26 Construction and Workshop Practice

In spite of the now worldwide commercial market of amateur radio there are still many items of equipment that are worth making for yourself. Cost is an important factor and often things may be made very cheaply by utilising ex-equipment components. For the newcomer it is worthwhile starting the 'junk box' (usually many boxes) of a variety of useful bits and pieces collected from junk sales, rallies and the like. If you belong to a radio club, many of its members may have items to exchange or give away which will just 'do nicely' for your project. The creatively satisfying work of home construction requires many skills, all of which make this an interesting and rewarding facet of the amateur radio hobby. The skills learnt and the pleasures gained are well worth the effort. It all takes time, and for the newcomer it is better to start on some simple project, just to get the 'feel' of things, rather than to dive in on some marathon project which usually finishes up as a complete deterrent to construction or as a collection of bits in someone else's junk box!

Most amateurs deciding to build some piece of equipment start collecting components, information on circuits, source of components and other technical data, but often forget to enquire about the manufacturing techniques required. Materials, tools and how to use them; methods of component assembly; and making the finished job look good are just some of these techniques.

The first requirement is an elementary knowledge of the materials useful and normally available to constructors.

METALS

Aluminium and aluminium alloys

Typical uses: cabinets, boxes, panels, masts, beam antennas, heatsinks.

These are good electrical conductors and are the lightest in weight of the normal metals available. They are non-magnetic, of medium to high cost, and available in sheet, rod, tube and other forms. The annealed quality usually bends and machines easily but soldering requires special fluxes and solders, and often the soldered joint is not good electrically. With the unknown quality of aluminium that most amateurs encounter, soldering is best left alone or experimented with before committing the project to this method of fastening. Long-term corrosion is also a problem with soldered joints in aluminium unless specialist methods are applied to prevent this. Adhesive bonding is very good but such joints are not usually reliable electrically. Aluminium is non-corroding in normal use, but direct contact with brass or copper should be avoided as these react and encourage corrosion with the resultant troubles of poor or non-existent electrical contact (see the section on corrosion.) Nickel-plated or stainless-steel screws, nuts and washers, rather than brass or steel, should be used to reduce the chances of corrosion around this type of fastening.

A metal that looks similar to aluminium, and which may come into the hands of the unwitting, is magnesium alloy. Filings and chippings from this metal are highly flammable. They can burst into a glaring flame with the heat generated by filing and drilling, and trying to put out such a fire with water only makes matters worse. (Factories where this alloy is machined use a chemical fire extinguisher, one type of which goes under the title of DX powder!) It is difficult to tell the difference by just looking, but size-for-size magnesium alloy sheet weighs less than aluminium and usually on bending there is a 'granulating-cum-scrunching' feel.

For reliable bending of sheet aluminium up to 1.5mm thick, it should be possible to bend a sample strip back on itself and hammer the fold flat without breakage. Annealing aluminium is possible, but under specialised conditions.

Before any heating is attempted it is essential to degrease the part thoroughly.

A workshop 'dodge' which sometimes works, and is certainly worth a try if bending or forming proves difficult, is to heat the aluminium slowly (the slower the better) to such a temperature that a small pine stick, when rubbed on the heated surface, just chars, but does not ignite (equivalent to approximately 300°C) Care needs to be taken to avoid overheating, for this will destroy the properties of the aluminium. This method of localised annealing has proved effective when bending tube or rod for the folded dipole elements of beams. In this case the area to be annealed is small and the 'dodge' can be applied easily. Another method, suitable for larger areas, is to rub soap on the surface and warm the aluminium until the soap turns black. However, it is essential that it is the aluminium which is warmed by the blow torch or hot air gun and not the soap. This is ensured by applying the heat to the non-soaped face. Any bending or forming should be carried out as soon as the annealed piece has cooled, because most grades of aluminium alloys start to re-harden and may actually improve in strength after such heating. Do not attempt to speed up the cooling process by quenching in water. Allow the part to air cool. Note that during the heating of the component there must be no visible change in the surface appearance of the aluminium, otherwise the aluminium will lose its properties and disintegrate. This fact can be verified, if you are so minded, by attempting to bring a small piece of aluminium sheet to red heat.

Heat treatment of aluminium and its alloys is a specialised process used to improve a particular characteristic of the metal, and is carried out in controlled conditions not usually available in the home workshop. Technically the above techniques are more of a part softening process rather than true annealing.

For interest, the usual method of commercially annealing most aluminium alloys is that the part is 'soaked' for about two hours at 420°C, air cooled, and then soaked for a further two to four hours at 225°C. All this is performed in a furnace or salt bath which has its temperature closely controlled. Most, if not all, of the aluminium used in extruded tube or sections has undergone this type of treatment immediately prior to extrusion, ie in the billet form.

Brass

Typical uses: Morse keys, terminal posts, weatherproof boxes, extension spindles, waveguides and other microwave components.

This is an expensive but good non-magnetic electrical conductor, and is available in sheet, rod, tube and other forms. It can be soldered easily but adhesive bonding can prove difficult. For work involving bending or forming, the most suitable grade is ductile brass. For panels and non-formed parts, the half-hard and engraving brasses are adequate.

It can be annealed like copper, though care is necessary as brass is nearing its melting point when heated to bright red. Brass is non-corroding in normal use but reacts with aluminium and zinc.

Copper

Typical uses: heatsinks, coils, antenna wires, tuned lines, waveguides, earthing stakes and straps.

This is a very good, though expensive, electrical conductor. It is non-magnetic and is available in sheet, rod, tube and other forms. Before work of a forming or bending nature is attempted, this metal should be annealed by heating as uniformly as possible to a bright red heat and air or water cooled. If considerable bending is required, this annealing should be repeated as soon as the metal begins to resist the bending action. In the annealed state, copper bends very easily. Soft or hard soldering present no problems but adhesive bonding can be troublesome. It is non-corroding in normal use but does react with aluminium and zinc, especially in an out-of-doors environment. Cuts on the hands etc caused by copper should be cleansed and treated immediately they occur, for such cuts can turn septic very quickly.

Steels

Typical uses: Masts and tabernacles, screw fixings, guy wire stakes and parts subject to high wear or heavy loads.

These are electrical conductors, which are magnetic except for the expensive stainless types. They are cheap and available in numerous forms and qualities. The common grades are called mild steel or GCQ (good commercial quality) steel. The black quality steels are usually cheaper and used for such things as the stakes for mast guys, or similar 'rough' work. Silver steel is a special grade suitable for making tools, pivot pins and other items which require the parts to be tough or hardened and tempered. Most steel sheet forms commonly available will bend, solder and machine easily, and can be annealed by heating to bright red and allowing to cool slowly in air. Do not quench in water or in any way cool rapidly, for this may cause some steels to harden. Corrosion is a problem unless plated or well painted. For outdoor use the commercial process of galvanising is perhaps the best form of protection. The next best thing is a few coats of paint.

Tin Plate

Typical uses: Boxes, screening cans and plates, light-duty brackets, retaining clips, spacers.

This is a good electrical conductor. It is very thin steel coated with an even thinner layer of tin on each side, and is magnetic, cheap and available in sheet form up to 0.5mm thick. It can be easily soldered, bonded, bent and machined, and is non-corroding in normal use. Cut edges should be re-tinned with solder if the full benefits of the non-corroding properties are required. It can be annealed but this will destroy the tin coating. This is a 'friendly' metal to use and is normally readily available in the form of biscuit tins and similar containers, hence the old timers' expression 'an OXO tin special'.

General Comments on Metals

All of the above metals work-harden and will break if repeatedly flexed at the same point. Annealing removes the effects of work-hardening, providing it is carried out before the part is over-stressed. There are professional standards which classify the above metals and each is given a specific identifier code. Fortunately, amateur constructors do not normally need to enter this maze of professional standards, and metal suppliers usually understand that to most of us steel is steel and brass is brass!

PLASTICS

Plastics are electrical and thermal insulators, and are not suitable as RF screens unless the plastic is specially metal coated or impregnated. The insulation can normally be considered as excellent for most amateur purposes. The following is a brief description of the more commonly available and useful plastics, and is a very small selection of the many plastics in use today.

Laminates

Typical uses: PCBs, matrix boards, coil formers, insulating spacers.

Various base fabrics such as paper, cotton, glass, asbestos etc, are bonded together by selected resins, and usually compacted and cured under pressure. The combination of the resin and the base fabrics produce laminates which may be used for many applications. Most are available in sheet, rod and tube form. The cured laminate cannot be formed easily. Normal machining is possible, particularly if attention is paid to the lay of the base material. Drilled or tapped holes should be arranged so that they go through at right-angles to, and not in the same plane as, the laminations.

Where components made from this material are exposed to the elements and expected to insulate, the glass-based laminates should be preferred. This also applies where the dielectric properties are important (VHF converters, RF amplifiers etc). The normal heat generated by valves and similar electronic components will not harm these laminates but the glass or asbestos fabric-based laminates should be used for higher temperatures (100-140°C). Costs range from expensive for the paper and cotton bases to very expensive for the nylon and glass bases. Glassfibre repair kits for cars are a useful laminate for weatherproofing antenna loading coils and making special covers or insulators. The filler putty supplied with these kits may contain metal.

ABS (acrylonitrile butadiene styrene)

Typical uses: antenna insulators, coil formers, handles, equipment enclosures.

This is expensive and is available in natural white coloured sheet. It machines easily and can be formed by heating, similar to Perspex®. Bonding requires proprietary adhesives. A tough plastic and a good insulator.

Acetal Copolymer

Typical uses: bearing bushes for rotating beams, Morse key paddles or electrical parts such as insulators or feeder spacers.

This is a medium- to low-cost plastic and is available in white or black rod and sheet. It machines very easily without specialist tools and is a useful plastic to have available in the workshop. It cannot be formed easily. Bonding requires proprietary adhesives and such joints are usually the weakest part of any assembly.

Acrylics (Perspex®)

Typical uses: decorative and protective panels, dials, Morse key paddles, insulated fabricated boxes and covers.

A medium-cost plastic which is available in clear or coloured sheet, rod or tube. It is non-flexible and can shatter or crack under shock or excessive loads, although it is often used for see-through machine guards. The clear sheet is ideal for covering and protecting the front panels of equipment.

Perspex® may be formed by heating but not with a flame as this plastic is combustible and gives off unpleasant fumes if burnt. If placed in a pan of water and simmered (or in an oven) at around 95°C, the plastic softens and can be formed or bent very easily. Forming should be stopped and the work re-heated the moment hardening or resistance to bending is felt, otherwise breakage will occur.

Bonding requires proprietary adhesives. A properly made bond is structurally sound and can be transparent. Normal drilling, sawing and filing are straightforward, providing the work is adequately supported. Most sheet forms are supplied covered with protective paper and it should be worked with this left in place. It is not very heat resistant and should not be placed in direct contact with any heat source such as lamps, heatsinks and valves. Where transparency is not required a better plastic to use would be Acetal or, for particularly tough applications, ABS.

Nylon 66

This is a cheap- to medium-cost plastic, and is available in sheet, rod or tube. It is usually supplied in its natural creamy white colour. It can be machined but it does tend to spring away from any cutting edge, making tapping or threading difficult. It is not easily formed. Proprietary adhesives are available which claim to bond nylon successfully. There are other types of nylon but most of these are expensive and intended for special applications, such as bearings, gears etc. For most amateur purposes the Acetal copolymer, mentioned previously, is generally an easier material to use.

Polyethylene (Ultra High Molecular Weight)

A medium- to high-cost plastic, normally available in sheet and rod. It is usually supplied in its natural white colour and it can be machined easily but not formed. Proprietary adhesives are available for bonding. This is an ideal plastic for outdoor components such as insulators, feeder separators etc as it is virtually rot-proof.

Polycarbonate

This is an expensive material, normally available in transparent sheet form. It can usually be bought at builders' merchants where it is sold as vandal-proof glazing. A very tough plastic, virtually unbreakable (bullet proof!) and, though it can be machined, it will wear out normal tools very quickly. It is ideal for making an insulated base for a vertical mast/antenna and in other areas where impact, high loads and temperature changes would rule out other less-durable plastics.

Polypropylene

This is an expensive plastic, normally available in opaque-coloured rod form. It can be machined and formed but not bonded. It can be sensitive to prolonged frictional contact with metals, particularly copper, and disintegration can occur in these circumstances. Because of its strength and resistance to atmospheric attack, it is usually used by amateurs in its rope form for halyards, mast guys etc.

The twisted strands are normally melt-welded together to prevent fraying, using a soldering iron. A naked flame should not be used as a substitute for the soldering iron as this plastic burns and melts, and burning droplets can go anywhere, even on the hands!

Polystyrene

This is a relative cheap plastic and is available in a variety of types, shapes and colours from black to transparent. It can be formed, machined, painted and bonded very easily - a model maker's delight! Usually used by radio amateurs for coil formers, insulated extender spindles and in other areas requiring insulation. It is a particularly tough flexible material, although some transparent types can be brittle. Some forms are also heat sensitive. A paper/card laminate of this plastic is available and this is very useful for making mock-ups of cabinets, boxes etc. Model-making suppliers usually stock extruded polystyrene sections, some shapes of which can be utilised in making bezels and other cabinet embellishments.

PTFE

This is an expensive material, noted for its excellent dielectric performance and low frictional properties. It is available in sheet, tube and rod, and is normally supplied in its natural off-white colour. Extremely difficult to machine and cannot normally be formed or bonded. Usually used for low-friction bearings, insulators (up to UHF), capacitor dielectric and the nozzles of de-soldering guns. The fumes from overheated PTFE are very toxic.

PVC

This cheap material is available in many forms including rod, tube and sheet. It is usually grey or black in colour, and can be easily machined, formed and bonded. Proprietary adhesives should be used (although hot-air welding with a filler rod is also possible) but skill is required to produce structurally sound joints. Certain of the building types of PVC encountered seem to have some conducting capabilities which can lead to problems if used in electrical or RF applications. A suggested test for this is to try to cook a small sample in a microwave oven (alongside a cup half full with water), and if no metal is present the PVC should stay cool to just warm.

PVC insulating tapes are strong, cheap and normally self-adhesive, and are supplied in a variety of colours and widths intended for wrapped insulation. Some of the poorer-quality tapes do not weather very well and suffer adhesion failure with the first frost.

ADHESIVES

Many modern adhesives are hazardous and it is essential to follow meticulously the manufacturer's instructions when mixing, using and curing them. Most are insulators and unsuitable for electrical joints.

Five general rules should be applied for bonding:

- Degrease the parts thoroughly; even finger marks impair results.
- Roughen the joint faces unless a transparent joint is required.
- Do not place bonded joints under a peeling type of load.
- Ensure that the work is dry and warm.
- Wear protective glasses and gloves and have the necessary first aid chemicals readily to hand.

Epoxides

A group of medium to expensively priced, cold- or heat-setting resins (usually self-generated heat) that can be used for bonding, surface coating, laminating or encapsulation. Air and gas bubbles are the biggest problem with encapsulation (this work is carried out professionally under vacuum). The problem can be minimised by warming the work and the resin to around 40°C and providing a generous shrinkage allowance with a large pouring area which can be cut off from the cured encapsulation. Careful thought should be given to the necessity of encapsulation, for once completed, the encapsulated module cannot be altered or repaired. Encapsulation is usually used when circuits are subjected to harsh vibrational and environmental conditions. (See also 'silicone sealants').

These are usually two-part adhesives and require careful mixing just prior to use. A structural joint should not be over-clamped during bonding, and a bonding gap of typically around 0.05mm is required for the joint to be made properly. In other words, don't squeeze out all of the glue!

Surface coatings can be applied by dipping, spraying or brushing. Flexible resins are usually used for this type of work and are ideal for protecting beams, traps etc.

Cyanoacrylates ('Superglue')

These expensive adhesives are available in various grades, each intended for bonding a particular set of materials. The low- to medium-viscosity grades are suitable for most amateur work. They are scientific marvels of bonding and as such require correct and proper application to ensure success. Releasing or debonding agents are available and it is a wise precaution to keep some of this handy in case of accidental bonding of fingers etc. These adhesives should be used and cured in well-ventilated conditions. It is advisable to wear protective glasses when using this adhesive.

Toughened Acrylics

These are expensive, fast-curing adhesives intended for structural joints. Various types are available and are usually supplied in two parts - the 'glue' and the primer/activator. The glue is applied to one side and the primer to the other. They are suitable for use on most of the materials already mentioned, but some may not be used with certain plastics as they dissolve the material and eventually the joint fails. They are usually easier to use than the cyanoacrylates.

OTHER MATERIALS

Silicone Rubber Compounds

These are medium-priced materials, available as paste in squeeze tubes and as a liquid in tins. When cured, they normally set to give a white or translucent silicone rubber finish. They are ideal for encapsulation and the sealing or weatherproofing of antenna connecting boxes and similar out-of-door items. The electrical insulating characteristics are excellent and can be used to prevent parts from vibrating in equipment used for mobile or portable work. One type of this compound emits acetic acid during curing and this may damage some insulators and component connections.

Though not normally sold as such, one type of this compound has been used successfully as a resilient adhesive for structural and pressure-sealing joints on metal, plastic and glass.

Self-amalgamating Tapes

These are a form of insulating tape which, when stretched and overlap-wrapped around cables, coaxial plugs etc, will amalgamate or flow together as one. They are reasonably priced and available in widths up to 50mm either with or without a self-adhesive face. Excellent weather-resistant properties. The self-adhesive form of this tape is ideal for waterproofing antenna traps, joints and connectors.

Nickel Silver

Typical uses: Boxes, screens, nuts, bolts and washers etc where the non-corroding properties are required.

An expensive non-magnetic electrical conductor which is corrosion resistant. Available in sheet and rod. It is often used by railway modeller's for it is a very 'friendly' metal to use, soldering and bending easily. It has some resistivity.

Wood

Typical uses: Aerial masts, booms, spreaders, storage boxes, and other parts which do not require RFI protection.

A common material, not usually used today for radio work as it has no ability to conduct electricity or to screen against RFI. Its insulating properties are marginal unless dried and treated to prevent ingress of water/moisture. The radios of the 1920s and 1930s were cabinetmaker's delights but this was before the 'enlightened' days of electromagnetic compatibility. Other joinery-type materials such as chip board, MDF, plywood etc are equally unsuitable for RF applications but may be utilised to make mock-ups of proposed designs, especially for the panels and cabinets.

CORROSION

There are two main processes of metal corrosion. The first relies on environmental conditions such as rain or condensation which results in an acidic electrolytic liquid being formed on the surface of the corroding metal. As the metal corrodes, the acidity of the liquid increases until the electrolytic process of corrosion becomes almost self-sustaining. The second occurs due to the electrolytic action occurring between dissimilar metals in contact, and is referred to as galvanic action. Both processes change the metal into a different form, which in the case of steel or iron we know as 'rust', and often refer to the process as oxidisation.

Table 26.1 shows the galvanic relationship between metals. The numbers are item numbers only to show the position of each metal in the galvanic series. The actual values depend on several factors such as temperature, radiation and acidity etc. This list enables metals to be selected which will have the minimum galvanic corrosion effect on one another. The greater the list separation, the greater will be the possibility of corrosion.

For example, brass and copper are adjacent and would therefore not cause problems if in direct contact with each other. Brass and aluminium alloy are widely separated and corrosion occurs if these metals are in direct contact with each other. This state can be reduced by tinning the brass with lead-tin solder, which falls about halfway between the other two metals (galvanic interleaving). The higher item-numbered metal will normally promote the corrosion of the lower item-numbered one.

Dissimilar-metal galvanic action corrosion is avoided by ensuring that the galvanic series separation is minimal. If widely separated metals do need to contact each other, then a suitable interleaving material should be used to reduce the galvanic separation level.

Corrosion by moisture or rain is more difficult to combat effectively. The commonly accepted anti-corrosion treatment consists of protection by paint and, providing the paint coat remains

1.	Magnesium alloys	8.	Lead
2.	Zinc	9.	Tin
3.	Aluminium alloys	10.	Nickel
4.	Cadmium	11.	Brass
5.	Mild steel	12.	Copper
6.	Stainless steel 18/8	13.	Silver
7.	Lead-tin solders	14.	Gold

Note: the numbers are item numbers only and are not values!

Table 26.1: Galvanic series

intact or is renewed regularly, this is a very effective treatment. Steel and iron can also be coated by protective metals such as zinc (galvanising) or nickel (plating), both methods being normally outside the range of the home workshop. Aluminium is slightly different, for this metal forms its own protective oxide barrier which, providing it is not disturbed, will prevent further corrosion. It is this oxide barrier which makes soldering aluminium difficult. Unfortunately, this natural protective oxide layer can be disturbed by stress or galvanic action, and the corrosion process bites deeper into the metal. Anodising is a process on aluminium which forms a controlled layer of oxide on the surface and presents a toughened surface finish which can be coloured by dyeing. Brass and copper can be considered as corrosion resistant for most amateur purposes. However, their surfaces do oxidise and this can impair good electrical contact. Certain platings, such as silver, nickel or chromium, can reduce this. The platings themselves can also corrode but usually at a much slower rate than the parent metal.

If not adequately protected, corroding metal will gradually lose strength and the device from which it is made will fall apart. This is usually seen as collapsed masts, broken antennas and similar expensive disasters.

Corrosion also affects RF and electrical connectors, particularly feeder-to-antenna connections, and causes a gradual decline in the overall performance of the system. Signals become weaker and calls to DX stations which used to be answered are ignored. Most observed lowering of performance in this area is usually (or eventually), discovered to be due to corrosion. This can be practically eliminated by first ensuring that no dissimilar metals are in contact to cause galvanic corrosion, and second that water is excluded from all connections. Copper coaxial-cable inners should never be connected directly to the aluminium elements of a beam but should be tinned first as previously stated. Coaxial plugs and sockets should be fitted with heat-shrink sleeving and wrapped with amalgamating tape to prevent the ingress of water. Connector boxes can be filled with silicone-rubber compound for a like purpose. Stainless steel antenna fittings are the least affected by corrosion but even these would benefit from a coating of protective lacquer, particularly on screwed fittings. The position of stainless steel in the above list is interesting, for sometimes the metal in contact with the stainless steel will corrode due to galvanic action, particularly in wet, smoggy or salt-laden conditions, and some stainless steel fittings are supplied with plastic interleaving spacers and washers to prevent this.

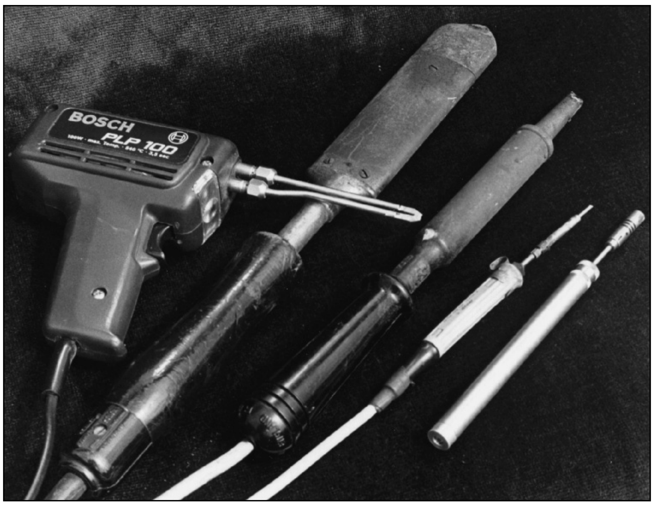


Fig 26.1: Soldering iron

Condensation is also a problem with outdoor enclosed or boxed-in items such as rotators, remote tuners, antenna traps, coaxial cable and the like - where there is condensation, there will be corrosion. The simplest, but not necessarily the easiest, solution is to allow the enclosed area to 'breathe' by introducing suitable weather-resistant holes as drainage vents, while ensuring that these are at the lowest point of the enclosed area and cannot be inlets for rain or the run-off water from the outside of the enclosure. Complete sealing usually makes matters worse, for a fully water and air-tight enclosure still produces internal moisture by condensation. Full hermetic sealing is difficult to apply for it normally requires the ability to pressurise the enclosure with an inert gas, as with some military or maritime equipment. If the items within the enclosure can be protected as if they were exposed to the elements, much of the corrosive effect of condensation is reduced.

In the case of rotators, attempts at filling the voids with grease does not help, for the grease forms small pockets which can hold water. It is better to lacquer or wax oil the moving parts and the inside of the housing, and to use grease for its intended purpose of lubrication. Any electrical items within the rotator should be sprayed with a commercial, non-insulating, waterproofing liquid.

The threads, screws, nuts, bolts etc should be given a light coating of anti-seize compound on assembly and, after assembly, sprayed over with lacquer or wax oil, or coated with a water-repellent grease such as lanolin. This makes for easier maintenance and reduces the possibilities of corrosion.

Corrosion is not limited to outdoor items. Corrosion of connector pins of microphones, plug-in PCBs, computers etc is not uncommon. Careful selection of mating materials to avoid galvanic action, combined with appropriate painting, plating etc and regular maintenance, will reduce the effects of corrosion.

TOOLS

Any tool bought with reliable use in mind should be the best you can afford, for cheap tools usually lead to frustration, like a cheap pair of wire-cutters that has its cutting edges notched by copper wire the first time used, and from then on will not cut but only fold the wire! Retiring toolmakers and fitters often sell their 'kit', and some very good but used tools can be obtained this way at reasonable prices. Tools also make very good presents!

Most amateurs have a shack, room or some place with a bench, hacksaw and a vice of one type or another. Accepting these, the range and type of useful tools available is virtually limitless, unlike most pockets. Basic tools and a few extras - some home-made - are listed here.

- Soldering irons (**Fig 26.1**). 15W instrument, 50W electrician's (and a useful extra, a 200W heavy-duty iron) all mains powered. The choice of type of iron in the above selection is a personal one, bearing in mind the cost. Temperature-controlled irons are excellent but expensive. The main factors to consider are the availability of the replacement parts (bits, heating elements, handles) and the ease with which these may be fitted. The anti-static properties of an iron should also be considered. Battery and gas-powered irons are worth considering if on-site or outdoor work is likely. Similarly, the rapid heat soldering gun is a worthwhile addition.
- De-soldering 'gun' (**Fig 26.2 bottom**). The miniature anti-static, hand-operated type is an effective and value-for-money device .
- Electrician's pliers (**Fig 26.2 top centre**). Also known as combination pliers (180mm).

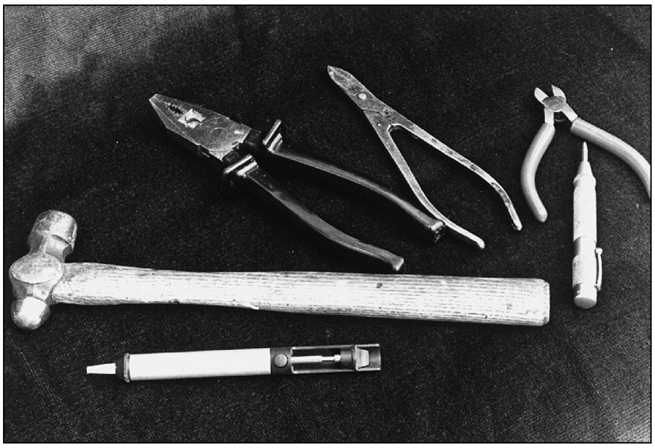


Fig 26.2: A selection of hand tools

- Side cutters (**Fig 26.2 top right**). Also referred to as diagonal cutters (120-180mm). There is a variety of wire-cutters and the type specified here is suggested as the most suitable for general use. They will cut most wires up to 2mm diameter (barbed or fencing wire excepted!)
- Watch-maker's shears (**Fig 26.2 top, half right**).
- Long-nosed pliers (also known as Snipe nose) (120-180mm).
- 8oz ball pein hammer (**Fig 26.2**).
- 8oz soft-faced hammer with replaceable heads.
- Twist drills. These should be of high-speed steel in at least 1.0-12mm diameter (fractional sizes from one-sixteenth to half inch diameter). Carbon-steel drills are cheaper but require sharpening much more often.
- A centre drill (BS1 size) is a worthwhile addition (**Fig 26.3**). Unfortunately, it is very easy to break the tips of these centre drills and it is worth considering keeping a few 'in stock'!

Fig 26.3: Anti-clockwise from the top left: centre drill, pin chuck, pin vice, taper reamer, file burr, countersink

- Drills need regular sharpening and some drill-sharpening device should be considered. There are many types available and the main points to consider when buying are that:
  - (a) it will sharpen the range of drills in use;
  - (b) spare grinding stones can be purchased;
  - (c) little or no skill is required to obtain the correct drill point; and
  - (d) the speed is not so high that it will soften instead of grind the drills.
- Electric drill. An electric drill should preferably be of the continuously variable speed type and should have a drill chuck capacity to at least match the range of drills on-hand. A drill stand is a valuable addition. The model-makers' variable speed, hand-held or stand-mounted drilling and grinding unit is a very useful extra, especially for the finer work of PCB making.
- Pin chuck (Fig 26.3). This device enables small-diameter drills (1mm downwards) to be held in the normal drill chuck. Most pin chucks come with interchangeable collets to cover a range of small-diameter drills. This pin chuck should not be confused with the pin vice which is intended to hold small components during filing or fitting, and not drills.
- Screwdrivers (**Fig 26.4**). Minimum requirement: parallel flat blade 3.2 x 100mm, 5 x 150mm and similar sizes for the cross-head types of screw (Phillips™, Pozidriv™ etc). A set of watch or instrument makers' screwdrivers are very useful.
- The interchangeable-bit screwdriver is also worth considering but it can become annoying to use - the right bit never seems to be in place when it's wanted!
- Spanners. Box and open-ended types in the BA and ISO metric sizes, plus a small adjustable spanner as the minimum starter requirement. Many older components require imperial/BA spanners but the newer European parts are usually ISO metric. Pliers are a poor substitute for spanners, leading to mangled nuts and scratched panels!
- Hexagon socket keys. BA and metric sizes up to 8mm. These keys are available mounted in screwdriver handles. The interchangeable-bit screwdriver mentioned previously often has hexagon key bits.
- Files with handles (**Fig 26.5**). 150-200mm second cut. Hand, half-round, round and three-square, also the same shapes in round-handled needle files. In the interests of

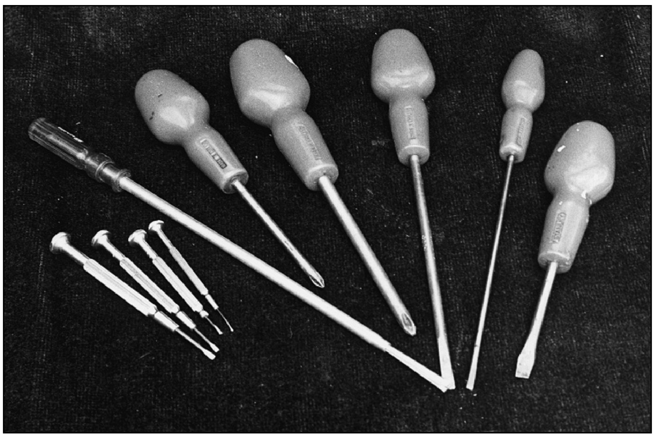


Fig 26.4: A selection of screwdrivers, including screw-holding type

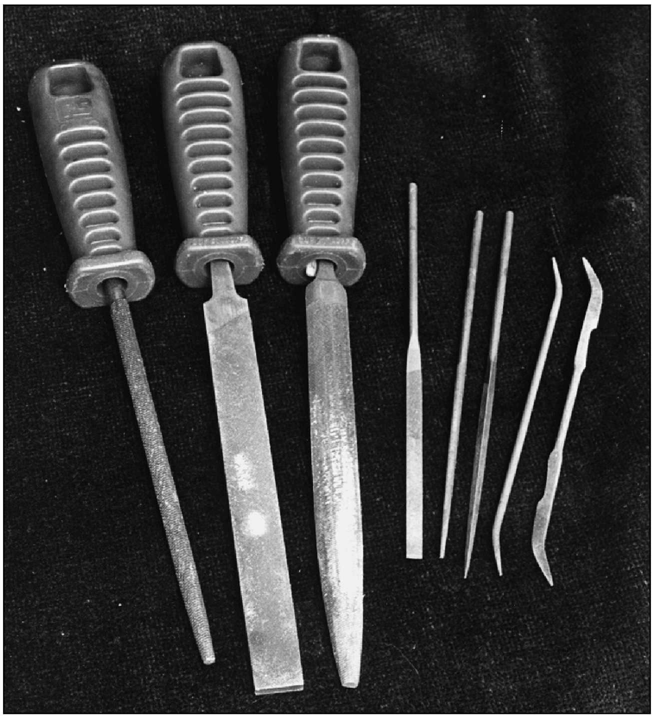


Fig 26.5: A selection of files. The two on the right are Reifler files which are useful for filing awkward shapes

personal safety, files should always be fitted and used with handles, for file tangs produce nasty cuts. There are sets of files available in the above selection, which are supplied complete with fitted plastic handles. The wood-worker's shaper plane/file (Surform™) is very useful for the rapid trimming of aluminium sheet. Files should be stored where they cannot contact and damage other tools.

- Tapered reamer (see Fig 26.3). Sometimes known as repairman's reamer. The 3-12mm size with handle will suit most requirements.
- Hand countersink (Fig 26.3). The 12mm size with five or more cutting edges will cover most work and, mounted in a plastic handle, it is very useful for deburring holes.

The above list of tools can be considered as a starter kit for the newcomer to construction. With these few tools it is possible to attempt many of the jobs encountered in making or repairing something but, as construction skills grow, so will the tool chest! A tap and die set is extremely useful and should be placed high on the 'tools required next' list.

Useful Extras

One of the problems most of us have in metalwork and the like is cutting or filing things square and straight. Also, marking out to ensure that parts will fit together correctly is sometimes not as easy as it appears. The few extras described here should simplify things.

Bending bars

See **Fig 26.6**. These are normally a home-made item, and the things to check when obtaining the steel angle are its straightness and squareness. If these are not 'true' the corrective actions needed will require skills which may be beyond those so far acquired. An old bed-frame angle, provided it has not rusted too badly, usually makes very good bending bars. One bed frame can be used to make several bending bars of different lengths. The choice of length and distance between the clamping bolts of the bars is related to the maximum width of metal or other sheet purchased and the maximum size of panel worked. Aluminium sheets, for example, usually come in 1.8 x 1.2m size and trying to cut this is rather difficult. It would be better, if buying in these sort of quantities, to have the sheets guillotined by the supplier to widths which will fit between the bending bar clamp bolts. (Suggest 482mm.) The length of the sheet will not matter.

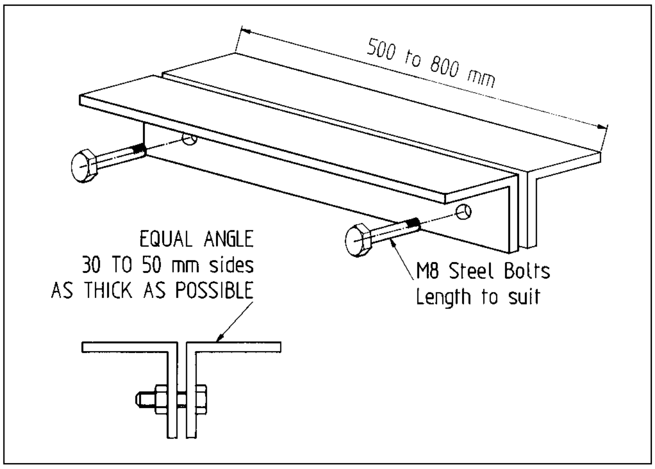


Fig 26.6: Bending bars

Hole embossing tool

See **Fig 26.7 and 26.8**. This very simple home-made tool forms holes along the edges of metal panels to accept self-tapping screws of about 2.5mm diameter (depending on metal thickness), and with an engagement length of about 12mm. It facili-

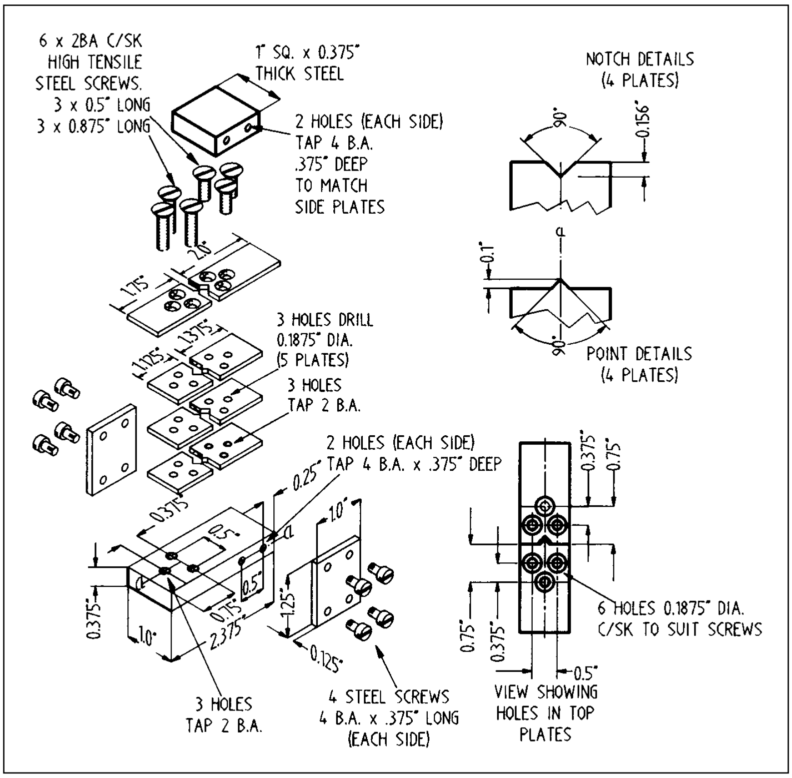


Fig 26.7: Hole embossing tool

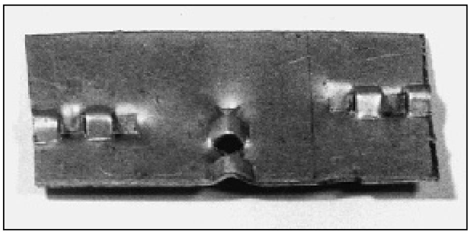


Fig 26.8: Holes made by the embossing tool

tates the rapid manufacture of cabinets, boxes and screens, eliminating much of the accurate metal bending normally associated with this type of work.

The working parts and the two side plates of the tool are made from 1in wide by 0.125in thick-ground gauge plate, which is a tough but workable steel capable of being hardened and tempered. It is not necessary to harden the finished tool, unless it is intended to form mild steel but, if facilities are available to do this, it will improve the durability. The base and top plates are made from 1in wide by 0.375in thick mild steel.

The vee points must be on the centre-line of the tool. The vee notches are not so critical for they play no part in the shape of the hole produced, but they should allow sufficient clearance for the formed metal to flow into. The point and notch sizes shown are suitable for most metal thicknesses up to 1.6mm (16SWG). The vee points can be made as a set, with the four plates clamped together. The fully shaped points should be polished with an oilstone to obtain square, burr-free, sharp edges along each face of the point. The edges of each point are the working parts of the tool and should be made with care. It is essential that the flat faces on both sides of the notch and point ends of each set of plates are square, parallel and level with each other. Tapping-size holes should be marked out and drilled on each top plate only, and these used as a template to drill the remaining holes on each plate. The holes in each bottom plate should be tapped 2BA and the holes in the remaining plates opened up to 0.1875in diameter - a good fit for the high tensile steel 2BA screws. ISO M5 may be used in place of the 2BA screws and tapped holes. The outside faces of the holes in the top plates should be countersunk deep enough to ensure that the screw heads are slightly under-flush. It is good practice to lightly countersink both sides of every hole to remove burrs and facilitate assembly.

The back edges should also be square and level to ensure that the vice pressure is applied evenly during forming. The 0.125in thick side plates and the 0.375in thick top and bottom plates form the bearing for the sliding part of the tool, which must slide easily with the minimum of play in any direction. Failure to get this right will ruin the action of the tool, for each point must just slide over the opposing one or two points with the minimum of clearance.

To operate, the tool is placed between the jaws of a 4in vice and supported by the extended top plates. The metal to be holed is rested on the base of the tool and the marked out hole position is aligned with the tip of the visible point. The vice is then closed with the minimum of force until each face of the working ends of the tool just contacts the metal sheet. It is pointless trying to go beyond this, for squeezing the tool and the work by excessive pressure from the vice will only ruin the tool and the work. The vice is then opened and the metal sheet gently prised away from the points. This method of releasing the formed sheet could be improved upon, but the tool would become more complex to make and, as a spot of oil on the working faces eases the problem, this extra complexity is not worthwhile.

The tool performs very well on aluminium, tin plate and annealed brass or copper in thicknesses up to 0.0625in

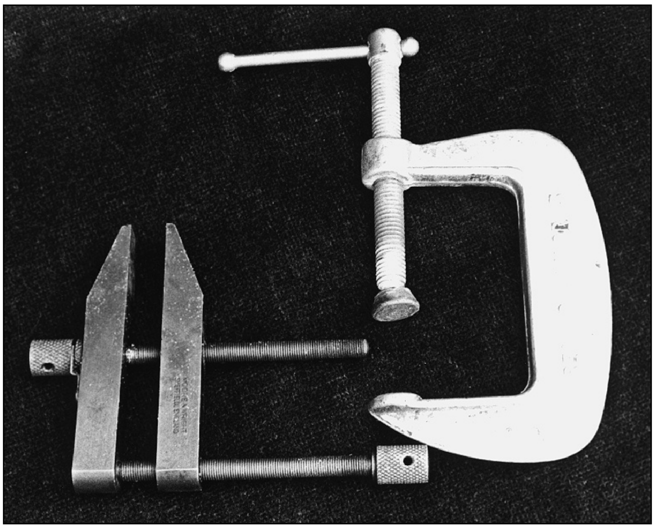


Fig 26.9: Toolmaker's clamp and joiner's G-cramp

(16SWG). It is not recommended for use on sheet steel unless the points have been hardened and tempered.

Tool-maker's clamps

See **Fig 26.9**. These are available in several sizes. Two 100mm clamps are suitable for most amateur purposes. These clamps should not be confused with the joiner's C- or G-cramps, which are also useful and certainly better than no clamping device at all.

Measuring and marking-out tools

After the soldering iron, these will probably be the most used tools and buying the best possible will pay in the long term.

- Engineers' combination square (**Fig 26.10**). The 300mm/12in ruler with square head only is preferred from the usefulness-to-cost viewpoint. Most of these combination squares have a small scriber, housed in a hole on the square head, and this saves buying a scriber separately. A complete quality combination square is expensive and, as well as the square head, it has a centre square and a clinometer head, neither of which is essential for normal amateur work. Beware of the cheap bazaar-type combination squares, for they are a waste of money and lead to corners which are not square and inaccurate measurements.
- Spring dividers (100mm size) (Fig 26.10).
- Jenny callipers (100-200mm size) (Fig 26.10). These are also known as odd-legs.

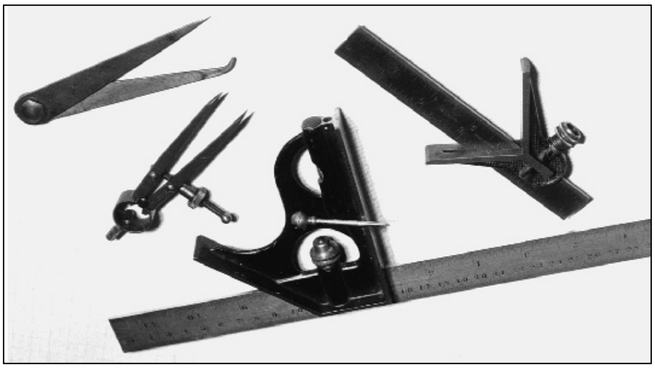


Fig 26.10: Anti-clockwise from the top left. Jenny callipers and spring dividers. 12in combination square with with square head fitted. 6in combination square with centre square fitted

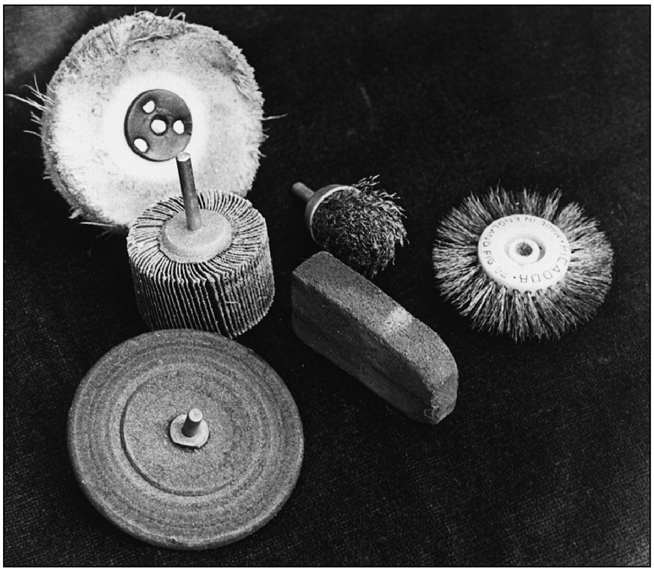


Fig 26.11: Finishing and polishing tools

- Centre punch (Fig 26.2). An automatic centre punch is preferred, but a simple and cost-effective punch can be made from a round 100mm long steel nail sharpened to a suitably tapered point.

Finishing Tools and Aids

Most construction work will require some form of finishing or pre-finishing such as deburring, emery dressing and polishing. The tools and other aids for this work are numerous, and a brief description of some of them is given here (**Fig 26.11**).

Abrasives

Emery paper or cloth is the most common for metal work. Grades are referred to as 'very coarse' (80 grit) to 'very fine' (800 grit). The 240 (medium) to 400 (fine) grades are suitable for most amateur uses.

Flap wheels for mounting in the electric drill come in various grit sizes and can save a great deal of work. The suggested grades are 60 grit to 120 grit, or finer.

Wet and dry paper is useful for the final smoothing before painting, or between coats of paint. Fine wire wool or plastic pan scouring pads are good substitutes for wet and dry paper.

Blocks of abrasive mounted in a rubber-like material (rather like erasers for paper) are also extremely useful and are available in fine to coarse grades. One of each grade is suggested. The super-fine grade block containing non-metallic abrasive is ideal for the cleaning and polishing of PCBs. (It cleans without removing too much copper.)

A glassfibre brush pencil is useful for cleaning the smaller areas prior to soldering. A brass wire brush insert is also available for this pencil.

An electric drill fitted with a hard felt disc or a calico polishing wheel used with polishing compound will save considerable effort when trying to polish a component to a bright and scratch-free finish. Polishing aluminium by this method is not recommended, for aluminium tends to 'pick-up' on the wheel and produce deep score marks on the panel being polished. The fine-grit flap wheel or the abrasive eraser are more suitable for aluminium, and the final polish can be made using a rotary bristle brush and thinned-down polishing compound.

Steel or brass wire brushes, either hand or machine types of various grades (coarse to fine), are very useful where paint, rust or other corrosion needs to be removed. These brushes can also be used (in skilled hands) to produce decorative effects on the surface of aluminium, brass, or stainless steel.

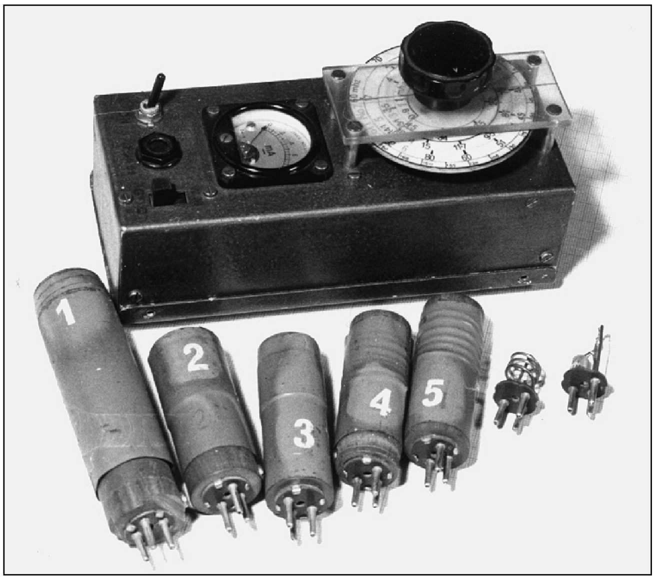


Fig 26.12: Dip oscillator using home-made box described in the text

Warning

The dust and fumes created whilst polishing or grinding can be harmful and a face mask and protective glasses should be worn. Always ensure that the work place is well ventilated. Some polishing compounds can cause skin irritation and the use of barrier cream on the hands is advised. The wearing of protective gloves can save the hands getting filthy, but take care when working with powered tools to ensure that the gloves do not become entangled with the rotating parts. Even a DiY electric drill can break a finger!

USING THE TOOLS

Marking out and measuring

This is the important bit of construction. If not done carefully and accurately, failure is certain, hence the saying: "cut once, measure twice". All measurements and squareness checks should be made from one or two datum edges.

Consider marking out the box used for the dip oscillator shown in **Fig 26.12**. The first operation is to obtain two edges straight and at right-angles to each other. The method of achieving this should be clear from the illustrations (**Fig 26.13**). These two

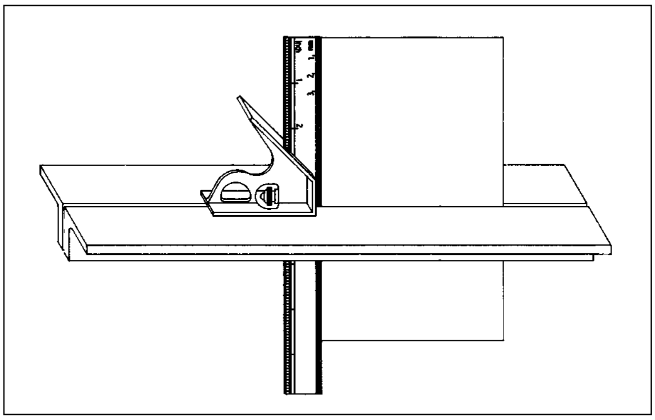


Fig 26.13: Squaring up the work prior to bending or cutting

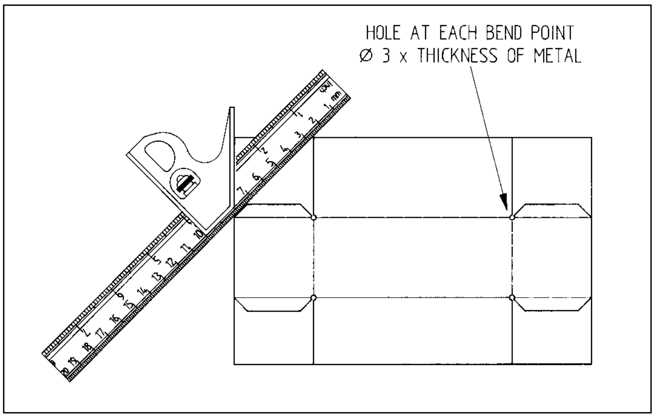


Fig 26.14: Marking out the box

edges are now the datum edges for vertical and horizontal measurements, and should be clearly marked. The overall size of sheet is marked out and cut to size. This results in a sheet with all corners square and all edges straight. With the bending bars as a guide it is really very simple! In this case the sides of the box are the same depth. Adjust the Jenny callipers to the required measurement and, locating from each edge in turn, scribe round the sheet. Check with the combination square from the datum edges that these lines are parallel and square with their respective edges. If Jenny callipers are not available, the combination square may be used by setting the ruler to the required measurement and scribing round the sheet with the scriber held against the end of the ruler. These lines show where the bending is to occur and are used to align the sheet in the bending bars (Fig 26.14). It is good practice to lightly centre-pop along the lines at about 20mm intervals to make 'sighting-up' in the bending bars easier - half the centre pop should be visible and the other half invisible inside the bending bars.

Existing boxes, panels etc, can be similarly marked out using two datum edges that are straight and at right-angles. If a truly square corner is not available, then the longest and straightest side should be used as a datum and the end of the combination ruler used to mark out the lines at right-angles. A suitably placed line at right-angles to this single datum can be used to mark off the measurements in this plane.

Lines marking the centres of holes and cut-outs should be scribed in, for the centre punch can then be located by feel into the notch formed by their respective intersections. It is worthwhile using the dividers to scribe-in each hole diameter around its centre-popped centre. This helps to ensure that the correct size hole is drilled and in checking that holes do not foul. If screw-up chassis punches are used, these scribed outlines can be used to locate the punch accurately.

When a gleaming or ready-painted cabinet, box or panel is purchased, marking out directly on to it would ruin the finish. Instead mark out in pencil on to a piece of draughting film cut to suit and then secure this to the required face with draughting tape. Check that everything is where it should be and, when satisfied, centre-pop through the hole positions and the outline of any cut-outs. Remove the film, scribe in the hole diameters and join up any cut-out outline dots. When scribing holes on to a ready painted surface, it is worthwhile gently scoring through the paint to reveal the metal, for this helps prevent the paint chipping off around the holes during drilling and reaming. Some constructors drill through masking tape stuck over the hole position to achieve the same results. However, some masking tapes really stick, especially when warmed by the drilling, and are very difficult to remove without lifting the paint.

Fixing holes for meters, sockets, plugs etc should be carefully measured from the component and these measurements transferred to the work. Where holes and cut-outs are related to each other, and not to some other edge of the chassis or panel, vertical and horizontal datum lines for these holes alone should be used. For example, a meter may require a hole for the meter body and four holes related to this for the fixing screws or studs. The centre lines of the meter body hole should be used as datum lines to mark out the fixing hole centres. The centres of the hole for the meter body will of course be related to the two main datum edges.

The centres of holes or studs of the same diameter can be found by simply measuring from the inside edge of one to the outside edge of the other.

It is tempting to use, and easier to see, markings made with a fine-point marker pen. Beware - the marking ink used is normally very difficult to remove, and if not removed, will usually bleed slowly through any subsequent paint work. A soft lead pencil, sharpened to chisel point, is also useful for marking out, particularly when 'trying things for size'. The marks can be wiped off easily using a dampened cloth or a very soft eraser.

Hole Making

Drilling is a straightforward operation providing a few key guidelines are observed. The drill speed should be adjusted to match the size of drill and the material being drilled. As a general rule, the smaller the drill, the higher the speed. A correctly sharpened drill should not require heavy pressure to cut. If it does, either the material is too hard or the drill needs to run slower. There is a tendency for normally sharpened drills not to cut some brass properly. This is due to the incorrect rake angle of the cutting edges of the drill. The problem can be solved by sharpening the helix edge on the face of the flute to give a rake angle of about 15 degrees, ie leaning backwards away from the normal cutting edge (Fig 26.15). Drilling some plastics can also present problems, such as chipping of the edges and breakaway of the material as the drill breaks through. Some improvement is possible by sharpening the drill to produce an included point angle of around 80 degrees. The standard included point angle is 118 degrees.

When drilling steel, it is advisable to use a coolant such as soluble cutting oil to keep the drill and the work cool. It also saves having to re-sharpen the drill so often. Paraffin is a good coolant for aluminium and copper. Brass and most plastics do not normally need a coolant, providing the drilling speed is correct, but treat as steel if necessary. These coolants may be applied either by an oilcan, or a brush. (Old liquid soap squeeze bottles make good coolant dispensers and any left-in detergent is not detrimental.) Soapy water is also a good coolant and certainly better than no coolant at all - it is best for most plastics.

Holes should always be centre-popped before drilling and, if the BS1 centre drill referred to previously is available, this should be used next to provide an accurate location for the drill. The holes drilled in thin sheet are often anything but round because the drill does not have enough depth of metal to round

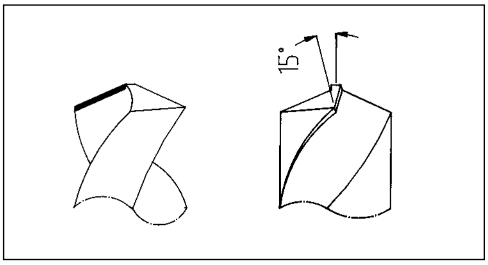


Fig 26.15: Modified drill rake angle to improve the drilling of brass

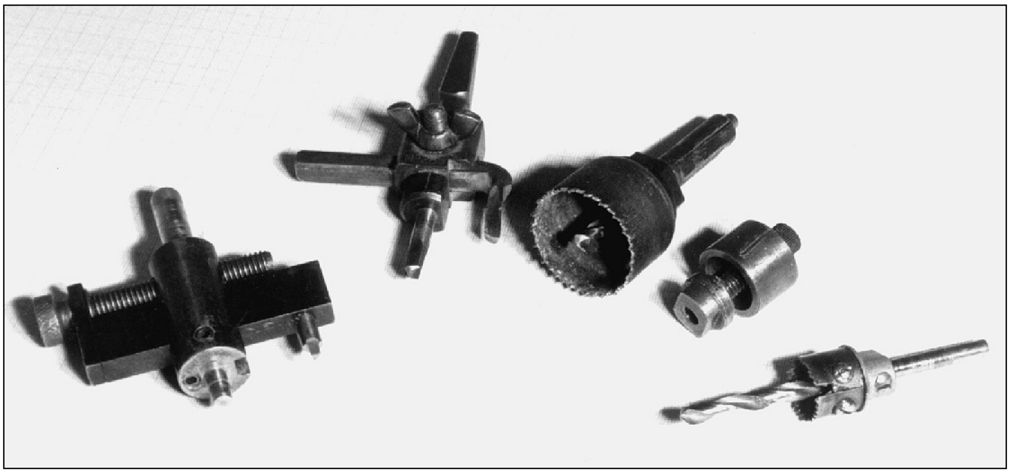


Fig 26.16: Large round hole making tools. Clockwise: deluxe home-made tank cutter, commercial tank cutter, screw-up punch, hole saw

the hole properly before it breaks through. There are at least two ways round this. The easiest is to drill the hole undersize and bring to size using the taper reamer, which must be allowed to cut without forcing, otherwise another fancy-shaped hole will be produced (another reason for scribing-in the holes beforehand.) Another way is to alter the cutting angle of the drill to an included angle of about 140 degrees and thin the chisel edge of the drill to a point. It is worthwhile keeping a set of drills sharpened in this manner especially for thin sheet drilling. These sheet metal drills normally require a much slower speed and the holes should also be pre-drilled using the centre drill.

Whatever is being drilled should be well supported and clamped to prevent rotation and lifting. Failure in this direction can lead at best to a broken drill and at worst to serious personal injury, for drills have a habit of picking-up just as they are about to break through the hole. (Plastic and copper are particularly susceptible to this.) A panel whirling round on the end of a 10mm diameter drill is a frightening sight!

All drilling will produce burrs around the hole edges and it is good engineering practice to remove these using the hand-held countersink bit referred to previously. A file will only scratch the rest of the surrounding surface and bend the burrs into the hole. The use of a large drill for hole de-burring is not recommended, particularly on the softer metals, unless the 'touch' for this method has been acquired.

It is usual to step drill holes larger than 10mm diameter, that is a hole of smaller diameter (3mm) is drilled first, then another slightly larger (+1mm), and so on until the finished size is reached. Step drilling is unsuitable for sheet material. There are special, though expensive, stepped drills available for drilling holes up to 40mm diameter in sheet material.

Making large round holes can be tackled in at least two ways. The first requires a washer or tank cutter (Fig 26.16) and an extra slow speed drill (a joiners' brace is effective). The biggest snag with this method is trying to obtain an even cut around the full circle. By clamping the work to a block of wood and drilling through into the wood for the centre pilot of the tank cutter, a guide is provided which improves things a little. The main thing with this method is not to be in a hurry. The second method can be applied equally well to non-round holes. Contiguous holes of about 5mm diameter are drilled on the waste side of the hole or cut-out and 1 to 2mm away from the finished size markings. The waste is removed, using tin snips. The hole is then carefully filed to size, using the bending bars for support, and as a guide for any straight portions.

To de-burr large holes, a small half-round needle file can be used in the 'draw' fashion. The file is held at both ends and drawn round the edges to be de-burred in a manner similar to using a spoke shave. The file should be held at an angle to produce a small 45 degree chamfer around each edge of the hole.

Machine countersinking of holes requires a very slow speed drill (60RPM). They can be produced using the handle-mounted countersink bit referred to previously. Even the multi-toothed rose-countersink bit will chatter and leave a very unsightly surface if too high a speed is used. Countersunk screws will not sit properly on such holes. There are countersink file burrs available which do a similar job and can be used in the DIY drill, providing the work is held securely with the burr square to the work. They do have a tendency to skid over the surface, leaving a trail of deep scratches, if not located properly.

Drilling accurately positioned holes can be a problem and templates can be used with success. Keeping the small holes for multi-pin DIL ICs in-line and at the correct spacing is difficult, but the job is made easy by using a piece of the correct pitch matrix board as a drilling template. One of the holes (pin 1 is suggested) is drilled first in the required position. The template is located from this by passing a drill through the hole and the matrix board. The matrix board is then aligned with the rest of the marked-out hole positions and clamped using the toolmakers' clamps. The remaining holes are drilled through using the matrix board as a template. It helps to mark each row of holes on the matrix board template. If a considerable amount of such accurate drilling is to be done, it is worth making a set of metal templates for each size of IC using this method.

Sometimes the component itself can be used as a template to reduce the risk of error, eg slide switches, coaxial sockets, dial fixing holes etc.

Filing

Accurate filing is a skill which can only be acquired by practice. General rules are:

- Always use a file handle. This eliminates the risk of running a file tang into the wrist and enables the file to be guided properly.
- Use a sharp file. It is normal practice to use new files for brass and, as their sharpness wears off, use them for filing steel or aluminium. New files should be kept separately or otherwise identified.
- Do not force the file to cut. Only a light relaxed pressure is required, which also aids the accuracy of filing.
- Keep the file clean by brushing with a file card or by rubbing a piece of soft brass or copper along the teeth grooves.
- Support the work properly. Trying to file with the work held in one hand and the file in the other is a guarantee of failure.

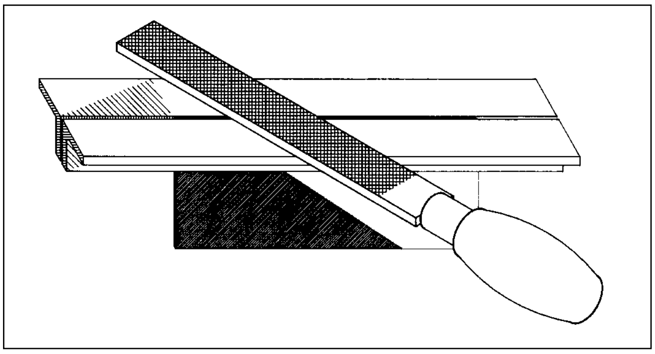


Fig 26.17: Bending bars as a file guide

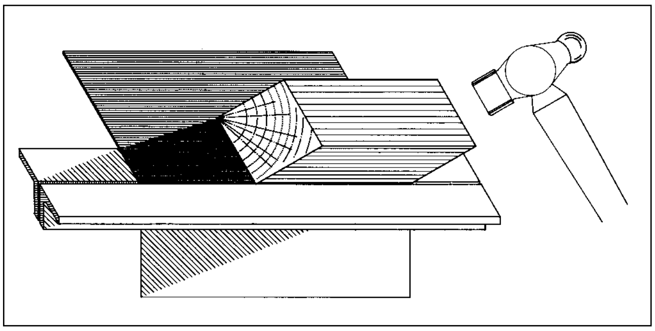


Fig 26.18: Method of bending in the bending bars. Note that the cutter block is held into the point of the bend

The height of the vice should be such that when the filer's arm is bent to place the fisted hand under the chin, the point of the elbow should just rest on the top of the vice jaws. An old but effective form of ergonomics!

A strip of emery cloth wrapped along the file can be used to obtain a better surface finish. This method was frowned upon in apprentice schools but it works and saves time. The draw filing technique referred to previously imparts the final touches to the filed edges and removes the filing burrs. The bending bars can be used as a filing guide (**Fig 26.17**) and a set of bars can be made especially for this purpose, checking them regularly to see that the guiding surfaces are not bowed by too much one-spot filing.

Bending and forming

The first essential is to ensure that the material can be bent. This sounds obvious but it is better to check first than to find out after all but the bending work has been done. Annealing can be applied as mentioned previously under the section on materials. A metal hammer should never be used directly on the metal when bending or forming. Either use a soft-faced hammer or a block of wood or plastic as a buffer for the hammer blows (**Fig 26.18**). This prevents all the humps and hollows which would otherwise occur. Do not use any metal as a buffer block as there is a danger of the metal chipping and flying into the face or eyes. The block should be kept into and near the point of bending. It seems easier and quicker to try to use the sheet as a lever and hammer as far away from the point of bending as possible. This will only produce a bend which curves up and back again. Where three sides are to be formed by bending, the point of intersection of the marked-out bend lines should be drilled before bending, with a hole diameter three times the thickness of the metal. This prevents corner bulge (Fig 26.14).

Fig 26.19 shows how to ensure that the end lugs of the box shown in Fig 26.12 fit snugly inside the box. **Fig 26.20** shows one method of bending the ends of a similar box.

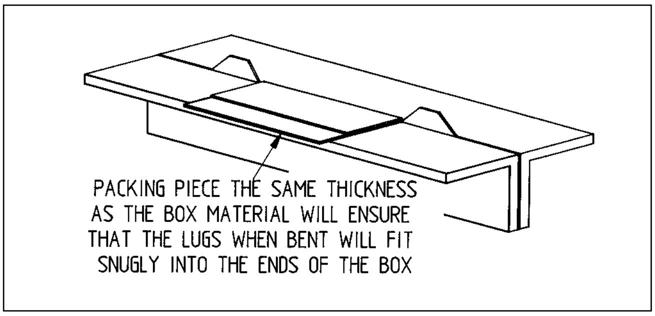


Fig 17.19: Making allowance for bending the end lugs of the box

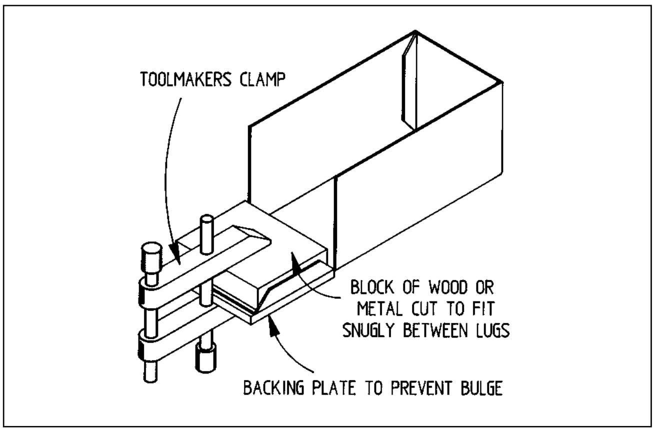


Fig 26.20: Bending the ends of the box using a toolmaker's clamp to secure the forming block

Tube bending for beams, tuned lines etc is not difficult and flattening or kinking can be reduced by observing the following:

- Ensure that the tube is suitable for bending. Anneal as necessary and re-anneal as soon as resistance to bending is felt.
- Unless skilled or equipped with specialised tooling, do not attempt to bend to a radius of less than three times the outside diameter of the tube, eg 12mm OD tube should have a 36mm minimum bend radius.
- Always bend round a former shaped to the required radius (**Fig 26.21**).
- Pack the tube tightly with fine sand (clean birdcage or builders' sand is ideal). Wet the sand and cork both ends. This will minimise the risk of kinking during bending, and the sand can be washed out afterwards. The tube can be re-annealed if necessary with the sand left in place but the corks should be removed to let the hot gases escape.

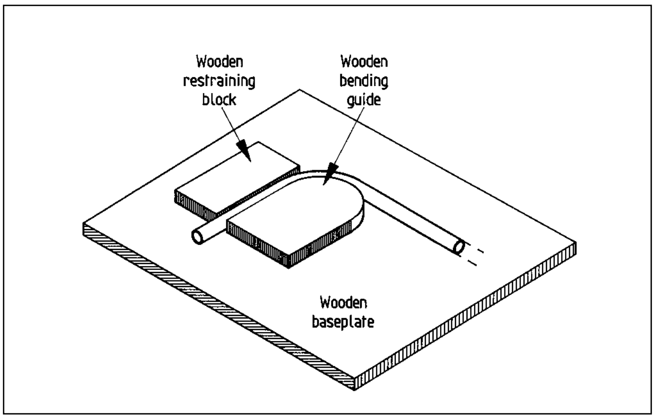


Fig 26.21: Tube or rod bending set-up

A low-melting-point, lead-like material is available which can be used in place of sand, and is known as bending metal. It is poured molten into the blocked, ended tube, allowed to set and, when the bending has been completed, is melted out to be used again. This process should be carried out with the tube at an angle to allow the hot air to escape. The molten bending metal should be poured very slowly for it has a tendency to 'blow-back'. Normal lead is not a substitute for bending metal and should not be used, particularly with aluminium tubes, for the melting temperature required for lead may destroy the aluminium's properties.

Modelling wax (also known as American wax) can be used in place of sand or the bending metal. The wax is heated, not boiled, until molten and then poured into the tube in the same manner as the bending metal. The wax should be allowed to set hard before bending. Unfortunately it is not possible to re-anneal with this wax left in place.

Another tube-bending tool is the bending spring. This is often used by plumbers and pipe fitters. Each tube size should have a matching bending spring, for it is all too easy to use the wrongly matched spring and have it permanently trapped inside the bent tube!

Cutting

Cutting long strips of metal with tin snips or shears is an expert's job. The cut edges usually produced by non-experts are anything but straight and they require flattening to remove the cutting curl. Tin snips are best used where a one-snip cut will remove the required amount of metal, such as 45-degree corners, or the trimming to length of narrow strips. Snips should not be used on plastics, laminates or copper-clad board (PCBs), for the cutting action can cause de-lamination or shattering of the edges.

A guillotine is by far the quickest way of cutting most sheet material but it is not a normal home-workshop tool. For the home workshop the cutting of nearly all materials is best done by sawing, using a hacksaw and the bending bars as a guide and support (Fig 26.22). The hacksaw should be fitted with a 24 to 32 teeth per inch blade for most sheet work, and coarser blades for cutting blocks of material. The blades known as ding-dong style, ie with their cutting teeth arranged along a wavy edge, are very good for most work. When sawing copper-clad laminates such as PCBs, it is advisable to score through the copper beforehand using a sharp chisel. This will bevel the edge of the copper and prevent delamination due to sawing. The coolants recommended for drilling can be used if required. A fine-toothed roofers' saw is very useful to cut sheets which are too big to pass inside the hacksaw frame. This is similar to a joiners' saw but shorter with a stiffer fine-toothed blade. A pad saw or fine-toothed machine hacksaw blade which is handle mounted is equally effective in these circumstances. Some constructors use a fretsaw with either a metal-cutting blade or an Abrafiler to overcome the problem, particularly when making large holes.

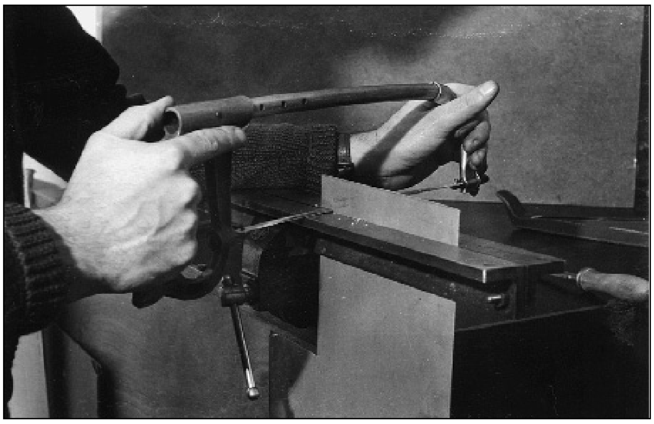


Fig 26.22: Bending bars as a sawing guide

Hand-operated nibblers are available for cutting most thin sheet materials, including laminates, although they are sometimes difficult to guide properly. The power-operated nibblers are not normally a home-workshop tool. The DiY jig-saw fitted with a fine-toothed, metal-cutting blade is very good but it is essential to support the work very well and even then it is a noisy process. Similarly the DiY router-cutter is extremely useful, especially for large holes, but it can be a dangerous tool to use.

Cutting and sawing is one of those areas where gadgets are forever appearing, each claiming to save time and produce a better job! The hacksaw has not yet been replaced as a good general-purpose cutting tool.

Soldering

Learning to solder properly is not difficult and it is an essential skill for the home-constructor.

There are two main types of soldering: soft and hard. For most amateur purposes soft soldering is the norm. The type of soft solder most commonly used in electronic work is that known as 60/40, ie 60% tin and 40% lead. A flux is required to enable the solder to 'wet' the surfaces to be joined, and in the case of electronic work it must be non-corrosive. To make things easier this type of solder is usually supplied with a built-in flux, in the form of core or cores surrounded by the solder alloy, and is known as 60/40 multi-cored solder. This multi-cored solder comes in various diameters and the 22SWG size is suitable for most electronic work. The melting point of this solder is around 185°C, which is low enough to reduce the risk of heat damage to most of the items being soldered. There are numerous other soft-solder alloys with differing characteristics, such as low-melting-point, low-residue, high-melting-point and others. The low-melting-point and low-residue solders are normally used with surface-mounted components. The high-melting-point solders are used for joints requiring high mechanical strength. Another type of solder is known as universal or all-purpose, and this can be used for soldering aluminium or stainless steel. Its main claim to fame is that it will solder most metals, but it requires too much heat for normal electronic work and is therefore best used for structural applications or work which is less sensitive to heat.

Structural parts may be joined by Tinman's solder. This has a high melting point, around 200°C, and will therefore require a hotter iron or even a gas torch. It is normally supplied in round or square bars, about 300mm long, and not usually in multi-cored form, to enable suitable external fluxes to be used for the metals being soldered. A suitable flux for this type of solder is a liquid known as Baker's fluid, which comes in various grades; the number 3 grade is suitable for most jobs. It is sometimes referred to as killed spirits, from the method used to make it - a hazardous process. This flux is corrosive and should not be used for electronic or PCB work. Soldered joints made using this flux may be neutralised by a good washing and brushing with hot soapy water. Commercially this neutralisation is carried out chemically but these chemicals are not too friendly to have around the home workshop. Paste fluxes are available which can be wiped along the faces before joining. Most paste fluxes are corrosive and some are susceptible to overheating which can nullify their fluxing action during structural soldering. Flux is used to enable the solder to wet or bond with the required surfaces to be joined. Its primary function is to prevent these surfaces oxidising during soldering.

Various grades/melting point solders with flux are available in paste/cream form. Some of these are particularly suitable for soldering surface-mounted components, where the exact amount of cream can be accurately applied before soldering. This is usually done using syringe-like dispensers. These paste solders are also helpful when it is required to join several parts together at one go. The paste can be applied and the parts positioned as required, then the complete assembly is brought up to soldering heat either in an oven or by a blow torch or hot-air gun.

Hard or silver soldering produces very strong structural joints, which are also sound electrically, on brass, copper and most steels. The solder is available in various grades, shapes and sizes to suit the type of work to be joined. Typical applications are self-supporting waveguide assemblies and in areas where lower-temperature soft-soldering is required at a later stage of assembly. A silver-soldered component can be heated to accept soft solder without falling apart. The parts to be silver soldered need to be heated to around 600 to 700°C, and a gas torch is essential.

The process is thus unsuitable for PCBs. The fluxes used are related to the melting temperature of the silver solder and the type of work - brass, copper, stainless steel etc. The standard Easy-floTM flux powder and No 2 silver solder in 22SWG wire form should cover most requirements. It is difficult to silver solder joints which were previously made with soft solder. No amount of cleaning of the previously soft soldered faces will alter this because the lead/tin in the former soft-soldered joint will not allow the silver solder to wet the surface properly. Similarly some metals with a high lead content will not silver solder.

Another process known as brazing is about the nearest most home workshops can come to welding. A workshop equipped for brazing is more for model making than amateur radio construction, although it is a useful process to have available.

Rules for soldering

- All surfaces must be scrupulously clean. This applies equally well to the bit of the soldering iron. These bits are often iron plated to prevent rotting, and this plating should not be removed but wiped clean using a damp cloth or sponge. The bit should be kept 'tinned' with the solder and flux in use. Note that some fluxes will corrode rapidly the iron plated soldering bits. In the case of PCBs, the copper cladding should be cleaned using the fine abrasive eraser block referred to previously. Component wires and pins etc should be similarly cleaned for, although many brand-new parts come with the wires dipped in a solder-through or flux coating, it is still worthwhile just making certain. There must be no dirty or greasy patches on any of the surfaces to be soldered and corrosion spots must be removed. Even finger marks can spoil the soldering, so "clean it and when you think it's clean, clean it again!"
- Ensure that there is just sufficient heat to make the joint. Too much heat is harmful to electronic work and, in the case of structural work, it causes distortion. Not enough and the solder will not bond correctly.
- Heat and apply solder to the greater conductor of heat first, which in the case of PCBs is usually the copper pad and in the case of switches etc. is the solder tag, and then finally the wire, (the lesser conductor of heat) in one continuous process.

Soldering technique

After cleaning the parts, the following technique should be used to make a sound mechanical and electrical joint on PCBs.

Apply the clean, tinned hot iron to the pad adjacent to the component wire to be soldered, and tin the copper surface by applying just sufficient multi-cored solder to the point where the tip of the iron is in contact with the copper. When the solder and flux starts to wet the copper surface, slide the iron into contact with the wire and apply a little more solder. As soon as both the wire and the copper surface are blended together in a small pool of molten solder, draw the iron up the wire away from the work.

This whole process should take seconds, not minutes. The less time any component is under this form of heat stress the better. In the case of particularly heat-sensitive components, it is advisable to heatsink the component's leads during soldering. A good soldering heatsink can be made from a crocodile clip, on to each jaw of which is soldered a small strip of copper. A small set of metal forceps will also serve as a clamp-on heatsink. The clamp-on action is required so that both hands are left free to do the soldering. Commercial soldering heatsink clips are available.

This method of soldering applies equally well to the joining of wires to components such as switches, potentiometers etc. In this instance, good practice demands that the wires should be wrapped and secured mechanically before soldering, but bear in mind that the joint may need to be unsoldered later.

Good soft-soldered joints should look neat and smooth, with no draw-off points, and be continuous around or along the joint. Large blobs of solder do not ensure that a joint is well-made. The cored solder should always be applied to the work and the iron at the same time, not carried on the iron to the work.

The results of incorrect soldering procedures are 'dry joints' which are either open-circuit or high-resistance points and will prevent the circuit from functioning correctly. Often the effects of such soldering will appear after several hours of operation, and this really leads to frustration especially to the novice constructor. Commercial equipment has exactly the same problems, if this is any consolation! In most instances it is difficult to locate a dry joint visually. Sometimes a perfectly sound looking joint turns out to be 'dry' immediately at the contact point, which is hidden under the solder. As a rough guide most 'good' joints appear shiny and devoid of any 'craters' or occlusions, whereas some 'dry' joints appear dull and pitted. There is no easy way to identify 'dry' joints but there is an easy way of avoiding them - follow the rules and guidelines set out above.

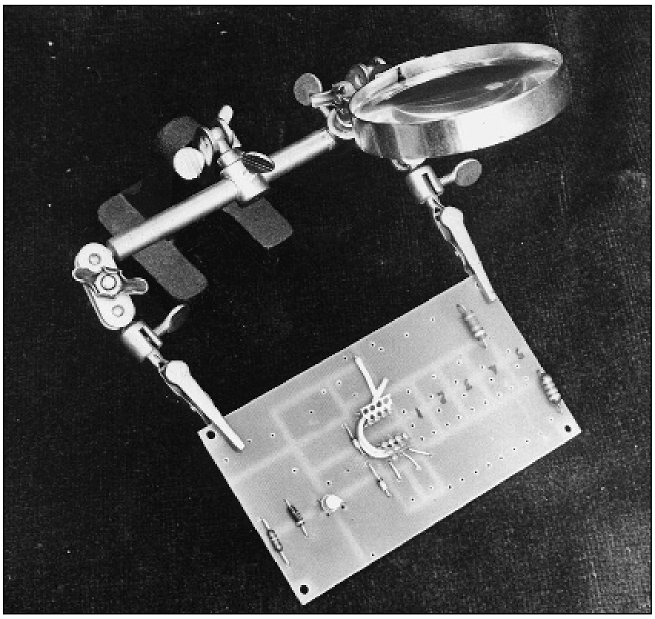


Fig 26.23: Work-holding fixture (the 'third hand')

To join structural parts together by soft soldering, each mating face should be pre-tinned, ie given a thin coat of solder using the appropriate flux to ensure proper 'wetting'. The tinned faces must be clean and shiny with no burnt or blackened flux spots. The two tinned faces are then painted with flux, brought together, heated to just melt the solder, and clamped together until the solder has cooled. There is no need to apply any more solder. If the job has been done properly, a neat, clean solder fillet will be seen along the mating edges. The flux residue must be washed away immediately after soldering to prevent long-term corrosion.

It is not good practice to have long soldered joints on PCB laminates. The expansion caused by the necessary heat will de-laminate the copper. In these circumstances it is better to tack solder along the required structural joint, placing 2mm long solder-tacks at about 10mm intervals. Any such joints on copper laminates will be as mechanically strong as the laminate-to-copper bond.

It is better practice to secure mechanical parts such as angle brackets, shaft housings etc by screws or clips which pass right through the laminate, and to use solder only to make a sound electrical connection.

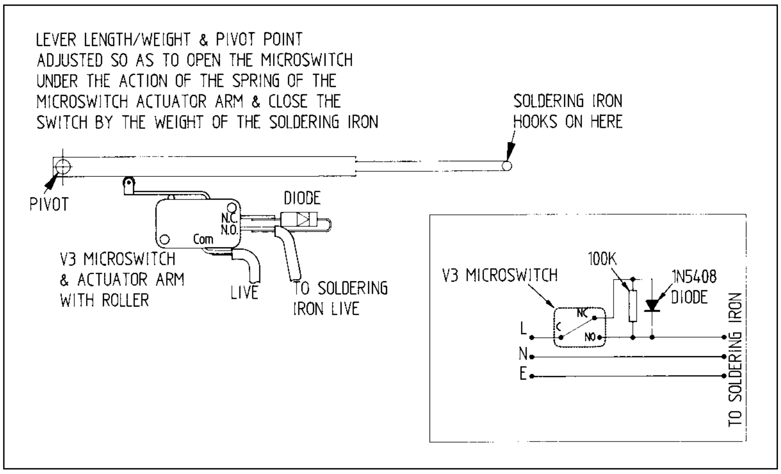


Fig 26.24: Circuit and mechanical details of soldering iron saver

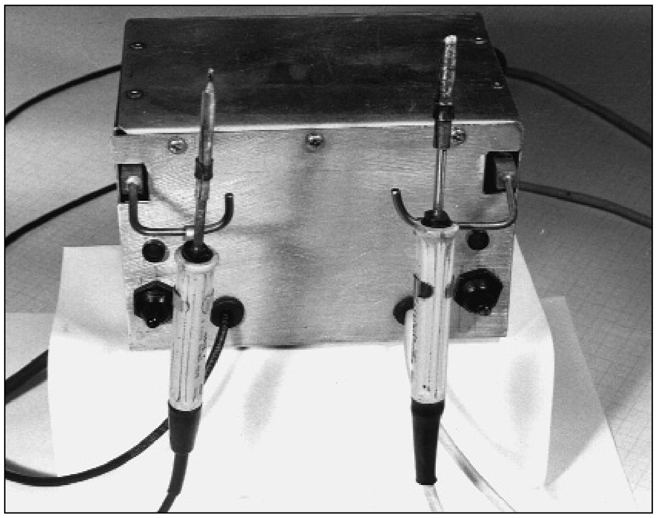


Fig 26.25: Dual soldering iron saver

General comments on soldering

All soldering should be carried out in a well-ventilated room. The fumes from flux and molten solder are irritants, especially to people with asthma. In the interests of safety, it is advisable to wear safety glasses when soldering. Molten solder and flux have a nasty habit of spitting and minute spots can fly anywhere, even into the eyes!

All work being soldered should be supported to leave the hands free to hold the soldering iron and apply the solder (**Fig 26.23**).

The greater the area to be soldered, the larger the soldering iron bit needs to be to transfer the heat to the work. A hotter iron is not a substitute for the correct bit size. The quantity of heat is related to the wattage of an electric soldering iron, and the larger the area to be soldered, the greater the wattage required. The soldering irons of various wattage specified previously should enable most soft-soldering jobs to be carried out.

Figs 26.24 and 26.25 show one type of soldering iron bit-saver. When the iron is placed on the holder arm, the diode is switched in series with the heater of the iron, approximately halving the voltage. This considerably reduces the 'bit rot' referred to previously, but at the same time allows the iron to remain hot - only a small delay occurs on picking it up again before soldering temperature is regained.

HEATSINKS

Heat levels for semiconductors are usually defined as 'not to be exceeded' junction temperatures. The power dissipation at these junction temperatures is specified in watts, and can range from milliwatts to several hundred watts. Whenever the device is operating, heat is being generated. Unless some means of heat dissipation is used, the recommended operational limits will be exceeded very rapidly and the device will fail. A semiconductor junction takes microseconds to reach its operating temperature and only a few more microseconds to destroy itself if heat is not dissipated. Electronic protection circuits can help safeguard the device but will not eliminate the requirement for heat dissipation. Semiconductor devices generate heat very rapidly and it is essential to ensure proper cooling.

The heat must be dissipated at the same rate as it is being generated in order to ensure that the device remains within its specified temperature operating limits. The usual system consists of a heat-conducting material which takes the heat from the device and transfers it to the atmosphere. The materials used for heatsinks should have high thermal conductivity to conduct the heat away from the heat source, and high emissivity to radiate this heat to the atmosphere. Emissivity depends on the surface finish and texture of the radiating elements, rather than the type of material, but thermal conductivity depends on the type of material. Most commercial heatsinks are made from aluminium, for it is lighter in weight, cheaper and can be extruded or cast into the complex shapes required for compact, efficient heatsinks. Aluminium can also be anodised and dyed black to increase its emissivity.

Heatsinks should be made and positioned such that the fins radiate to atmosphere. Fan cooling enables heatsinks to be smaller for the same thermal resistance, and as a guide, a substantial airflow over the fins can reduce the existing thermal resistance by up to 40%, depending on the number of fins receiving air. Painting a natural metallic finished heatsink with a very thin coating of matt black paint will also produce a reduction in overall thermal resistance by increasing the emissivity. The actual amount of reduction depends on the mattness of the black paint and the thickness of the coating but a 10 to 25% improvement could be expected.

Fig 26.26 shows the thermal resistance possible at various volumes for different metals, finishes and fin positioning. The bands indicate the effects of a matt black finish and the vertical or horizontal positioning of the fins. The top edge of each band represents the thermal resistance of natural-finished horizontal fins. The bottom edge represents matt-black-finished vertical fins. The band for aluminium or brass is an approximation, for the thermal conductivity of either metal varies widely depending on the alloying metals, but it can be considered reasonably accurate for most amateur purposes.

The heat transfer path is considered as flowing from the semiconductor (heat source) to ambient air, with each junction or transitional point treated as a thermal resistance (**Fig 26.27**). The thermal resistances of fins and heatsink to ambient are considered in parallel to give the total heatsink value. Similarly the thermal resistance of the device junction to air is considered to be in parallel with the total thermal resistance.

Heatsink formulas:

$$P_D = \frac{T_j - T_a}{\theta_{jc} + \theta_{cs} + \theta_{sa}} \qquad (1)$$

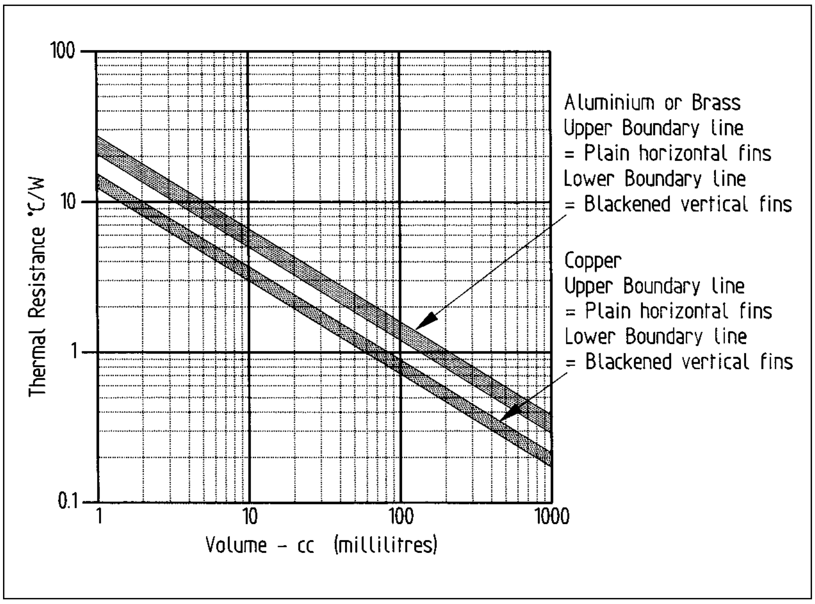


Fig 26.26: Heatsink thermal resistance / size chart

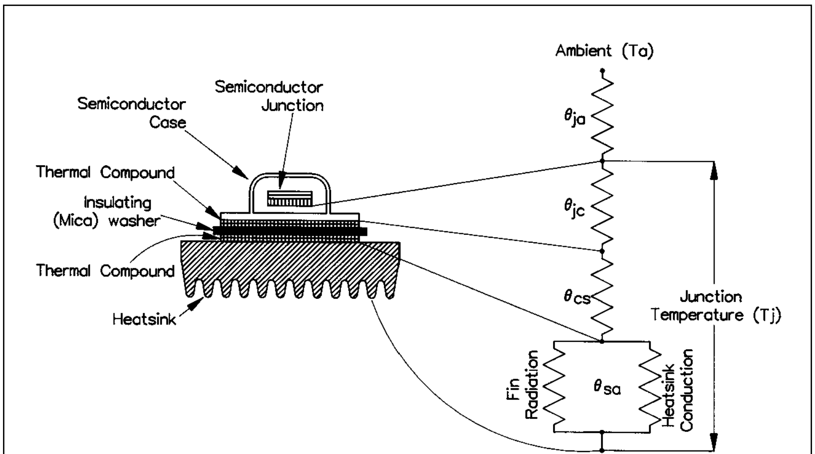


Fig 26.27: Heat transfer path and thermal resistance zones

and

Total thermal resistance x Power dissipation

= Temperature rise in °C above ambient of the transistor junction (2)

from which:

$$\theta_{sa} = \frac{T_j - T_a}{P_D} - (\theta_{jc} + \theta_{cs}) \qquad (3)$$

also:

$$T_j - T_a = P_D \times \theta_{ja} \qquad (4)$$

where:

- T_j = Maximum allowable junction temperature (°C)
- T_a = Ambient temperature (°C)
- θ_{ja} = Thermal resistance, junction to air (°C/W)
- θ_{jc} = Thermal resistance, junction to case (°C/W)
- θ_{cs} = Thermal resistance, case to heatsink, plus any insulating washer and heat-conducting compound (°C/W). (Can be assumed to be between 0.05 and 0.2°C/W).
- θ_{sa} = Thermal resistance, heatsink to ambient air (°C/W).
- P_D = Power dissipation (W)

Readily available semiconductor data do not always specify all of the above details but approximations may be used to design a heatsink suitable for most amateur applications. The usual data includes P_{tot} in watts (P_D) at a case temperature of usually 25°C. This can be used to derive the junction temperature (T_j) for substitution in formula (1). Because θ_{ja} = 25°C/P_{tot} and T_j = 25°C/θ_{ja} then T_j= P_{tot}°C.

Example: A 2N3055 is to be used as the pass transistor in a 13.8V DC regulated PSU. The available data shows P_{tot} as 115W at 25°C, thus T_j = 115°C and θ_{jc} = 0.2°C/W (25°C/P_{tot}). It is estimated that, for most applications, θ_{cs} = 0.1°C/W, assuming thermally conducting compound and a mica insulating washer are used. (If no insulating washer is used, θ_{cs} = 0.05°C/W but the heatsink may be 'live'.) Substituting in formula (3):

$$\theta_{sa} = \frac{115 - 25}{115} - (0.2 + 0.1)$$

$$= 0.3°C/W$$

which is the heatsink thermal resistance required to ensure correct thermal operation.

The above example assumes that the 2N3055 is working at its limit, and this should seldom be the case. In this example it would be usual to supply the pass transistor with 18V DC to allow adequate regulation, and the transistor would be run at 5A, or half the rated amperage. The difference between the supply voltage and the output voltage is 18 - 13.8 = 4.2V DC, hence the power to be dissipated will be 4.2 x 5 = 21W. Substituting this in formula (3) gives:

$$\theta_{sa} = \frac{115 - 25}{21} - (0.2 + 0.1)$$

$$= 4.0°C/W$$

This is the thermal resistance required for this power supply. If necessary a further allowance could be made for the inefficiency of the semiconductor and the calculated thermal resistance decreased to allow for this. In this example this factor has been ignored.

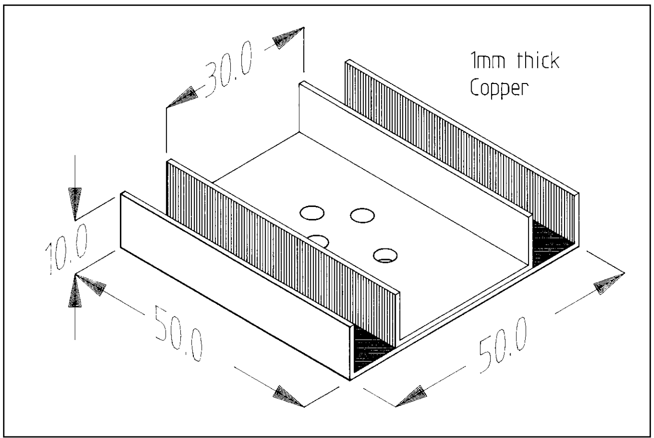


Fig 26.28: Heatsink based on the calculations of the example in the text

From Fig 26.26 it can be seen that about 6cm³ of blackened or 9cm³ of natural finished copper (vertical fins) will be a suitable minimum size. **Fig 26.28** shows a typical home-made heatsink based on the above calculations. Ideally the two bent plates should be soldered together to minimise any thermal resistance at this junction. Thermal conducting compound should be used if this joint is not soldered. The copper should be annealed before bending.

Using a heatsink with a lower-than-calculated thermal resistance will not affect the operation of the cooled semiconductor. It would be unwise to use a heatsink with a higher-than-calculated thermal resistance. In other words, a larger heatsink is better than one too small !

In use the heatsink will become warm to the touch but it should not become untouchable. If it does, then the semiconductor providing the heat is probably being overworked. It would be worthwhile checking the calculations and ensuring that each mating joint is made properly. Some semiconductor devices are designed to run at high temperatures and a hot heatsink would be expected. This heat represents waste energy, and the necessity of large cooling systems, though seeming to be the norm, indicate inefficiency.

Professional designers use very sophisticated computer programs to design their heatsinks. Even then they rely on trials and measurements to tune-up their results! The above formulas and chart are accurate for most amateur purposes, eliminating the need for complex equations or computers.

Heat can also be dissipated from the connecting pins, together with the case, of semiconductor devices, and this can be useful if trying to keep the finished unit compact. A heatsink can be attached to the pin side of the board by a layer of thermally conducting, electrically insulating, elastomer and mechanically fastened to the board with screws. This method can provide about a 5 to 10% reduction in the required overall size of the main heatsink. Large soldering pads for the pin connections also act as heatsinks, and these can be used in conjunction with a suitable heatsink for such devices as audio amplifiers, power regulators, rectifiers etc.

The duty cycle of the device also affects the size of heatsink required. A 50% duty cycle can allow about a 20% reduction in the size of heatsink, depending on the heatsink design. During the OFF cycle, the heatsink must be able to dissipate all of the heat generated during the ON cycle, and it is usual in these circumstance to provide forced-air (or water) cooling to ensure that this is achieved. Many solid-state transceivers specify ON and OFF times for continuous full-power carrier (FSK, AM etc) operation. The small handheld transceivers start to get very warm if they are transmitting for longer than they are receiving. In the case of handheld transceivers, the batteries usually limit the transmit time but, if such transceivers were operated from a mains PSU, it would be essential to ensure that the heatsink arrangements were adequate.

MAKING CIRCUITS

Translation from diagram to working circuit is another accomplishment. The systems available are numerous and varied. Before making any circuit, experimental or permanent, it is worth considering what is expected of the finished project and relate this to the type of circuit construction available. All of the components should be collected together, tested and identified A well-organised storage system, good test equipment and a magnifying glass are invaluable. It is worth trying to understand how the proposed circuit is supposed to work and what function each component performs.

If it is intended for personal use only, then the circuit board needs to be functional rather than reproducible. If it is to be portable in use, as distinct from transportable, then weight, power consumption and compactness are important. If more than a few of the same circuits are needed, then it will be worth considering setting up to design and make printed circuit boards.

The following list suggests some of the factors worth considering before starting on any circuit design and making:

1. Permanent or experimental?
2. How will the circuit/s be housed and mounted?
3. What power supplies are required (battery, mains, internal, external etc)?
4. What types of inputs/outputs are required?
5. What controls are required?
6. What safeguards are required (eg accidental switch-on, wrong polarity, over-voltage etc)?
7. Methods of construction. (Can you make it?)

In the rush to make the circuit, it is all too easy to discover afterwards that some of the above factors were important!

Many solid-state devices are susceptible to damage by static discharge. Handling and soldering such components requires care. It is safer to assume that all semiconductor devices are prone to static discharge damage and treat accordingly. Assembly and repair should be carried out using the normal anti-static precaution of connecting the soldering iron, PCB and operator to a common point. This equalises the static level and is further improved if the common point is properly grounded.

Commercial equipment is available, consisting of an anti-static mat, wrist strap and connecting leads for the other tools. Semiconductors which are very sensitive to static are usually supplied mounted in a metal strip or wire clip (or a carbon-conductive foam in the case of ICs) which shorts together every pin of the device. This anti-static protection should be left in place until the device is plugged or soldered in position, and then carefully removed. A suitable size 'Bulldog' clip connected to the ground mat by a length of flexible wire makes an excellent anti-static connector for ICs.

Methods for Experimental or Temporary Circuits

The main factor with this sort of work is adaptability. It should be possible to change components, and even the whole circuit, with the minimum of effort. The variety of methods devised over the years by fellow amateurs are ingenious and effective.

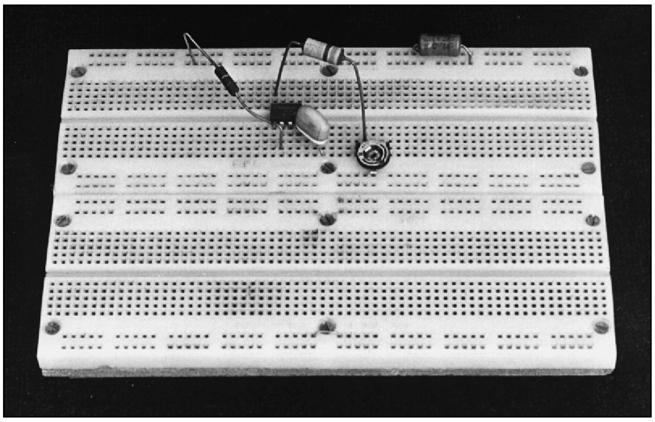


Fig 26.29: Example of a plug-in prototype board

An old-time experimental circuit construction method was to use pins nailed into a wooden board and wrap or solder the wires and components to these. This was further improved upon by using drawing pins in place of pins and trapping the wires under the heads. If brass-headed drawing pins were used the wires could be soldered in place. Several of the subsequent methods of experimental circuit construction can trace their origins to these early techniques.

Many experimental circuits may be made using plug-in matrix boards of the type shown in Fig 26.29 which are also known as prototyping boards.) The RF characteristics of these boards are not of the best, but for digital, AF and other work they are ideal. This board can also be used to do trial component layouts during the designing of a printed circuit or a strip board layout.

Copper-clad laminates have become the accepted base for most circuit assembly. The types of laminates available have been mentioned previously in the section on materials. The glassfibre boards are preferred, whether single or double-sided, for they are kinder to repeated soldering and de-soldering than other laminates, reducing the chances of copper de-lamination. For some experimental work, PCBs are made consisting of small copper pads in a grid pattern on the board (Fig 26.30). Components are soldered directly on to these pads without drilling holes (Fig 26.31). Commercial boards of this type are available for the experimenter who does not wish to go to the trouble and hazards of etching.

An allied technique is that of sticking the main components such as transistors and ICs etc on to the board with their wires uppermost and interconnecting as required with wire, resistors or capacitors, using the copper or one of the supply rails as ground. Tag strips or insulated connection pillars can be fastened to the board

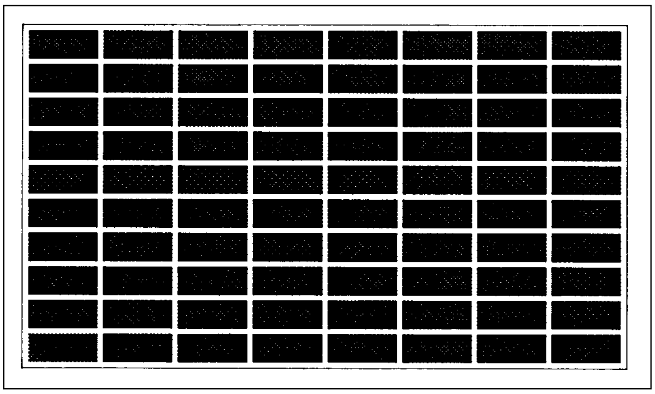


Fig 26.30: Grid pattern PCB for experimental circuits

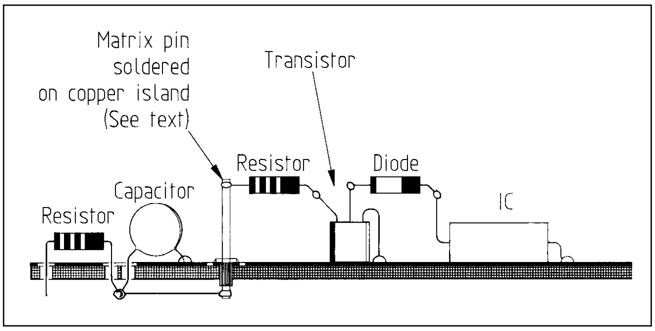


Fig 26.31: Various component mounting and connnecting methods for experimental circuit construction

to provide more support for components and connections. This is a very quick way of making a circuit and has the advantage that changes may be made with the minimum of trouble. However, it's not a 'pretty sight', and it has been referred to as the ugly system, although it works very well, particularly for RF circuits.

Some of the simpler circuits can be made using only tag strips, eliminating the need for any copper laminate board.

Fig 26.32 shows a commercial system which provides a PCB with the same conductor layout as its matching plug-in prototype board.

Drilled matrix board without copper cladding, using special pins which are press-fitted into the appropriate holes for component mounting, is yet another method.

A combination of the above methods may be used to achieve a working circuit. A set of counter-boring drills are very useful, for they can be used to remove circles of copper around holes or to form small annular islands of copper to secure items which need to be insulated from the rest of the board. A counterboring drill is similar to an ordinary drill but with the cutting faces square to the axis of the drill.

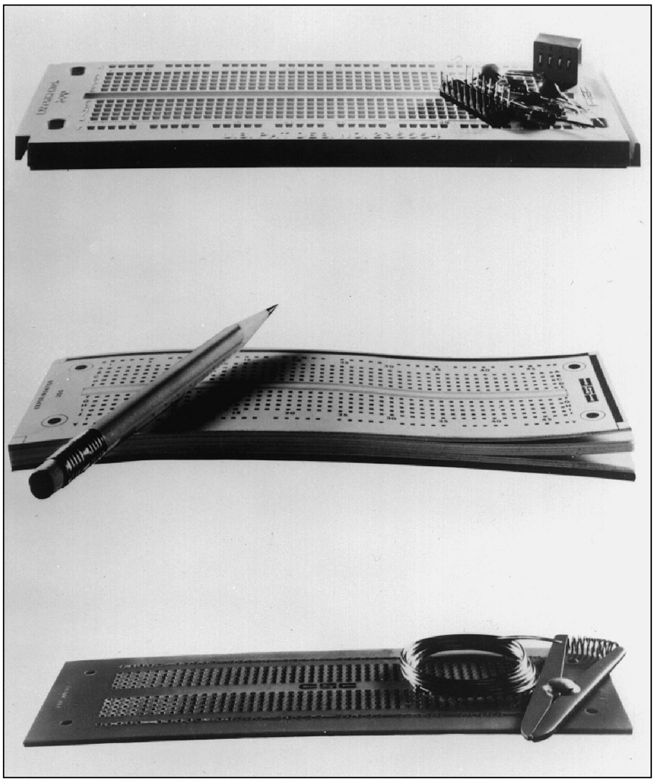


Fig 26.32: Another prototype-to-PCB system: plug-in board, sketch pad, PCB

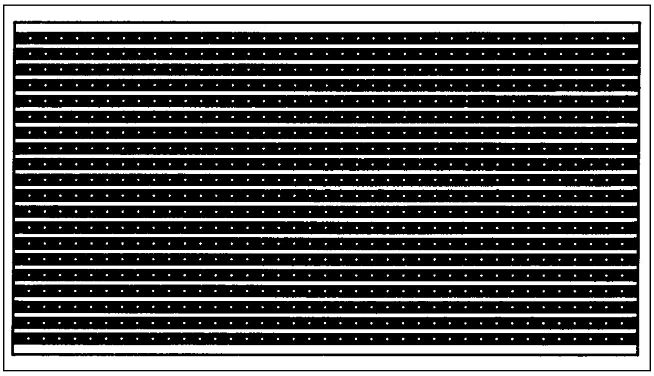


Fig 26.33: Strip board PCB suitable for experimental or permanent circuits

Permanent Circuits

Many of the above-mentioned experimental circuit assembly systems can be used for permanent circuits, but for repeatability and more robust construction it is usual to turn to other methods.

One form of permanent circuit assembly which requires no home etching of boards uses the 0.1in pitch matrix of holes and copper strips, commonly known as strip board (Fig 26.33). The techniques of using this sort of board are relatively straightforward and it is very easy to translate from the experimental plug-in board assembly mentioned earlier. The main consideration is the number of holes required per connection and this is derived by careful scrutiny of the circuit diagram. For the more complicated circuits, it is possible to use a grid reference system; the copper strips lettered 'A' to 'Z' and the holes numbered '1' to 'n'. The connections per component may then be identified on the circuit diagram by its appropriate grid reference. A drawing of the layout beforehand can often show up better ways of placement.

The unwanted strips of copper may be cut away using either a sharp knife or a special strip board cutter. The finished assembly can be made to look neat and tidy, particularly if any track interconnecting wires are dressed against the board. These track interconnecting wires do sometimes present the problem of the insulation melting during soldering. To avoid this it is possible to use either bare wire or sleeve the wire with heat-resisting sleeving. Connecting wires for power supplies or controls should be wrapped to pins soldered to the board. This eliminates the problem of wire fracture that often occurs when these wires are passed through the holes and soldered to the tracks. Similar boards are available for digital circuits, with holes and copper pads suitable for dual-in-line ICs. Many of these digital boards are available for wire wrap, or point-to-point wire and solder methods. These normally require expensive tools, components and wires but are favoured by digital equipment experimenters. They can save considerable time for things like memory boards, microprocessors etc and save the effort of designing and making special one-off PCBs for such circuits.

Etching

The next set of techniques involves etching. A brief outline of the equipment, materials and methods required for this are given as a guide.

The usual etchant is ferric chloride which is corrosive. It should not be allowed to contact any part of the body, particularly the mouth and eyes. Work should be carried out in a well-ventilated room, and protective glasses, gloves and overalls should be worn. No child or pet should be allowed near when using or preparing etchants. The initial action in the event of accidental skin contact is to wash immediately with running water. Splashes to the eyes should be first-aided using a proprietary clinical eye wash and medical advice sought immediately. This etchant is made by dissolving ferric chloride (hexahydrate) crystals in water. The proportions are around 1kg of crystals to 2 litres of boiled water. It is difficult to mix ferric chloride crystals and warm, not boiling, water helps. The solution should be mixed in a non-metallic vessel using a plastic or glass stirring rod. Nothing metallic should be used in the preparation and storage of this substance; plastic containers with plastic screw-top caps are ideal. Child-proof caps are recommended where there is the slightest chance of exploring little fingers. Most chemists will be pleased to advise and possibly supply suitably safe containers.

The container should be clearly labelled 'POISON - FERRIC CHLORIDE'. A permanent marker pen can be used to write on the plastic container, eliminating the risk of a sticky label dropping-off or becoming obliterated.

A small quantity (10-20ml for the above) of hydrochloric acid may be added to improve the solution.

Fig 26.34 shows a suggested arrangement for an etching bath. The essential requirements are that the etchant can be warmed to around 50°C and agitated continuously during etching. The etching bath should be large enough for the work to be fully immersed. The aquarium aerator block is glued to the bottom of the bath and air from an aquarium electric aerator pump is fed through a small bore plastic pipe passed over the lip of the container. The pump should be placed clear of the bath to prevent splashes of the etchant ruining the pump.

The PCB to be etched should be clamped in a plastic carrier and placed in the warm (60-80°C) foaming etchant. It usually takes 10min or more with this set-up to completely etch a PCB. Check from time to time. The shorter the etch time, the less the risk of under-cut and of the etch-resistant materials being washed or dissolved away. The board should be washed and scrubbed in water immediately after etching to remove all traces of the etchant. Failure to do this results in continued erosion even after the board has been assembled. Some of the faults of early commercial PCBs were found to be caused by inadequate cleaning after etching.

The cooled etchant can be poured back into its container and saved for future use. The partially used etchant can be kept for many months, particularly if hydrochloric acid has been added. It does not deteriorate but becomes saturated with copper and it is this which prevents further etching. It is interesting to place a small iron bar or plate into the seemingly spent etchant. The copper attaches itself to the bar and forms artistic surface patterns depending on the cleanliness of the bar - it might even be a method of reclamation!

Check with the local authority before disposing of ferric chloride for it is unlikely to be acceptable to just pour it down the drain.

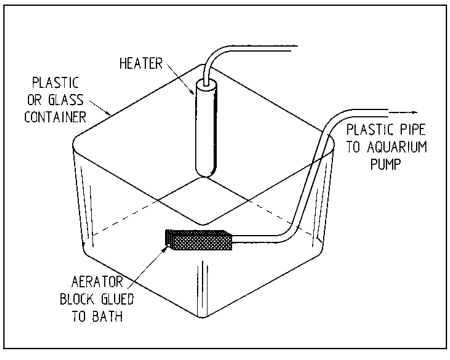


Fig 26.34: Etching bath using aquarium devices

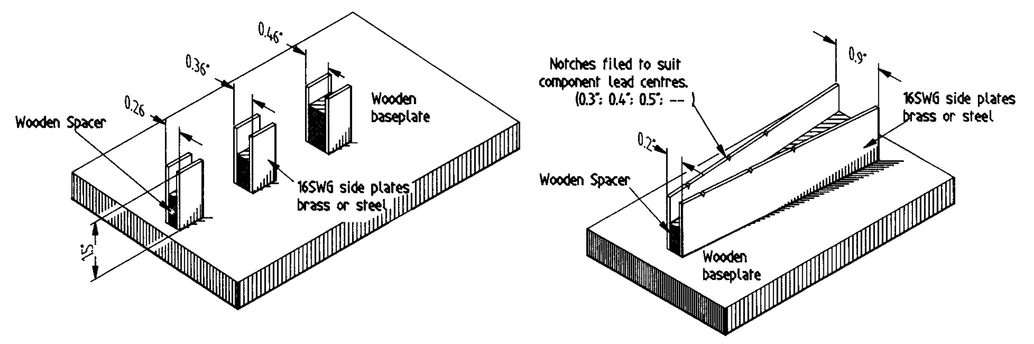


Fig 26.35: Component wire bending jigs

Designing Printed Circuit Boards

Designing a PCB requires skill, time and a great deal of patience. The process is intended for quantity reproduction of circuits and its value to the amateur constructor is worth careful thought. For the individual constructor, as distinct from a club project or a published design, it is better to consider 'modularisation' rather than an 'all-on-one-board' approach to printed circuits. This is the exact opposite of some commercial philosophy but it gives the home constructor much more flexibility, as well as being less prone to error.

Standardisation of board size helps during the design and making stages, and later when fitting the assemblies into a cabinet.

The standardising of the fixing centres of resistors is also helpful. Fig 26.35 shows two types of component wire-bending jigs which can be used to bend the leads to accurate centres for resistors of various wattage. It is particularly necessary to consider all of the previously mentioned design criteria, for PCBs are very restricting, especially in the size of components used and in the ability to make changes. For example, it is difficult to use, say, 0.5W resistors in place of the specified 0.125W ones or to change from a discrete transistor to an integrated circuit. With this in mind, the first essential before designing a PCB is to have either the components on-hand or to have accurate details of their sizes and fixings: it is pointless guessing (see Fig 26.36). It is possible to design the circuit such that more than one size of component may be used (Fig 26.37), but this may detract from the intended compactness and repeatability of the PCB.

Commercial PCB designers use computer software to speed up the very tedious task of track routing and component layout. The software even produces data for controlling such things as hole drilling, board shaping and the mechanised placing of components on the board.

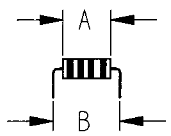
There are some very good programs available for the home computer which facilitate the designing of printed and schematic circuits (see the chapter on computers).

Some home constructors use less expensive methods, the most popular being a sheet of 0.1in pitch graph paper as a guide, placed under tracing paper.

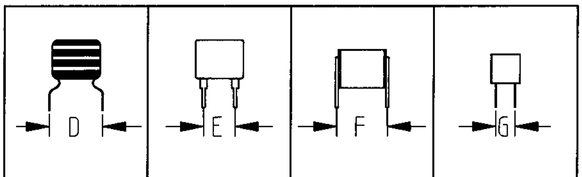
The approach to designing the printed circuit, by any method, consists of four main areas, as follows.

- Positioning the active devices (semiconductors, ICs etc).
- Positioning the passive components such as resistors, capacitors etc.
- Positioning inputs and outputs (connections).
- Linking together the tracks.

A different coloured pen or pencil and a separate sheet of tracing paper may be used for each of the above areas. Draw the active devices, say, in red on sheet one and resistors etc in blue on sheet two and so on. This way it is possible to try various combinations without having to redraw everything. The more compli-



Wattage \ Size	A mm	B inches	TYPE
0.125	4.1	0.5	CARBON
0.25	8	0.6	HIGH STABILITY
0.5	11	0.7	HIGH STABILITY
1.0	16	1.0	HIGH STABILITY
2.0	24	1.3	HIGH STABILITY



Mini Polyester Dip Coated 250 VDC Wkg		Silvered Mica 350 VDC Wkg		Mini Polyester Layer 100 VDC Wkg		Monolithic Ceramic 100 VDC Wkg	
VALUE	D"	VALUE	E"	VALUE	F"	VALUE	G"
0.01–0.1μF	0.4	2–70pF	0.3	0.1–0.47μF	0.3	10pF - 0.047μF	0.1
0.22μF	0.6	80–220pF	0.5	1μF	0.4	0.1–1μF	0.2
0.47μF	0.8	220–10000pF	0.8	2.2μF	0.6		
1–2.2μF	1.1						

Fig 26.36: Some component fixing centres

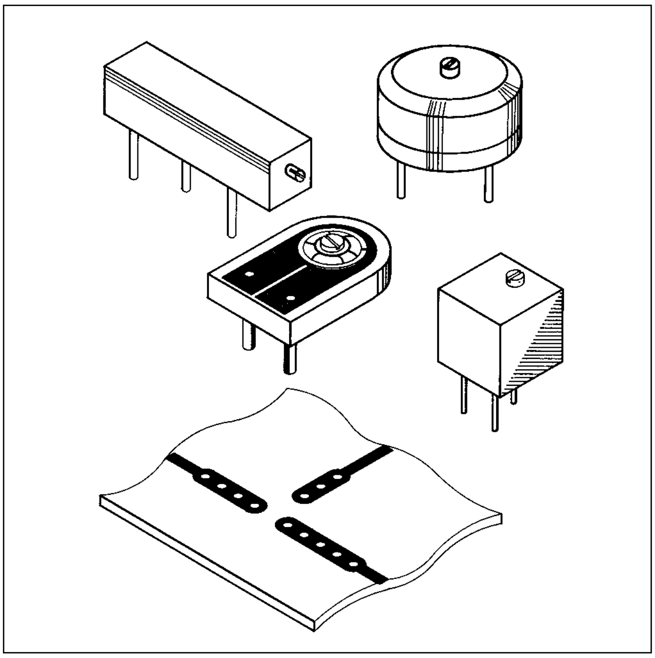


Fig 26.37: Accommodating different sizes of components

cated the circuit, the greater the likelihood of many, many trials. A multiplicity of circuit jumper links usually indicates either a poor layout design or that the designer has had enough!

It is also essential to adopt some standard form of viewing, to avoid the all-too-easy pitfall of producing a beautiful but mirror-imaged board. Most designers seem to adopt the 'as viewed from the component side' standard even for double-sided boards.

Eventually, an acceptable circuit layout will be produced. At this stage a thorough check should be made to ensure that there are no crossed tracks, mirror-imaged components or other mistakes which would be annoying to discover when the board has been made. If you don't find any errors, look again! Some designers tick off each item on a copy of the schematic diagram as they verify that it is on the PCB layout. As with the previously mentioned strip board construction, it is worthwhile marking the number of components connected to each interconnecting track. It is all too easy to either miss one or to find that connections are made to the wrong track.

Guidelines for RF circuits, including high-speed digital

1 Use double-sided board with one face, usually the component side, as a ground plane.

2 Keep the input and output of each stage as separate as possible consistent with (3).

3 Keep tracks short.

4 Decouple all supply leads at the point of entry to the board as well as at the points specified by the circuit. Small ferrite beads placed over each supply lead usually eliminate any possibility of circuit interaction occurring through these leads. These ferrite beads can sometimes be used on signal leads in digital circuits to reduce the possibility of interaction or external RFI, and if these sort of problems occur it is worth trying.

General PCB guidelines

1 Keep mains and high-voltage circuits well away from other circuits, preferably by using separate boards. In the interests of safety, any tracks etc carrying high voltages should be covered by an insulating material to prevent accidental contact.

2 Avoid high current density points. Rapid changes of line width should be avoided, particularly in circuits carrying several amperes. The recommended current density I in amps is:

$I = 3(\sqrt[3]{w^2})$

where w is the width of the copper track in millimetres. Circuit board tracks make excellent fuses if incorrectly designed!

3 The capacitance C in picofarads between each side of a double-sided board is:

$C = 0.0885 \times K \times (A/h).$

where A is the area (sq cm) of the smallest side; h is the thickness (cm) of the laminate excluding copper, and K is the dielectric constant of the laminate material, which for glassfibre is about 4.5.

4 The recommended line or track width varies with wattage, but for most home production a 1mm width is about the smallest possible, with a minimum gap between tracks of not less than 1mm unless you are good at drawing. Commercial artwork for PCBs is often drawn four times full size and photographically reduced.

5 An 8mm minimum margin should be allowed around the board for handling during working and etching. This margin can be removed later.

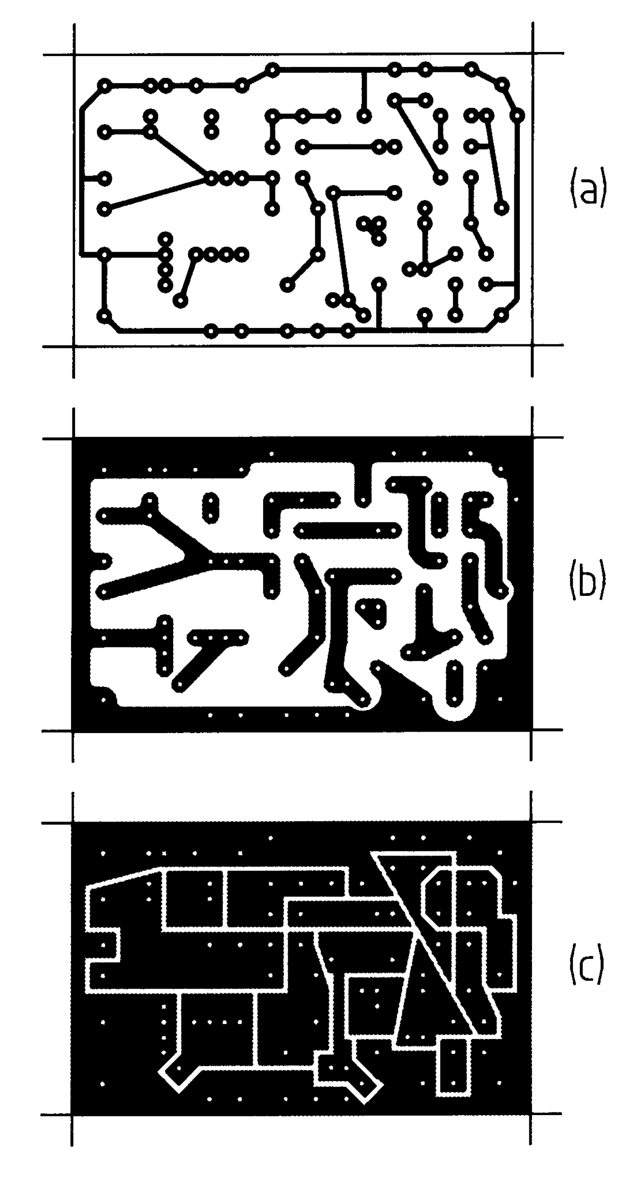


Fig 26.38: Three layout modes for PCB. An alternative is to use a computer PCB design program, a laser printer and special iron-on film (see text)

Making Printed Circuits

There are several methods of transferring a home-designed or a published layout to the copper laminate. Which one to use depends on the number of boards required and the facilities available.

Suggested methods for a one-off PCB

The traced PCB layout is attached to the appropriate side of the laminate; which side depends as previously mentioned on the drawing system used. All the hole positions are carefully marked through using either an automatic centre punch set at its lowest level, or an ordinary centre punch which should be very lightly pressed to mark the surface. Heavy thumping centre popping will cause de-lamination and should be avoided. The tracing paper is removed and all the holes drilled using a 0.8-1.0mm diameter drill. In the case of dual-in-line IC holes, the matrix template mentioned previously can be used to assist accuracy. The holes are deburred and the board cleaned. Three different styles are shown in **Fig 26.38**

Fig 26.38(a) is the usual type of line track and pads. This can be hand drawn using a special fibre-tipped pen or a tubular draughting pen. Fibre pens with a special etch-resistant ink are available especially for drawing directly onto copper. The fibre pens used for drawing overhead transparencies may also be used, providing they are of the etching or permanent ink types. Special ink is required for use in tubular drawing pens and is known as 'K' or 'P' ink. These inks etch into plastic and must be used in special tubular pens, which should be cleaned out thoroughly immediately after use with the matching solvent for the ink. The etching ink dissolves the plastic of ordinary tubular drawing pens.

An alternative to drawing with ink is to use special etch-resistant tapes and rub-on transfers. These must be very well burnished on to the clean and grease-free copper to ensure adhesion during the subsequent etching process. Most normal rub-on lettering will not withstand the rigours of etching and is easily washed away.

A PCB that is designed on a computer (see the computers chapter) can be printed onto special film using a laser printer. Alternatively, an existing printout (including those in Appendix B of this book) can be photocopied to the film using a laser copier. This can be literally ironed onto the PCB and the filmed peeled back leaving the etch-resistant tracks. It is important to ensure that the image is the correct way round - it may need to be printed onto a transparency which is then flipped and re-copied. More can be found about this method in the 'PIC-A-STAR' chapter.

Fig 26.38(b) shows the simple lines and pads system, which can be drawn with either the pens mentioned previously or which can be painted using an artist's fine brush and cellulose paint or the special 'P' ink.

Fig 26.38(c) shows the scratching system, which requires no draughting skills. The copper side of the drilled board is painted all over with either cellulose paint or the 'P' ink; allowed to dry thoroughly, and the gaps between the tracks scratched away using a 0.5mm wide chisel-pointed piece of metal. It may be helpful to first mark out the scratching lines using a soft lead or wax pencil. The circuits produced by this method perform very well at all frequencies from AF up to UHF, and are very useful in providing extra heatsinking when heat-producing components are used. As a result, soldering requires more heat due to the larger areas of copper.

The circuit may also be transferred to the copper by using carbon paper and going over the tracing paper circuit with the carbon paper in contact with the copper. However, the transferred image needs to be inked-in and the transferred carbon often prevents this being done successfully.

Suggested method for multiple board production

This method uses photographic techniques to copy the circuit layout on to the copper. It is an expensive process and, as well as the etching bath, a further similar bath and agitator is required for developing the exposed board.

A source of ultra-violet light is also necessary, preferably with some form of accurate automatic timer. As UV light is harmful, this light source needs to be totally enclosed and incapable of being switched on until fully covered. Commercial high-intensity UV light exposure boxes are available which meet all of these requirements and, unless fully conversant with the hazards of UV light, it is safer to use one of these commercial units rather than attempt to make your own. High-intensity UV light produces serious permanent eye damage with effects similar to that experienced by the accidental viewing of an electric welding arc. Lower-intensity UV light boxes are available but exposure times usually become very long and the safety factor is not much improved.

Full darkroom facilities are not required, only protection from direct and reflected sunlight. A normally darkened room is usually adequate with subdued tungsten or non-UV lighting.

The copper-clad board is coated with a photosensitive etch-resistant coating, the thickness and smoothness of which controls the quality of the finished PCB. The positive type of photo-resist is the easiest to use for it does not require the making of a negative 'master'. With positive photo-resists, the unexposed parts remain in place during developing and the exposed parts are washed away. All photo-resists are expensive and usually have a limited shelf life.

Ready-photosensitised copper laminates are available and are usually supplied with an opaque plastic covering which is peeled away immediately prior to exposure. The board is usually cut with this plastic left in place to protect the sensitised coating and to ensure that no fogging occurs. The margins already referred to should be used, for sometimes light does fog the edges of these sensitised boards. However, if required, it is possible to 'roll your own' using either a spray or a paint-on photo-resist. Full instructions are usually supplied with either and these should be followed. It is essential that during and after coating no UV light strikes the coated surface, for this will cause 'fogging' and attendant poor quality of the finished circuit.

The coating must be of even thickness and free from dust. It is this which makes DiY coating very difficult, especially if repeatable results are required. Spin coating is about the best and an old variable-speed record player turntable set at about 100RPM makes an ideal spinner. The immaculately clean, grease-free and smooth board to be coated is secured as centrally as possible, copper side up, to the turntable. Allow the turntable to spin for a few minutes just to ensure that the board is securely fastened and, using a glass squeeze-dropper, gently apply drops of the photo-resist to the centre of the spinning board until it is seen that the whole board is covered. Photo-resist flies everywhere and it is preferable to place the turntable in a high-sided box. Usually by the time the turntable has come to rest the coating is dry enough to touch but only by the margins.

Normally the board is then dried by heat at the temperature specified by the manufacturer or else it is just air dried. Baking the coating at the correct temperature hardens it and improves the potential quality of the finished board. A clean and light-proof metal box (biscuit tin) can be used to house the freshly coated board, reducing the risk of dust settling on the surface and preventing UV light from pre-exposing the board. The same spin method can be used with the spray-on photo-resists for it does ensure fairly repeatable even coatings. If the coatings vary in thickness, the exposure times will vary, which makes repeat production difficult. It is similar to having a camera loaded with film with each frame having a different and unknown exposure rating.

Double-sided boards may be coated in a similar manner, coating and drying each side in turn. The double-sided board should be attached to the spinner using the 'margins' to ensure that the already-coated side is not scratched or marred by the fastenings. Obviously, UV light must not be allowed to fog the existing coating.

Using the previously generated circuit board design, a further drawing is required which must be on fully UV-transparent material (usually clear plastic film), and the tracks and pads etc must be completely opaque to UV light or failure is certain. The previously mentioned pens, inks, tapes and rub-on transfers can be

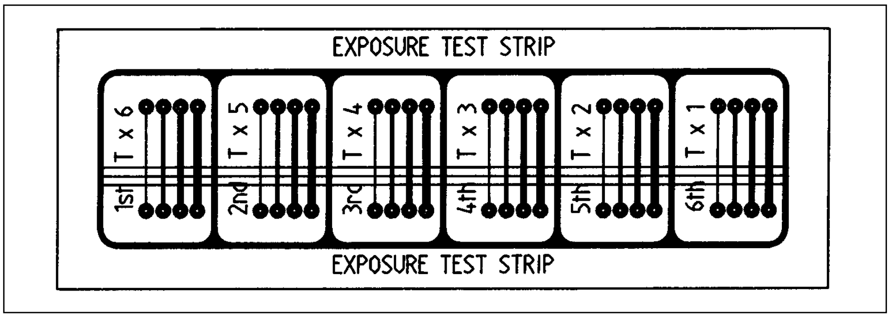


Fig 26.39: Exposure test strip for photo-sensitised PCB

used to make this 'master' transparency. Ordinary rub-on transfers can be used, for there is no etchant to resist. If the 'as viewed from the components side' system of drawing was used, this should be continued for single-sided boards when applying the ink or the transfers etc. These ought to come into direct contact with the photosensitised copper surface of the PCB during the exposure stage to ensure the best possible clarity of lines etc. The master for the component side of a double-sided board should also be produced to ensure this.

A strip of the photosensitised board should be used to assess the exposure time required. Fig 26.39 shows a suggested exposure testing strip, which should be made of the same materials as those used for the master transparency. Each section of the test strip is progressively uncovered until the complete strip has been exposed. For example, if the timer is set to, say, 20s then each step would be 20s greater than the previous one. This is normal photographic practice. The fully exposed strip is now developed. The image of the test strip should be visible, at least in sections, and at this stage the board is washed thoroughly in running water, dried and then etched. It is possible to assess the correct exposure without etching but etching is more reliable and much easier to see. The developing is usually carried out by using sodium hydroxide dissolved in water in the ratio of between 7 and 16g per litre, depending on the resist type. Cooled boiled water is preferred. During mixing, the sodium hydroxide tends to produce a boiling effect and great care should be taken to prevent contact with the eyes etc. The usual safety precautions should be observed: glasses, gloves, no children or pets etc. The mixed solution has a limited life and a fresh solution should be made for each batch of developing.

Some types of photosensitive resists use developers other than sodium hydroxide and most need careful handling, particularly in the home workshop.

Having established an exposure time, the set of PCBs can now be made. The master transparency is attached to the photo-sensitised board by one margin edge only, using either masking or double-sided tape. The assembly is placed face down towards the light source in the UV light box and the lid closed, ensuring that the master is in full contact with the photosensitised face of the board. Some exposure devices use a vacuum hold-down system to ensure this but, providing the board is not too big and the master transparency is allowed to roll into contact with the board, all should be well, with no air bubbles trapped to distort the image. Expose for the time determined by the test strip, develop, wash thoroughly and then allow the board to dry thoroughly before etching. If the coating has been hardened by baking, it is possible to go straight into the etching process, for the coating should not have softened too much during development. To give some idea of the time involved, providing the boards are correctly coated, it is possible to produce a board ready for etching about every five minutes using the set-up and methods described. In the case of double-sided boards, each side is exposed before developing, and great care is needed to ensure that the previously exposed side is not fogged during the second exposure.

Registration is a problem with double-sided boards. The simplest method is to drill a few of the holes beforehand in a manner similar to that described in the one-off method and locate each 'master' to these holes. The holes are best drilled after the board is coated, otherwise the holes will cause variations in coating thickness. In the case of the ready-coated boards, the plastic protection is left in place during drilling. This is a technique commonly used in commercial prototype work and is referred to as spotting through. In this case all of the holes are drilled using computer control. Spotting through is made simple by holding the work against a non-UV light source.

Some constructors make a master transparency from either a published circuit or their own layout, using a photocopier. Unfortunately, some of these copiers do not produce opaque enough images for use with UV light. Also, a slight, non-uniform, scale change usually occurs, which makes hole centres inaccurate. This is particularly noticeable on the multi-pin dual-in-line ICs. A transparent photocopy of the exposure test strip shown in Fig 26.39 may be used to find out the quality of transparency produced, and this could save a considerable amount of wasted effort.

The completed boards made by either of the above methods should be washed thoroughly to remove all traces of etchant, and the resist, ink, transfers or paint should be removed using the appropriate solvent. Proprietary brush-cleaning solvent usually works. Some photosensitive resists need not be removed for they can be soldered through. Final drilling should be carried out and the last stage should be the removal of the handling margins. Commercial boards are usually tinned using either chemical plating or hot dip tinning. Tinning by running the soldering iron around the tracks is unnecessary and can cause de-lamination.

CONSTRUCTION USING SURFACE MOUNT TECHNOLOGY

Although most people have seen surface mount technology (SMT), relatively few without a professional involvement in electronics have used it in construction. SMT dominates commercial technology where its high-density capability and automated PCB manufacture compatibility are of great value. The arrival of SMT combined with the increasing dominance of monolithic IC parts over discrete components means that amateurs will have to move with the technology or rapidly lose the ability to build and modify equipment. SMT has an image of being difficult but this is not necessarily the case and it is quite practical for amateurs to use the technology. An incentive is that traditional leaded components are rapidly disappearing with many recently common parts no longer being manufactured and new parts not being offered in through-hole format. The cost of SMT parts in small quantities has fallen dramatically and through-hole construction will become increasingly expensive in comparison when it is possible at all.

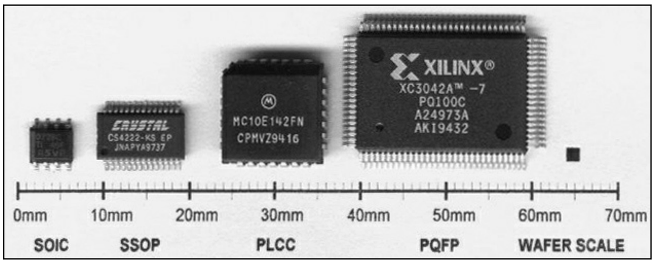


Fig 26.40: SMT integrated circuit packages

The variety of available SM components is enormous and growing rapidly. While the fundamental component types are familiar, the packaging, benefits and limitations of SM components are significantly different to their through-hole equivalents and a brief review is worthwhile.

Active Components

There is a wide range of packages in use at present and the competitive drives for miniaturisation, higher densities and lower costs mean that packaging designs are changing quite rapidly. It is not possible to discuss all types but there are a number of dominant styles that are worth gaining familiarity with. Some SMT packages are illustrated in the chapter on Passive Components.

The small outline diode (SOD) package is a simple two-leaded plastic package for diodes. There is a wide range of competing styles and sizes (SMA, B, C, D etc) and care must be taken to check the actual package style of individual parts.

The small outline transistor (SOT) package family is dominant for parts with three to five leads. The name is totally misleading as the package is used for diodes, ICs and transistors. The commonest types are the small SOT23 series used initially for discrete transistors and diodes in three-lead form and now typically in five-lead form for small monolithic parts such as op-amps and individual logic gates. A number of larger thermally efficient packages has emerged such as SOT223 for higher-power parts such as voltage regulators which are replacing the familiar TO220 through-hole parts.

Metal electrode leadless face (MELF) parts are essentially surface-mount versions of existing axial-leaded packages that have the leads removed and replaced by end metallisation. They are becoming less common as SOD and SOT packages dominate for devices of less than eight leads.

Modpacks are small four-leaded parts that are frequently used to house monolithic gain blocks. They are quite suitable for amateur construction and are very similar to the early RF transistor packages. They are normally a plastic package but sometimes ceramic package parts will be encountered. These must be treated with caution if the part cannot be identified, as a few higher-power parts use beryllium in their construction and a health hazard may exist if the parts are cracked or damaged.

The plastic leaded chip carrier (PLCC) package (**Fig 26.40**) is intended to be either socket mounted or soldered directly to a PCB. These are sometimes referred to as J-lead parts due to the way that the leads come down the body side before bending under around the body. They will probably become less common as they are relatively bulky but are fairly easy to work with.

The small outline package (SOP) or small outline integrated circuit (SOIC) housing is very common with a 1.27mm lead pitch and between eight and 28 leads but with various body widths. They are quite suitable for hand construction but are being displaced by the shrunken small outline package (SSOP) (**Fig 26.40**) and thin small outline package (TSOP) packages with 0.635mm and 0.5mm lead pitches. Although care is required to solder or lift individual pins on these denser parts it is relatively easy to solder or remove entire parts with the correct techniques. These parts are sometimes called gull wing due to the way the leads come out of the package when viewed from the end.

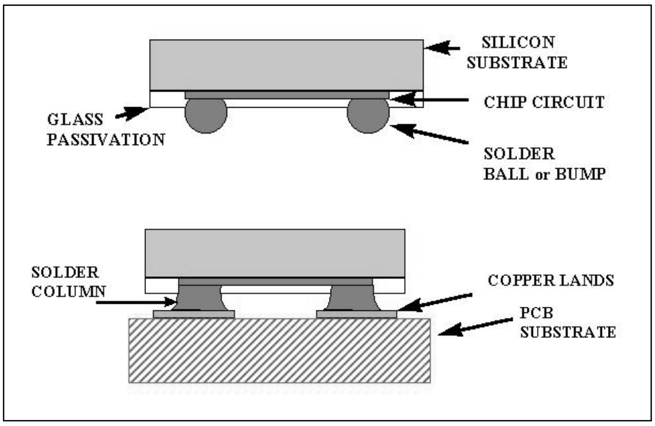


Fig 26.41: Wafer-scale package

The plastic quad flat pack (PQFP) (Fig 26.40) is common for parts with between 40 and 208 leads which are arranged on four sides of a rectangular package. The lead pitches vary with package size from 0.5 to 0.8mm. Care is required to solder to or lift individual pins on these parts but it is possible to solder or remove entire parts with the correct techniques.

Amateurs are less likely to use ball grid array (BGA) packages that are becoming common on devices with high pin counts (typically 225-560 connections). The connections are underneath the device in the form of an array of small solder balls formed on top of connecting pads on the device base. The part is carefully placed on top of the PCB land pattern. During subsequent reflow soldering the balls are melted and surface tension draws the package slightly closer to the PCB, leaving small columns of solder linking the pads on the device to pads on the PCB. These devices require specialist tools and techniques to mount and X-ray inspection to assess the solder bonds which are almost entirely hidden under the device. BGA parts are not well suited to amateur use.

The wafer-scale packages (Fig 26.40) can be regarded for amateur purposes as a smaller version of the BGA with solder balls typically on a 0.5mm pitch. The reduction in size is possible since there is no actual package, simply a 'bare' IC with glass coating for protection and solder balls for connections (**Fig 26.41**). The solder balls are sitting directly on metallised areas on the chip surface which have been left clear of the outer glass passivation. The resulting device is little larger than the minimum size of the chip which enables parts with 100 connections to be fabricated at sizes of under 1cm square. This interconnect density hidden under the chip causes even more difficulties than the BGA. A recent development from National Semiconductors is to use this technology for low-lead-count ICs such as the LMC60351BP dual CMOS op-amp, sized 1.45mm square and 0.9mm high. This is a 95% PCB area reduction in comparison to an equivalent SOIC part. Wafer-scale packages may largely replace other packages due to the size and possible long-term cost advantage. There are problems, however, such as the need to match thermal expansion coefficients of chip and substrate as well as PCB design and manufacturing difficulties. When using surface-mount active devices additional care must often be taken over PCB design as many parts rely on conduction cooling via the PCB copper tracks to stay within design limits. Moderate power devices such as SOT223 regulators require

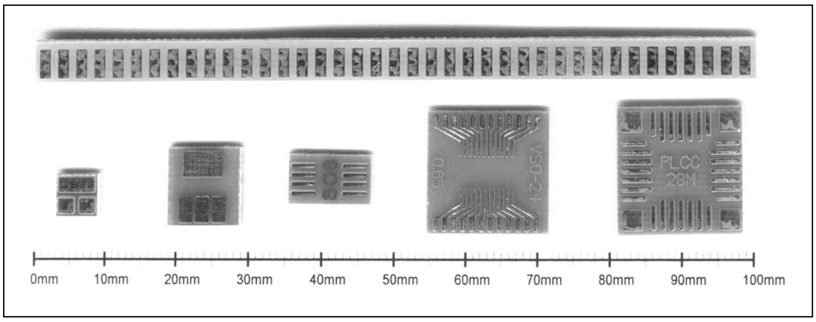


Fig 26.42: Mini Mounts

particular attention to the manufacturer's PCB specifications to ensure long-term reliability.

Passive Components

Surface mount resistor, capacitors, inductors and connectors, together with their component markings, are described in the chapter on Passive Components.

Construction Techniques

PCB

This is the ideal construction method and can make surface mount construction easier than through-hole construction due to the reduced number of holes that need to be accurately drilled. The limit of PCB etching resolution for the amateur may make finer-pitch ICs difficult to use but it is feasible to use SSOP and TSOP parts with care. An additional limit is imposed by the difficulty of making multi-layer PCBs and this makes larger parts more tricky to use. An alternative method to etching PCBs is the use of small PC-controlled milling systems that mill the non-required copper off a plain copper-clad PCB to leave the required track pattern. These are commercially available (at the price of a second-hand car!) but have been built by some amateurs using pen plotter mechanisms.

Veroboard

Strip board still has uses in surface mount work as resistors and capacitors can be soldered directly between tracks and across cuts in tracks. Transistors and diodes are also simple as SOT23 and SOT143 can also be mounted directly on the track side. The big problem is how to handle ICs but SOIC parts can just be managed since the pin pitch is 0.05in, enabling every second pin to be soldered to a 0.1in strip with the unsoldered ones bent up 90 degrees with flying leads soldered directly to them.

Mini Mounts

The German company Wainwright manufacture small pieces of self-adhesive PCB called Mini Mounts with land patterns for a wide variety of components (**Fig 26.42**). These can be placed onto either plain copper board or a PCB and inter-wired to rapidly build prototypes or one-offs. The pads are available in the UK via Wessex Electronics [1] but are normally subject to a minimum order.

Ugly construction

There are numerous styles of 'dirty' construction and most SMT parts can be used at least as easily as leaded components. One trick that can make things easier is to use small pieces of Veroboard to make 0.1in pitch pads or busses when glued onto plain copper board.

The method shown in **Fig 26.43** can be extended to make mounts for devices such as SOT23 which can then be glued down where required.

An even simpler method is to use self-adhesive copper tape intended for EMC purposes stuck on top of self-adhesive KaptonTM (polyimide) tape to form self-adhesive insulated tracks of pads (**Fig 26.44**). Kapton tape is often used as masking tape in PCB soldering operations and is very resistant to heat. The tapes can be cut to any desired shape or size then be stuck where required, eg on a copper ground plane. The only real problem is that the adhesive used on copper tapes is very soft when heated so care must be taken when soldering. It is best to tin the copper tape before cutting it to size as smaller parts will be more difficult to solder as the adhesive melts. Extending the method slightly, multiple layers of tape and foil can be used to run tracks past each other without wire links. A final variation would be to photo-etch the tape composite to obtain a self-adhesive flexible PCB structure but a better adhesive is really required for the copper tape. If 50-ohm transmission lines are required then the Kapton tape is problematic as track widths will be impracticably narrow due to very thin dielectric. Single-sided glassfibre PCB should then be used with the copper side used as a ground plane and the copper tape applied to the glassfibre side to form microstrip. The copper plane side can still be used with tape to add more circuitry.

When soldering this type of work ensure proper ventilation to avoid breathing fumes from flux, adhesives or plastics.

Soldering and desoldering

For hand soldering there is no requirement to use solder paste as standard soldering tools and materials are adequate. Similarly there is no need to glue (stake) components down before soldering and this is only done on certain automated soldering systems. When desoldering components, great care must be taken to avoid damaging the PCB as it is very easy to lift pads when removing components. Similarly, care must be taken to avoid excessive temperatures or heating for excessive times as components are heated much more directly than their through-hole equivalents and are thus more vulnerable. Working on valuable equipment should be left to the experienced as it is easy to damage assemblies when learning.

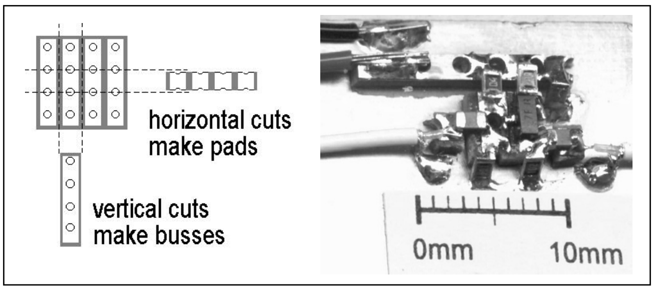


Fig 26.43: 'Ugly' construction using Veroboard strips

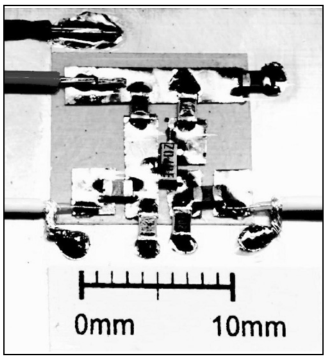
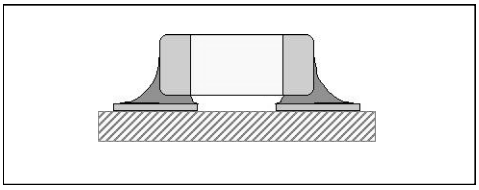


Fig 26.44: Kapton/copper tape construction



Flg 26.45: Ideal solder meniscus

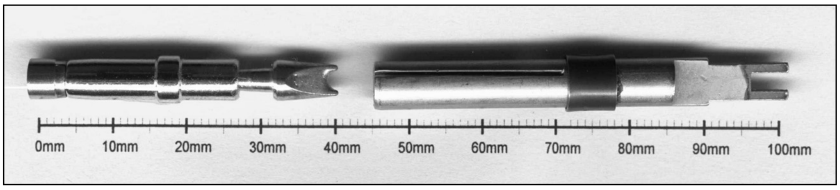


Fig 26.46: Desoldering bits

Resistors and capacitors are soldered quite easily and the key is to prepare the pads or lands prior to presenting the component. Tin the pads first and use solder wick to get a flat surface on one of the pads. Hold the component on the pads using tweezers and use the iron to heat the junction of the component and the unlevelled solder pad until the solder melts and the component is pressed gently so that it is parallel to the board. Apply a little solder to the opposite pad/component end and then a little more to the first end again. There should be a meniscus of solder at both ends of the component with a bright shiny surface (**Fig 26.45**).

Desoldering passive components is normally done with a pair of desoldering tongs or a special forked bit in a standard iron (**Fig 26.46**). If a spare iron is to hand then it is possible to desolder both ends simultaneously with two standard irons but with a little desperation and practice a single iron can be used to desolder these parts.

Soldering active devices requires more care but discrete semiconductors and SOIC ICs are quite easy. For these parts prepare the lands by tinning and flattening with solder wick. Hold the part in place with tweezers and without using solder press one of the leads down onto the pad for a couple of seconds using the iron to form a weak joint. Go to another lead and repeat the process so it should then be possible to release the part and it will not move. Then individually solder down the other leads and finally solder down the 'tacked' leads.

If specialist desoldering tools are not available desoldering SOIC ICs is easier if a slightly aggressive approach is taken. Using a large-sized solder bit, apply a large amount of solder quickly down one side if the IC; this will probably short out quite a few leads but this does not matter. Then get a thin pointed object such as a thin knife blade or a probe and, while pushing it in from under one end of the IC body so as to gently lift the soldered side, run the iron back over the newly applied solder so that it is simultaneously melted. This will allow one side of the IC to be lifted off the PCB. When it has cooled press the IC back to its original position and repeat the process on the other side so the IC becomes free. Done quickly, this method will not harm the IC and it can be reused if necessary.

Soldering fine pitch parts is less easy with hand tools but with care it is possible to attach wires to or lift individual pins on 0.5mm pitch parts. Soldering down or removing a whole part is actually slightly easier with a slight variation of the above techniques. To fit a part, first tin the pads then clean them with wick. Then present the part and gently push down some of the corner leads with a soldering iron to form weak joints. Using a large soldering bit and a good quantity of solder run the iron and solder along the outer end of a line of leads so that there is solder over every pin and possibly many of them shorted out. Repeat on the leads on the other side then use wick to remove the surplus solder - use an eyeglass to check that there are no shorts remaining. It is best to avoid getting solder between the leads and the component body as it is much harder to remove it from there.

If a part is being removed another method is to first cut the leads to remove the part from the board then to desolder the leads. This can be done with a scalpel or a similar blade by cutting directly at the junction of the IC body and the emerging lead. With any of the techniques for working on surface mount boards it is best to practice them first, and scrap SMT consumer electronic assemblies are readily obtained for this purpose. It is very easy to accidentally remove PCB lands when removing components and some practice is essential.

Some final points must be made about cleanliness as it can cause significant problems with high-density boards. Flux splashes often cause mating problems on high-density connectors so ensure that these are kept protected when soldering and clean them afterwards. A general point with flux is that some very-high-impedance amplifiers must be de-fluxed after soldering as the flux can represent a significant shunt resistance. Tiny solder flecks can also cause shorts on connectors or between IC pins so again keep all work and work surfaces clean.

Commercial Manufacturing Methods

It is worth mentioning commercial methods as these give some idea as to what conditions components are designed to survive. The first consideration is should the board be surface mount or not? If it is necessary to use many through-hole parts it may be best to avoid mixing technologies and only use through-hole parts to arrive at the minimal cost solution.

The commercial boards use solder paste (tiny solder spheres within a liquid flux) which is applied by a silk screen process to the solder pads. To help avoid shorts it is normal to apply a varnish known as the solder resist over areas that are not to be soldered. The parts are then loaded onto the boards using automated 'pick and place' machines. Depending on the subsequent solder process, dots of glue may have been applied to the PCB prior to placing the components to help retention during soldering.

There are two basic types of process - reflow and wave soldering. Since boards may have components on both sides and pass through several processes, occasionally both processes may be used on a single assembly.

The wave soldering process originated with through-hole boards where the board is passed just above a bath of liquid solder. The solder has waves on its surface which brush the underside of the board and so solder the components - surface mount components will be totally immersed by this solder wave and will have been glued to the board. The reflow processes are simply means of melting the solder paste either by infra-red heating or by passing the assembly through a bath of high-temperature inert gas. With the reflow method, components are not normally glued to the board. Whatever the process components are completely subject to molten solder temperatures for many seconds.

Tools and Working Conditions

Lighting

Good lighting is essential and can be provided with relatively cheap domestic desk lights. The lamps that also include a magnifier are not always ideal since they may provide insufficient light and not provide enough magnification. A cheap jeweller's eyeglass is very useful - a magnification of about x9 is about optimum as very high magnification can be difficult to use.

Component storage and control

Components must be stored properly since the parts are small and fragile. Ideally they should be stored in whatever packaging they are delivered in and only removed when they are going to be used. Components should not be handled directly as oils, acids and salts from the skin will affect the solder quality. It is particularly important always to use tweezers to take things out of storage containers as fingers touching other components which are than going to remain in storage will result in significant corrosion before the stored components are finally used. Unless care is taken it is very easy to confuse small components - only have one container open at a time and seal the container as soon as the required part has been removed. It is very easy to drop and lose these parts - always keep the work surface clean and clear of extraneous items.

Tweezers

For handling small parts needle-pointed tweezers are essential and generally the types which are curved or angled are more convenient than the straight types.

Desoldering braid

Solder wick is invaluable for cleaning tinned solder lands prior to soldering components and removing excessive solder. Even on very small parts braid with widths of 2 to 3mm is generally most useful as the very fine braid has only a limited ability to remove solder.

Solder

Getting hold of the finest available is to be recommended but there do not appear to be any sources of small quantities for amateurs. Unfortunately very fine (26SWG) solder only appears to be available in 0.25kg reels and can cost two to three times as much as 18SWG solder. At present 22SWG is probably the finest readily and economically available size. The solder should be flux cored and of medium or low melting temperature. Remember that the iron temperature and the solder melting point must be compatible.

Flux

Flux is useful for soldering and desoldering larger parts but only use electronic fluxes and not the plumber's types.

Flux cleaner

Ideally the use of solvents and cleaners should be minimised for environmental and health reasons but even with 'no clean' solders it is sometimes necessary to remove flux from critical areas such as connector surfaces.

Soldering and desoldering bits

Surface mount parts are soldered directly with much shorter leads than through-hole components and it is therefore much easier to damage parts in the process. A temperature-controlled iron is ideal but small low-power irons can be used. A large copper area such as a ground plane is difficult to solder with low-power irons but a good PCB design can usually avoid having large copper areas directly contacting components.

It is useful to have a variety of bits with conical bits for fine work and chisel bits for larger components. Special desoldering bits (Fig 26.46) can be useful but if you only have a single iron it can be inefficient to be constantly changing the bits as you add and remove parts.

Soldering and fumes

When soldering, great care must be taken to avoid breathing fumes and it is advisable to wear safety glasses. The use of tiny components means that the eyes tend to be close to the point of soldering and are vulnerable to solder/flux splashes and fumes from adhesives (see also 'Safety' below).

Static control

Static control must be exercised to avoid damage to semiconductors. This damage is not always immediate in nature and can result in mysterious failures at a later date. Static control involves grounds and the amateur must make personal safety the main concern. Wrist straps and ground cords must contain appropriate current limiting resistors and should not be worn if high voltages are potentially exposed.

Safety

- When working with live equipment or soldering, eye protection is advised and most DiY stores have suitable items available.
- Soldering should take place in a well-ventilated place and the fumes should not be breathed.
- Caution must be exercised with any chemicals used such as solvents or PCB cleaners as some people are particularly vulnerable to these materials.
- Some SMT devices may contain beryllium in their construction - this represents a serious health hazard if the package is broken or damaged.

CABINETS

Housing the finished project is another important area. The cabinet is always on view and therefore should reflect the care and time devoted to the project. Commercially made cabinets appear to be the easy way out but often these cabinets do not meet the requirements exactly. They are either too big or too small. Also, they do not always allow for easy changes in layout. These restrictions, combined with the expense of commercial cabinets, are a great encouragement to make your own. This is

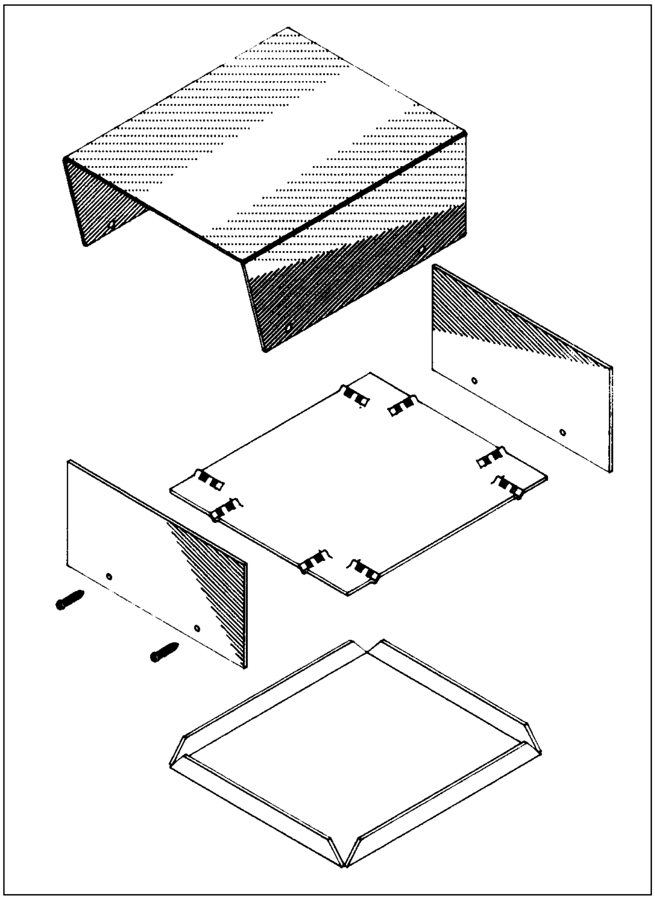


Fig 26.47: Small cabinet design with alternative base plates

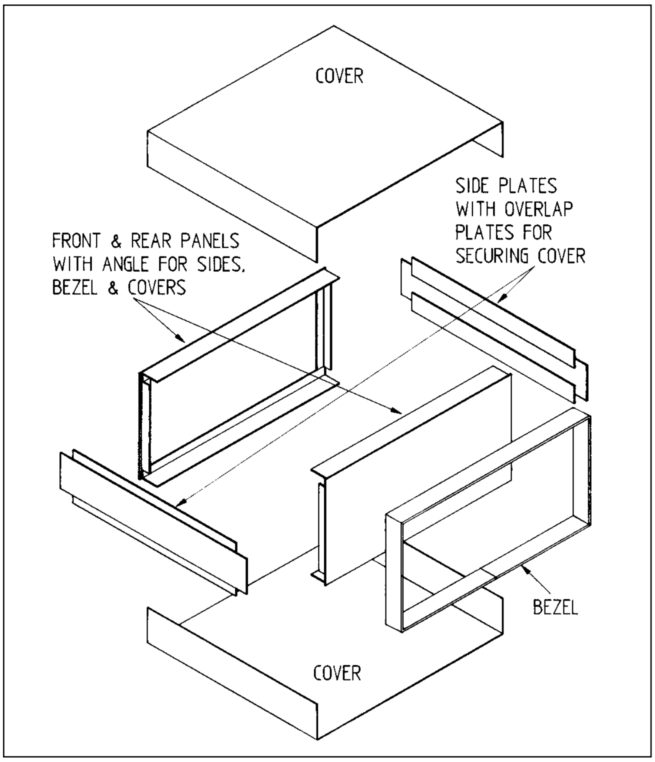


Fig 26.48: Large cabinet design

Fig 26.49: Home-made equipment housed in the small cabinet design

Fig 26.50: Home-made equipment housed in commercial boxes. The items in the foreground and on the right use the paper/Perspex panel system described in the text

a relatively easy thing to do, especially if the techniques and tools previously mentioned are acquired. It is also possible to re-use old cabinets from obsolete equipment, modifying these to suit your requirements.

Ideally any box or cabinet should be able to be altered with the minimum of effort and waste. To this end, the base and the front and rear panels should be separate items. The two cabinets shown in **Figs 26.47 and 26.48** are very easy to make and meet this requirement. That shown in Fig 26.47 is intended for the smaller projects, such as keyers, QRP ATUs and active filters etc. Typical sizes are 130mm wide, 80mm high and 150mm deep. It can be sized for larger work but the cover becomes difficult to make. The cover of the larger version really needs making from heavy-gauge material to reduce flexing, and bending becomes difficult. The cabinet shown in Fig 26.48 overcomes this problem and is suitable for such things as high-wattage ATUs and linears etc. The cabinets can be made from steel or aluminium, and a small version of Fig 26.47 can be made from tin plate.

Fig 26.47 shows two possible base plates. The flat base plate utilises the hole-embossing tool, and the edges of the cover should extend beyond the base plate to form feet. These feet can be edged with plastic strip of the type that is used to bind papers together. This plastic binding is available in various colours and, if used correctly, the finished job is very professional looking. The alternative bent base plate can be made using a former. The finished base plate and the former can then be used as a former to bend the cover, thus ensuring a good fit. The sides of the cover do not need extending if using the bent base plate.

In the transmitting radio shack, it is advisable to use metal boxes or cabinets to house electronic devices. This gives some measure of screening, which helps to reduce mutual RF interference. Plastic, wood and other non-conducting materials, though often making things easier to construct, do not provide such protection unless lined with metal foil which is grounded. These materials are best used to provide cabinet embellishments, such as bezels, feet, handles etc.

Fig 26.49 shows home-constructed equipment using the small cabinet or box. **Fig 26.50** shows home-constructed equipment fitted into commercially made boxes. Also, the front and right-hand side pieces of equipment shown in this diagram utilise the paper panel methods referred to later.

FINISHING

Having built the equipment, the urge to use it may be so great that there is no time to finish it off. This is a shame, because the finish affects the appearance, which in turn adds to the pleasure of using home-made equipment. The time spent on construction may be considerable but that spent on finishing is undoubtedly the most rewarding.

Painting

This is probably the most common form of finish used. The combination of two or more colours can enhance the equipment. The choice is limitless and it is usual to try to adopt some standard colour scheme. If commercial equipment is already in the shack, it is possible to try to match or blend with its colour scheme. Brush painting very rarely gives a good surface over large areas and a considerable amount of work is required to burnish this form of painting into anything like a smooth finish. Brush-applied hammer or crinkle finish paints are useful for covering the outsides of cabinets but front panels look far superior and workmanlike with a monotone finish.

Spray painting has been available for sometime in the form of aerosol sprays and these are a reasonably cost-effective form of painting. A durable and pleasing appearance can be obtained, once the simple technique of using them has been learnt. The directions, usually given with product, for the method of application should be followed. The main area of difficulty usually arises when spraying the three-sided corners of a box. It often happens that too much paint goes on to one surface and runs; the other surfaces are left unpainted or just lightly coated. The trick is to spray each corner face in turn, masking-off the other faces, which may or may not be freshly painted, by holding a piece of cardboard in the path of the unwanted spray. A few practice runs on an unwanted piece of metal enables the technique of aerosol spray painting to be acquired quickly.

Before any painting is done, the surfaces should be suitably prepared, for the resultant ease of obtaining a smooth finish depends on the quality of the unpainted surface. The surface must be smooth and burr-free. This can be achieved quickly by using the flapwheel and drill mentioned previously or by rubbing down with emery cloth. In the case of aluminium, ensure that the emery cloth does not pick up the aluminium dust and form an abrasive lump which will score the surface. Any scratches or score marks should be smoothed out or, after priming, filled with one of the proprietary fillers which should be blended-in completely to leave a smooth flat surface. The abrasive block should be used for the final rub-down. The surfaces should then be washed and degreased thoroughly with scouring powder and the scouring pad. The now clean and grease-free surface should not be handled, for any finger marks will affect the finish.

Surfaces can also be prepared and sometimes finished by etching but, as most of the substances used for this technique are hazardous, this method is not recommended for the home workshop. A solution of ferric chloride will etch to produce a reasonable ready-to-paint surface on copper, brass, mild steel and aluminium. The surfaces must be clean and grease-free otherwise uneven etching will occur.

The next stage in painting is priming. Most aerosol paints have details of the recommended primer to use printed on the can, and these instructions should be followed because the manufacturer is as anxious as you that the painting works properly. If no instructions are given then the following types of primer should be used:

- For steels use the oxide primers to suit the type of paint that will be used for the final finish.
- For aluminium use the etch-type primers.
- If it really is necessary to paint brass or copper then the oil-bound undercoat paints should be used. Zinc or aluminium-based primers do not always work well on brass or copper and tend to lift after a short period of time.

After priming, and when the work has dried thoroughly, carry out any filler work necessary. When this has dried a light rub-down with very fine wet and dry paper will smooth off ready for the finishing coat or coats in the colour of your choice.

Many of the modern enamel spray paints require neither primers nor undercoats and still produce a durable pleasing finish, providing the surface of application has been well prepared. There are so many types of paint to choose from that a little personal experimenting is advisable. Most paint manufacturers will supply literature on their products, giving full details of the methods of application, durability etc. A few types are listed here.

Acrylic paints

A good gloss finish is possible with these reasonably priced paints but they are susceptible to some cleaning solvents. They are suitable for use on most metals or plastics and are available in aerosol cans. These paints are probably the best all-round paint for the finishing of home-constructed projects. Some of the hammer finish paints are of this type.

Bitumen paint

A useful and cheap paint. It is protective rather than decorative and is suitable for the protection of masts and other outdoor metal work. Usually it gives a black semi-gloss finish and is normally brush applied. White spirit can be used to clean brushes etc.

Cellulose dope

This is a fast-drying liquid which, like shellac, can be used as an adhesive or a coating to secure and waterproof. Unlike shellac, the dope may dissolve some plastics. It is usually available from model aircraft shops in clear or coloured form and is reasonably priced. The coloured dopes contain pigments and in some cases metal powder. These may provide an electrical conductive coating. The non-shrinking clear dope weathers very well. It is a good protective coating for beam elements and does not appear to upset the beam's performance. Normally it is brush applied, although it can be thinned with cellulose thinners for use in DiY-type paint sprayers.

Cellulose lacquer

A reasonably priced, quick-drying lacquer, giving a high and reasonably durable gloss which can be improved by polishing. It can be affected by some cleaning solvents. The rapid drying properties considerably reduce the risk of dust-marred work. It is available in aerosol cans and as normal paint. Special thinners are required for cleaning brushes etc.

Stoving paints

These are usually of the acrylic or alkyd types, which rely on stoving to complete the chemical changes of drying. They are usually applied by spray and the resultant finishes are hard, durable and can be very glossy. This is about the best paint finish possible but the stoving and spraying requirements usually present a problem in the home workshop. However, some commercial concerns do offer a small-quantity painting and stoving service, which is worth considering for that extra-special job. Some car body repair shops have these facilities also.

The number of coats of paint and the method of application is entirely a matter of choice. All painting should be carried out in an atmosphere as warm, dry and dust-free as possible, and in very well-ventilated conditions. If the painted work can be placed in an electrically heated oven at around 70°C, drying will be greatly assisted.

Putting the work in a tin with a lid and placing this on top of a stove or central heating boiler is the next best thing, for it will keep dust from marring the work during drying. Rubbing down and cutting-in compounds supplied for car paint retouching are also very useful in obtaining that final smooth finish.

Other Finishing Materials

Shellac lacquer

A lacquer which is made by dissolving shellac flakes in methylated spirits or similar solvents. This is a well-tried, inexpensive waterproofing, insulating and light-duty adhesive-cum-lacquer. It can be used to protect antenna elements and connectors, and to secure wires, coils and components. The lacquer dries to a hard brown translucent finish. The drying process can be speeded up by the application of heat.

The shellac flakes and methylated spirits are normally available from dispensing chemists, or it can be bought ready made as French/Button polish or knotting compound. The ready-made lacquers are usually very 'watery' and may contain solvents other than methylated spirits.

Self-adhesive plastic sheets

These are an alternative finish that can be used to good effect on the outsides of cabinets and boxes, saving a great deal of painting and rubbing down. Leather-effect cloth provides a very professional touch, particularly on the larger surfaces such as covers of ATUs, PSUs etc. This cloth, if not self-adhesive, may be glued down using contact adhesive very evenly applied to both surfaces. The previously mentioned panel cleaning should be carried out before applying either of these types of sheet finishings. The main problem with using these sheets is that of shrinkage and the edges curling with age. This can be eliminated or reduced by heating the panel to around 60°C (just too hot to hold) immediately before applying the sheet. Also, wrapping the sheet around the edges can sometimes improve the problem. With wrapping, edge bulge can become obtrusive. Trapped air is the bane of this process (a bit like wall-papering), and the knack is to peel-on the sheet using a straight edge or a rod to peel against from the non-adhesive side.

Self-adhesive coloured or metallic finish tapes can be used to line-in features of the panel or cabinet. There is a strong tendency, due to the ease of application, to overdo this and finish up with a cross between a juke box and a 1960s car radiator grill.

Lettering Panels

This is now very easy and, though machine engraving is still considered the best, it is little used because of cost. Most modern commercial equipment has the lettering screen printed on to panels, knobs and push-buttons etc. Screen printing can be another home workshop process.

The wet slide-on transfers are effective and can be complementary to the more popular rub-on lettering such as Letraset™, Chartpak™ and others. These are expensive and it is worth considering carefully what style and sizes suit your tastes. The Helvetica Medium style seems to match the lettering on most commercial equipment, and is available in black or white in various point sizes. The range 10, 12 and 14 point should cover most requirements. A sheet of numbers only in the same range is also worthwhile. Variations of importance can be made using a combination of upper and lower case, with different point sizes of the same style. Mixing styles of lettering is not usually aesthetically effective.

Sometimes these rub-on letters can be difficult to apply, usually because the surface is uneven, cold, damp, greasy or too glossy. A very light rub-down with wet and dry paper should be adequate preparation for the surface. The paint will have a matt finish but this is taken care of at a later stage after lettering. The pre-release method will usually ensure success, particularly on the smaller characters. To pre-release the required character, the lettering sheet should be placed on to its non-stick backing paper and, with the two sheets resting on a hard surface, the area of the character should be rubbed over as normal. A change of texture can be seen through the carrier sheet when the character has released. In this state, the character, still lightly attached to its carrier sheet, may be applied where required, and usually a very light pressure will allow the carrier sheet to be withdrawn, leaving the character in place. The newly placed character must be burnished immediately into place through the non-stick paper, to ensure that it will not be lifted off during the next character application.

The earlier chapter on the PIC-A-STAR transceiver project contains much additional information on construction strategies and techniques

Alignment of the lettering during application is facilitated by using the guide markings on the lettering sheet. Some have the guides under each letter and some at the ends of each row of lettering. A strip of card can be arranged as a ruler guide and its alignment checked using the combination square. Lining-up the bottom of each letter as the lettering progresses is difficult and will not produce correctly aligned work. Also, for some reason, there is a tendency to gradually curve downwards, particularly if referencing from the immediately previous character. Spacing the characters equally, say around the centre line of a switch or volume control, is best carried out by working outwards from the centre letter or space. Typesetting is an art and a few experiments with the chosen style can help in getting things right on the finished work. The guide-bar under each letter on some lettering sheets is also a guide to spacing. Each bar should be positioned such that a continuous straight line is produced, and then the lettering will be at the correct spacing for that style. Rubbing on characters is a slow process, but this serves to ensure that only essentials are given, which in turn produces a good workmanlike labelled panel, not an instruction book! For interest, using the smallest letters available, it is worthwhile to date the work, say, in the bottom right-hand corner - this way you can see how your workmanship has improved over the years!

Unfortunately, transfers are easily rubbed off and require some form of protective covering. The quickest way is to spray the completed panel with clear lacquer but some lacquers react with the surface of application and this should be checked beforehand. Another effective way is to face-up the work using a thin sheet of transparent Perspex®, which can be secured to the panel using screws and/or the existing component fixings. Self-adhesive clear sheets can also be used but this has the problem that they must be applied right first time, for any attempt to peel off and start again will remove all of the lettering. This technique can be used to remove unwanted or misplaced letters at the time of lettering and is superior to scraping. A quick dab with the sticky side of masking tape on the unwanted letter usually does the trick.

If clear plastic sheet is used to face the panel, other possibilities occur, which can eliminate painting the latter. Paper of the coloured art sort can be cut to size with all holes cut to match the panel, and the lettering etc applied to this. The lettered paper or card can be secured to the panel by the Perspex® sheet. It should not be glued to the panel, for this will cause the paper or card to buckle and not sit flat. If a computer with a desktop publishing (DTP) package and printer is available, this can be used to produce paper/card panels very easily. Coloured card (which will pass through the printer) has been found very effective with this system. When properly applied, this paper or card system of panel marking and covering is very effective. A very pleasing effect can be produced by placing the coloured or metal finish narrow, self-adhesive tape, as previously mentioned, along the edges of the card/paper. Do not try to stick the card to the panel in this manner, as the differential expansion and contraction will cause the card to buckle even under the Perspex®.

Etch engraving is also very effective and the same techniques used in the production of printed circuits are applied. It is a system worthwhile experimenting with in those lulls between projects.

Self-adhesive strip labels made on hand-operated lettering machines are a useful way of marking controls but do not add much to the appearance of the equipment. However, this type of strip is very useful in making Braille labels for equipment used by a blind operator. Matrix board (0.1in pitch) can be used as a guide for the Braille characters, for it is about the correct spacing for the Braille dots. These are formed through the guide and from the peel-off backing side of the tape, using a suitably thinned centre-punch, with the tape resting on a strip of rubber or soft plastic.

Home-made dials for dip oscillators and field strength meters etc can be made by attaching card on to a metal or plastic supporting disc and then calibrating and lettering as required. A final spray with clear lacquer and a lasting job is produced. Using these lettering techniques, it is also possible to recalibrate meter dials and so utilise functional meters which others would have thrown away.

Other Finishes

Plating, anodising and colouring etc which have to be carried out by an appropriate firm are well worthwhile but a few words of advice may be helpful. Most finishing firms do not pre-polish or dress the work prior to finishing. With plating, the article is usually plated 'as received', scratch marks and all. The techniques described in the sections on materials and tools should be applied therefore as required to obtain a smooth and scratch-free surface before any item is sent for plating. Aluminium is usually anodised and coloured and does not require a highly polished surface, only a scratch-free one. The contractor may, on request, carry out some form of etch treatment prior to anodising. It is possible for lettering and other characters to be colour dyed on to aluminium during anodising and a master 'see-through' layout of this, to size, should be supplied to the finisher if this is required. These finishes are expensive but do provide corrosion protection as well as enhancing appearance.

If none of the aforementioned methods of finishing appeal, an old-fashioned method can be used to produce whirl patterns on the surface of the work. This is done by sticking a disc of emery cloth on the end of a piece of 12mm diameter dowel rod mounted in the electric drill. The patterns can be generated, either randomly or sequentially to suit, by bringing the emery/dowel straight down on to the work, holding it there briefly, and repeating as required. The same problem of metal pick-up with aluminium can occur. This process, derived from the days of hand scraping, is a quick way of visually achieving what was then considered a quality finish. Nowadays, it is considered wasteful and uneconomical! Yet another alternative is to 'grain' the work, using either fine emery cloth or an abrasive eraser, retaining and enlivening this surface by a spray of clear lacquer.

The polishing of cut edges or the removal of scratch marks on Perspex® and most plastics can be done by sequentially filing, emerying (using first the medium grade and working down to the Crocus paper grade) and finishing off with a mixture of metal polish and powder cleaner, the proportions of which are reduced until the final polish is achieved with metal polish alone. Commercial compounds are available to do the same job. A hard felt pad mounted on the end of a drill can also be used with the normal buffing compounds to polish and remove the sharp edges. However, care should be taken with this method of polishing to avoid overheating which produces an 'ocean wave' effect on the surface being polished!

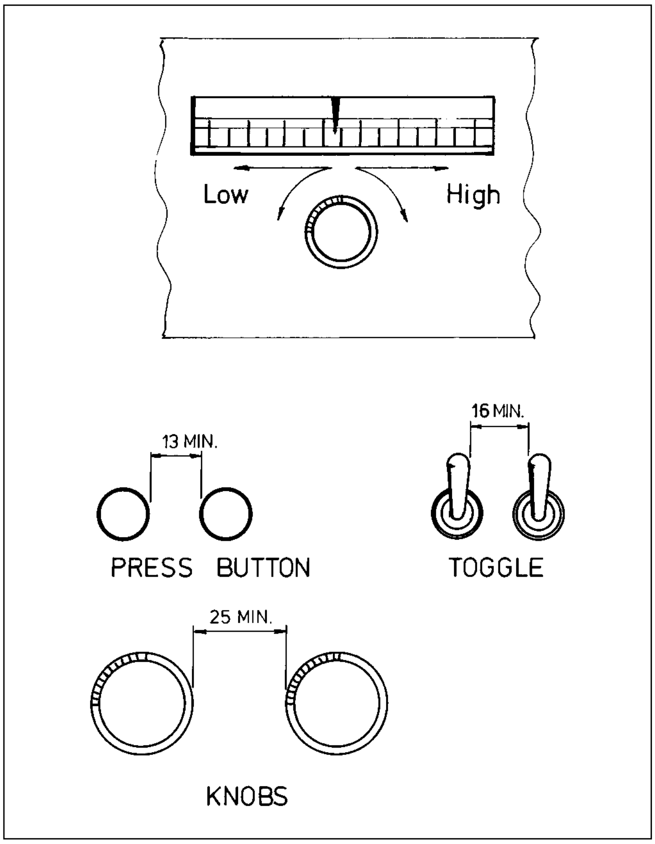


Fig 26.51: Suggested ergonomic strategy for some controls

DESIGN THOUGHTS

Home construction allows individual ideas to be designed into the project being made. With commercial equipment 'you pays your money' but you don't always get exactly what you would like. Some controls you find unnecessary and others which you want are not there or are hidden inside the case. These factors are often overlooked until you make something for yourself and then aspects of commercial designs take on a different meaning. The quality or lack of it becomes apparent and it is very difficult to acquire this appraisal ability without having made, or having tried to make, something for yourself.

Over the years there has become an awareness of the value of ergonomics (see **Fig 17.51**). Most of us now know that controls should be positioned according to their purpose and that this purpose should be self-evident from either the type of control or the area in which it is placed. For example, most transceiver tuning knobs appear adjacent to the tuning display and, when rotated clockwise, the frequency increases. Usually, it is evident by looking at most transceivers which is the tuning knob. Unfortunately the same cannot be said about press buttons and other controls. The use of press buttons needs great care, especially where accidental operation could cause damage. If correctly designed, it should be impossible to accidentally press two or more buttons at the same time.

Also, if such an action is done accidentally or deliberately, it should not destroy the device, or send it into an unusual operating or locked-up state. Ideally, any button-type control should be accompanied by an indicator which shows what mode the button is in. Power supply switches are particularly important in this respect, especially with portable equipment, where it is all too easy to switch it on and not be aware of this fact.

Safety recommendations for the amateur radio workshop

1. All equipment should be controlled by one master switch, the position of which should be well known to others in the house or club.

2. All equipment should be properly connected to a good and permanent earth (but see the box about PME in the chapter on Practical HF Antennas, and Note A).

3. Wiring should be adequately insulated, especially where voltages greater than 500V are used. Terminals should be suitably protected.

4. Transformers operating at more than 100V RMS should be fitted with an earthed screen between the primary and secondary windings or have them in separate slots in the bobbin.

5. Capacitors of more than 0.01μF capacitance operating in power packs etc (other than for RF bypass or coupling) should have a bleeder resistor connected directly across their terminals. The value of the bleeder resistor should be low enough to ensure rapid discharge. A value of 1/C megohms (where C is in microfarads) is recommended. The use of earthed probe leads for discharging capacitors in case the bleeder resistor is defective is also recommended. (Note B). Low-leakage capacitors, such as paper and oil-filled types, should be stored with their terminals short-circuited to prevent static charging.

6. Indicator lamps should be installed showing that the equipment is live. These should be clearly visible at the operating and test position. Faulty indicator lamps should be replaced immediately. Gas-filled (neon) lamps and LEDs are more reliable than filament types.

7. Double-pole switches should be used for breaking mains circuits on equipment. Fuses of correct rating should be connected to the equipment side of each switch in the live lead only. (Note C.) Always switch off before changing a fuse.

8. In metal-enclosed equipment install primary circuit breakers, such as micro-switches, which operate when the door or lid is opened. Check their operation frequently.

9. Test prods and test lamps should be of the insulated pattern.

10. A rubber mat should be used when the equipment is installed on a floor that is likely to become damp.

11. Switch off before making any adjustments. If adjustments must be made while the equipment is live, use one hand only and keep the other in your pocket. Never attempt two-handed work without switching off first. Use good-quality insulated tools for adjustments.

12. Do not wear headphones while making internal adjustments on live equipment.

13. Ensure that the metal cases of microphones, Morse keys etc are properly connected to the chassis.

14. Do not use meters with metal zero-adjusting screws in high-voltage circuits. Beware of live shafts projecting through panels, particularly when metal grub screws are used in control knobs.

15. Certain chemicals occur in electronic devices which are harmful. Notable amongst these are the polychlorinated biphenyls (PCBs) which have been used in the past to fill transformers and high-voltage capacitors and beryllium oxide (BeO) which is used as an insulator inside the case of some high-power semiconductors. In the case of PCBs, the names to look out for on capacitors are: ARACLOR, PYROCHLOR, PYRANOL, ASBESTOL, NO-FLAMOL, SAF-T-KUL and others [3]. If one of these is present in a device, it must be disposed of carefully. The local Health and Safety Authority will advise. In the case of beryllium oxide, the simple rule is DON'T OPEN ANY DEVICE THAT MAY CONTAIN IT.

Note A. - Owing to the common use of plastic water main and sections of plastic pipe in effecting repairs, it is no longer safe to assume that a mains water pipe is effectively connected to earth. Steps must be taken, therefore, to ensure that the earth connection is of sufficiently low resistance to provide safety in the event of a fault. Checks should be made whenever repairs are made to the mains water system in the building.

Note B. - A 'wandering earth lead' or an 'insulated earthed probe lead' is an insulated lead permanently connected via a high-power 1kΩ resistor or a 15W 250V lamp at one end to the chassis of the equipment; at the other end a suitable length of bare wire with an insulated handle is provided for touch contacting the high-potential terminals to be discharged.

Note C. - Where necessary, surge-proof fuses can be used.

Rotary switches are less susceptible to accidental switching but they must be positioned and have suitable style knobs to facilitate switching. Most rotary switches occupy more space than push buttons and it is this which usually restricts their use on the compact rigs of today. Rotary switches are ideal for such controls as mode and band selection. One look at the switch position shows immediately what mode or band is selected. It is impossible to attempt to select two modes or two bands and there is no need for any other form of indicator: a power-saving factor also.

Toggle and slide switches are an equally effective form of self-indicating switches but toggle switches are prone to accidental operation.

Potentiometric rotary controls, such as AF volume, Morse speed and RF gain etc should all be self-indicating. Also, clockwise rotation should increase the function. Rotary concentric controls should give each control a related and easily identified function.

Knob styles can also affect the quality of presentation of the finished work. Unfortunately, knobs are expensive but ex-equipment knobs can often be used as a cheaper alternative. The size of knob should relate to the accuracy required from the function it controls. For example, a tuning knob would not feel right if it was less than say 40mm diameter, but the same diameter for a volume control would be unsuitable and usually unnecessary. Slider controls are very good, especially when simultaneous operation is required on such as faders and mixers, but this facility is not usually required on radio equipment. These controls also take up space if they are to be accessed easily. Some commercial amateur radio equipment use the smaller type of this control for the less-utilised or preset controls.

Many more factors can be found, and it is discovering these which adds to the pleasure of home construction.

REFERENCES

[1] http://www.wessexelectronics.co.uk/