Currents, wires and connectors

I'd like to thank my friend Keith Eldred for his help with this article. He has had a long career in electronic design and maintenance, including aviation, and he put me right over several things. The sections on soldering techniques and crimping are largely his.

DC and low frequency AC only

In a future article I will cover the way that wires react to high frequency alternating currents. This article will be about wires that handle direct (one-way) currents and low frequency alternating currents, say 50 or 60 hertz up to a few hundred. Names for types of wire are used loosely so let's sharpen up. A made up wire with connectors is called a lead in the UK and a cord in the US. The raw wire on a reel without connectors is called cable or just wire. Normally it really doesn't matter, but I'll use lead and wire in this article. I will also cover our connectors and soft soldering tools and techniques. Why is it called soft soldering? Because lead is soft and relatively weak. For stronger non-wire joints you need silver soldering or brazing.

Wire dimensions

There are six data you need to know about a wire:

- Material that the conducting part is made from, normally for us copper. This metal part is called the core.
- Number of individual wire strands that make up the core.
- Material that the insulation or sheath is made from.
- Overall size of the core given as a diameter or as a cross-sectional area of the whole core. It can also be specified as the number of, and area of, the individual strands. There are three ways to specify the thickness or gauge.
- Material used for the sheath.
- Current it can safely carry. This one is very uncertain as you will see.

Core material

Copper is usually used as it is a very good conductor. It is also fairly plentiful though increasingly expensive, and is mined mostly in Chile, the Congo and the US. Aluminium is sometimes used but there are problems making connections to as it oxidises easily which makes an insulating layer and it gradually deforms under pressure. It is a poorer conductor so the cores have to be larger. Silver and gold are also used, mostly by high fidelity audio buffs with more money than sense.

Strands

The wires we use always have many strands. As the individual strands are thinner this makes them more flexible and less likely to break. It does mean more care is needed when making the connections, especially when soldering. Here are some examples of wire specifications:

For hook up wire	14/0.2 mm meaning fourteen 0.2 mm strands
For very flexible wire	55/0.1 used as probe leads for meters
Heavy duty wire	1050/0.16 for thick '4 gauge' wire in car audio

Wire gauges (sizes)

There are three in common use: american wire gauge (awg) in the USA, standard wire gauge (swg) in the UK, and metric used everywhere. Awg and swg sizes are given a number, eg 16 awg. Strangely, the larger the number the smaller the wire.

Metric sizes are given as a cross-section area in mm^2. You can calculate actual resistances from them and hence safe currents and voltage drops, so metric sizes are much more useful and this time larger numbers mean larger wires. However most of our wires are still given in gauges, usually awg.

There are lots of tables on the web so I will just add a few sizes typical to us and add an address at the end of the article. The awg sizes are correct and can have several different sizes and numbers of strands. The swg and metric sizes are not exact equivalents but are close.

Awg	Dia mm	Area mm^2	Swg	Metric mm^2	Used for	Current A	Resistance/m for awg
10	2.59	5.26	12	6	Power	15	0.003
12	2.05	3.31	14	3 or 4	Power	9.3	0.005
14	1.63	2.08	16	2	Power	5.9	0.008
16	1.29	1.31	18	1.5	Power	3.7	0.013
22	0.65	0.33	23		Servo lead	0.92	0.053
24	0.51	0.20	25		Servo lead	0.58	0.084
26	0.40	0.13	27		Servo lead	0.36	0.134

When you look at the current carrying capacity, sometimes called ampacity, you will see that we modellers routinely and seriously overload our wires, but it doesn't seem to matter as they are usually in ventilated free air in the fuselage. The specified currents are for when the wires are restricted, for example bundled in a conduit. Most ESC leads are 12 or 14 gauge and we run many tens of amps, or even a hundred, through them. I always now only use 22 awg servo leads but of course retracts or powerful servos can go up to five amps.

Resistance

If you push a current through a wire it will absorb some of the energy (voltage) and heat up. Sometimes this is desirable as in fuses, but normally it is a waste. You can calculate these voltage losses by finding out the resistance of the wire. Typical values for ohms per metre for the awg sizes are in the above table. Say you were pushing 50 A through a total length of 0.25 m of 14 awg wire. What would be the voltage drop?

$V = I R \qquad = 50 \times 0.25 \times 0.008 \qquad = 0.1\ V$

Nothing to worry about then.

Sheath material

As always there are many materials used, including those for hazardous environments. I will just deal with those relevant to us, where the main hazard is over-heating, though abrasion can cause wear if the wires are free to vibrate.

Polyvinyl chloride (PVC)

This is generally the most common as it is cheap and easy to form. It is water and oil resistant though it can be damaged by high temperature. It can be recycled.

Silicone
This is much more expensive and cannot be recycled. It is less resistant to abrasion than PVC. However it isn't affected by high and low temperatures so is the preferred material for us. We only use short pieces so the cost isn't important.

You can tell what the sheath is made from by touching it with a hot soldering iron. If it quickly melts or burns it is PVC.

Polytetrafluoroethylene (PTFE or Teflon)
This shrugs off attack by heat and chemicals but isn't very flexible so probably isn't useful for us. Or do gas turbine modellers use it near their jets? Must ask.

Radio control electric power connectors

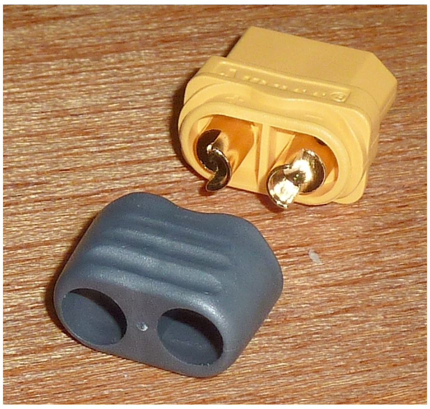
Wherever you look in electronics you see a bewildering number of different connectors. Some manufacturers even invent their own that no-one else uses. Apple is bad for that as is my Waterpik tooth cleaner. The latter has the most weird mains lead connector. I dislike that 'Daddy knows best' attitude. Why can't everyone just use the larger (kettle) three pin or small (figure of eight) two pin mains connectors and the micro USB for low voltage charging leads? OK, there are now two micro USBs but that's better than a zillion.

I must clear up one thing. A connector with one or more metal pins is the male part. A connector with one or more hollow sockets is the female part. Please don't get wokey on me for that nor for the fact that joining them is called mating. It is what it is. Some suppliers use the shape of the plastic body for the male/female name, especially for servo leads. Always look at the part, or a picture of it, before buying.

These are what we use in radio control. Yes, only eight! I'll cover soldering later in the article.

HXT2 HXT3.5 HXT4 HXT6 HXT8
In effect bullets in sleeves

XT30 XT60 XT90 XT150
This of course shows the male part.



I now use this variant of the XT60. It has a clip-on shroud. Combined with heatshrink over the joint it makes fatigue failure much less likely. However they are longer.

EC2 EC3 EC5

JST/Molex crimps

Bullet 2 3.5 4 5 6 6.5 8

JST-XH (3 4 5 6 7 pin)

Deans/ T-style (HCT)

MT60

Current ratings

Please note these are a guide and only for modelling applications. How much current the connection will carry depends on the cable size, how much ventilation there is and for how long the current flows.

	Current (A)
HXT2	30
HXT3.5	75
HXT4	90
HXT6	150

HXT8	250	
XT30	30	
XT60	60	
XT90	90	
XT150	150	
EC2	20	
EC3	50	
EC5	80	
JST	5	for indoor and light outdoor models
Bullet 2	30	the Bullet number is the plug diameter in mm
Bullet 3.5	50	
Bullet 4	60	
Bullet 5	80	
Bullet 6	150	
Bullet 6.5	200	
Bullet 8	250	
JST-XH	Low current for balancing, telemetry and indoor flying	
Deans micro	10	
Deans ultra	60	
MT60	50	handy for ESC to motor leads

My preferences

I wish I could like Deans. They are small and light, but easy to damage when soldering and more difficult to make fatigue-proof even with heat shrink. I like EC connectors. You solder the connectors to the wire then push them into the housing when still warm. They lock into place. However I mostly use XT60 or XT90 as they are the usual lipo battery fitting. In the shrouded version they are very resistant to fatigue, especially when sleeved with heat shrink.

Soldering

Always use resin core 60:40 tin/lead solder, not the lead-free type used for plumbing. The resin acts as a flux, improving adhesion and keeping out the oxygen. Lead solder is best for electric joints and circuit boards. There were experiments done with low- or non-lead solders a while back but they didn’t work well in electronics due to whiskering and other factors. Good sizes for electronics are 1.2 mm diameter for larger joints like connectors and 0.7 mm for finer work on circuit boards.

The tools you need

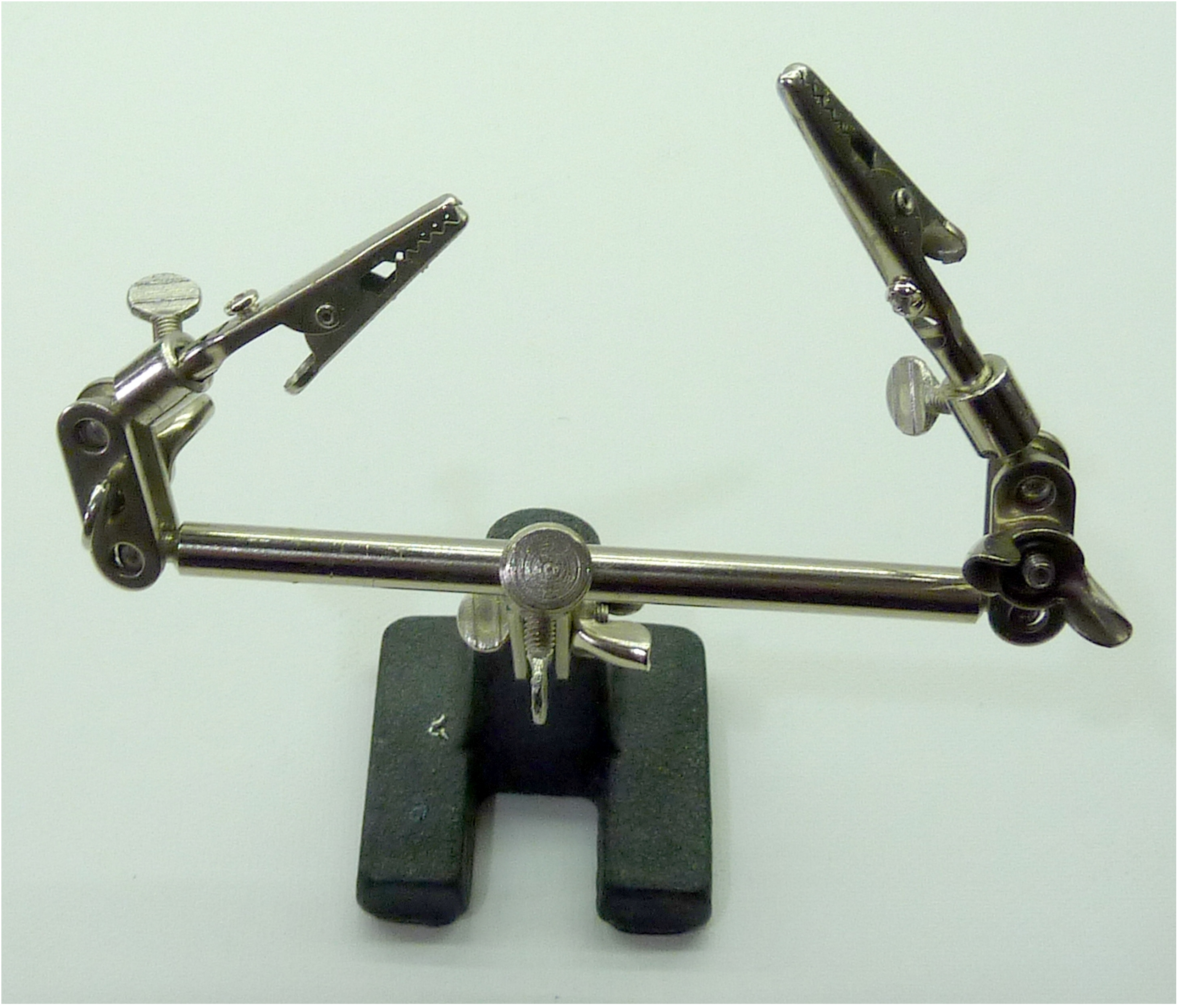
First you need a soldering iron. For small joints a temperature-controlled solder station is best. For larger joints get a 100 or 150 W solder gun. For really thick wires the very best is a gas soldering iron. I had a lot of trouble soldering 12 and 10 awg wires into connectors even with a 175 W gun until a fellow flyer suggested a gas iron. None of these cost a lot. Probably no more than £20 ($25) for each, yes, even the station. The supermarket Lidl, which is now almost worldwide, often has such equipment. You can of course also use the gas iron at the field.

Cheap solder station from Lidl
Photo Peter Scott

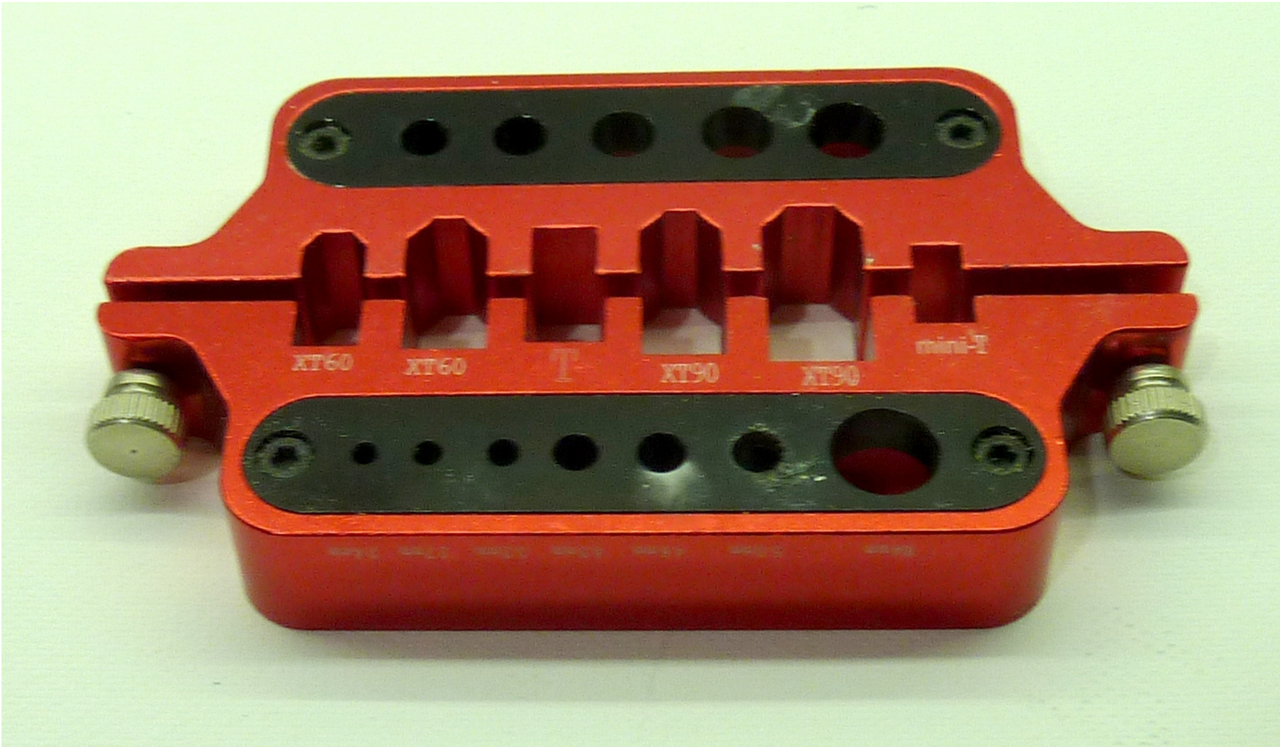
175 W solder gun
Photo Peter Scott

Gas soldering iron (no, not gasoline!)
Photo Peter Scott

Secondly you need a support for the things you are soldering. Helping hands with crocodile clips are useful, as are the jigs that take standard size connectors.

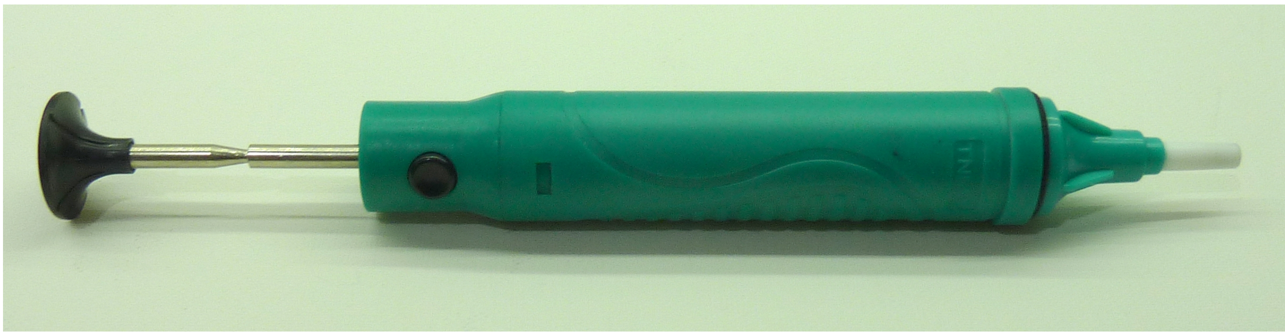


Helping hands
Photo Peter Scott



Soldering jig
Photo Peter Scott

If remaking joints a spring loaded solder sucker is useful to clean up first. Or you can touch copper braid onto the melted solder and it will be removed by capillary action.



Solder sucker
Photo Peter Scott

Soldering techniques

Bullets can just be held in croc clips on a helping hands stand. Plastic bodied connectors like XT60 are best put in a jig ideally with the mating part fitted as a heat sink.

When you start using a new soldering iron the bit is likely to have a coating of another metal, usually iron. The worst thing you can do is clean it on something abrasive. That will immediately destroy the coating and lead to shortened life. There's a flux for every application you can think of. For our purposes use a flux that is a grease-like paste that's in a flat tin. I just dunk my soldering iron in it to clean it and use the damp sponge to wipe the stale solder off and reapply fresh solder and flux. And do it frequently. Also the parts being soldered benefit from being smeared with flux or have a liquid flux dripped on. It can be applied with something like a cocktail stick. Be sure not to use an acid base flux like the plumbers used to. Tin the iron tip by waiting until it is hot then wiping some solder on.

Liquid and paste flux
Photo Peter Scott

Never carry a blob of solder on the iron to a joint as it is almost certain to form a poor joint. As the tips get old, especially the cheaper ones I use, they will need cleaning up with a fine file or emery paper. I am too mean to replace them earlier.

Now prepare the wires. Make sure your hands are clean. After removing the insulation from the end, twist the strands to firm them up. Then clip the wire into the helping hands, heat the strands with the iron and push on some solder all round so they look solid. This is also called tinning. The name helping hands is a good one. Without its clamps most soldering jobs require you to be an alien with three hands.

Now the connector. Don’t touch the metal parts where the solder goes. There will be a hollow, sometimes called a bucket, into which the wire end goes. Heat it and push solder in until half full or so. Immediately heat it again and insert the tinned wire end. Wait till the two lots of solder merge and form a shiny surface. Hold steady while it hardens. If it goes wrong, reheat and try again. The silicone sheath should take a bit of abuse. However if the plastic part starts to distort throw it away and use a new connector.

Some people prefer to push the untinned stranded ends into an unfilled bucket then to solder both together. I think this heats the joint up for longer but you might find it preferable.

Never try to solder anything that is not shiny clean. Beware so-called solder tags plated with some coating that is years old and so oxidised that it is impossible to solder. Usually you can tell just by looking whether the soldering is successful. You can see if it is bright and has ‘wetted’ the parts fully.

Soldering is a skill that needs practice. To start with you might get bad dry or ‘cold’ joints that have a cloudy dull surface or you’ll melt a few connectors. Speed, flux and cleanliness are the keys and you will soon acquire the skills.

Desoldering for repairs

A solder sucker, or desoldering braid, performs badly without flux so use generous quantities of the stuff. The aim should always be to get in and out as fast as you can. Flux will enable you to do this without running the risk of overheating. The most important aim with desoldering is to not do more damage. Struggling for a long time with a hot iron to clear the work site of unwanted solder will often result in just that. But flux it well and the problem goes away, leaving you with a reusable device which might otherwise have been destroyed. Initially I [Keith] was taught always to make a wire joint mechanically strong before applying the solder. Then it was realised that so much damage occurred trying to separate it for servicing/repair that that practice was banned. From then on a joint had to come apart as soon as the solder melted. Result was a huge reduction in scrapped parts during workshop time. The saying, “The equipment is good despite the servicing,” lost its meaning.

Heat shrink

Always strengthen your connector joints with heat shrink sleeving. You need several different sizes so it is probably best initially to buy a box with lots of sizes until you know what ones you use most. Wait until the joint is cool. At this point you discover that you should have slipped the sleeve on the wire before you soldered the wire on. You will only make this mistake once, perhaps. The sleeve needs to slip on to the connector easily so will usually be much larger than the wire. It will shrink to half or even a third of its size depending on make. You can heat it with the iron or a cigarette lighter but the best tool is a heat gun. Again there is no need to pay more than £20.

Heat gun
Photo Peter Scott

Heat shrink is useful when joining two wires together for example to extend a lead or make up a special one from two different leads. Slide the sleeve onto one of the wires if there are connectors at the other ends. Remove about 10 mm of insulation from each wire then push the strands together to merge them. Twist to firm them up then it is easy to fill them with solder. Finally heat shrink the joint. Oh no! I forgot the heat shrink.

Crimping

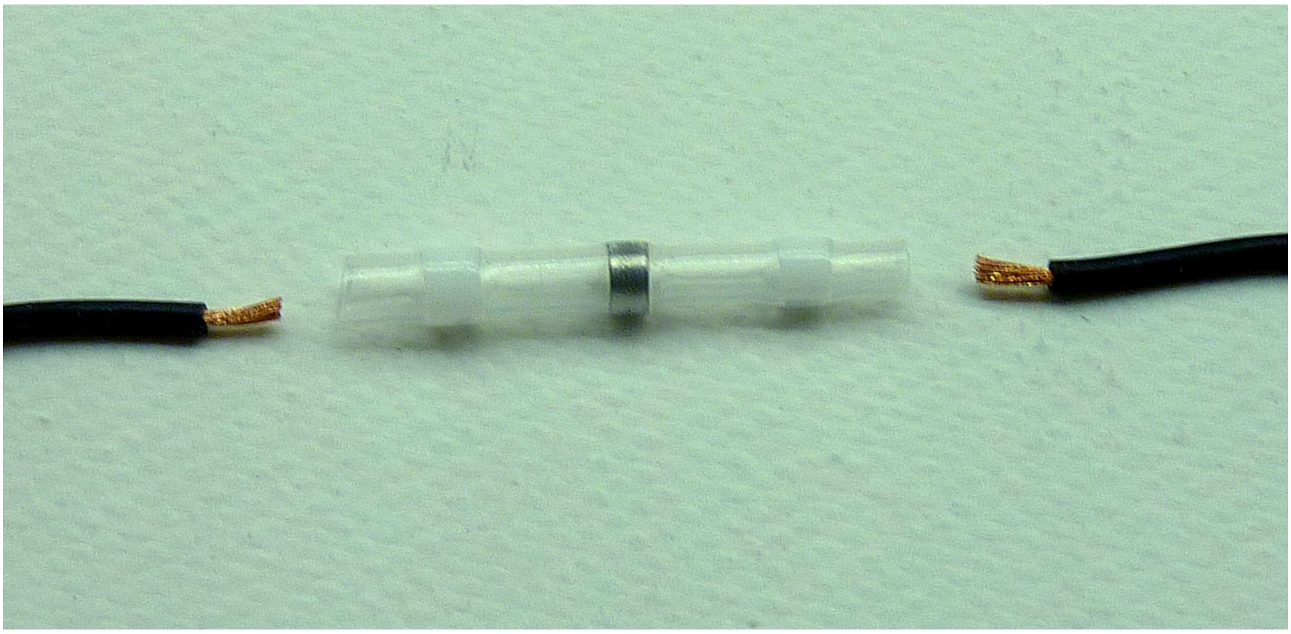
This doesn’t apply to our power connectors but could apply to others such as servo leads. To me crimping is counter-intuitive. I used to think that solder was always best but Keith put me right. It is of course vital to use the correct crimping tool, so buy the best.

In applications in high vibration situations, the moment you tin a high flexibility cable it becomes the least reliable link in the chain and a crimped joint becomes the method of choice. The auto industry didn’t choose it just because it is quicker to do, cheaper and stronger. It is far more capable of withstanding the vibrations found in cars, etc. The act of tinning a multi-stranded cable turns it into a single strand and if flexed at the point where the solder has wicked to, it becomes highly susceptible to fracture. In fact, you will find a requirement to crimp written into most military specs.

Heat shrink soldering

One exception to the solder ban is where you join two wires. The heat shrink sleeve will resist the bending stress and bending will be at the ends of the sleeve. You can now buy heat shrink joiners with solder built in. These were new to me until Keith Eldred told me about them. The idea is a piece of heat shrink sleeving with a ring of low melting point solder in the middle. You trim the two wires to be joined and push them in so the bare bits are meshed together inside the solder ring. The ones I bought shrink to one third the diameter.

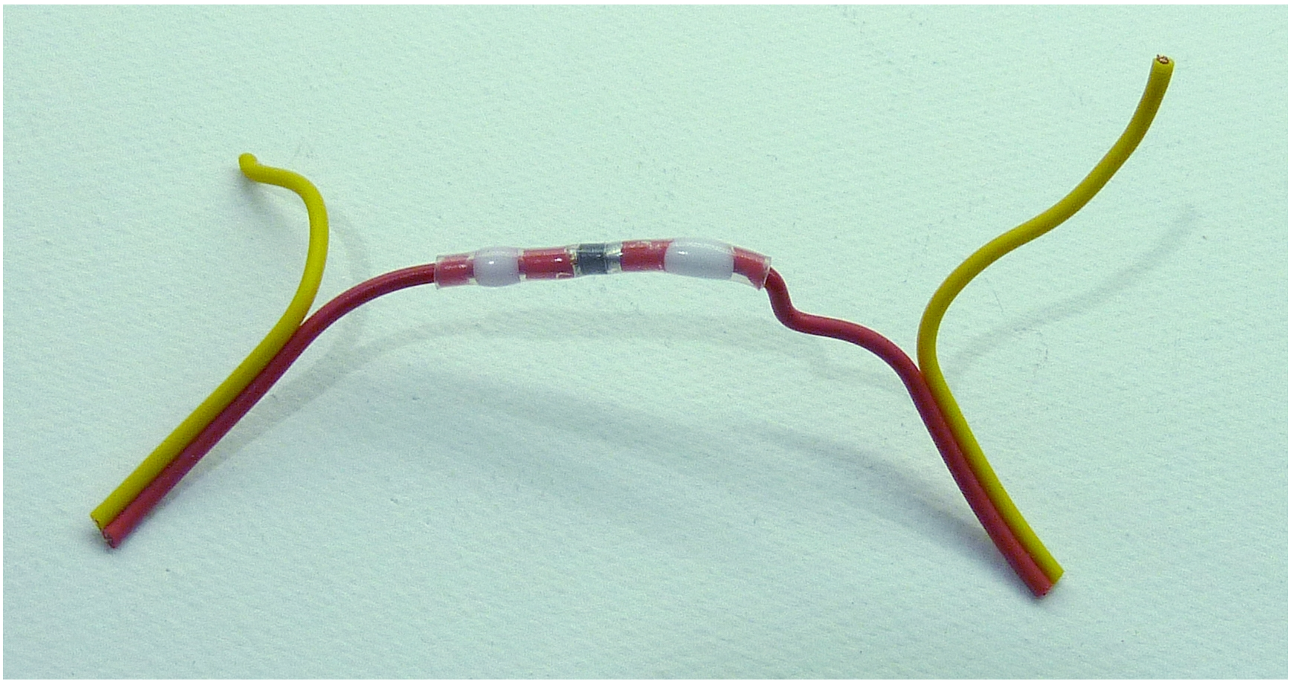
These are bared a bit too long.



Here the 22 awg servo wires pushed in.

I messed up the black wires due to too low a temperature. The data said minimum of 135ºC. I tried 150 but it was much too low. In the end I did the red join at 270. The coloured part spreads as the shrinking happens.

Here you can see that the solder has wicked into the wires on each side.



This is the kit I bought. Sizes are colour coded from 26 – 10 awg (0.25 – 2.5 mm^2) with one size covering two sizes of wire. This set will cover just about every size we are likely to need. It cost £7 on eBay. No point in adding dollars at present and I don't see the point of the black heat shrink either.

https://www.electricaltechnology.org/2022/04/american-wire-gauge-awg-chart-wire-size-ampacity-table.html

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