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Cable Assemblies:

Determining a Reliable & Cost Effective Approach

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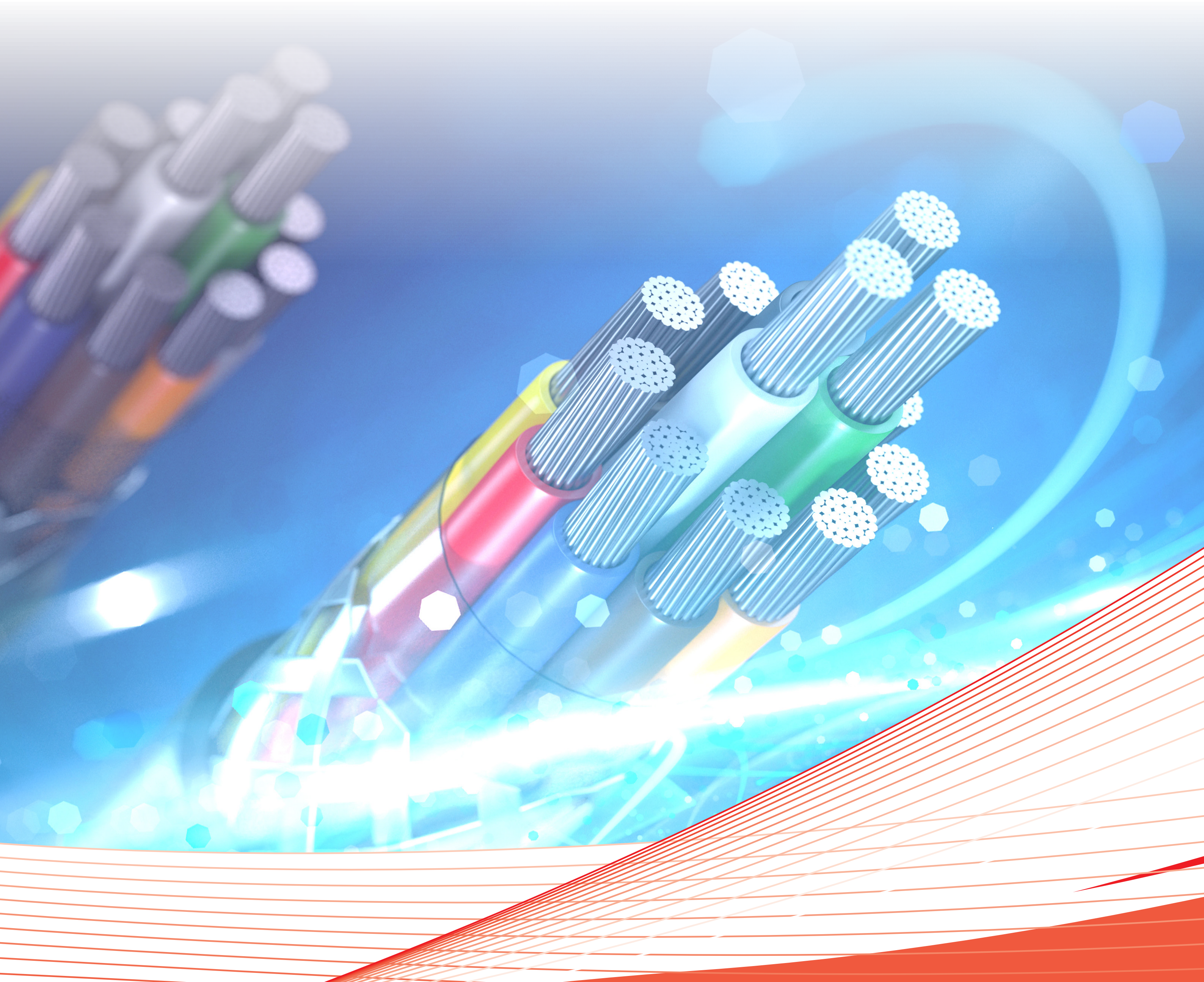

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Defining Your Assembly

Creating a robust cable assembly....

Cable assemblies fulfil an important role in today's high-density electronic systems, facilitating connectivity between different parts of the system. Sometimes thought of as being 'just a couple of connectors and some cable', these are in fact an essential element of modern engineering design and should not be underestimated, but instead given the consideration that they deserve.

In this technical white paper, we will outline the process of creating cable assemblies for application sectors requiring the highest levels of reliability, such as aerospace and motorsport. Details will be given of the considerations that need to be factored in when creating a robust cable assembly to support a long operational lifespan, with areas being highlighted that can have an influence on reliability.

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Introductory aspects

A cable assembly is a form of electronic sub-system and can have bearing on the overall performance of the system into which it is incorporated, depending upon the design followed. Therefore, it is important to spend time, at the earliest possible stage, to think through the arrangement of the cable assembly and how it may affect the system.

Cable assemblies can have a variety of names; wiring assembly, cable loom or wiring loom, cable harness or wiring harness. These interconnection systems all involve connectors designed for cable attachment, connected by one or more wires. Cable bundles can be bound together for cable management, protection and ease of installation.

Selection and design

In some cases, the connectors are defined by what is already on the PCBs, and the cable assembly needs to provide a connection between boards (or to a test fixture). In other cases, if the PCB designs are not finalised, there may be an opportunity to change connectors to a type that not only suits the PCB/system, but is also simple and effective in relation to the cable assembly. This could include selecting a connector type that you have prior experience of using, and considering readily available tooling.

Tooling is one of the most expensive parts of building high quality and reliable cable assemblies and can have a significant impact on the cost of a project. This is especially true for low volume cable assemblies, such as prototypes and test rig cables. With higher volume projects, the investment in tooling can be amortised and, consequently, have a relatively small impact on the cost of each cable assembly produced.

Harwin has already produced a separate article covering the subject of connector selection. This is available at **https://www.harwin.com/get-connected-whitepaper/** to download. Key elements that can potentially impact upon the ease of use of any cable assembly include polarisation features, jackscrews or latching, and backshells or hoods. These should all be considered at this early stage.

While the connectors are often pre-defined, selecting an appropriate cable is not as simple – there are many more options and more criteria to consider. The main elements that will drive this decision are the type of signals (or power) to be carried, the application/environment and the cable routing.

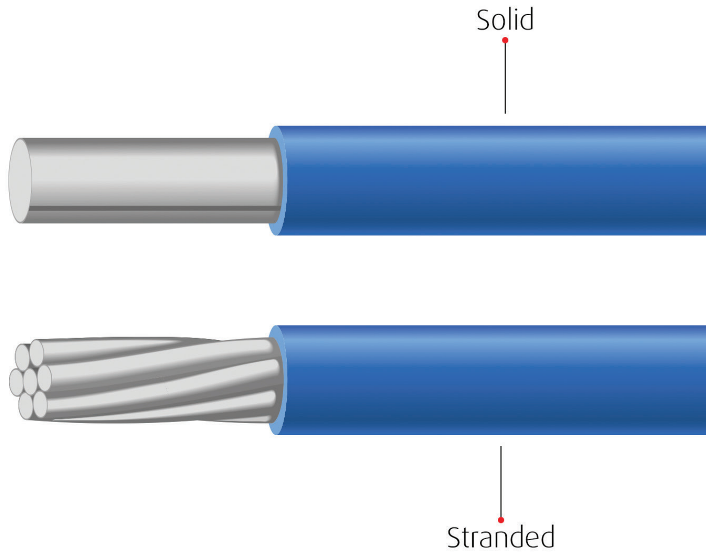
Certain specialist applications (such as RF, data communications or products like thermocouples) have standards that define the cable. This, in many ways, means that the decision-making process is easier. However, for more general applications, the following sections highlight some of the criteria to be contemplated.

- **Cable Type**

  The cable type is often defined by the application as well as the connector style. This could be co-axial for RF applications, ribbon cable for insulation-displacement contact (IDC) connectors, shielded for sensitive applications, or just simple equipment wires for general purpose applications. If some or all of the cable is to transmit power, these conductors must be sized appropriately, not only to ensure that they can handle the current but also to ensure that the voltage drop along the cable length is acceptable in all operating conditions. The conductor count is often intuitive, but techniques such as using multiple cores to transmit power may have an impact.

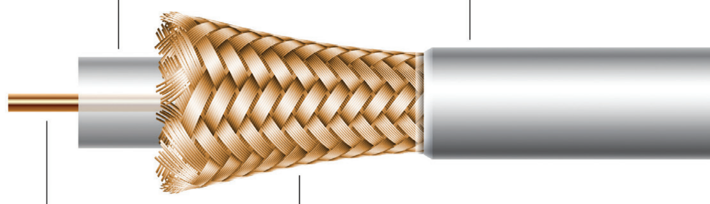
  - **Solid Core or Stranded**

    If the application is outdoor or involves exposure to harsh environmental conditions, or if cost is likely to be a significant factor, then solid core can be a good option, as it is resistant to damage and generally easier to implement (hence, making it cheaper). However, these cables can also be harder to crimp, and are more inflexible and resistant to reshaping than an equivalent stranded version. In the smaller applications of electronics (as opposed to electrical deployment), multi-strand is preferred.



- **Shielding**

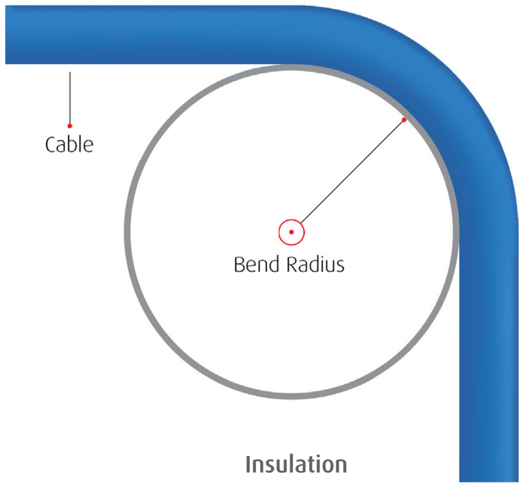
Cable assembly shielding needs to be considered in a two-way environment. In some applications, the shielding may be required to protect high-impedance signals in the cable from interference as they pass noisy areas of the system. Conversely, if the cable assembly is carrying high-speed digital signals, then shielding can protect sensitive areas of the system that the cable passes through. Taking this one step further, the shield may cover all conductors as a group or as pairs or individually. This can be important if the cable is to carry both analog and digital signals, as it will shield one core from another – thereby preventing crosstalk.



Shielding

- **Insulation**

The routing of the cable assembly is a key criterion for selecting insulation. Is the outer sheath of the cable likely to be exposed to extreme temperatures, chemicals or physical damage, such as abrasion? Any damage or degradation that exposes conductors can impair function and create a serious safety hazard. The insulation on individual cores also needs to be considered, especially with regard to the dielectric strength that prevents any electrical breakdown. Insulation is also a key factor in determining the minimum bend radius for the cable, which is an important parameter for routing, especially in restricted locations.

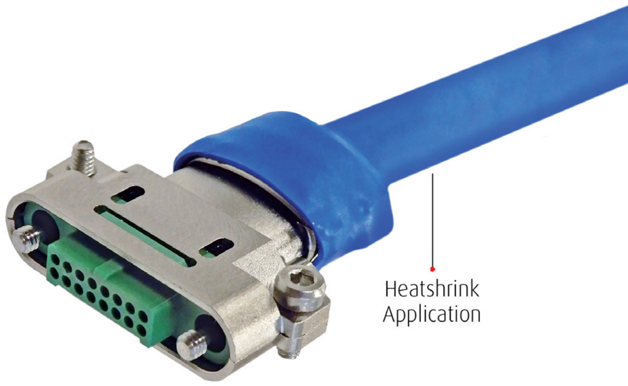


Insulation

- **Strain Relief**

The application and environment will also have an effect on some of the finishing operations that could form part of the design. For example, some shell-type connectors include an inset that can be filled with an epoxy resin after assembly. This process, known as 'backpotting' provides a degree of strain relief on the cable assembly and also mitigates against the ingress of dust which can be a source of premature failure. **See part 2 of this whitepaper for further information on the backpotting process.**

With other connector types where no backpotting void is present then the simple application of heatshrink can group individual cables and provide strain relief. Heatshrink can also be applied over the outer sheathing of cables to provide increased rigidity and protection against wear mechanisms, such as abrasion.



Strain Relief

Another strain relief method is to add backshells to the connector assembly. While only possible with connector systems that have a provision for this, backshells are available in plastic and metal versions that provide significant mechanical strength as well as somewhere to grip the connector when mating/un-mating. Metal versions are often used with shielded cables offer a means of termination for the braiding/shielding, ensuring that the connector itself is also shielded.

"Any damage or degradation that exposes conductors can impair function and create a serious safety hazard."

- **Routing**

  When considering the cable run, there may be a need for 'forming' the cable so that it avoids sensitive parts of the system, or simply makes use of available space for routing the cable assembly. In systems with movement or vibration, the cable assembly has to be routed close to the chassis so that it can be attached and supported. Cable management products can assist with securing looms to chassis or PCBs, and (depending on vibration), further anti-wear measures could be required at these points. Cable clip design should be considered as part of the complete harness installation.

- **Twisted Pairs**

  This is a method of twisting two or more cables within the cable bundle, most typically in pairs. It has the effect of reducing electromagnetic radiation and crosstalk between neighbouring pairs of lines. The twist will have a specific pitch, usually defined in TPI, or twists per inch.

- **Lacing and Cable Ties**

  Cable ties are the most common and cheapest form of cable management, and taking this approach is perfectly sensible when the space allows, and wear due to vibration is a factor. Cable lacing is an older type of cable management for binding cable bundles. The lacing forms a single cable assembly without any obstructions along the length, unlike plastic or hook & loop cable ties, making it still a valid choice in tight spaces.

- **Identification**

  The final consideration at the design stage is whether any cable marking/identification is required. This can be in context of the overall assembly (so that spares can be ordered) or for individual wires to identify routing of important signals. If the cable assembly is intended to be a service item in the field, assembly marking should be deemed essential to assist service technicians.

Once all these aspects have been considered, the outcome should be a drawing package for the final cable assembly that includes a schematic, a mechanical outline and a complete bill-of-materials (BoM) that lists all of the components (including wire, connectors and accessories). As a result of creating this drawing package, the designer should also have a good idea of the manufacturing processes and tooling/jigs that will be required, whether this is for low-volume prototyping or a full-scale production run.

In the second part of this white paper we will describe the crimping, soldering and finishing activities associated with cable assemblies. We will then discuss whether in-house or outsourced assembly is the most suitable strategy and look at the basis upon which such a major decision should be made.

Part 2

Addressing the Practical Issues of Cable Assembly

crimping or soldering?....

In Part 1 of this white paper, we looked at the initial criteria involved, and how these will have bearing on the cable assembly procedures employed. In Part 2, we will deal with the actual practicalities of carrying out such work, before discussing what underlying dynamics will effect companies' strategies here.

"it is on the manufacturing floor where the reliability battle can be won or lost."

Manufacturing process

Although the design will naturally determine the theoretical reliability of the cable assembly, it is on the manufacturing floor where the reliability battle can be won or lost. While the attachment of connectors may seem simple, there are many aspects that need to be executed well, each and every time, to ensure a reliable end product.

The two principal methods of making connections to an individual terminal are crimping or soldering, each of which is a completely different process. In addition, multi-contact connection is possible with IDC.

Figure 1: Open crimp example

Crimping

With crimping, the wire is stripped and inserted into a metal terminal. The terminal is then squeezed and deformed around the wire strands to ensure a good mechanical and electrical connection. There are two main styles of crimp, and although the crimping process is quite similar, the visual result is very different and the tooling must be correctly matched to the crimp type.

Figure 2: Barrel crimp example

- **Open Crimps**

  There are a number of names of crimps that fall into this category - B, D or F crimp, open-barrel, O crimp or overlap crimp. They are typically recognisable due to the flat material used to make the complete contact, which will be bent into a U-shape where the wire will be attached. The exposed conductor and the end of the insulation is placed into the U-channel, and the tooling will then bend the two arms of the U over or into the wire conductor (depending on the product) and over the insulator (for additional strain relief).

- **Barrel Crimps**

  So-called because the crimp section of the contact resembles a barrel (or tube), here the wire is inserted into the bore inside the crimp, and the tooling will deform a number of indents evenly spaced around the barrel.

Figure 3: Solder contact example

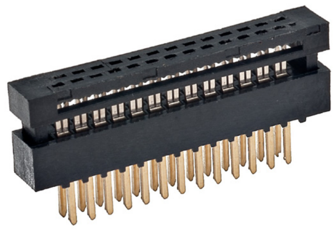
Soldering

With soldering, the wire is again stripped and inserted into the terminal. The joint is then heated, and solder is subsequently introduced to make a good mechanical and electrical connection. No tooling is required, but the process is generally manual.

IDC

These types of contacts are generally pre-assembled into the connector body, and wire is inserted in all contacts in one process. The wire used will normally be ribbon cable (although individual IDC connections do exist). This wire is not stripped – the IDC end of the contact has sharp cutting edges, which pierce through the insulation when the cable is pressed down onto the contact. These edges penetrate to the conductor in the middle, and make a good compression joint for electrical connection. The whole ribbon cable is clamped in place for mechanical strength.

It is very unusual for connectors to be available in more than one connection type, so the cable connection method will have been determined at the design phase when the connector and terminals were chosen.



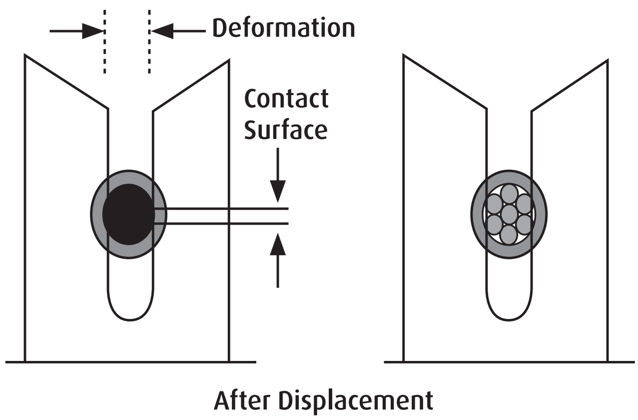


Figure 4: IDC connector, with cross-sectional views

Key process issues

It is easy to cause reliability issues even with the simplest processes involved in cable assemblies.

- **Wire Stripping**

  If the blades of the stripper are not set correctly then the insulation may be torn, or the wire strands could be scratched or cut. If the blades are misaligned, then the insulation may be cut at an angle. These can cause failure modes; the wire may not sit in the terminal correctly, so it may not crimp as expected or be held securely, and weak points on the conductor from scratches or cuts can lead to the wire separating from the connector while in use.

  Different wire types, such as power and signal, can require different stripping tools and will certainly need different tool settings to be applied; meaning that at least one tool per wire type/size will be mandated for efficient production. Simple jigs and hand tools can be used for low volume production/prototyping, but stripping machines are recommended for mid-to-high volume operations. This will also aid repeatability – ensuring that the correct length of insulation and total cable length is stripped consistently each and every time. More complex cables, such as coaxial, are harder to strip by hand, and can only be stripped accurately and with consistent repeatability by automated processes.

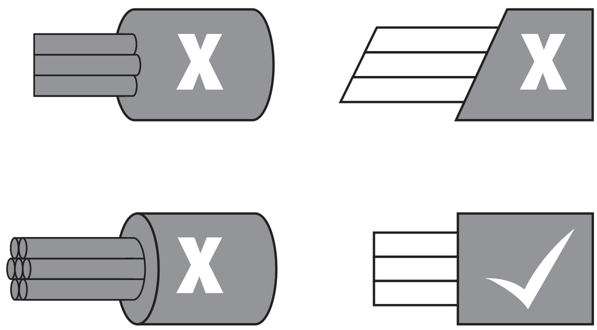


Figure 5: Examples of poor stripping

- **Crimping**

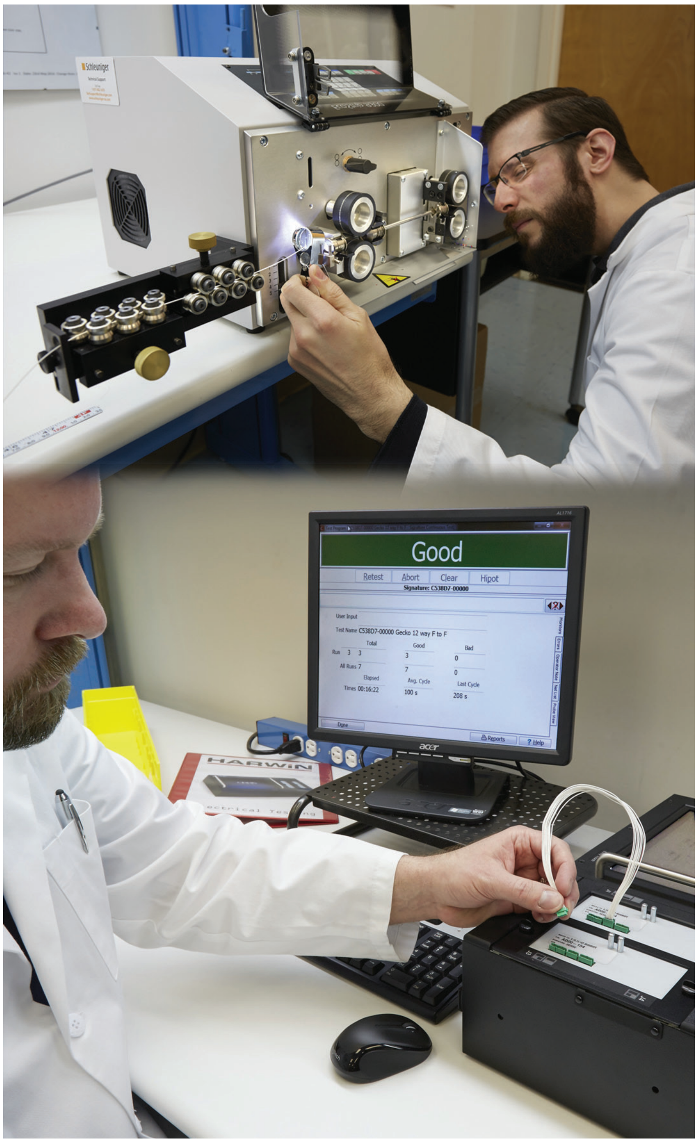
  Similar issues exist at the crimping stage. Tooling will again be specific to each crimp type and wire size, and additional tooling needs to be considered every time a new crimp is introduced. Hand tools are generally available, but for higher volumes automated or semi-automated tooling is recommended. Full automation machinery exists to complete the whole strip and crimp process within one workstation. Better repeatability can be assured with the more automated processes.

- **Consistency and Repeatability**

  Repetition is one of the key factors in ensuring that good quality is maintained, and thus producing reliable cable assemblies. In order to provide consistency, most cable assembly companies have adopted the IPC-A-620 standard. This standard is a collection of visual quality acceptability requirements for cable, wire and harness assemblies and describes acceptability criteria for producing crimped, mechanically secured or soldered interconnections. It also covers associated lacing/restraining criteria for cable and harness assemblies.

  It is important that manufacturing staff are adequately trained so that they are able to meet the requirements of IPC-A-620, and that their training is maintained and continuously updated (in addition to any specific training required in relation to the connectors involved). This, in itself, can be a significant hidden cost to companies, especially those that are just starting out in cable assembly.

  While consideration of these process issues will help uncover quality-related problems, they are also very useful to identify longer-term dynamics, such as tool wear. Over time, tooling (and even jigs) will wear and require either replacement or adjustment to safeguard against any drop in quality levels. The associated downtime or tooling replacement represent further operational expense, which will need to be factored in to the overall cost of the cable assembly.



Finishing stages

Once the cable assembly is assembled and has passed the initial stages in-process inspection and testing, then the finishing processes can begin.Again, the processes involved here will have been defined at the design stage and can include things such as backpotting, overmoulding, lacing and labelling to name just a few.

- **Backpotting**

  This process is a method of sealing the rear of a connector with an epoxy resin or similar compound. It gives the advantages of additional strain relief without too much additional connector weight. The strain relief afforded will resist both removal by direct pulling on wires, but also with side-loading of wires. Strength is therefore improved and this increases the reliability of the whole connector – when processed correctly.

  A step-by-step guide to the backpotting process is attached to the end of this whitepaper.

At this stage, compliance with IPC-A-620 remains crucial, as each of the finishing processes can still have an impact on the reliability of the final assembly. Some processes will require the development and use of fairly elaborate jigs to ensure that the final cable assembly meets the required mechanical specification. Each jig will be unique to a specific cable assembly so this again can represent a significant expense if multiple types of cable assembly are to be produced.

The last step will be the final inspection and test. This will vary significantly, depending upon the type of cable assembly and the technologies involved (e.g. power or RF). However, it will almost certainly involve a visual inspection, plus mechanical testing and some electrical testing. Any failures at this point are likely to result in scrapping, ther by adding significantly to the overall cost through lower yield rates.

The big question – make or buy?

- **The cost of production:**

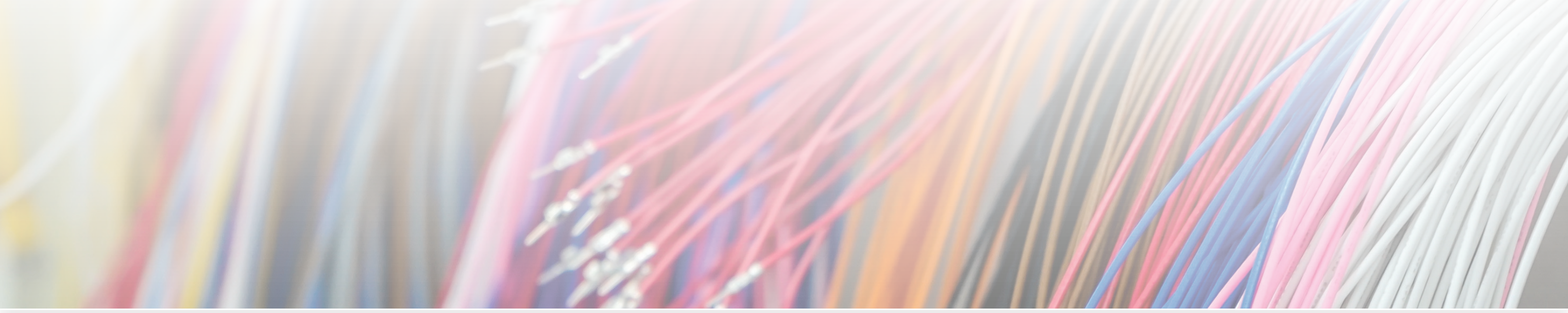
  Many companies still make cable assemblies in-house, especially for prototypes and low volume production runs, believing that to outsource would be an expensive proposition. However, with the reliability of the cable assembly being influenced by so many different dynamics – including design, workmanship, production process, staff knowledge/ experience and a well-formed production environment with appropriate tools, jigs and fixtures – building a reliable cable assembly in-house can prove to be a very expensive proposition.

- **The cost of failure**

  As systems rely on high quality interconnection, a sub-standard cable assembly will almost certainly lead to full or partial system failure sooner or later, especially in rugged applications. Replacement costs can be high and the damage to reputation can be even higher. Prototypes might fail testing due to a bad cable assembly, thus leading to longer development periods and also higher testing costs while the nature of the fault is traced.

For simple cable assemblies, with low volumes involved and experienced engineers available, in-house cable assembly is an easy decision and probably quite low risk.

If any or multiple factors change, the costs – whether that is additional tooling/equipment investment, jigs/ fixtures, new and ongoing staff training, maintenance of production equipment, inspection and test – can escalate rapidly. A point can soon be reached where it is an unjustifiable expenditure. At this point, a specialist cable assembly house becomes a much better proposition for future requirements. In situations where no cable experience exists in-house, the decision to outsource this activity should be a much more straightforward decision.



Outsourcing to experience

Experienced and dedicated cable assembly facilities, such at those available at Harwin, provide a viable and practical alternative to in-house manufacture. Costs are reduced as the manufacturing staff are all IPC-A-620 trained and then re-trained on an ongoing basis as part of the operating costs of the sub-contractor themselves. Tools are often already in place and regularly maintained, and many simple jigs are directly available, with the knowledge and experience to rapidly build more complex jigs as required.

The expertise at Harwin

With a flexible production approach, such as that in place at Harwin, it becomes economically viable to build extremely low volumes, even a single cable assembly. Indeed, while the company can handle production builds in the thousands, its minimum order quantity (MOQ) remains very low for all cable assembly types, often less than 10 units. This allows customers to purchase production-standard cable assemblies using Harwin connectors for prototyping or the very shortest of production runs.

As a global company, Harwin has dedicated support centres in Europe, North America and Asia-Pacific, allowing customers to discuss designs and requirements in their local language and time zone. Harwin also offers as standard many complete or single-ended cable assembly options ready-made and in stock, or individual contacts with pre-assembled wires. Customers are then able to finish the cable assembly operations themselves with confidence that one of the most important processes, namely attaching the wires to the contacts, has already been carried out to the highest standards and, consequently, reliability is assured.

Summary

For all but the most simple of cable assembly requirements, serious consideration should always be made as to every element of the cost profile – comparing in-house cable assembly manufacture to sub-contract services.

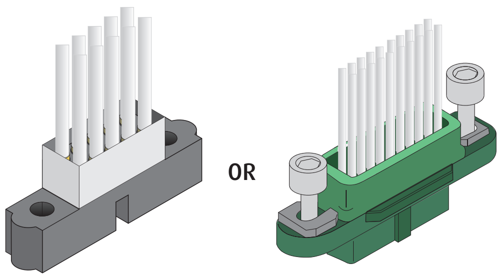
All aspects of expertise, available resources, training and materials will impact on the long-term reliability of the resulting product – which in turn has its own costs in safety or mission success, field servicing and repairs, plus (of course) reputation.

Harwin can offer the skills, resources and prolonged reliability needed to manufacture cable assemblies to meet a diverse spectrum of application and logistical demands. If the correct choice is still in house production, Harwin can provide continued support with online documentation, training videos and one-on-one advice, in order to ensure project success.

A Step-by-Step Guide to Backpotting

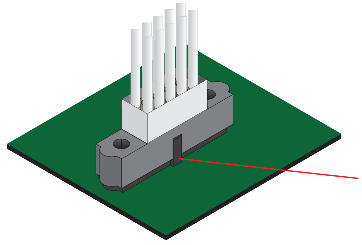
When using epoxy resins, always have a clean working area (and not to get resin on things you don't want it on)! Most epoxy resins are a two-part compound or a resin and a hardener, which stays liquid before mixing. Each compound has its own detailed instructions on mixing, application and drying times, but here is the basic step-by-step process that is generally applicable:

1



Create a potting wall (using tape or similar)
if the connector does not already have a recessed area.

2

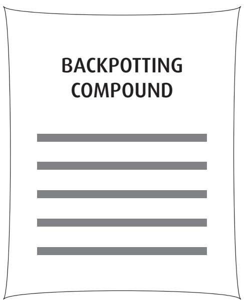


Use a fixture to hold the connector steady.

Mating connector fixed to a board

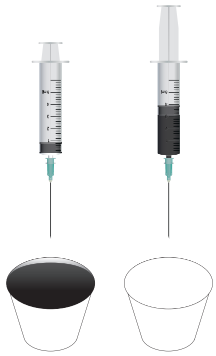
The simplest fixture is to glue a mating connector to a rigid board, and mate the connector being potted. Alternatively the connector could be held in a small vice – it is recommended that the connector is still mated in this method.

3



Mix the epoxy compounds (resin and hardener) to the manufacturer's specification – not too vigorously, to minimise the presence of air bubbles.

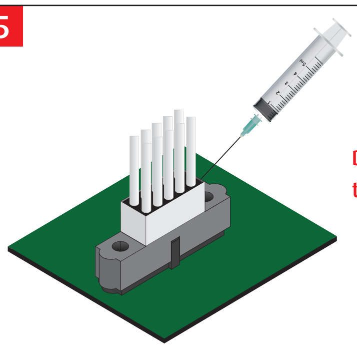
4



Load the mixed epoxy into a syringe or dispensing system, with the appropriate nozzle size.

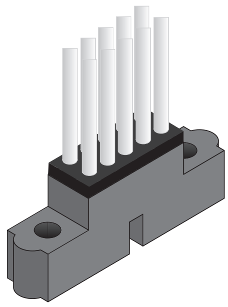
In situations where a small applicator nozzle is employed, a powered dispensing system may be needed.

5



Dispense the amount needed to fill the area, still being careful of creating air bubbles.
(see also Considerations*)

6



Once the assembly is set, remove any material used to create a temporary potting wall and inspect the completed product.

Considerations:

- If required, use a vacuum environment to de-gas the dispensed fluid – to remove trapped air bubbles.
- Place the assembly somewhere safe whilst the epoxy compound sets.
- For some resins, heat curing may be necessary.