the earthing points on the aircraft.

(e) Install the undercarriage ground locks.

(f) Fit jacking pads to the aircraft jacking points and adapters to the jacks as required. Load cells should also be fitted to the jacks at positions where a maximum jacking load is specified.

NOTE: The capacity and extension of the jacks should be adequate for the aircraft size and weight. The minimum requirements will normally be stated in the relevant Maintenance Manual.

(g) Position the jacks at each jacking point and raise them until the adapters are located centrally in the jacking pads. Care must be taken to ensure that the jacks are vertical, and that the weight is evenly distributed over the legs of each jack.

(h) Remove the wheel chocks and slowly raise the aircraft, maintaining it in a horizontal attitude as nearly as possible, until the undercarriage legs are fully extended and the wheels are a few inches off the ground. As a safety measure the locking nuts on the jack rams should be kept in close proximity to the jack shoulders as the jacks are raised.

(j) Tighten the jack ram locking nuts, and place supports under the outer wings and rear fuselage as indicated in the Maintenance Manual. The positioning of these supports is most important, as they are usually shaped to fit the undersurface of the wing or fuselage and must be located at a strong point such as a rib or frame; they are not intended to support the weight of an aircraft.

5.5 A 'bottle' jack and an adapter or special fitting are often used when raising a single undercarriage or part of a bogie beam for the purpose of changing a wheel. The remaining wheels should be chocked front and rear to prevent aircraft movement, and it may sometimes be specified that a tail support is located at the rear fuselage jacking point when raising a nose undercarriage. The jack should be raised only sufficiently to lift the unserviceable wheel a few inches clear of the ground (lowering the tail support, when applicable, as the jack is raised). Any applicable safety precautions outlined in paragraph 5.4 should be observed.

5.6 Before lowering an aircraft to the ground, all ground equipment, work stands, supports, etc., should be moved clear of the aircraft structure to prevent inadvertent damage, and the wheels should be rotated by hand to check that the brakes are free. The jacks should be lowered slowly in unison, by opening their pressure release valves, and, to guard against failure of a jack, the locking nuts on the jack rams should be unscrewed while the jacks are lowered and kept within 50 mm (2 in) of the jack heads. The jacks should be fully lowered after the aircraft is resting on its wheels and the pressure release valves should be closed. Chocks should then be placed in position, the jacks, jacking pads and adapters should be removed from the aircraft, and any electrical circuits which were disarmed as a safety measure should be reinstated.

NOTE: Undercarriage shock absorbers occasionally stick in the extended position, and care should be taken not to leave any equipment in a position beneath the aircraft where it could cause damage, until it is certain that the shock absorbers have compressed.

6 LEVELLING For some purposes, such as rigging or weighing, an aircraft must be levelled laterally and longitudinally, and a number of different methods may be employed.

6.1 **Spirit Level.** Many aircraft are levelled by use of a spirit level, which is placed at jigged positions on the airframe structure. On light aircraft the longitudinally level position is generally obtained by placing the spirit level on two pegs or on the heads of two partially withdrawn screws on the side of the fuselage, and adjusting the jacks (or the shock absorber extension or tyre pressures, if the aircraft is resting on its wheels) until the spirit level is centred. The laterally level position is obtained by placing the spirit level on the centre-section spar boom (or other nominated position), and again adjusting the jacks or tyre pressures until the level is centred. With some large aircraft a spirit level may be used in conjunction with special fittings, which are secured to locations in the centre fuselage or in one of the wheel bays; these fittings must be removed before flight and should have warning streamers attached. If adjustments have been necessary to level an aircraft laterally, the longitudinal level should be re-checked.

NOTE: In cases where tyre pressures are adjusted to level the aircraft, care must be taken not to over-inflate or to completely deflate a tyre.

6.2 **Plumb Bob.** On many aircraft a plumb bob is used in conjunction with a levelling plate. The plumb bob is suspended from a fixed position in the cabin roof or upper part of a wheel bay, and hangs over a levelling plate, which may be a permanent fixture or a separate fitting accurately located on the cabin floor or lower part of the wheel bay. The levelling plate is marked with a zero position and scales indicating the adjustments required about the lateral and longitudinal axes to centre the plumb bob.

6.3 **Engineers Transit.** The most accurate means of levelling an aircraft is by the use of an engineers transit (theodolite) in conjunction with range poles or scales located on the aircraft's lateral and longitudinal axes. The transit is set up below the aircraft centreline and between the lateral levelling points, and levelled horizontally. Range poles or scales are then located at the four marked levelling points on the lower surfaces of the fuselage and wings. Sightings are first taken on the lateral range poles or scales, and the main jacks are adjusted until identical readings are obtained. Sightings are then taken on the longitudinal range poles or scales, and the nose jack is adjusted until identical readings are again obtained. The aircraft is then considered level and the transit can be removed.

NOTE: The transit method is also employed when checking alignment of the aircraft structure, graduations on the range poles being used to check dihedral and incidence.

7 SERVICING Servicing may often be carried out in a crowded environment and must be properly organized to ensure that the necessary operations are carried out, to provide adequate safety to passengers and ground crew, and to protect the aircraft from damage. The procedures and precautions generally applicable to the routine servicing of aircraft are dealt with in the following paragraphs.

NOTE: For the purposes of this Leaflet, the term 'servicing' means those operations which are required to check and replenish an aircraft's systems, and to maintain an aircraft in an operational condition. In cases where an aircraft Maintenance Manual is produced in accordance with ATA Specification 100, detailed information on servicing operations will be found in Chapter 12.

7.1 **General.** The maintenance of a satisfactory surface contour and finish on an aircraft is most important, and care is necessary to prevent damage to the outer surfaces and to access panels and fasteners. Walkways are provided on the wings of many aircraft for access to the cockpit/cabin or for servicing purposes, and areas which must not be trodden upon, pushed or pulled, are clearly marked. Mats and suitable rubber footwear must be used when it is necessary to walk on the wings, and every precaution should be taken to prevent damage by tools or servicing equipment. It is also advisable to wear clothing without buttons or buckles which could scratch the wing surface, and without pockets in which loose tools could be carried, since they could fall out and become a loose-article hazard.

7.2 **Ground Equipment.** Many types of ground equipment may be required during aircraft servicing, and all must be compatible with the aircraft systems on which they are to be used. The ground equipment should be kept scrupulously clean and should be maintained in accordance with a schedule recommended by the manufacturer. Delivery pipes from all liquid and gas servicing trolleys should be blanked when not in use and their cleanliness and serviceability should be checked before connection to an aircraft. Fire extinguishers suitable for fuel and electrical fires should always be readily accessible wherever an aircraft is being serviced, and should be subject to regular inspection.

7.3 **Refuelliug.** The various methods of refuelling or defuelling an aircraft are fully described in Leaflet **AL/3-17**, but the main precautions to be observed are repeated here for ease of reference.

7.3.1 Before refuelling it should be ensured that the refuelling vehicle contains the correct grade of fuel, as shown at the refuelling points on the aircraft.

7.3.2 Precautions should be taken to provide a path to earth for any static electricity which may be present or which may build up as a result of the fuel flow. The aircraft and the refuelling vehicle should be earthed to a point which is known to be satisfactory, and the earthing wire on the refuelling pipe should be connected to the earth point provided on the aircraft before connecting the refuelling pipe or removing the tank filler cap. The earthing wire should remain in position until after the refuelling pipe is disconnected or the tank filler cap is replaced, as appropriate. When draining fuel into buckets, containers or tanks, these should also be bonded to the aircraft and/or the refuelling vehicle. No radio or radar equipment should be operated while refuelling or defuelling is taking place, and only those electrical circuits essential to these operations should be switched on.

7.3.3 When pressure refuelling, a float switch or fuel level shut-off valve is often used to cut off fuel flow when the tanks are full, or have reached a pre-set level. Since pressure refuelling rates are very high, failure of these components could cause a rapid build-up in pressure and serious damage to the tanks. The tanks of some aircraft are fitted with pressure relief valves which can be checked manually prior to refuelling, but when this is not the case persons engaged in refuelling operations should be prepared to shut off the supply instantly, should the automatic cut-off system fail to operate.

NOTE: When refuelling, the wheel chocks should be moved a short distance away from the tyres, to prevent them being trapped when the tyres absorb the additional weight.

7.3.4 Particular care should be taken when refuelling high-winged light aircraft, since the upper wing surface will not normally be safe to walk on and the filler cap may not be within easy reach. A step ladder or stand should be used to gain access to the filler cap and assist in preventing damage to the wing surface. Use of the steps will also facilitate correct locking of the filler cap.

7.3.5 When a spillage of fuel has occurred, care should be taken to ensure that all traces of fuel and vapour are removed. Any residual fuel should be mopped up and any fuel-soaked lagging or fabric should be removed and cleaned. The effects of the fuel on other parts such as cables, seals, bearings and windows should also be considered and the appropriate action should be taken.

7.3.6 After refuelling an aircraft it is usually recommended that fuel is checked for contamination. Drain valves are provided in the tank sumps, pipelines and filters, by means of which a small quantity of fuel may be drained into a glass jar and checked for the presence of water, sediment and microbiological contamination (see Leaflet **AL/3-17**). Because of the slow rate of settlement of water in turbine fuels it is usually recommended that the tanks are left as long as possible after refuelling before the sample is taken. With turbine-engined aircraft, samples may also be taken to determine the specific gravity of the fuel in the tanks.

7.4 **Connection of Electrical Power.** It is often necessary to connect an external electrical power supply to an aircraft, either for engine starting purposes or to permit operation of the aircraft systems and equipment. Certain precautions must be observed when connecting the external supply, to prevent damage to the aircraft electrical system.

7.4.1 Most light aircraft have direct current (d.c.) electrical systems, and although alternating current (a.c.) is provided for the operation of certain equipment it is not usual for the aircraft to have provision for the connection of a.c. external power. The external power socket is, therefore, usually for the connection of a d.c. supply, which may be provided solely by batteries or from a generator and battery set. The following actions should be taken when connecting an external d.c. supply to a typical light aircraft:

(a) Check the voltage and polarity of the ground supply.

(b) Check that the external power plug and socket are clean, dry and undamaged.

(c) Check that the external supply and the aircraft battery master switch are off and connect the external supply, ensuring that the plug is fully home in the socket.

(d) Switch on the external supply and the aircraft battery master switch, and carry out the servicing operations for which the external power was required.

(e) To disconnect the external supply, switch off the battery master switch, switch off the external supply, disconnect the external power plug, and if the aircraft electrical system is to be used (e.g. after engine starting), switch the battery master switch on again.

7.4.2 Most large aircraft are provided with multi-pin plugs or sockets, by means of which external d.c. or a.c. power may be connected into the aircraft electrical system. The external supply is usually provided by a towed or self-propelled unit, which has its own power-driven generator and can provide d.c. power at various voltages and a.c. power at a particular voltage, frequency and phase rotation. Aircraft electrical systems vary considerably, and the checks which are necessary after connecting the external power will vary between aircraft, but the following procedure is applicable in most cases:

(a) Check that the external supply is compatible with the aircraft system (i.e. it has the same voltage, frequency and phase rotation as the aircraft system), and is switched off.

(b) Check that the external plug and socket are clean, dry and undamaged.

(c) Connect the external plug/socket, ensuring that it is fully mated and secure, and switch on the external power supply.

(d) Check the voltage and frequency of the external supply on the aircraft electrical system instruments, and perform the operations specified in the relevant Maintenance Manual to engage the external supply with the aircraft a.c. system.

(e) To disconnect the external supply, disengage it from the aircraft a.c. system, switch off the external power at source, and remove the external power plug/socket.

7.5 **Connection of Compressed Gases.** Any component containing compressed gas must be handled and serviced carefully, because the sudden release of gas under pressure could have disastrous consequences. Oxygen systems present an additional hazard in that oil and grease are prone to spontaneous combustion in the presence of undiluted oxygen.

7.5.1 The gas pressure required in some components varies according to the ambient temperature, and in order to ensure that the correct working pressure is maintained, the relationship between temperature and pressure is generally presented in the form of a graph, both in the Maintenance Manual and on a placard adjacent to the charging point. In the case of tyres and shock absorbers on large aircraft the required gas pressures may vary according to the aircraft weight and centre of gravity position, and the requirements for a particular aircraft should be obtained from the relevant Maintenance Manual.

7.5.2 Since the rapid compression of a gas produces heat it will affect the gas pressure in a component; heat will be minimized by charging slowly. The sudden release of a compressed gas will have the reverse effect, i.e. lowering its temperature, and this is particularly important when deflating a tyre (see Leaflet **AL/3-18**), as ice may form and block the valve, giving the impression that the tyre is fully deflated when in fact it is still partially inflated. Prior to working on any unit from which compressed gas has been exhausted, the charging valve or valve case should be completely removed.

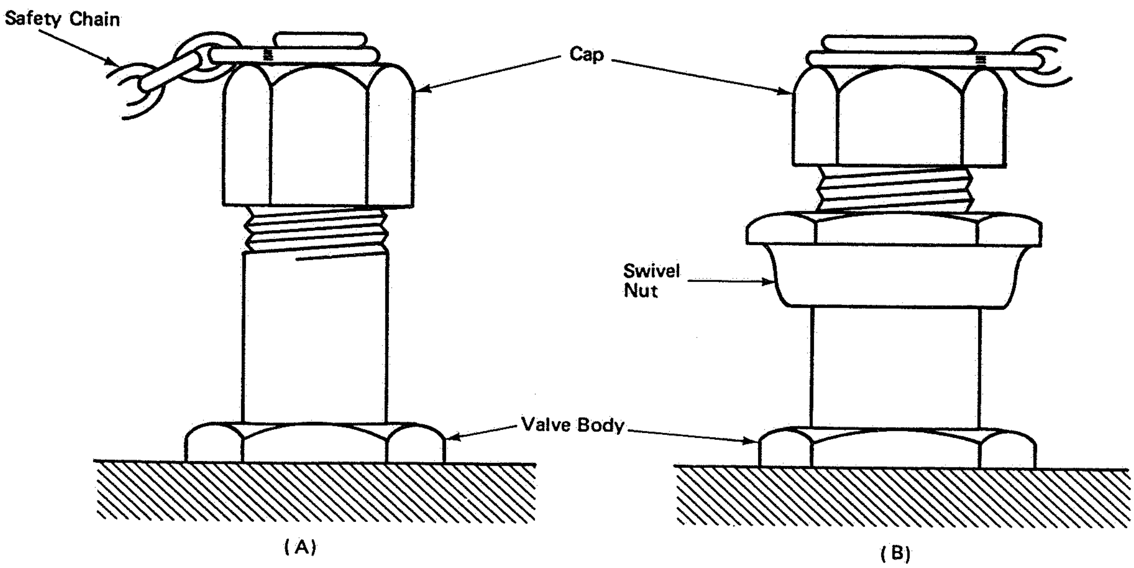

Figure 1 CHARGING VALVES

7.5.3 **Charging Valves.** The valves fitted to components which are charged with gas may be of two types. One is a needle-type valve (Figure 1(A)) which opens and closes automatically, and the other is a poppet-type valve on which the swivel-nut has to be unscrewed one full turn to release the valve stem (Figure 1(B)). A valve cap should always be fitted to prevent the entry of dirt and moisture, and should be removed only when it is necessary to charge the component or to release gas pressure. On no account should the valve body be unscrewed while the component is pressurized, since this could result in the valve blowing out and causing damage or injury.

7.5.4 **Charging Rigs.** A compressed-gas charging rig is generally a self-propelled or towed trolley, on which are mounted one or more high-pressure gas cylinders, a flexible supply hose, a supply shut-off valve, and pressure gauges showing storage cylinder pressure and supply hose pressure. Some rigs are also fitted with a pressure regulator, by means of which the supply pressure may be limited to the maximum required in the component, and this type of rig is used when the aircraft system does not have its own supply shut-off valve and pressure gauges.

7.5.5 **Charging.** Charging a component with compressed gas should be carried out carefully and the following precautions should be observed:

(a) The pressure to which the component is to be charged should be checked according to the ambient temperature, or weight and centre of gravity of the aircraft, as appropriate.

(b) The supply connection should be clean, dry and free from oil or grease; any contamination should be wiped off with a lint-free cloth moistened in a solvent such as methylated spirits.

(c) The aircraft system should be charged very slowly, so as to minimize the rise in temperature.

(d) When the required pressure is reached, the shut-off valve should be closed and the system pressure allowed to stabilize. The pressure should then be checked, and adjusted as necessary.

(e) The supply hose should not be disconnected unless the shut-off valve and the charging valves are closed, because of the dangers associated with rapid decompression. On some rigs provision is also made for relieving pressure from the supply hose before disconnection.

(f) Blanking caps should be fitted to the charging valve and supply hose as soon as they are disconnected.

(g) When charging oxygen systems, adequate and properly manned fire-fighting equipment should be positioned, and if illumination is required, explosion-proof lamps and hand torches should be used.

7.6 **Replenishment of Liquids.** On modern aircraft, replenishment of engine oil, hydraulic fluid, de-icing fluid, water, and other systems containing liquids, is achieved by the use of servicing trolleys which are specially designed for the task and are connected into the system by quick-release couplings; alternatively, and with older aircraft, these systems may be replenished by removing the tank filler cap and pouring in the required liquid. Whichever method is used, the utmost care should be taken to ensure that only the approved liquids are used, and that no foreign matter is allowed to enter the system. Servicing trolleys should be inspected regularly for cleanliness, and their delivery pipes should be capped when not in use; all utensils should be kept scrupulously clean, and should, preferably, be retained for use with one particular liquid.

7.6.1 The quantity of liquid in a system may be indicated by a sight glass, by use of a dip-stick, by its visible level in a filter fitted in the filler opening, or, in some cases, by means of a contents gauge, the transmitter unit for which is mounted in the tank. When required, the system should be replenished to the 'full' level; no system should be overfilled, as this could affect system operation.

7.6.2 Precautions applicable to the replenishment of systems containing liquid are outlined in paragraphs (a) to (d) below:

(a) Some systems are pressurized in normal use, and this pressure should be released before replenishing with liquid.

(b) When replenishing a hydraulic system, it may be necessary to pre-set the hydraulic services to specified positions to prevent overfilling (see Leaflet **AL/3-21**).

(c) Some liquids, such as methanol, synthetic lubricating oils and hydraulic fluid, may be harmful or even toxic if their vapours are breathed in or if they come into contact with the skin or eyes. Particular note should be taken of any warnings of dangers to health which may be contained in the relevant Maintenance Manuals, and the recommended procedures for the handling of these liquids should be observed.

(d) The liquids mentioned in paragraph (c) may also have an adverse effect on paintwork, adhesives and sealant, and thus inhibit corrosion prevention schemes. Care should be taken not to spill any of these liquids, but if a spillage does occur, immediate steps should be taken to mop it up and clean the affected area.

7.7 **Lubrication.** Lubrication should be carried out in accordance with a schedule approved for the particular aircraft, the intervals normally being related to flying hours, with certain positions requiring additional lubrication after ground de-icing operations (see Leaflet **AL/11-13**) and after cleaning the aircraft.

7.7.1 The lubricant to be used, and the method of application, are usually annotated on a diagram of the aircraft in the appropriate chapter of the aircraft Maintenance Manual. The method of annotation is often by the use of mimic diagrams (e.g. an oil can for oiling or a grease gun for greasing) and the type of lubricant is indicated by a symbol.

7.7.2 The utensils used for lubrication purposes should be kept scrupulously clean, and should only be filled with new lubricant. Each utensil or container should be clearly marked with the lubricant it contains, and should be kept solely for that lubricant.

7.7.3 When lubricating a component, care should be taken to ensure that the quantity applied is adequate but not excessive; in some cases a particular quantity may be specified in the Maintenance Manual (e.g. "apply 8 drops of oil . . .") but normally a quantity sufficient to cover the bearing surfaces, as evidenced by the exuding of new lubricant, should be applied. The lubricating point should be wiped clean and dry with a lint-free cloth before applying the oil or grease, and any excess exuding from the component should be wiped off to prevent the accumulation of dirt or foreign matter.

7.8 **Cleaning.** Cleaning an aircraft improves its appearance and aerodynamic qualities, helps to prevent corrosion, and facilitates the detection of fluid leakage. It is, therefore, often included in the servicing schedule.

7.8.1 **Exterior Surfaces.** Before washing down the exterior surfaces of an aircraft, all doors and windows should be closed, all apertures such as air intakes, engine exhausts, fuel jettison pipes, static vents and vent pipes should be blanked, covers should be fitted to pitot heads and sensor vanes, and transparencies should be covered to prevent contamination by cleaning fluids. The structure should be washed down using a cleaning agent recommended by the aircraft manufacturer and mixed according to the instructions provided, caked mud or other foreign matter being removed with lint-free cloth soaked in the cleaning agent. The wash should be followed by swabbing with clean water, and care should be taken to prevent cleaning fluid or water becoming trapped in parts of the structure where corrosion and seizure of mechanisms could result. The aircraft should be thoroughly dried after washing and rinsing, and it is usually recommended that lubrication should be carried out, particularly if pressure hoses have been used.

(a) If it is necessary to remove concentrations of oil or grease, a cloth moistened in solvent should be used, but chlorinated solvents should be avoided since they may be toxic. The minimum quantity of solvent should be applied, since prolonged saturation of parts may have an adverse effect upon adhesives and jointing compounds. When solvents are used, adequate fire-fighting equipment should be available.

7.8.2 **Internal Structure.** Internal structure is generally cleaned with a vacuum cleaner, but a cleaning agent and water may be used when necessary. Only a small area should be washed, rinsed and dried at a time, so as to prevent flooding of the structure and trapping of fluids in inaccessible places. Clean lint-free cloths should be used for all operations and the structure should be finally dried by circulating warm air.

7.8.3 **Engines.** An engine and its compartment should be cleaned by spraying or brushing with solvent or degreasing fluid, after first blanking all vents and apertures in such components as the magnetos and alternator. This solvent should be left on for five to ten minutes, then the engine should be washed with clean solvent and allowed to dry. All controls, hinges, etc., should be lubricated after cleaning, and the engine should not be operated until all solvent has evaporated or otherwise been removed. The precautions stated in paragraph 7.8.1(a) regarding the use of solvents should be observed.

7.8.4 **Upholstery.** Soiled carpets and seats may usually be cleaned by means of a vacuum cleaner and an approved non-flammable air-drying type cleaner or foam-type upholstery cleaner. The manufacturer's instructions for the use of these materials should be carefully followed, and soaking or harsh rubbing should be avoided.

7.9 **Cold Weather Operations.** Particular care is essential in the operation of aircraft when temperatures are likely to fall below freezing point at ground level. When snow or ice is present towing and taxying should be carried out with extreme caution and aircraft movements should be kept to a minimum; parking areas should, if possible, be cleared of snow and ice, so as to prevent aircraft tyres from freezing to the ground. If sand or grit is used to increase the tractive effort of tractors or assist the braking of aircraft, care should be taken to prevent these materials being drawn into operating engines; taxiways and hard standings should be swept to remove any sand or grit after the snow and ice have melted.

7.9.1 **After Flight.** When parking an aircraft, all covers, plugs and ground locks should be fitted as soon as possible. If the airframe is wet or affected by snow or ice, the surface under the covers should be given a light coating of anti-freeze liquid; anti-freeze liquid should not, however, be applied to the windows, since it has an adverse effect on plastics materials. Engine covers should be fitted as soon as the engine has cooled sufficiently, but in the case of turbine engines an inspection should be made for the presence of ice in the air intake, since this could melt while the engine is hot, drain to the lowest part of the compressor, and subsequently re-freeze when the engine cools, locking the lower compressor blades in ice. If ice is present it should be allowed to melt, then removed before finally fitting the covers. Drain valves in the fuel and pitot/static systems should be opened to remove any accumulation of water, and the domestic water and toilet systems and water injection tanks should be drained or treated with anti-freeze liquid as appropriate.

7.9.2 **Before Flight.** All external surfaces must be free of snow, frost or ice before an aircraft takes off, and de-icing operations should be carried out as necessary (see Leaflet **AL/11-3**). Particular care is necessary when an aircraft has been removed from a heated hangar into falling snow since the snow will melt on the warm aircraft then re-freeze as it cools down, forming a thin layer of ice which may not be easily visible. Water systems should be filled with warm water, and all covers should be kept in place until as near to departure time as possible.

8 ENGINE STARTING AND RUNNING An engine should not be ground run more often than is absolutely essential to ensure its serviceability. With a piston engine more wear takes place during cold starts than during normal operation, and with a turbine engine the engine life may be directly related to the number of temperature cycles to which it is subjected. It is, however, frequently necessary to run an engine to check its performance; in these cases and when starting an engine prior to flight, certain precautions are necessary to ensure the safety of the aircraft, of surrounding aircraft and of personnel.

8.1 **General Precautions**

8.1.1 An aircraft should, whenever possible, be headed into wind before starting its engines. This is particularly important with light piston-engined aircraft as the wind direction will affect the engine speed obtained during checks and from certain directions could produce vibration and may adversely affect engine cooling. Turbine-engined aircraft are not usually affected so seriously by wind direction, but a strong tail wind could result in increased jet pipe temperatures during starting; care should also be taken not to engage the starter of a turbo-propeller engine if the propeller is being rotated backwards by the wind.

8.1.2 An aircraft should normally be parked with brakes on and chocks in front of the main wheels. The ground immediately in front of the propellers or intakes, and beneath and behind the aircraft, should be checked for loose gravel or other foreign objects which could be drawn into the engine, cause damage to the propeller, or be blown against other aircraft, buildings and personnel. Jet blast can also have serious consequences, and diagrams will be found in the Maintenance Manuals of turbine-powered aircraft showing the extent and velocity of the blast created at various power settings, and the areas which should be kept clear of personnel and equipment. These diagrams also indicate the extent of the danger areas in front of the engines, which result from intake suction. When specified, intake guards should be fitted to turbine engines when they are run for maintenance purposes. A look-out man should be stationed in front of the aircraft, and should be in visual and/or radio contact with the cockpit/cabin crew.

8.1.3 Whenever an aircraft engine is being started, adequate fire-fighting equipment should be readily available and manned.

8.2 **Piston Engines.** Piston engines are generally fitted with electric starter motors, and an external power source should be connected to the aircraft whenever possible.

When cold, engines should always be turned at least two revolutions before being started, to free the reciprocating and rotating parts and to determine whether a hydraulic lock (oil draining into the lower cylinders) has formed. The engine should normally be turned over by hand but when this is not possible the starter may be used. The magneto switches must be 'off' when turning the engine and the engine must always be treated as 'live', in case the switches are defective and not earthing the magneto primary circuits.

8.2.1 Piston-engine installations vary considerably, and the method of starting recommended by the aircraft manufacturer should always be followed. Engine speed should be kept to a minimum until oil pressure has built up, and the engine should be warmed up to minimum operating temperature before proceeding with the required tests. High power should only be used for sufficient duration to accomplish the necessary checks, since the engine may not be adequately cooled when the aircraft is stationary. After all checks have been carried out the engine should be cooled by running at the recommended speed for several minutes, the magneto switches should be checked for operation and the engine should be stopped in the appropriate manner.

8.2.2 Extreme care is essential when starting piston engines by hand swinging. Many accidents have occurred in this way, and both pilots and maintenance personnel should be given demonstrations and be checked out on this method of starting before being allowed to hand swing a propeller. The engine must always be treated as 'live' and no part of the arms, legs or body should be moved into the propeller disc at any time. No attempt should ever be made to start an engine without someone in the cockpit/cabin to operate the throttle or brakes as necessary, or without chocks placed in front of the wheels. A set sequence of calls and responses should be used to ensure that the ground crew and the pilot are fully aware of the actions being taken.

(a) **Sucking-in.** To prime the engine cylinders, when necessary, the ground crew should stand away from the propeller, face the pilot and call "Switches off, petrol on, throttle closed, suck in". The pilot should repeat these words, carrying out the appropriate actions at the same time. The ground crew should then set the propeller to the beginning of a compression stroke and turn the engine through at least two revolutions. Starting at the position shown in Figure 2, the propeller should be swung by moving the arm (right in this case) smartly down and across the body, turning away from the propeller and stepping away in the direction of movement of the aircraft.

(b) **Starting.** The ground crew should set the propeller at the start of a compression stroke (as in Figure 2), stand away from the propeller, face the pilot, and call "Contact". The pilot should set the throttle for starting, switch on the magnetos, and repeat "Contact". The ground crew should then swing the propeller as outlined in paragraph (a). If the engine does not start, the ground crew should ensure that the magnetos are switched off before re-setting the propeller, and switched on again before making another attempt to start the engine.

NOTE: The manufacturer's manual should be referred to for the operation, during starting, of magnetos which are fitted with impulse starters or retarded contact breakers.

(c) **Blowing-out.** If the engine fails to start through over-richness, the ground crew should face the pilot and call "Switches off, petrol off, throttle open, blow out". The pilot should repeat these words, carrying out the appropriate actions at the same time. The ground crew should then turn the propeller several revolutions in the reverse direction of rotation to expel the mixture from the engine. This will usually entail swinging the propeller up from the 6 o'clock position (approximately), using the opposite hand. The throttle should then be closed, the petrol turned on, and the operations outlined in paragraph (b) continued.

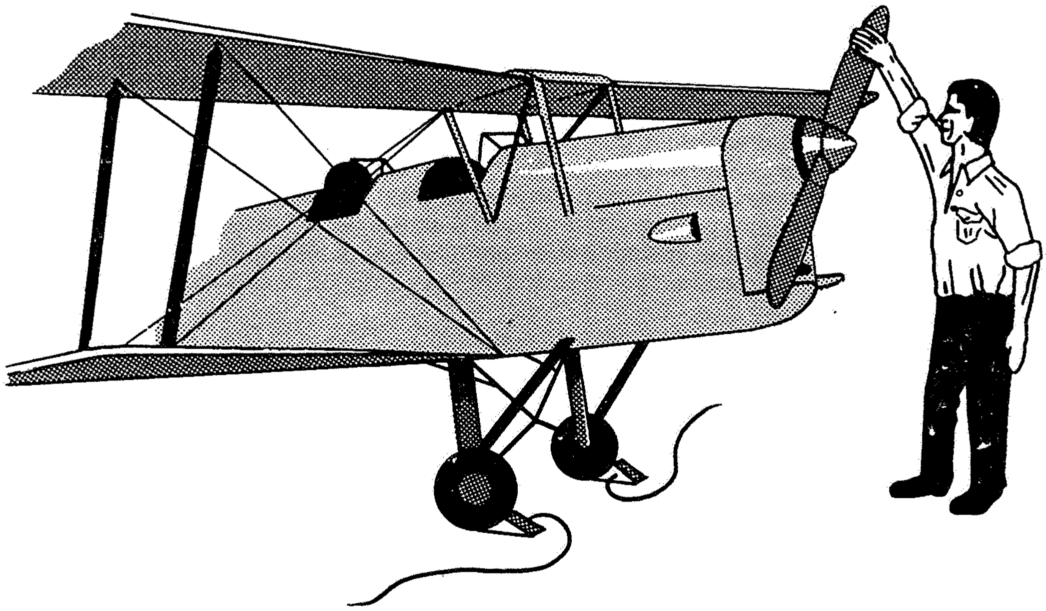

Figure 2 HAND SWINGING

8.3 **Turbine Engines.** Turbine engines may be started by an electric motor or by an air turbine, and may use either an internal power unit or an external power source to provide the necessary power. The danger areas in front of and behind the engines should be kept clear of vehicles and personnel, and if an auxiliary power unit is being used, from the vicinity of this exhaust also. Vehicles supplying electrical power or compressed air should be located in such a position that they can be moved away quickly in the event of an emergency. Qualified personnel should be located outside the aircraft and be in telephonic communication with the cabin crew, so as to be able to provide warning of situations not visible from the cabin and to prevent vehicles or personnel from entering the danger areas. Air intakes and exhaust pipes should be inspected for loose objects or debris before starting the engines. Information on the methods of starting turbine engines and the procedures for ground testing which should be adopted are contained in Leaflet **EL/3-10**.

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AIRCRAFT

GROUND OPERATIONS

OPERATION AND MAINTENANCE OF GROUND EQUIPMENT

1 INTRODUCTION This Leaflet gives general guidance on the operation and care of the ground equipment which is used during the servicing and maintenance of aircraft. Most manufacturers publish operating and maintenance instructions in respect of their equipment and this Leaflet should, therefore, be read in conjunction with the appropriate handbook or manual.

2 GENERAL The efficient ground handling of medium and large aircraft is dependent on the use of sophisticated ground equipment to supply, for example, external power for the operation of aircraft services and for engine starting. Facilities provided in hangars, and other equipment such as hydraulic system test rigs are essential for maintenance purposes.

2.1 In order to be available for instant use, all equipment of this nature should be kept serviceable and in good working order. It is recommended that all aircraft operators should employ planned maintenance schemes for their ground equipment, with comprehensive schedules and work sheets. Maintenance activities should be based on the manufacturer's recommendations and a record should be kept for each piece of equipment.

2.2 Where particular types of ground equipment and vehicles carrying ground equipment are fitted with internal combustion engines, particular care should be taken to ensure that these engines are maintained in such a condition that the possibility of sparks or flame being emitted from the exhausts is remote. For certain vehicles the use of flame-damped exhausts may be recommended.

3 GROUND POWER-UNITS The provision of external electrical power to aircraft for engine starting purposes or for the operation of aircraft systems and equipment, is normally by means of an engine-driven generator set mounted on a trailer. The engine is normally coupled to a brushless revolving-field generator, and the power-unit is provided with full controls and instrumentation. Units suitable for static installation are also available and normally comprise a motor-generator unit consisting of a brushless synchronous motor and a brushless revolving-field generator on a common shaft.

3.1 **Power Outputs.** Ground power units are typically capable of supplying a selection of power outputs such as the following:—

(a) **A. C. Outputs**

(i) 75 kVa, line voltage 200, 400 Hz, 3 phase, 0·8 continuous power factor.

(ii) 100 kVa, line voltage 200, 400 Hz, 3 phase, 0·8 power factor for 20 minutes.

(iii) 180 kVa, line voltage 200, 400 Hz, 3 phase, 0·4 power factor for 5 minutes.

(b) **D.C. Outputs**

(i) 28·5 volts:

800 amperes continuous; or
2,000 amperes intermittent.

(ii) 112 volts:

300 amperes continuous; or
1,000 amperes intermittent for 30 seconds; or
1,200 amperes peak instantaneous.

3.1.1 D.C. outputs are usually available simultaneously or independently at continuous ratings, or independently at intermittent ratings; d.c. outputs are not available at the same time as an a.c. output.

3.2 **Trailers.** The trailers, upon which the engine and generator units are mounted, are usually provided with leaf spring suspension, cable operated brakes and steerable front wheels; a suitable canopy, with transparent panels, where required, encloses the equipment.

3.3 **Operating Procedures.** It is essential that personnel who are required to use ground power-units are trained and fully familiar with the operating instructions defined in the appropriate technical manual for the equipment concerned. The following practices would be typical:—

(a) Before starting the engine, the unit should be placed on firm, level ground, the parking brake should be applied and the bonding connection should be connected to the aircraft.

(b) After starting the engine, the oil pressure should be checked and the engine should be allowed to warm up for several minutes before an electrical load is applied.

(c) Oil pressure, coolant temperature and battery charging current should be checked periodically while the engine is running.

(d) When selecting the required a.c. or d.c. power output the manufacturer's procedure should be followed.

(e) When connecting or disconnecting the external power supply to the aircraft, it must be ensured that electrical power is first disconnected from the external power line. On many ground power units a 'power on' indicator is provided to show when power is being supplied to the socket.

3.3.1 The electrical power produced by a ground power-unit is sufficient to cause damage to an aircraft and serious injury to personnel. In addition, careless use of the equipment could result in a discharge of electricity which could lead to the ignition of flammable vapours in the vicinity. It is therefore important that any safety measures contained in the manufacturer's manuals or in notices on the equipment should be observed.

3.4 **Maintenance.** A record should be kept of all ground power-unit running times, and maintenance should be carried out in accordance with the schedule drawn up for the particular equipment. During normal use, the checks outlined in paragraphs 3.4.1 to 3.4.3 should be carried out to ensure continuing serviceability of the equipment.

3.4.1 A daily inspection should include checks on coolant, oil and battery electrolyte levels, serviceability of lamps and indicators, and an examination for damage, leaks and security of attachments. Any bonding connections should be checked for condition and security.

3.4.2 Cables and aircraft connectors are subjected to hard usage and should be inspected weekly for abrasion, tears and general deterioration. The aircraft connector should be examined to check the condition of its insulation and contact tubes, and to ensure that the tubes are not proud of the insulation.

3.4.3 At monthly intervals an electrical quality check should be carried out. This should test the voltage and frequency protection units, phase rotation polarity at the output sockets and current overload. In addition, the resistance and continuity of the bonding lead should be checked.

4 AIR STARTER UNITS Air starter units are designed to start aircraft engines which are equipped with air turbine starters; they can also be used in checks on auxiliary systems, for limited air conditioning or for de-icing. The units generally consist of a turbo-charged diesel engine driving a single-stage compressor, mounted on a truck chassis and enclosed by a suitable canopy. The compressor delivers a continuous flow of warm, oil-free, compressed air. The engine is completely self-contained and has its own electrical system, starter system and fuel supply. A regulating valve controls the delivery air pressure, exhausting all air while the engine is being started (to reduce load), and thereafter maintaining a constant working pressure of 275 to 300 kN/m^2 (40 to 43 lbf/in^2) irrespective of the air take-off. A safety valve fitted to the delivery manifold opens at approximately 325 kN/m^2 (47 lbf/in^2). All instruments, controls and warning lamps are grouped on a control panel.

4.1 **Operating Procedures.** Operating procedures for air starter units will vary according to the particular design, and the manufacturer's instructions and recommendations should always be followed. The following practices would be typical:—

(a) Before starting, the unit should be placed on firm, level ground, and the bonding lead should be connected to the aircraft.

(b) After starting the engine, it should be ensured that oil pressure is building up and that all warning lights are extinguished. The engine should be allowed to warm up for several minutes.

(c) When the engine has warmed up, the throttle should be opened to check that air pressure builds up to normal operating pressure.

(d) During an aircraft starting operation a constant check should be kept on the air pressure gauge, and the starter unit throttle should be adjusted as necessary to maintain normal operating pressure without exceeding the maximum permissible starter unit engine speed.

4.2 **Maintenance.** A record should be kept of engine running hours and engine starting cycles, and maintenance should be carried out in accordance with a schedule drawn up for the particular equipment. A daily inspection should include the topping-up of fuel, coolant and oil systems, and a check for damage, leaks and security of components.

4.2.1 The air delivery hose is generally seamless and lined with silicone rubber, and normally has low temperature flexibility and high resistance to abrasion. However, the rubber will eventually deteriorate, particularly at the ends; shortening the ends by a small amount (approximately 50 mm (2 in)) may rectify this, but other cracking or damage will necessitate replacement. The life of a hose can be prolonged by exercising reasonable care in its use, and by avoiding sharp bends, tautness and twisting.

4.2.2 Inspection of an air delivery hose should be carried out after approximately 50 hours of operation or 600 aircraft starts.

5 HYDRAULIC TEST RIGS The testing of aircraft hydraulic systems requires a controlled and filtered supply of hydraulic fluid at high pressure, and this is normally provided by a specially designed servicing trolley. A typical hydraulic test rig would consist of a 75 kW (100 HP) electric motor operating from a 380/440 volt, 3 phase supply, driving a variable-delivery hydraulic pump through a gearbox, clutch and flexible coupling; the output from the rig would be up to 175 litres/min (38 gal/min) at 20 MN/m^2 (3,000 lbf/in^2), with a filtration of 3 microns. The hydraulic circuit would function by drawing fluid from the aircraft system through a heat exchanger and low pressure filter, and returning it to the aircraft system through suitable flow control valves and flow meters and a high pressure filter; self-sealing, quick-disconnect couplings, installed in the aircraft, permit the connection of flexible hoses from the test rig to the aircraft system. In some cases provision is made for fitting a different pump on the test rig, but usually a rig is designed specifically for one type of aircraft and one type of fluid.

5.1 **Operating Procedure.** Hydraulic test rigs vary considerably in design, and operating instructions for a particular type are usually printed on a plate attached to the trolley and/or contained in a manual or booklet; these instructions should be carefully followed when carrying out a test, since incorrect operation could cause damage to the rig or aircraft system. General guidance on operating procedures is outlined in paragraphs 5.1.1 and 5.1.2.

5.1.1 Before starting a test rig, all flow valves should be closed and, where applicable, the aircraft hydraulic system reservoir air pressure should be checked. Because of the filtration requirements of hydraulic systems, the suction and pressure hoses from the rig should be carefully inspected for cleanliness before they are connected into the aircraft system. The hose connections are fitted with caps which should only be removed immediately before the hoses are connected to the aircraft; the caps should be replaced immediately after the hoses are disconnected from the aircraft.

5.1.2 After starting the electric motor, the pump can be brought on line by operation of the clutch, and pressure will be indicated on the rig pressure gauge. The main rig flow control valve can then be opened and the rig will form part of the aircraft system; enabling functional tests to be carried out by use of the aircraft system selector valves. By utilising additional low-flow valves and low-reading flow meters on the test rig, the measurement and monitoring of internal leakage in the aircraft system components is possible.

5.2 **Maintenance.** Because, during tests, a hydraulic test rig shares the hydraulic system of an aircraft, the degree of filtration, and condition of the pump and fluid, must be at least as good as those in the aircraft. Cleanliness is, therefore, of the utmost importance, and regular quality checks should be carried out on fluid samples from the rig to prevent fluid which is contaminated or degraded by overheating, from being carried, via the rig, from aircraft to aircraft. To ensure satisfactory operation of the rig, the following operations should be carried out on a regular basis:—

(a) The rig should be kept clean and free from leaks. This is particularly important with the hoses and hose connections, which must be capped when not in use and must be checked for cleanliness each time they are coupled to an aircraft.

(b) The filter should be cleaned or renewed regularly according to rig usage, and special procedures such as ultrasonic cleaning, which may be required for wire cloth filters, should be followed. Paper filter elements should be discarded when removed (see Leaflet **AL/3-21**).

(c) All gauges should be subjected to calibration checks at regular intervals.

(d) The condition and functioning of all electrical equipment should be checked at intervals depending on rig usage.

6 AIRCRAFT JACKS There are two main types of jacks used on aircraft, namely tripod jacks and bottle jacks; both types are hydraulically operated. The base of both jacks forms a reservoir for hydraulic fluid, supplying a hand pump which is used to extend the jack ram. A release valve (which is sometimes operated by rotating the pump handle) allows fluid to return to the reservoir and the jack to retract.

6.1 A tripod jack has three equally-spaced support legs and a central vertical column which houses a hydraulic cylinder, the ram of which is threaded and fitted with a locking collar as a safety feature. These jacks are used at main aircraft jacking points and are fitted with an adaptor at the top of the ram which engages the jacking pad on the aircraft; the adaptor is sometimes used in conjunction with a transducer for aircraft weighing purposes.

6.1.1 Tripod jacks may be extended to nearly twice their original height during use, and care is necessary to ensure that the ram is vertical; if it is not, side forces on the jack could result in its toppling over, with serious consequences to the aircraft and to personnel. When the ram is extended or retracted, the locking collar should be kept in close proximity to the top of the tripod, to prevent the collapse of the ram through hydraulic failure; the locking collar should be locked onto the tripod when the ram is fully raised (see also Leaflet **GOL/1-1**).

6.2 Bottle jacks, which are similar in principle to tripod jacks, are made in various sizes and may have a single or double ram depending on the extension required. Bottle jacks are used mainly for raising individual undercarriage legs for the purpose of changing wheels, brake units, etc., and may be used on their own or in conjunction with a special fitting which attaches to the undercarriage leg or bogie beam.

6.2.1 As with tripod jacks, it is essential that the ram is vertical during use and the locking collar is kept close to the jack body.

6.3 **Maintenance.** It is essential that aircraft jacks should be maintained in a serviceable condition at all times, and the following checks are recommended:—

(a) Jacks that stand idle for prolonged periods—exercise over full range and check the operation of the pump and release valve, and check visually for leaks, corrosion and hose condition before use.

(b) Jacks in constant use—visually check for leaks, corrosion, hose condition, etc., at approximately two-monthly intervals.

(c) All jacks should be overhauled and proof loaded every two years.

7 COMPRESSED GAS REPLENISHING TROLLEYS The equipment for replenishing compressed gas systems on aircraft normally consists of a trolley (which may be towed or self-propelled) on which are mounted one or more compressed gas cylinders, together with the necessary storage and supply pressure gauges and valves and, in some cases, a pressure regulator. Because of the dangers associated with the sudden release of a compressed gas, all parts of the trolley directly associated with the storage and supply of compressed gas should be checked daily, and should be kept scrupulously clean.

7.1 Replenishing trolleys should bear suitable markings to clearly identify the specific gas they contain, and should also bear a warning regarding the dangers of frosting when high pressure gas is discharged.

7.1.1 Gauges, valves, regulators, etc., should normally be retained for one type of gas only, and should not be interchanged with similar items on a rig containing a different gas.

7.2 Information on the operation of compressed gas replenishing equipment is contained in Leaflet **GOL/1-1,** and regular inspections should be carried out as follows:—

(a) All high pressure hose and end fittings should be inspected for cleanliness, security and damage.

(b) Storage cylinder pressures should be checked and the cylinders should be re-charged or renewed depending on the facilities available.

(c) A visual check for serviceability should be carried out on all gauges, valves, cylinder clamps, pipes, tyres and the trolley tow bar.

7.3 In addition to the visual inspections, all gauges should be calibrated at regular intervals.

8 TOW BARS Tow bars for large transport aircraft are generally designed specifically for use on a particular aircraft type and can seldom be used on other aircraft types; tow bars for light aircraft are generally capable of being used on a range of aircraft types. Steering arms, which are used to turn the nose undercarriage when an aircraft is being manhandled or towed from the main undercarriage attachments, are not designed for towing and should not be so used; steering arms should, however, be subjected to the applicable maintenance procedures specified for tow bars.

8.1 Tow bars vary considerably in design, but consist basically of a tube or frame with end fittings designed for connection to the aircraft towing fitting and the tug; a 'towing head' connects to the aircraft and a 'towing eye' connects to the tug. The tube or frame usually incorporates a buffer arrangement to prevent shocks being transmitted to the aircraft and one or more shear pins to prevent excessive force being applied to the nose undercarriage of the aircraft. Heavy tow bars are also fitted with jockey wheels to facilitate movement and these may be either mechanically or hydraulically retractable. To prevent damage to the aircraft towing fitting, a plug gauge is provided to enable checks for wear or damage to be carried out on the tow bar attaching hook.

8.2 **Servicing.** Servicing operations should be conducted in accordance with a schedule drawn up for the particular tow bar, and records should be kept of all work carried out. A minor check of all tow bars should be carried out twice-weekly and a major check should be carried out at either three- or six-monthly intervals, depending on the complexity and amount of usage of a particular tow bar. The checks outlined in paragraphs 8.2.1 and 8.2.2 are typical of those recommended for tow bars for large aircraft.

8.2.1 **Twice-Weekly Check.** The following checks should be carried out, as applicable; damaged or excessively worn parts being renewed as necessary:—

(a) Check the towing hook assembly for damage or wear, using the appropriate plug gauge.

(b) Examine the towing head, towing eye and sheer pins for damage.

(c) Examine the jockey wheels and tyres for damage and inflate the tyres to the correct pressure.

(d) Lubricate all pivot points and bearings as necessary.

(e) Check the operation of the hydraulic system and top-up as necessary.

(f) Check the tow bar structure for damage, and touch-up paintwork as necessary.

(g) Check the condition of any cables, switches and connectors attached to the tow bar.

8.2.2 **Three-monthly or Six-monthly Check.** The following checks should be carried out at the appropriate intervals, as determined by experience with a particular tow bar at a particular location.

(a) **Towing Eye.** Check the eye for excessive wear, cracks and damage.

(b) **Towing Head**

(i) Remove the shear pins and remove the towing head.

(ii) Check the shear pin bushes for wear.

(iii) Check the latching lever and mechanism for wear, and lubricate as necessary.

(iv) Check the jaw hook for wear and jaw width, using the appropriate gauges.

(v) Refit the towing head to the tow bar, using new shear pins.

(vi) Check all welds for cracks.

(c) **Main Tube or Frame**

(i) Check for damage and distortion.

(ii) Check the condition of any cables and the operation of any switches.

(d) **Tow bar Jockey Wheel Assembly**

(i) Check the framework for damage and cracks.

(ii) Check the tyres and wheels for damage, and inflate the tyres to the correct pressure.

(iii) Check the wheel bearings for wear, and lubricate as appropriate.

(iv) Check the operation of the assembly, and lubricate all pivot points. Check the hydraulic system for leaks, and replenish as necessary.

(e) **Paintwork.** Check the condition of all paintwork and notices, and repaint as necessary.

9 HANGAR FACILITIES The provision of safe and adequate facilities in hangars is important with respect to both aircraft serviceability and safety of personnel. This paragraph is not concerned with the fixed installations in a hangar, and gives general guidance only on the subjects of mobile transformer/rectifier units (9.1), portable lighting equipment (9.2), compressed air supplies (9.3) and work platforms, staging and rostrums (9.4).

9.1 **Mobile Transformer/Rectifier Units.** In some hangars, mobile transformer/rectifier units are used to provide d.c. power for general use during maintenance work. The units are connected to a mains outlet (usually 440 volts) and can provide power at several selectable voltages for the operation of various d.c.–operated types of equipment and for connection to the external ground supply socket on an aircraft; in some cases the units may also be used to provide power for engine starting.

9.1.1 Mobile transformer/rectifier units should be maintained in a serviceable condition at all times. The input and output cables should be subjected to regular inspections for tears, abrasions and general deterioration, and the mains and aircraft connectors should be examined to check the condition of the insulation and of the contact plugs and sockets. The output voltage at each selectable position should be checked regularly, and any instruments fitted to the unit should be calibrated annually.

9.2 **Portable Lighting Equipment.** Portable lighting equipment is used in most hangars to provide illumination for inspecting or carrying out work on aircraft, and varies considerably in design. Any lighting which is used in areas where flammable or explosive vapours are likely to be present should be of the flameproof (BS 229) or intrinsically safe (BS 1259) types. For work inside aircraft structures, low-voltage hand-held lamps and other inspection aids are often used (see also Leaflet **AL/7–13**).

9.2.1 Portable lighting equipment is usually connected to the standard 240 volt mains, and cables of considerable length may be used, together with extension cables and junction boxes. These cables are prone to physical damage in a working environment and require frequent inspection for cuts, abrasions and general deterioration. The lamp stands or trolleys should be inspected to ensure that the wire mesh protective screens are secure and in good condition, that all connections and switches are secure and functioning correctly, and that any cable restraining clamps or ties are secure, thus preventing force being applied to the electrical connections.

NOTE: Care must be taken not to overload a circuit by the use of adaptors which permit multiple connections to be made.

9.2.2 Loose cable lying on a hangar floor can present a considerable hazard, and lighting equipment which is not in use should be disconnected and its cable should be coiled and secured.

9.3 **Compressed Air Supplies.** Many hangars are fitted with a fixed compressed air supply, which consists of a static engine-driven compressor supplying a reservoir from which compressed air is piped to quick-release fittings located at convenient positions around the hangar. As an alternative, mobile compressors may be provided, with similar components and one or more outlets.

9.3.1 Maintenance of this equipment should be carried out in accordance with a schedule which follows the manufacturer's recommendations and includes the relevant operations outlined in paragraphs 3, 4 and 5.

9.3.2 It is usually important that a compressed air supply is clean and dry, particularly when it is used, for example, for inflating tyres, and particular attention should be given to ensuring that the filters are clean and that the water traps are drained frequently.

NOTE: If the compressed air supply is being used to inflate tyres, a pressure regulator must be incorporated in the delivery line (see Leaflet AL/3-18).

9.3.3 The sudden release of compressed air can be very dangerous, and it is essential that frequent inspections should be carried out to determine the condition of any flexible pipes and to ensure that all quick-release fittings are secure and operate correctly.

9.4 **Work Platforms, Staging and Rostrums.** Large aircraft require the use of sophisticated equipment to provide access to all parts of the structure. The equipment is usually mobile (often being self-propelled) may be designed for use with a particular aircraft type, and may also be provided with built-in power points and other facilities necessary for aircraft maintenance.

9.4.1 The framework of this equipment should be maintained in a safe condition to avoid injury to personnel or damage to the aircraft. All electrical cables and associated switches and connections should be regularly inspected for security and condition.

9.4.2 When assembling any type of access equipment around an aircraft, it is important to ensure that the aircraft brakes are applied or the wheels are chocked to prevent movement and that the equipment is moved carefully into position and secured from movement by whatever means is provided (e.g. braking the wheels or lowering fixed legs). Sufficient space should be left between the aircraft and the equipment to allow for any relative movement likely to result from aircraft maintenance operations.

9.4.3 The edges of the staging or platforms which are likely to be in contact with the aircraft are usually padded to prevent damage to the aircraft skin. This padding should be inspected for condition and security whenever the equipment is used.

10 TYRE PRESSURE GAUGES It is important that aircraft tyres are inflated to the correct pressure, and it is essential, therefore, that the gauges used to check tyre pressures should be accurate.

10.1 'Stick' type gauges can be expected to have errors of up to 4% and are suitable for use on light aircraft and older types of transport aircraft where such errors are acceptable. Gauges of greater accuracy should be used where considered operationally necessary. A suitable type of gauge is a dial-type gauge operating on the Bourdon tube principle; such gauges are available with an accuracy of ½% within the range of pressures specified for these aircraft, and should be used whenever possible.

10.2 A suitable system for checking gauges would be to keep one which has been newly calibrated as a master gauge and to check other gauges by comparison at, for example, weekly intervals (depending on usage). In addition, a gauge should be checked whenever its accuracy is in doubt, and all gauges should, in any case, be re-calibrated annually.

10.3 Gauges should be marked for identification, and records should be kept of all checks and calibrations carried out.

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AIRCRAFT

HELICOPTERS

INTRODUCTION TO HELICOPTER SECTION

1 INTRODUCTION This Leaflet is intended as an introduction to the Helicopter (HCL) Section of CAIP. It points out the main differences between the modes of operation of aeroplanes and helicopters which lead to the need for different maintenance practices, and indicates the Leaflets contained in other Sections of CAIP which may be taken to be applicable to helicopters as well as aeroplanes.

2 FACTORS AFFECTING HELICOPTER MAINTENANCE Although the maintenance aspects of aeroplanes and helicopters are basically similar, certain features must be given particular care in the maintenance of a helicopter. These features are outlined in paragraphs 2.1 to 2.3.

2.1 An aeroplane derives its lift mainly from the air passing around the wings and tailplane, and its thrust from a propeller or turbo-jet engine. Aerodynamic control is exercised by the operation of movable control surfaces, lift spoilers, airbrakes and a variety of high lift devices such as wing flaps, slats, etc. These control surfaces are of rigid construction, are operated only intermittently and because of the nature of their construction have a high degree of reliability. In addition, it is often possible to provide redundancy of some of the components and systems used to activate these control surfaces.

2.2 Unlike the aeroplane, the helicopter derives both lift and thrust from the rotation and manipulation of its main rotor blades through the medium of the rotor head, generally in association with a tail rotor or other anti-torque device. The factors involved in controlling lift, thrust and direction, and those which result from rotation of the main rotor and which have to be taken into account, are blade pitch angle, blade angle of attack, coning angle, rotor torque, blade lead and lag, centrifugal force and Coriolis effect. To obtain control of combinations of these factors requires a complex control system, parts of which can be subject to continuous movement. Because of the nature of helicopter design, helicopters are also subject to vibration, both aerodynamic and mechanical, which adds to the stresses imposed on the structure, systems and components, and increases the incidence of fatigue damage.

2.3 A helicopter thus has a complex rotor head and control system, which have to operate in severe conditions, often without the benefits of the multiple redundancy which can normally be provided on an aeroplane. Maintenance Manuals and Schedules take account of helicopter characteristics, but a thorough knowledge of a particular helicopter and continuing awareness of the potentially more serious effects of corrosion, wear and fatigue, are essential as a background to satisfactory maintenance.

3 LEAFLETS APPLICABLE TO HELICOPTERS Whilst some Leaflets in other Sections of CAIP contain information which is related specifically to helicopters, many refer to aircraft and their systems in general. When the information is meant to be applicable only to aeroplanes, this may be obvious from the text in some cases, but may not be so in others. Paragraphs 3.1 and 3.2 indicate the Leaflets which contain information which, although not specifically identified as such, may be taken to be applicable to the maintenance of helicopters as well as aeroplanes.

3.1 **Part I—Basic.** All Basic Leaflets, except the following, are applicable—**BL/1-11, BL/6-6, BL/6-7, BL/6-25, BL/6-26.**

3.2 **Part II—Aircraft.** All Aircraft Leaflets, except the following, are applicable—**AL/3-7, AL/3-22, AL/3-23, AL/7-1, AL/7-9, AL/7-12, AL/11-1, AL/11-2, AL/11-5, PL/1-1, PL/1-3, PL/1-4.**

HCL/1-2

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AIRCRAFT

HELICOPTERS

HELICOPTER VIBRATION

1 INTRODUCTION This Leaflet provides an introduction to the fundamentals of vibration analysis as applicable to helicopters and gives guidance on the routine measurement and recording of vibration levels. Whilst certain proprietary damping systems are described, the appropriate manufacturer's manuals should be consulted when it is necessary to make adjustments to such systems.

1.1 The topics discussed in this Leaflet are as follows:—

2 PRINCIPLES OF VIBRATION

2.1 Vibration may be described as a rapid oscillatory motion, which, in a helicopter may be either aerodynamic or mechanical and may be produced by the main and tail rotors, the transmission and the power-plant. Basic units are necessary to describe vibration in practical terms, and these are discussed in this paragraph 2.

2.1.1 The speed at which vibration takes place is known as the 'frequency' and is expressed in Hertz (Hz); one Hertz is a frequency of one cycle per second, where a cycle consists of movement in one direction followed by a movement in the opposite direction and return to the starting point (see Figure 1). Typical vibration frequencies found in helicopters vary from approximately 3·5 to 1000 Hz, although much higher frequencies are found in certain gearboxes. When dealing with the vibration of a main rotor it is quite common for the frequency to be expressed in terms of the rotor revolutions, e.g. a five per revolution (5/rev or 5R) vibration; 5 cycles of vibration for each revolution of the rotor.

2.1.2 The amplitude of the displacement that takes place during vibration is normally measured from the mean or equilibrium position (see Figure 1), the units used being either inches or mils (1 mil = 0·001 in). However, since it is difficult to measure amplitude directly the related function of 'velocity', expressed in inches per second (in/s or IPS), is often used. Since the velocity is not constant the figure used is the velocity of the point being measured as it passes through the mid-point of its oscillatory motion. Velocity may be related to actual displacement at a given frequency (see 6.2) by evaluating the formula:—

$$D = \frac{V}{2\pi f}$$

where D = displacement amplitude in inches (±)
V = velocity in inches per second
f = circular frequency (Hz)

$$Hz = \frac{rpm}{60} \text{ (cycles/sec)}$$

A typical very severe imbalance of a tail rotor might produce a vibration having a velocity of 4·0 in/s and causing a displacement of approximately ±0·013 in at 3000 rpm.

NOTE: It should be noted that American publications may define amplitude on a peak-to-peak basis and this should be taken into consideration when using any related formulae.

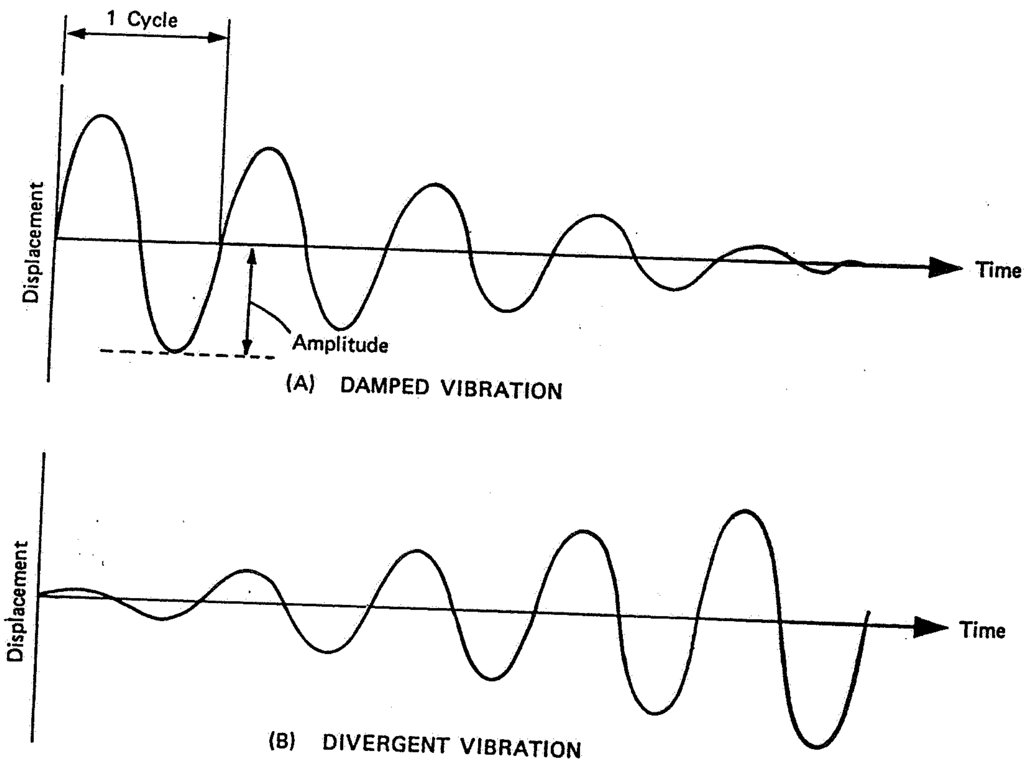


Figure 1 FORMS OF VIBRATION

2.1.3 Another term encountered when dealing with the subject of vibration is 'resonance'. Any object which is flexibly mounted has a natural vibration frequency, that is, a frequency at which it will naturally vibrate when stimulated by an outside source. For example, if a thin wooden ruler overhanging a desk is struck at the end it will vibrate at a particular frequency, which depends on how much of the ruler is overhanging the desk. If a small weight is fixed to the end of the ruler the natural frequency will be lowered. The force with which the end of the ruler is struck will not alter the frequency of vibration but will alter the amplitude. In the case of the ruler, the vibration decays as the stimulation is removed, and this is shown in Figure 1(a). However, should the outside stimulus continue in phase, with the natural vibration, the amplitude of the vibrations will increase to the point where the strength of the ruler is exceeded and it breaks. Where such a situation could exist in a helicopter a means of damping is used to control the amplitude at the resonant frequency. Ground resonance is an example of vibration which can reach a destructive level if, for example, the landing gear dampers are unserviceable.

2.2 The dynamic behaviour of a helicopter structure is illustrated diagrammatically in Figure 2. In Figure 2(a), a spring A and weight B form a system which is suspended from a rotor from which it receives excitation. The predominant excitation frequency (Hz) will be given by the number of blades in the rotor multiplied by the speed of rotation in revolutions per second. Weight B responds to this excitation in a way which is dependent upon the value of the weight and the natural resonant frequency of the weight/spring system. This response could be naturally damped (attenuated) or it could be divergent (amplified). If a further weight C is hung on weight B by means of a further spring D (see Figure 2(b)), then the original response to vibration of weight B will be modified. Weight C will respond in opposition to the exciting force from weight B, and tend to reduce it, or cancel it if the natural frequencies of the two spring/weight systems match each other. Under these conditions the structural response is zero, i.e., the vibration has been absorbed.

2.3 In practice the absorption of vibration in a helicopter is a much more difficult problem, since the structure is not a single homogeneous mass, rotor speed varies, and the main rotor is only one of several sources of vibration; it is thus not possible to eliminate all vibration from a helicopter. Basic vibration resulting from the design is taken into account when establishing safe operating lives for various primary components, although individual helicopters will vary because of engineering tolerances. However, vibration resulting from an out-of-rig condition or from damaged or worn parts, which will either increase the normal levels of vibration above an acceptable threshold or produce vibration at abnormal frequencies, must be eliminated.

2.3.1 An increase in vibration beyond acceptable levels subjects all parts to much higher repetitive stress levels than those for which they were designed, resulting in a greater likelihood of fatigue failure. In the same context the likelihood of failure is increased many times if the component has already suffered an overload or damage in the form of a stress raiser, such as a nick or a scratch, at which there will be a concentration of stress; some materials are more sensitive than others to this type of failure. Self-locking nuts may not remain secure at the increased vibration levels, leading to fretting of the parts they attach. Split pins can chatter in their holes and ultimately fail. Pipes, cables, hoses and controls are more likely to chafe and suffer failure through fatigue. Sensitive instruments and avionic equipment are all likely to experience a lower time between failures in the presence of excessive vibration.

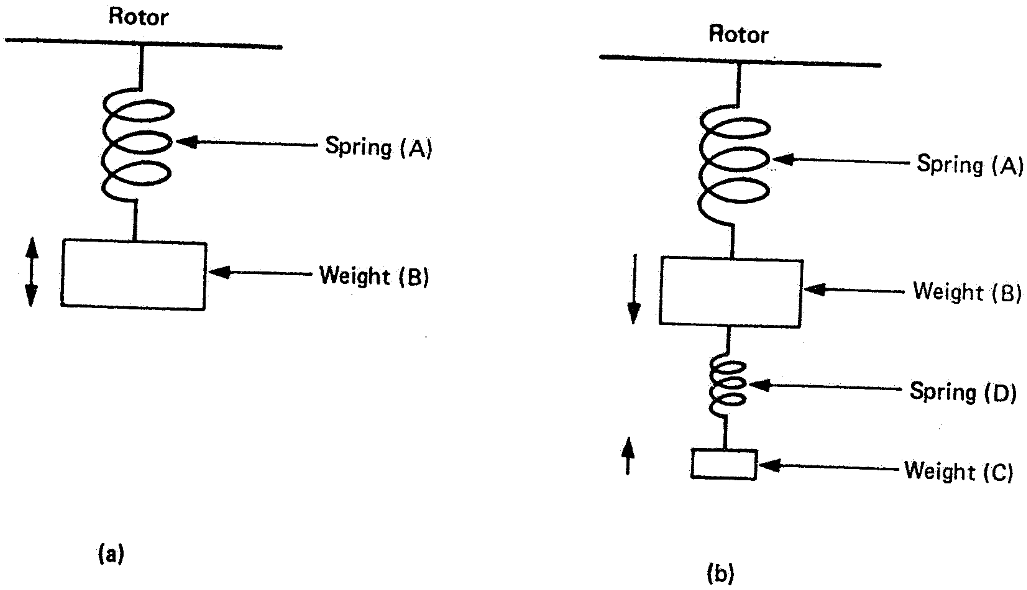


Figure 2 DYNAMIC RESPONSE TO VIBRATION

3 SOURCES OF VIBRATION

3.1 **Aerodynamic Sources.** The primary sources of vibration with an aerodynamic origin are the main and tail rotors. Each blade is of aerofoil section, providing lift (or thrust), and aerodynamic disturbances will cause vibrations of a frequency depending on the speed of rotation and the number of blades in the rotor. For example, a two-bladed, semi-rigid rotor will have an inherent vibration of 2/rev, whilst a five-bladed rotor will have an inherent vibration of 5/rev. However, anomalies relating to one blade only, such as the development of more or less lift in respect of slight variations in aerodynamic shape (which may be caused by minor damage or natural ageing) will produce an additional vibration of 1/rev. In a fully articulated rotor, variations in blade spacing (blade phase) or track, will cause similar vibrations, and if only one blade is affected the vibration frequency will again be 1/rev. The same is true of a tail rotor except that since the rotational speed is higher the actual vibration frequency will be higher. Under some conditions disturbed airflow can cause the vibration of elevators, stabilisers, cowlings and access doors, but more often these will vibrate in sympathy with some other source if their attachments are loose or worn.

3.2 **Mechanical Sources**

3.2.1 **Transmission Sources.** This heading includes, for the purposes of this Leaflet, everything that rotates other than the engines and the aerodynamic sources mentioned in paragraph 3.1.

(a) Rotors may be considered as mechanical components, and vibration may arise from several causes. One primary consideration is balance of the rotating assembly. An out-of-balance tail rotor will produce vibration at a higher frequency than that of a main rotor, and it will be in a different plane. Any wear in rotor head control linkage will permit the development of abnormal vibrations, and once the clearance exists wear will take place at an accelerated rate.

(b) Drive shafts are balanced to prevent excessive vibration, and special assembly techniques are often used with shaft couplings to maintain the balance of the whole assembly. Mis-alignment of a shaft will cause vibration as a result of the slight flexing motion introduced into the shaft. Wear in the shaft support bearings and coupling splines are further sources of vibration in the drive shaft system.

(c) Gearboxes, with components running at different speeds and supported on different kinds of bearings, provide sources of vibration at several frequencies. Due to the accumulation of manufacturing tolerances, gear teeth may vary slightly in position and as a result tooth loadings may vary at different points on the gear. Varying loadings resulting from variations in attitude and airspeed are transmitted through the rotor mast to the supporting bearings, resulting in changes in loading and therefore in vibration. In addition, many gearboxes provide drives for a variety of accessories, such as generators, hydraulic pumps and tachometers; each of these components produces a characteristic vibration, which may vary under differing operating conditions.

3.2.2 **Power-plant Sources.** Power-plants fall naturally into the two divisions of piston engines and turbine engines, each having totally different vibration characteristics.

(a) A piston engine, with one power stroke per cylinder every other revolution of the crankshaft, is a prime source of vibration, the severity of which depends on the number of cylinders; the greater the number of cylinders, the smoother is the running of the engine, since there is a smaller rotation of the crankshaft between firing impulses. Because of the nature of the operating cycle, vibration is not merely transmitted through the engine mountings but a torsional vibration is also transmitted through the crankshaft. For this reason many piston-engined installations incorporate a flexible type of coupling between the crankshaft and the gearbox. The crankshaft itself usually embodies counterweights to absorb torsional vibration.

(b) The turbine engine presents a different vibration case altogether. Whilst the engine is inherently smooth running, the higher rotational speeds mean that the effects of any imbalance are magnified as much as ten times compared with a piston engine. Ingestion damage to compressor blades and creep damage to turbine blades, and wear on bearings and seals, are all causes of abnormal vibration. Similarly, the engine driven accessories can all produce characteristic vibrations.

4 METHODS OF REDUCING VIBRATION Whilst good maintenance practices and attention to detail are the main ways of reducing vibration to an acceptable level, there will always be a degree of vibration inherent in the design of a helicopter. Different manufacturers adopt different methods of damping the basic vibration and these methods are outlined in paragraphs 4.1 to 4.4.

4.1 **Resonant Mass.** The simplest form of vibration damper uses the same principle as the ruler overhanging the edge of a desk (paragraph 2.1.3) where the frequency of vibration can be varied by adding or subtracting mass at the end of the ruler. If the characteristics of the mounting spring and weight (paragraph 2.2) are adjusted to resonate at the basic frequency, then the vibration will be damped and not transmitted to the airframe.

4.1.1 One helicopter has a resonant mass vibration damper mounted under the cabin floor, where it is known as the 'cabin resonator'. Another application of the same principle is to be found in the cyclic controls of a light helicopter, to prevent vibration being transmitted through the control runs. A third variation of the same principle is to be found in the resonant battery mounting used on one large helicopter. In this arrangement the battery itself forms the resonant mass and is supported by three cantilever springs. The spring length is adjustable and is set up during construction using special equipment. Tuning of the vibration absorber to compensate for variations in battery weight is achieved by adding or subtracting weights, weight being added to lower the resonant frequency.

4.1.2 A further application of the same principle is to be found in a type of damper installed on the main rotor head of a small helicopter (see Figure 3). Being mounted on the main rotor head, the vibration damper absorbs much of the excitation at source before it can be transmitted to the rest of the helicopter. In this design a weight is supported in the rotor head by a ball joint which permits it to move in any direction in the horizontal plane. The weight is restrained by three equally-spaced springs, which control its movement and form a tuned system. This system is excited by the vibratory loads developed in the rotor head and responds in opposition to them, thus reducing them.

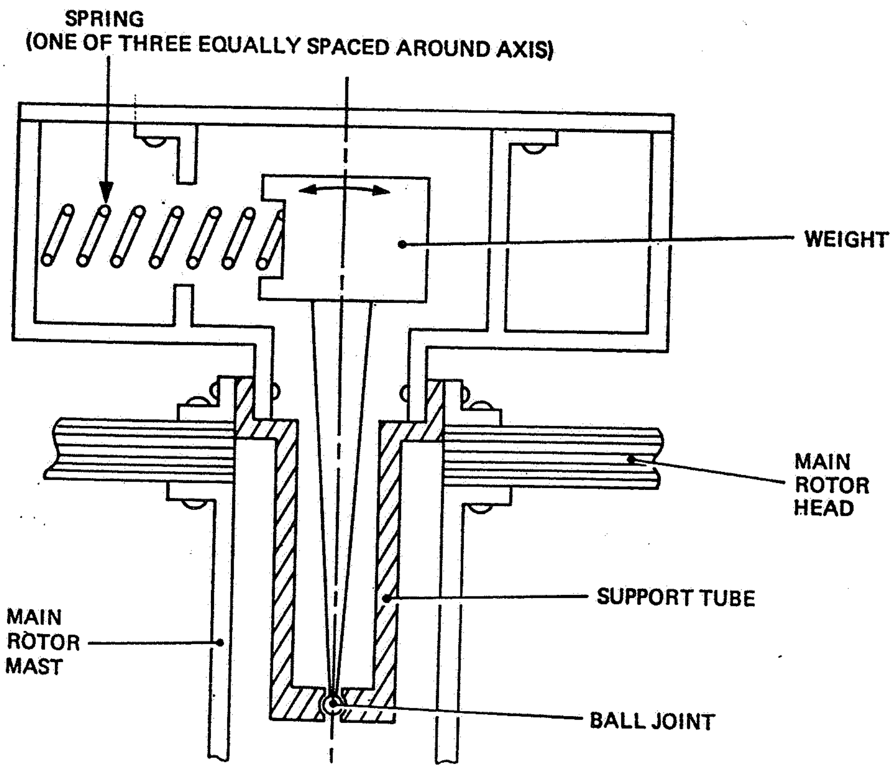


Figure 3 SPRING-LOADED MAIN ROTOR DAMPER

4.2 **Nodal Beam.** The response of a weight tuned by a spring is utilised in other forms of vibration damper systems which, at first sight, appear to have little in common with the systems already described.

4.2.1 In one system, the main rotor and gearbox are coupled to the airframe through a nodal beam, which is used to isolate vertical vibrations (see Figure 4). The principle can be demonstrated with a long thin piece of wood. If the wood is held horizontal at its mid-point and shaken vertically, the ends, because of the flexibility of the wood, will move in opposite directions to the mid-point, that is, they will be out of phase; this will occur when the induced vibration is near to the natural vibration frequency of the piece of wood. The locations in the beam where the motion changes from one direction to another are known as 'nodal points' and here there is no movement. If a helicopter fuselage is attached at these points then it will not be subjected to the vertical vibration induced by the rotor. For a helicopter the beam consists of flexible members at the ends of which are attached inertia weights. The flexible members forming the beam on some helicopters are made of glass fibre, which has a low ~~Young's modulus and high allowable~~ stress, and is relatively easy to form into complicated shapes. The mounting to the airframe is via elastomeric bearings, and the response of the system is adjusted by the use of tuning weights mounted on arms.

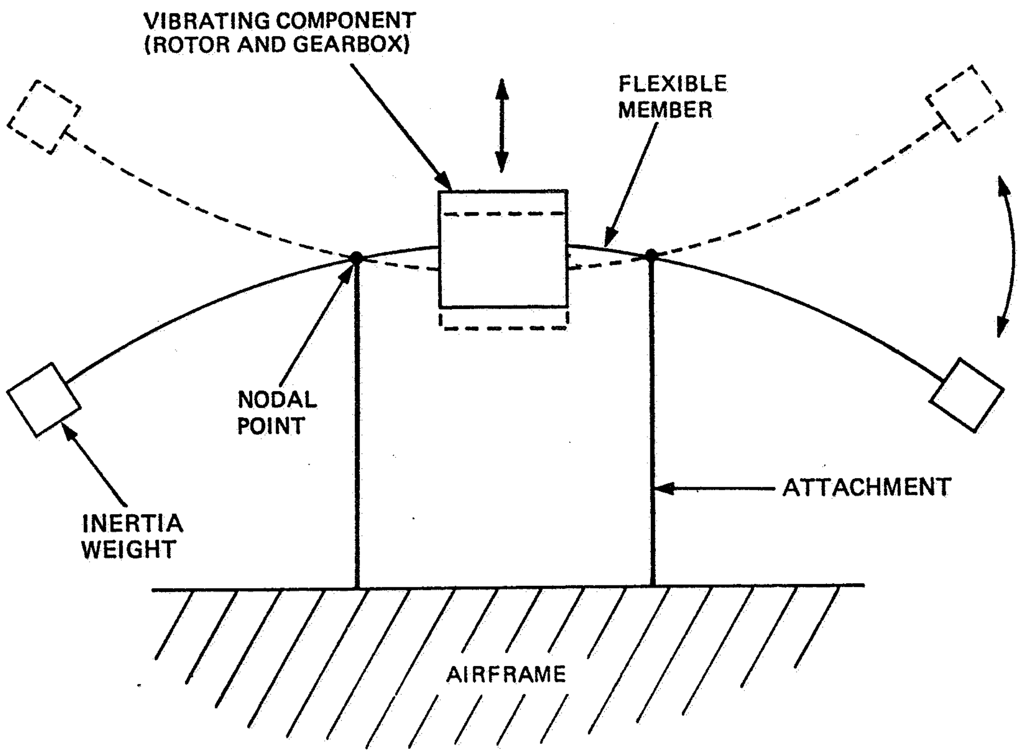


Figure 4 PRINCIPLE OF NODAL BEAM DAMPING

4.3 **Counterweights.** A type of vibration damper in which springs are not used, is incorporated on some types of rotor head and is known by the generic name of 'pendulum dynamic vibration damper'. This is secured to the main rotor hub and shaft, and therefore rotates with it in the same plane as the rotor. It consists of a support forging with a number of radial arms, to each of which is attached a weight, which is loosely mounted and is free to move within restrictions imposed by the mounting bushes. The vibration damper uses the concept of in-plane pendular dynamic weights which generate inertial forces in opposition to the forces generated by the rotor. Since the weights are subject to centrifugal force, which varies with rotor speed, the damping provided by this type of absorber is effective throughout the operating speed range.

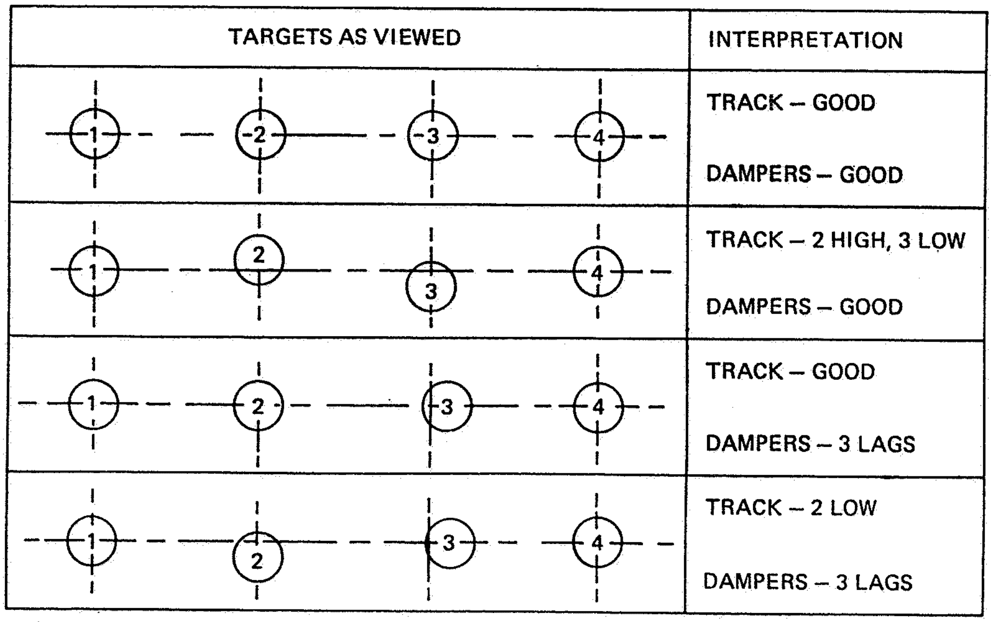
5 MEASUREMENT OF VIBRATION A subjective assessment of the level of vibration in a helicopter may be sufficient in coming to the conclusion that something is wrong, but is inadequate when it becomes necessary to ascertain the cause. Some faults have fairly obvious and well defined symptoms but many can be hard to locate and careful analysis is necessary to identify them. In making such an analysis it is essential that the method used will enable the frequency and velocity of the vibration to be determined. The manner in which this information is used to diagnose faults is dealt with in paragraph 6 but the three main methods of obtaining the information are outlined in paragraphs 5.1 to 5.3. Further information on these equipments may be obtained from the manufacturers' manuals.

5.1 **Hand Vibrograph.** In its basic form, this instrument consists of a steel reed with a weight at one end. It has already been seen that such a device will have a natural vibration frequency that is determined by the length of the reed and the mass of the weight. Varying the length of the reed varies the natural vibration frequency. Measurements should be conducted under the flight conditions in which the vibration is most noticeable (in order to pick up the maximum amplitude), with the instrument placed against the airframe structure as close as possible to the suspected source of vibration. Since vibration may be found in both lateral and vertical planes the test should be carried out first with the instrument in the lateral position and then in the vertical position. The main object of this testing is to identify the fundamental frequency of the vibration in order that its source may be accurately located; a variation of the instrument provides a read-out in the form of a graph, analysis of the indicated waveform is often difficult and requires considerable skill in interpretation when one vibration is superimposed upon another. For many years there was no alternative to this instrument for portable use in the maintenance of helicopters, but latterly the vibrograph has been superseded by electronic instruments.

5.2 **Electronic Vibration Measurement.** In this system, an accelerometer is mounted in the helicopter in either a lateral or vertical (and in some cases the fore and aft) position (for balancing the main rotor the accelerometer is mounted laterally, but for tracking it is mounted vertically) the equipment often provides for two accelerometers to be connected simultaneously, and for the signals to be selected as required. Signals from the accelerometer are processed electronically, and displayed on a meter as 'vibration amplitude', although actually the peak velocity of the vibration is recorded and the scale marking is in inches/second (IPS). In addition to the accelerometer(s) a magnetic pick-up is used to provide a phase reference, i.e. one signal per revolution of the rotor. This signal is fed into a display which shows the phase relationship between the rotor and the vibratory motion and is used to determine the location of the required balance weights. In the case of the main rotor this display, known as the 'clock angle', is in the form of a circle of 24 lights, numbered in the same way as a clock face. Where a tail rotor is being investigated the clock angle is displayed by use of a reflective target (i.e. a patch of reflective material temporarily stuck or otherwise fixed to the rotor blade) on one blade, which is illuminated by means of a strobe light slaved to flash in time with the vibration. The strobe light is also used in conjunction with reflective targets to permit in-flight tracking of the main rotors, including observation of the blade spacing (lead/lag).

5.2.1 When carrying out a fault diagnosis of a main rotor, the rotor track should be checked first, and if necessary corrected, before proceeding with rotor balancing; the tests should be carried out with the helicopter in the hover. Before carrying out either check, the accelerometer(s) should be mounted on the helicopter in the agreed position(s) and the helicopter should be headed into wind on flat, level ground; operation in gusty conditions or wind-speeds above 15 knots should be avoided since these conditions introduce variables which may hide the real fault. The rotor should then be run on the ground at its nominal speed and the equipment rough-tuned to the frequency corresponding to 1/rev of the rotor being checked. The helicopter should then be put into the hover and the equipment fine-tuned and checked using its own internal test facility.

(a) Rotor track is checked by observing the blade reflective targets with the strobe light. Although different modes of operation are generally available, typical usage would present all targets superimposed upon one another at a fixed position in azimuth. If the frequency of the strobe light oscillator is then reduced slightly, the targets will be seen to spread, making them easier to identify and interpret (see Figure 5).



NOTE: Targets of Four-Bladed Rotor as Viewed by Strobe Light and Spread to Aid Identification

Figure 5 BLADE TRACKING

Any error in track or in blade spacing may thus be readily seen and the appropriate corrective action may be taken. In most helicopters the track is adjusted by altering the length of the pitch change rod of the incorrect blade, but in some it may also be necessary to adjust the blade trailing edge trim tab. It is very important that adjustments be made in the sequence recommended by the manufacturer. Incorrect blade spacing is often the result of faulty blade dampers, which should be renewed or repaired as appropriate.

(b) Once the rotor is correctly tracked, two readings may be taken from the balance part of the equipment as follows:—

(i) Phase—note which clock angle light is on (example, Figure 6, 5:30).

(ii) Amplitude—note reading on meter scale (example, Figure 6, 0·15 IPS).

After the helicopter is landed and shut down, these values should then be plotted on a nomogram (see Figure 6), from which it is possible to determine the number or size of balance weights required to be added to achieve balance. It is unlikely that one of the plotted points will lie exactly on a zero line (i.e. the centreline of a blade), so that balancing a rotor will usually involve adding weights to two blades as in the example in Figure 6. When corrections have been made, the check should be repeated until good balance is obtained, as indicated by a reading on the meter which is within the tolerance specified by the helicopter manufacturer. It should be noted that whilst it is still possible to read a definite clock angle the balance can be improved; as the balance improves the clock angle becomes more and more 'jittery'.

NOTES: (1) The helicopter manufacturers provide certain points on a rotor to which weights may be attached for balancing purposes.

(2) The nomogram (or balance chart) is valid for only one type of helicopter, with a specific configuration of accelerometer(s) and magnetic pick-up. There is a separate chart for each helicopter and each rotor.

5.2.2 The equipment may also be used to determine the amplitude and frequency of a vibration from an unknown source. In this case an accelerometer is mounted in the area where the vibration is most obvious and the equipment tuned slowly through the ranges until the meter reading reaches a peak. Knowing the frequency of the vibration, the location of its source may be more readily determined.

5.3 **Vibration Signature Analyser.** This is an extremely useful diagnostic tool particularly when used on a schedule basis. The analyser is a self-contained piece of equipment which measures vibration frequency against peak velocity and automatically produces a permanent record of the test in the form of a graph. The output from the accelerometer is processed electronically by a tuneable band pass filter, which separates vibrations on the basis of their frequency. The filter automatically scans through the selected frequency range and a pen records the result on a card (see Figure 7), which may be kept as part of the helicopter records. This equipment is not an alternative to the electronic vibration measurement equipment but supplements it.

5.3.1 From the signature drawn on the card, a vibration peak at a particular frequency can be readily seen and its source determined. When the fault has been corrected, a further signature record should be made in order to confirm correction of the fault and provide a fresh datum with which to compare future signatures in the event of a suspected fault. One analyser is equipped with two frequency ranges, 0-100 Hz and 0-1500 Hz, and three velocity ranges, 0-0·2 IPS, 0-1·0 IPS and 0-5·0 IPS, the selection being automatically recorded on the card when the machine is in use.

BALANCE MEASUREMENT		1	2	3	4	5
BLADE TRACKING		Good				
Balancer	CLOCK ANGLE	5:30				
	AMPLITUDE (IPS)	0.15				

Corrections					
RED BLADE	525 g				
YELLOW BLADE	300 g				
BLUE BLADE					
BLACK BLADE					

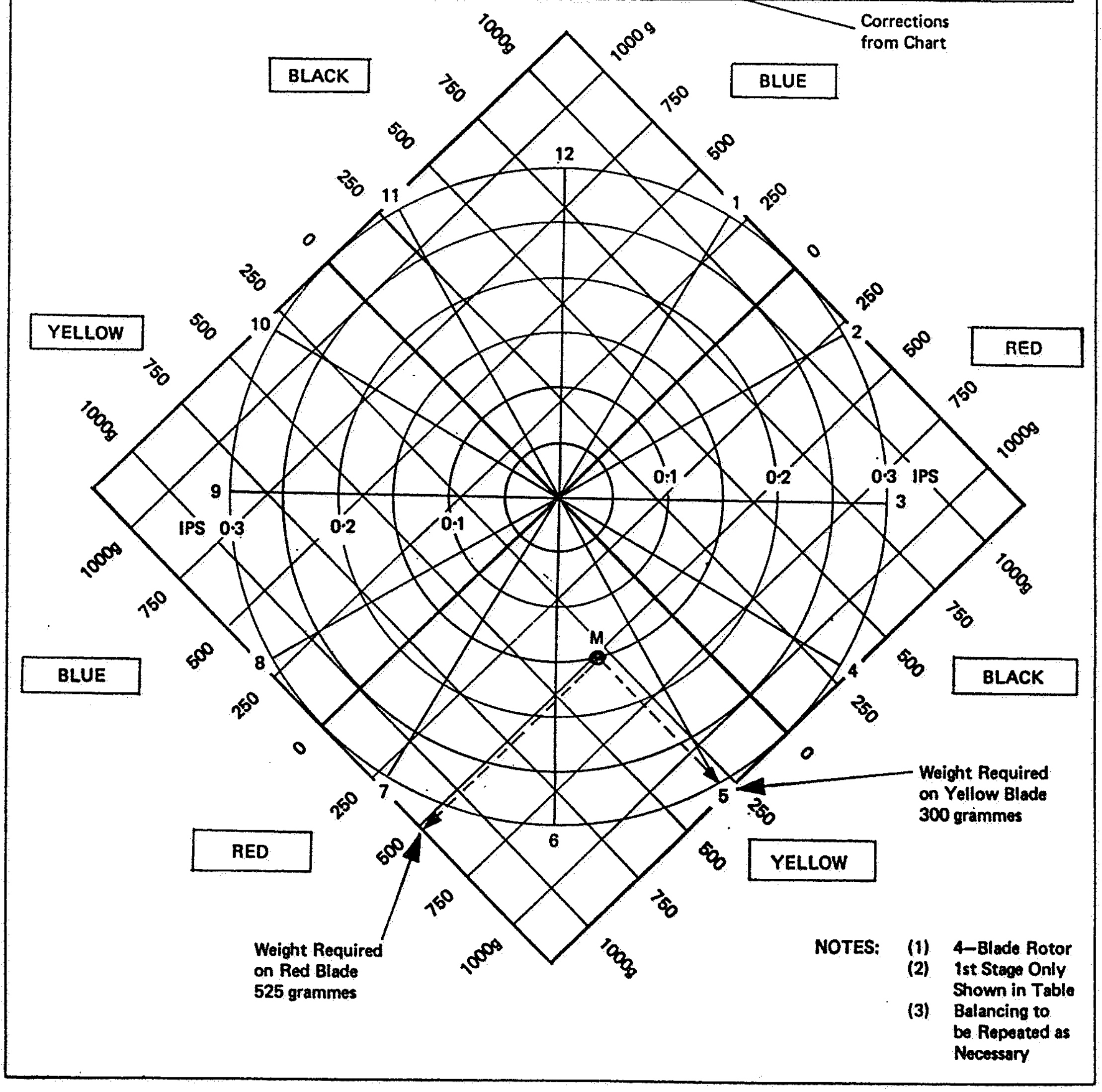
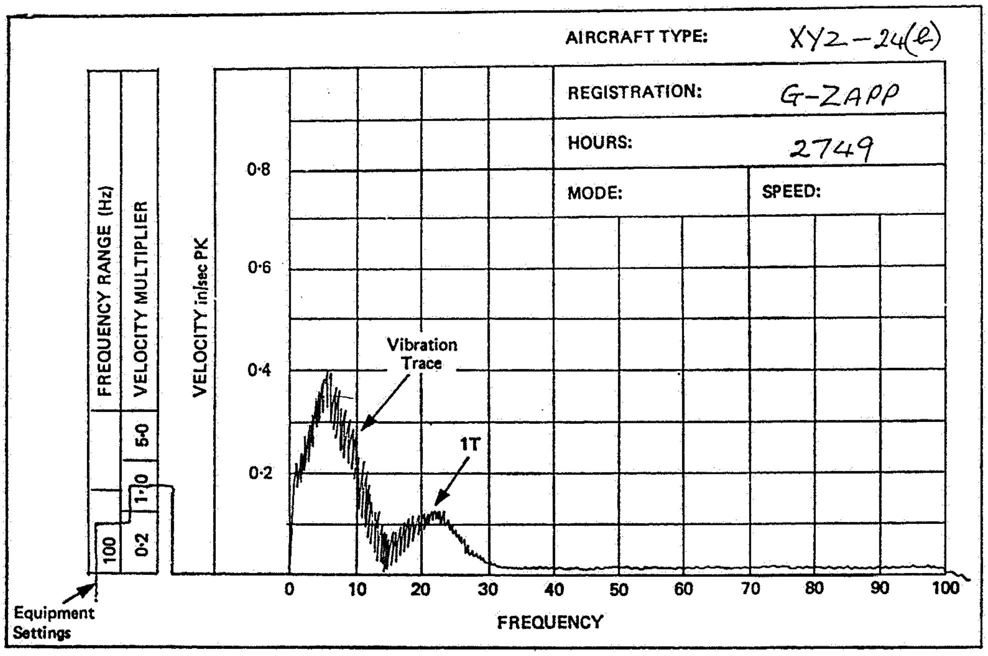


Figure 6 TYPICAL VIBRATION NOMOGRAM



NOTE: Tail Rotor Vibration Peak (1T) = 0·13 in/sec

Figure 7 TYPICAL VIBRATION SIGNATURE RECORD CARD

5.3.2 As with other types of vibration measuring equipment a specific location must be used for the accelerometer, and be used every time if the readings on a subsequent occasion are to be comparable. Normally both lateral and vertical (and in some cases fore and aft) signatures would be obtained on each frequency range, making a total of four signatures. Any significant peaks are then analysed and the faults corrected. In this way a complete vibration history is built up for a particular helicopter and the information can also be used to form the basis of a data bank for each type of helicopter.

5.4 **Calibration.** As with any precision instrument the usefulness of the data collected is determined by the confidence level established in use. Periodic calibration of measuring equipment is essential, although the interval will need to be determined by the frequency of use and the known stability of the particular equipment. The results of such calibration should be recorded so that a history may be built up for a specific instrument, on the basis of which it may be desirable, or necessary, to change the calibration interval. Some electronic filters are known to be subject to frequency drift with changes of temperature and this should be taken into account when recalibrating the equipment.

6 ANALYSIS OF VIBRATION Whichever method of vibration measurement has been used with a helicopter two parameters will have been obtained, namely frequency and amplitude (or velocity). With these two parameters it is possible to locate the source of vibration and determine its severity. Since the frequency is a function of the speed of various rotating components on the helicopter, it is possible to use this information to locate the source of the problem.

6.1 **Vibration Classification.** When determining the source of vibration it is usual to classify the frequency of the vibration as low, medium or high. Each range of frequencies may then be associated with particular components in a specific helicopter, although the actual range will be different with different helicopters. For example, low frequency vibrations are normally associated with the main rotor and are of the order of 1-2/rev in a two-bladed machine and 1-5/rev in a five-bladed machine; in terms of actual frequency ranges these could be between 3 Hz and 20 Hz, dependent upon the design of the machine. High frequency vibrations may be associated with the speed of the tail rotor and faster rotating components, whilst medium frequency vibrations will lie somewhere between the two extremes. Different manufacturers suggest different classifications for the medium and high frequency vibrations, the differences generally stemming from the number of blades and the gearing of the tail rotor.

6.1.1 In addition to the frequency and amplitude, the plane of the vibration will also be known. This will narrow the range of possible faults causing a vibration at a specific frequency. For example, in the case of a vibration associated with the speed of the main rotor, a lateral vibration would indicate an out-of-balance rotor, whilst a vertical vibration would indicate that the rotor was out-of-track. To verify the plane of the vibration and so cross check any measurements made the helicopter should be flown at different forward speeds and at different rotor speeds. An out-of-balance condition producing a lateral vibration will be worse at higher rotor speeds, whilst an out-of-track condition will produce a vertical vibration that becomes worse with increasing forward airspeed.

6.1.2 Whilst carrying out the flight test of a helicopter additional checks should be made. With the helicopter in the hover the cyclic stick should be moved slightly out of neutral and it should be noted if it rotates in time with the rotor (a symptom known as 'stick stir'). Typically this is symptomatic of faulty pitch change or flapping hinge bearings. If vibration is felt through the cyclic stick and the fuselage when the blade angle and/or power are rapidly changed in flight, the blade dampers may well be at fault. If the vibration is felt predominantly throughout the fuselage, particularly with rapid changes in the rotor tip path plane, faulty bearings in the flapping or dragging hinges should be suspected. Note should be taken of the circumstances under which vibration occurs or under which its nature is modified, in order to assist in correct diagnosis of the cause.

6.2 **Frequency/Speed Relationships.** To be able to relate the frequency of the measured vibration to the speed of different rotating components requires an intimate knowledge of the particular helicopter. A vibration of the order of 1/rev may be related to the speed of rotation by multiplying the measured frequency (F) in Hertz, by 60, to give the speed in revolutions per minute (rpm). This may be expressed as follows:—

$$\text{rpm} = F\ (\text{Hz}) \times 60$$

A 1/rev vibration is typical of an out-of-balance condition affecting a rotating component. For example an out-of-balance main rotor rotating at 203 rpm will produce a vibration frequency of:—

$$F\ (\text{Hz}) = \frac{\text{rpm}}{60} = \frac{203}{60} = 3{\cdot}4\ \text{Hz}$$

However, not all vibrations are 1/rev. In the case of a condition affecting all five blades in the above rotor the frequency would be:—

$$F\ (\text{Hz}) = \frac{\text{rpm} \times \text{No. of Blades}}{60} = \frac{203 \times 5}{60} = 16{\cdot}9\ \text{Hz}$$

In the same way the frequency produced by the meshing of gear teeth in the gearbox may be calculated if the number of teeth on the gear and the nominal speed of the gear are known. In this way it is possible to produce a table of vibration orders for a specific helicopter and some manufacturers publish such a table in the Maintenance Manual (see Table 1). In identifying the different orders abbreviations are often used, examples of which are as follows:—

1R = 1/rev main rotor
5R = 5/rev main rotor
1T = 1/rev tail rotor
1E = 1/rev engine output shaft
MGB = main gearbox
TRG = tail rotor gearbox

The letter M, used a prefix, would indicate that the vibration emanates from the meshing of the gear identified. For example:— M.TRG identifies the frequency generated by the meshing of the gears in the tail rotor gearbox. It is usual to quote the vibration orders based on speeds related to 100% main rotor speed.

TABLE 1

TYPICAL VIBRATION ORDER TABLE

Frequency (Hz)	RPM	Component
3·4	203	Main Rotor (1/rev)
15·7	939	Main Bevel Gear (MGB)
17·0	—	Main Rotor (5/rev)
20·7	1243	Tail Rotor (1/rev)
50·5	3031	Tail Rotor Drive Shaft
53·2	3195	Input Bevel Gear (MGB) or Rotor Brake Disc
101·0	6060	Oil Cooler Fan (MGB)
140·0	8410	Tail Take-off Freewheel Unit
316·0	—	Nos. 1 and 2 Input Pinion Gears
325·0	—	Engine
832·0	—	Meshing, Tail Rotor Gearbox, (M.TRG)

6.3 **Vibration Level Comparisons.** Having located the source of the vibration from an analysis of the frequency and its plane of vibration, it remains to determine whether the amplitude of the vibration is normal or excessive. In the cases of the main and tail rotors some manufacturers specify a maximum acceptable vibration amplitude, but some do not. For the main rotor, one manufacturer states that the balance may be deemed satisfactory if the vibration level does not exceed 0·05 IPS, whilst for the tail rotor the maximum acceptable level is 0·2 IPS. It should be noted that these figures are concerned only with vibration resulting from unbalance.

6.3.1 It is not recommended that decisions to accept or reject a component should be made solely on the basis of one set of vibration measurement readings. Where measurements are made on a scheduled basis it should be possible to notice a trend from the recorded data and the nature of this trend will be a more reliable indicator as to the action to be taken. A steadily worsening trend would indicate the need for careful monitoring but would not necessarily indicate the need for an immediate component change. However, a sudden, and large increase in the vibration level from, for example, a tail rotor gearbox, would be positive indication of the need for immediate investigation. In any given set of circumstances it should be borne in mind that there may be more than one source of vibration, and that a combination of sources may falsely amplify a specific reading. Such a case underlines the fact that there is no substitute for a detailed knowledge of the vibration history of the helicopter type and preferably of the specific helicopter. Where the Vibration Signature Analyser (see paragraph 5.3) is in regular use, the record cards provide a ready reference to the vibration levels previously experienced, in addition to making it easier to identify any abnormal peaks.

7 **CORRECTION OF EXCESSIVE VIBRATION** If a rotor goes out of track or balance on a helicopter which has previously flown satisfactorily, the primary cause must be established and corrected before commencing track or balance adjustments.

7.1 In the case of vibration which has been traced to the tail rotor, the investigation should include an inspection of all parts for wear and damage. Items requiring special attention include the pitch change bearings, the pitch change links and spider, tail rotor hub and gearbox attachments. Where mounting bolts are found to be slack it will be necessary to assess whether the slackness is the cause of the vibration or an effect of it. The follow-up work will not only involve re-tightening the bolts but also a check of the bolts, nuts, holes and locking devices for wear and cracks. Care must be taken to ensure that the inspection covers a sufficiently wide area to discover symptoms of secondary damage, such as cracking in the structure of the tail pylon. As items are renewed it is important that fits, clearances and tightening torques specified by the manufacturer are adhered to, in order that the unit shall perform as designed.

7.2 When dealing with vibration problems emanating from a rotor there is little point in trying to correct balance unless it is known that the track is correct and, in the case of a fully articulated head, that the dampers are operating properly. When considering main rotor track it must be ensured that the blades are compatible with one another and, where provision exists, are correctly pre-tracked. With some types of helicopters it is preferable that all blades be of a similar age since this will usually necessitate less correction to individual blades. With some types of tail rotor blades it has been discovered that quite significant weight differences can exist between one blade and another and corrections will be kept to a minimum if they are first matched in sets by weight. Great care should be taken when repainting blades, as a small difference in the thickness of the coating can produce a significant difference in weight.

7.2.1 Once the track and blade spacing are known to be correct, the rotor may be dynamically balanced using electronic vibration measurement equipment. With some main rotors and most tail rotors it is advisable to statistically balance the rotor prior to fitting it to the helicopter; this will reduce the amount of work required subsequently when the rotor is dynamically balanced. If either the track or the balance is changed the other condition should be re-checked, especially when dealing with articulated rotors.

7.2.2 After track and balance are confirmed to be correct in the hover, it will be necessary to fly the helicopter at different speeds, and to adjust the pitch change rods or the blade tabs, in order to achieve correct track in flight at all airspeeds. Some manufacturers publish a chart of step-by-step actions to facilitate the adjustment of rotors; such a chart may be included in the relevant Maintenance Manual.

8 VIBRATION ANALYSIS RECORDING Whilst the measurements made with the various types of equipment described have an immediate application in the rectification of a particular fault, the recording of results in such a way that it is possible to establish acceptable levels of vibration for a helicopter type, and trends in vibration for a specific helicopter, may be more important. In a fleet of helicopters, a vibration history should be built up for each helicopter by taking vibration signatures on a scheduled basis, that is, during the course of normal maintenance. In addition to the regular signature recording, analysis should be carried out in response to a pilot's report of abnormal vibration. From the record cards it is possible to extract a record of velocity at a certain frequency and to plot this on a graph at each successive check. The result will show a trend for the particular frequency selected, and thus indicate the condition of the component producing that frequency. A deteriorating trend would alert maintenance personnel to an impending problem and indicate the need for additional checks, such as, for example, oil analysis, to be carried out.

8.1 In addition to providing the basic data in relation to a specific helicopter the same material should be used to establish fleet averages for a helicopter type. Manufacturers are increasingly providing this kind of information in their Maintenance Manuals in order to assist engineers in making a decision as to whether or not a measured vibration is normal. Generally speaking this information will be in graphical form so that normal levels at specific frequencies may be readily discernible.