WHITE PAPER

CABLE ASSEMBLY SOLUTIONS

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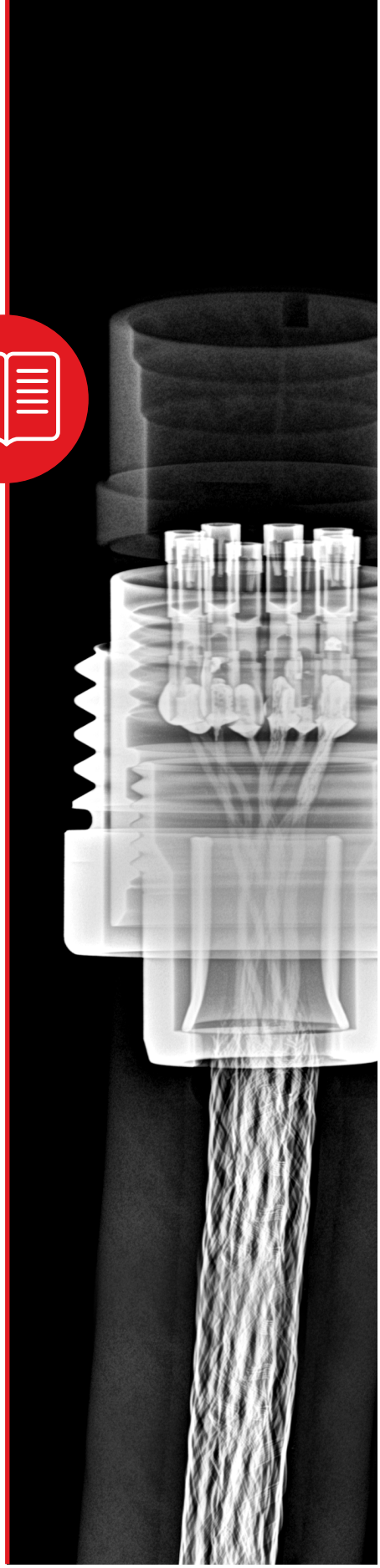

Fischer® CONNECTORS

REIMAGINING CONNECTIVITY TOGETHER

CABLE ASSEMBLY SOLUTIONS

Cable assembly solutions bring together connectors, cables, accessories and more to create reliable signal and power connections between pieces of equipment. This document explains the benefits of cable assembly solutions and what engineers need to consider when working on the interconnect solution. It covers topics such as applications, connector types, termination methods, sealing requirements and other parts of the cable-design process.

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David Cianciolo is Fischer Connectors Connectivity Solutions expert. His electro-mechanical education, initially applied in the design of medical devices and military connectors, has allowed him to build and develop, over the last two decades, the US Engineering skillset in the assembly design of interconnect and active solutions including the critical pursuit of proper cable selection, for various successful customer applications. David has been granted several design patents in his career. His strong experience makes him uniquely qualified to leverage the Group's R&D expertise to design tailored solutions that ensure high-performance connectivity when it matters most.

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INTRODUCTION

Cable assembly solutions bring together connectors, cables, accessories and more to create reliable signal and power connections between pieces of equipment. While each of these components could be sourced separately, cable assembly solutions streamline design, procurement, production and testing. Frequently used in defense, medical and heavy industrial applications, cable assembly solutions meet the challenging requirements of their industries including extreme environments, flexibility, weight reduction, sterilization, electromagnetic shielding and more. A cable assembly may have active electronic components integrated into the assembly or they may be just a wire-to-wire interconnect.

Engineers designing cable assembly solutions need to consider conductor size, material, configuration, the form factor of the connector, the cable configuration including jacket material, strength members and shielding. Termination options and options like bend reliefs and sealing caps need to be considered. To make sense of the many options and myriad combinations, it can help to work with industry experts who have the experience and partner connections to recommend the right materials and configuration.

THE BENEFITS OF CABLE ASSEMBLY SOLUTIONS

Cable assembly solutions simplify supply chains and reduce cost. Companies choosing cable assembly solutions deal with a single trusted partner for their cable assembly needs instead of sourcing connectors, cables, accessories individually. Companies find that approach not only reduces bill-of-materials entries, but also reduces cost by up to 15-30% over purchasing the items separately. Since providers of cable assembly solutions already have partnerships and supply chains in place, they are able to ensure quick production turnaround.

Using custom cable assemblies also simplifies production flow and cost. Instead of investing in the manpower, expertise, tooling and supplies required to create robust cable assemblies in house, companies using custom cable assembly solutions receive assemblies that are already finished, tested and ready to install in the product.

From an engineering standpoint, custom cable assembly solutions simplify the design process. Cable assembly experts can act as extensions of a company's engineering department, seeking to understand the application and collaborating with in-house engineers to design the best solution. These experts are positioned to produce design drawings, proofs of concept and prototypes quickly when required due to their extensive experience and partnerships.

CABLE DESIGN CONSIDERATIONS

Applications

Identifying the cable assembly application and all of the requirements early in the design process can strengthen product development efforts. Also avoid overdesigning cable assemblies that cost too much, or underdesigning cable assemblies that fail to meet customers' requirements.

Conductor Size

Determining the electrical requirements is key to conductor size selection. The conductor size should be selected based on the necessary power load of the application. Ambient temperature always needs to be taken into consideration when selecting the conductor size of the cable. Below are charts that define the ampacity of a conductor and its correction factor based on ambient temperature and the number of conductors.

Cable Current-carrying Capacity

Example: An 8-conductor cable with 20 AWG conductors, insulation rated to 150°C and used in a 50°C environment, is rated at **8.645 AMPS**.

20 AWG = 13 AMP (150°C column)
X
Multiply Conductor Correction Factor = 0.7 (8 conductors)
X
Ambient Temperature Correction Factor = 0.95 (150°C column, 50°C ambient)
= 8.645 AMPS

This table should be used to select a conductor size in the following conditions:

- Copper conductor
- 1-3 current-carrying conductors in a cable
- Ambient temperature of 30°C (86°F)

AWG Size	Conductor Insulation Temperature Rating						AWG Size
	80°C	90°C	105°C	125°C	150°C	200°C	
40	0.21	0.32	0.36	0.39	0.46	0.51	40
38	0.30	0.44	0.50	0.55	0.64	0.71	38
36	0.41	0.59	0.67	0.73	0.85	0.95	36
34	0.57	0.80	0.91	0.99	1.1	1.3	34
32	0.78	1.1	1.2	1.3	1.6	1.7	32
30	1.3	1.5	1.7	1.8	2.1	2.3	30
28	2.0	2.0	2.2	2.4	2.8	3.1	28
26	2.6	2.6	3.0	3.2	3.7	4.2	26
24	3.9	3.6	4.0	4.4	5.0	5.7	24
22	5.2	6.0	7.0	8.0	9.0	10	22
20	6.5	8.0	9.0	10	13	15	20
18	9.8	14	15	16	17	20	18
16	12	18	19	20	22	25	16
14	18	25	29	31	34	36	14
12	23	30	36	39	43	45	12
10	31	40	46	50	55	60	10
8	42	55	64	69	76	83	8
6	62	75	81	87	96	110	6
4	81	95	109	118	120	125	4
3	94	110	129	139	143	152	3
2	111	130	143	154	160	171	2
1	130	150	168	181	186	197	1
1/0	150	170	193	208	215	229	1/0
2/0	176	195	229	247	251	260	2/0
3/0	205	225	263	284	288	297	3/0
4/0	241	260	301	325	332	346	4/0

Multiply Conductor Cable Correction Factor	
Number of conductors	Multiple ampacity by factor for number of current-carrying conductors
4-6	0.80
7-9	0.70
10-20	0.50
21-30	0.45
31-40	0.40
41+	0.35

Ambient Temperature Correction Factors (Multiply ampacity by factor for desired ambient temperature)							
Ambient temp (°C)	Conductor Insulation Temperature Rating						Ambient temp (°F)
	80°C	90°C	105°C	125°C	150°C	200°C	
31-35	0.94	0.96	1	1	1	1	87-95
36-40	0.88	0.91	1	1	1	1	96-104
41-45	0.82	0.87	0.93	0.94	0.95	0.97	105-113
46-50	0.75	0.82	0.93	0.94	0.95	0.97	114-122
51-55	0.67	0.76	0.85	0.87	0.9	0.94	123-131
56-60	0.58	0.71	0.85	0.87	0.9	0.94	132-140
61-70	0.33	0.58	0.76	0.8	0.85	0.9	141-158
71-80		0.41	0.65	0.73	0.8	0.87	159-176
81-90			0.53	0.64	0.74	0.83	177-194
91-100			0.38	0.54	0.67	0.79	195-212
101-120				0.24	0.52	0.71	213-248
121-140					0.3	0.61	249-284
141-160						0.5	285-320
161-180						0.35	321-356

Courtesy of New England Wire Technologies

Conductor Materials

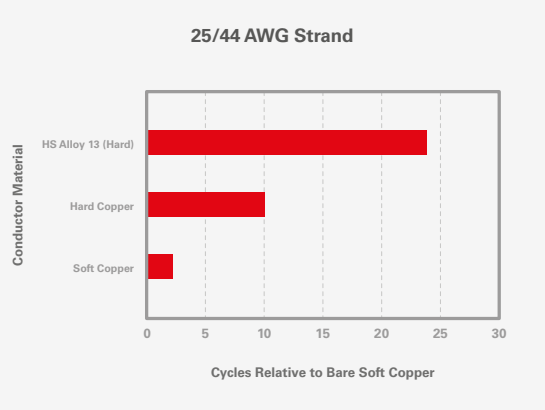
Copper is used on most assembly applications, but there are various copper alloys available that offer unique benefits and should be considered. Typically copper alloys can offer increased hardness, tensile strength, flex endurance and resistance to elevated temperatures – although these benefits come with a small sacrifice of electrical conductivity. These alloys may be desired for fine-gauge applications, 28 AWG or smaller.

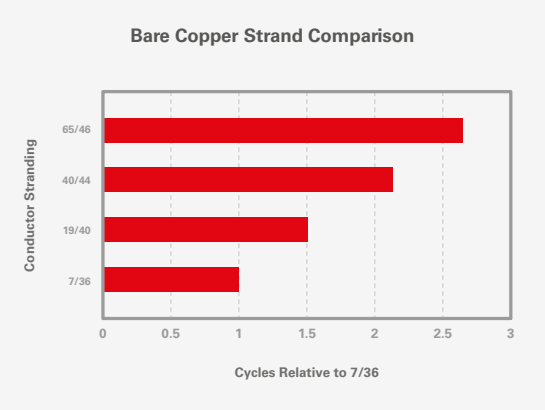
Material	Tensile Strength (PSI)	Elongation	Conductivity
Copper (soft)	35,000	10 - 25%	100%
Copper (hard)	60,000	1%	100%
HS Alloy 13 (soft) RoHS	40,000	10 - 25%	77%
HS Alloy 13 (hard) RoHS	90,000	1%	73%
Alloy 14 RoHS	55,000	6%	85%
HS Alloy 23 RoHS (soft)	40,000	10 - 25%	-
HS Alloy 23 RoHS (hard)	90,000	1%	77%

Courtesy of New England Wire Technologies

Flex Life

Two major factors affecting the flex life of a cable are the conductor material and the conductors' stranding. High-tensile-strength alloys are shown to exhibit longer flex life. Strand construction has an effect on the overall flexibility of a conductor or cable. Higher flexibility, achieved by finer stranding, leads to longer life. The graph below shows the results of uninsulated conductors made of different materials and a variety of stranding.





Courtesy of New England Wire Technologies

Conductor Construction

The circular mil is the wire cross-sectional area used in American and British wire tables. The circular mil area (CMA) is the area of a circle one mil (one-thousandth of an inch) in diameter. Therefore, the area of a circle in circular mils is equal to the square of its diameter.

Solid Wire: CMA = D^2

Stranded Wire: CMA = D^2 x N

D = Strand OD (in thousandths of an inch)

N = Number of strands

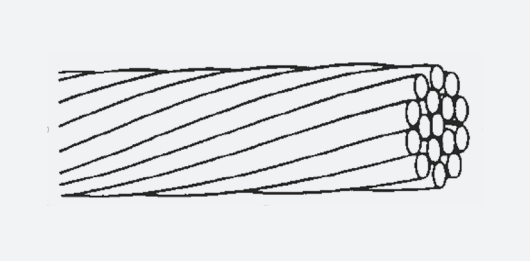
Conversion from CMA to mm^2 : Multiply CMA by .000507

Strand Construction

While solid conductors (single-strand) are available, most assemblies are designed using stranded wire, consisting of many fine strands of wire twisted together. The gauge assigned to such a conductor is determined by the total cross-sectional area of all the individual strands added together. Stranded conductors are used where flexibility is needed. Flexibility varies based on conductor construction: bunched lay, unilay, rope lay and concentric.

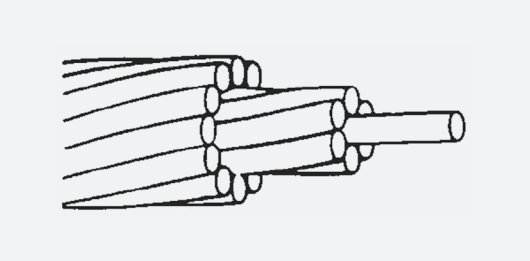
Bunched Lay

Any number of strands in a random pattern. Twisted in one operation, all strands have the same lay direction and same lay length. However, the result is a rougher surface and lower dimensional tolerance than concentric constructions. The number of strands is determined by the size of the individual strands and the total cross-sectional area required. Bunched lay conductors are the most common, as they provide optimum flexibility which is typically desired in a cable design.



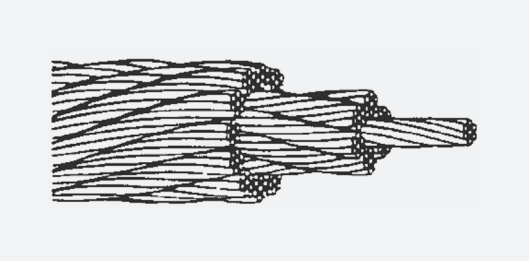
Unilay

Central wire surrounded by one or more layers of helically laid wires in a geometric pattern, with the same lay direction and the same lay length. The strands are typically larger in diameter. Unilay conductors are the next most common and they bring good flexibility and a slightly lower cost than bunched lay.



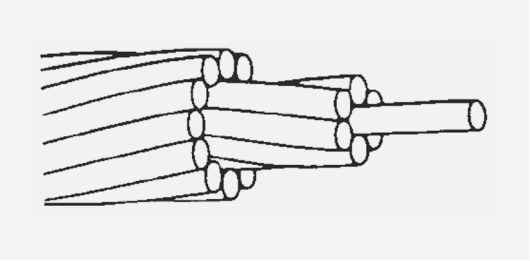
Rope Lay

Single strands assembled together into concentric or bunched configurations. Rope stranding has the advantage of increasing flexibility by using a larger number of finer strands while maintaining a tighter diameter tolerance than a simple bunched construction. Constructions vary and can contain thousands of strands. Rope lay conductors are most flexible, but require multiple twisting operations which bring extra cost, lower copper density and larger diameter. Rope lay conductors are typically sold as single conductors and not typically used in multi-conductor cables.



Concentric Lay

Central wire surrounded by multiple layers of helically laid wires with alternately reversed lay direction and increasing lay lengths. Concentric lay conductors are not very common; they are the roundest conductor type (besides solid), which is good for electrical purposes where concentricity of the insulation wall is critical.



Plating Options

If the assembly will be in a high-humidity environment, copper will quickly oxidize. The most common plating options to prevent oxidation are tin, silver and nickel plating. Tin and silver plating options prevent copper oxidation and corrosion and improve the solderability and termination of the conductors. If the application is in a high-temperature environment, silver or nickel plating is the best choice to protect the conductors.

Operating Temperature Specification	
Bare Copper	100°C
Tinned Copper (TC)	150°C
Silver Plated Copper (SPC)	200°C
Nickel Plated Copper (NPC)	260°C

Insulation Materials

The majority of insulation materials fall into two groups: rubbers and thermoplastics.

Rubbers

SBR: Normally used in the 0 - 600 volt range

- Good flexibility, tear strength and water resistance
- Limited resistance to oils and hydrocarbon fuel

EPR: Very good ozone resistance and weather resistance

- Resilient over a wide thermal range -30°C to 90°C
- Good chemical resistance, poor oil resistance

Silicone: Excellent thermal ratings

- Widest thermal range -60°C to 180°C
- Medium abrasion resistance and cut resistance
  (these properties can be improved by adding aramid fibers)

Neoprene: Very good weathering properties

- Resistant to oil, flame and ozone
- Good mechanical toughness

Thermoplastics

PVC: Many varieties / formulations available

- Generally inexpensive
- Not ideal for high-temperature or high-speed data applications

Fluorocarbons (FEP, PFA, PTFE, ETFE):

- Higher cost
- High temperature ratings
- Low dielectric constant
- ETFE best cold-flow characteristics of the Fischer Connectors Group and radiation resistant

Rubber Insulation Properties				
	SBR	Silicone	EPR	Neoprene
Tensile strength (N/mm²)	5 - 10	5 - 10	5 - 10	10 - 20
Elongation (%)	300 - 600	300 - 600	200 - 400	400 - 700
Max. operating temp (°C)	60	180	90	100
Min operating temp (°C)	-65	-60	-30	-40
Dielectric constant, 50 Hz	3 - 5	3 - 4	3 - 3.8	6 - 8.5
Breakdown (KV/mm)	20	20	20	20
Abrasion resistance	Medium	Medium	Medium	Medium
Water absorption (%)	1.0	1.0	1.0	1.0
Weather resistance	Medium	Good	Very Good	Very Good

Thermoplastic Insulation Properties						
	PVC	Polypropylene	FEP	PFA	PTFE	ETFE
Tensile strength (N/mm²)	10 - 25	20 - 35	15 - 25	25 - 30	80	40 - 50
Elongation (%)	130 - 350	300	250	250	50	150
Max operating temp (°C)	105	100	205	260	260	150
Min operating temp (°C)	-20	-10	-100	-190	-190	-100
Dielectric constant, 50 Hz	4.5 - 6.5	2.3 - 2.4	2.1	2.1	2.1	2.6
Breakdown (KV/mm)	25	75	25	25	20	36
Abrasion resistance	Medium	Medium	Very Good	Very Good	Very Good	Very Good
Water absorption (%)	0.4	0.1	0.01	0.01	0.01	0.02
Weather resistance	Medium	Medium	Very Good	Very Good	Very Good	Very Good

SHIELDING TYPES

Cable-shield options include three types: braid, serve / spiral, foil.

The shield is a conductive barrier that surrounds the insulated wires inside a cable. The purpose of a shield is to prevent noise emitted from other nearby cables or electronics, and even noise emitted from adjacent wires within a cable, from interrupting signals within the cable. It also prevents electromagnetic interference (EMI) from radiating out of the cable.

Shielding effectiveness is the shield's ability to prevent EMI passing in or out of the cable. Percent coverage defines the % of shield-coverage / EMI protection.

Shield Characteristics	Braid	Serve / Spiral	Foil
Percent coverage (%)	65-98	80-95	100
Low Hz effectiveness <1 MHz	Excellent	Good	Fair
High Hz effectiveness >100 MHz	Good	Fair	Excellent
Mechanical strength	Excellent	Good	Fair
Flexibility	Good	Excellent	Good
Flex life	Good	Excellent	Fair
Abrasion resistance	Medium	Medium	Medium
Water absorption (%)	1.0	1.0	1.0
Weather resistance	Medium	Good	Very Good

Foil in combination with a braided shield provides the best of both worlds. It combines the shielding effectiveness of the foil shield with the flex life of the braid.

Shield-to-connector Termination

Good overall shielding effectiveness for a cable assembly is achieved only if the shield is properly terminated to the connector, on both ends of the assembly. As a rule, the overall shielding effectiveness will be dictated by the size of the largest opening throughout the assembly; the smaller the better. Shield coverage openings often occur at the cable to connector transition. It is important to maintain 360° coverage across the full length of the cable assembly.

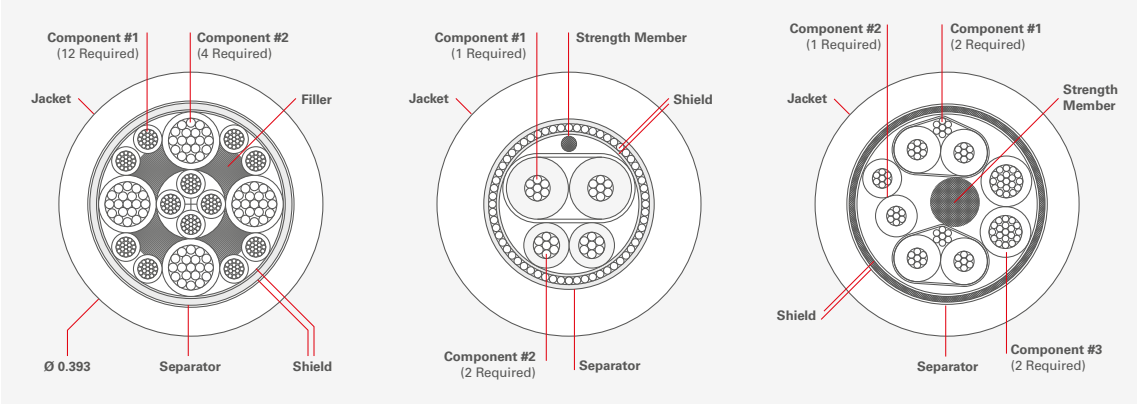
FILLERS & TAPES

Fillers are used to fill in gaps in the cable construction to improve the roundness of a multi-conductor cable. This facilitates overmolding of a cable. Fillers improve the durability and flex life of a cable. Fillers can also be used to prevent fluid entry into a cable. Common filler materials are cotton strings or yarn, extruded thermoplastic and foam.

Tapes and wraps, also referred to as separators, can offer noise suppression and reduce cross-talk between cable components. The most commonly used materials are:

- **Paper Tape:** Used between cable jackets and shield to facilitate ease of cable jacket removal. It is also very inexpensive.
- **PTFE Tape:** Also used between cable jackets and shield. PTFE tape provides abrasion resistance, uniformity and performance. PTFE tape is often used to reduce loss in high-speed data cables.
- **Mylar Tape:** Excellent tensile strength and durability, used as cable insulation. With an operating temperature of 150°C.
- **Kapton Tape:** Mechanically tough, abrasion and cut-through resistant. It also improves a cable's weather resistance. It has an operating temperature range of -200°C to +200°C. Kapton is radiation resistant and will not burn. Kapton also has excellent electrical properties.

Below are some illustrations of how and where fillers, tapes / separators and strength members are used.



STRENGTH MEMBERS

A strength member is a component within the cable that provides added tensile strength to a cable and removes the stress from the conductors. It is critical to position the strength member as close to the center of the cable as possible to relieve the stresses applied to the cable. Typically made of aramid fiber (Kevlar), a strength member is added to increase the overall strength of a cable assembly. Aramid fiber is a strong material ideal for increasing the tensile strength of cables. It is available in a variety of configurations with varying break strengths. For example, a .034 in. x .024 in. (.86 mm x .61 mm) aramid fiber has a break strength of 120 lbs (540 N). When selecting a strength member, ask what pull strength is required and if the strength member needs to be terminated to the connector.

CONNECTOR TYPES

Defining connector requirements is just as important as defining the cable requirements. Connectors must be compatible with the cable, and vice versa.

Consider the environment the cable assembly will be used in. The connector manufacturer will be the best source of technical support regarding:

- Connector durability and weight
- EMI & RFI shielding available
- Connector pull-out strength
- Overmolding cable assemblies
- Overmold geometries available
- Electrical requirements; voltage hold-off, current carrying capabilities, insulation resistance, data-transmission rates
- Electrical and leak-seal testing
- Connector / cable thermal capabilities
- Cable / connector assembly sealing
- Bend reliefs available
- Number of connector mating cycles
- Connector materials

TERMINATION METHODS

The two major types of wire / contact terminations are crimp and solder.
Below are the pros (+) and cons (-) of these two types.

Crimp Termination:

+ Automated machinery requires less skill by the operator to produce reliable terminations
– Provides reliable terminations only when using stranded conductors
– Special crimp tooling and dies are required
– Limited range of conductor sizes can be used

Solder Termination:

+ Provides reliable terminations using solid or stranded conductors
+ No special tooling required
+ Wider range of conductor sizes can be used
– More skill required to terminate reliably

STRAIN RELIEF REQUIREMENTS

The cable entry to the connector needs to be secured to prevent premature cable breakage. Overmolds and heat-shrink tubing provide some strain relief at the junction of the cable to the connector. Overmolding should not be relied upon as the only strain relief. The most basic options are the two-piece cable clamp or the collet. The latter is the more effective option of the two. Both are connector components and both provide cable-strain relief. If a bend relief is also needed to reduce cable-bend stresses at the connector exit, consider heat shrink or a pre-molded bend relief. These are usually offered by the connector manufacturer. A custom overmold can also provide bend relief and give a very finished appearance to the cable assembly.

SEALING REQUIREMENTS

The connector and cable entry may need to be protected from fluid ingress. Overmolds and heat-shrink tubing provide sealing at the junction of the connector and the cable. Adhesive-lined heat-shrink tubing offers moderate resistance to moisture. A better solution is overmolding the cable and connector. The mating surface of the connector may also need to be sealed; this will require additional sealing processes within the connector. Each connector sealing requires a specialized product, process and test method to ensure that a reliable and high-quality sealed product is produced.

CONCLUSION

Understanding the end-use application and its environment is crucial to the overall interconnect-solution design. This information will help guide the cable assembly engineer in selecting the most appropriate materials to ensure optimal performance. It can also help with the different material options that can affect the interconnect-solution design of a device and how these materials are chosen. Knowing the information that is needed upfront, at the start of the design process, will help complete a successful cable assembly design.

Fischer Connectors can provide the design, development support and manufacture of custom interconnect solutions. Whether it be project sketches or fully defined solutions that are submitted, our cable assembly design engineers are available to help select the proper materials to optimize form, fit and function. Regardless of the cable assembly requirements, the Engineering team at Fischer Connectors has the expertise to assist in the design and manufacturing of any cable assembly need.

One aspect of the company that helps it stand out from the competition is that, instead of offering ready-made solutions, Fischer Connectors will provide the right customer solution that is both high-quality and competitively priced. Our engineers work closely with the customer to find the right solution for the most demanding applications by integrating precision connectors, components, parts and engineered cables. Fischer Connectors' skilled technical and support teams will help build the perfect cable assembly for any unique application, providing advice through design, prototype, assembly, testing, manufacturing, installation and beyond.

ABOUT FISCHER CONNECTORS

Fischer Connectors has been designing, manufacturing and distributing high-performance connectors and cable assembly solutions for more than 65 years. Known for their reliability, precision and resistance to demanding and harsh environments, Fischer Connectors' products are commonly used in fields requiring faultless quality, such as medical equipment, industrial instrumentation, measuring and testing devices, broadcast, telecommunication and military forces worldwide.

Primary design and manufacturing facilities are located in Saint-Prex, Switzerland, with subsidiaries and distributors located worldwide.

Fischer® CONNECTORS

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