Terminating ultraflexible and high-strength cables

Complete cable assembly methods used to meet stringent military specifications will be addressed in this article, including jacket removal, shield termination, insulation stripping, and attaching of the contacts to the shield termination and final potting or sealing of the assembly.

By Donald Dodge

Foot soldiers in our modern Army now are "walking computers." Night vision goggles, GPS receivers, computers and radios are becoming commonplace. The interconnecting cables must be lightweight and strong, but still contain all of the circuit conductors to carry out their mission. The cables can be snagged on environmental hazards such as bushes or protrusions from vehicles. Increased strength demand means that the addition of strength members, such as Kevlar or PPO fibers, are now the "norm."

Satellite cables need to have lightweight shields while still maintaining the same or higher shield effectiveness. Aracon, which is nickel- or silver-plated Kevlar, can assist in these applications. As a plated fiber that will spread across the cable core, it can easily give greater shield coverage than can be obtained with flat or round copper wires.

Ground support equipment, while relying more and more on radio communications, still has the need for robust cables between communication huts. Fiber optics can pass large amounts of data, but there is still the need for power to the equipment. Composite cables can do both. The need for high tensile-strength members to keep the cables from pulling apart as well as crush-resistant materials to protect the fibers calls for tougher materials.

The design process starts with a source control drawing (SCD), as most harsh-environment cables do not conform to the old MIL-spec system. Many cable designs use the material and physical properties and testing requirements from existing MIL-specs as a starting point and then delineate the additional requirements on the SCD

Designing a cable

We can design the cable from the inside out. Starting with the conductors, insulation, cabling, shielding and jacketing.

Conductors made with bare tin or silver-plated copper now need to switch to higher-strength alloys. The move to materials that meet the new European restriction of hazardous substance or (RoHS) had caused problems for many military and medical applications. The RoHS-compatible materials have not had sufficient time to be verified that they can withstand the rugged requirements of today's cables. The high-strength cables have been granted waivers from the RoHS by the European Union (EU).

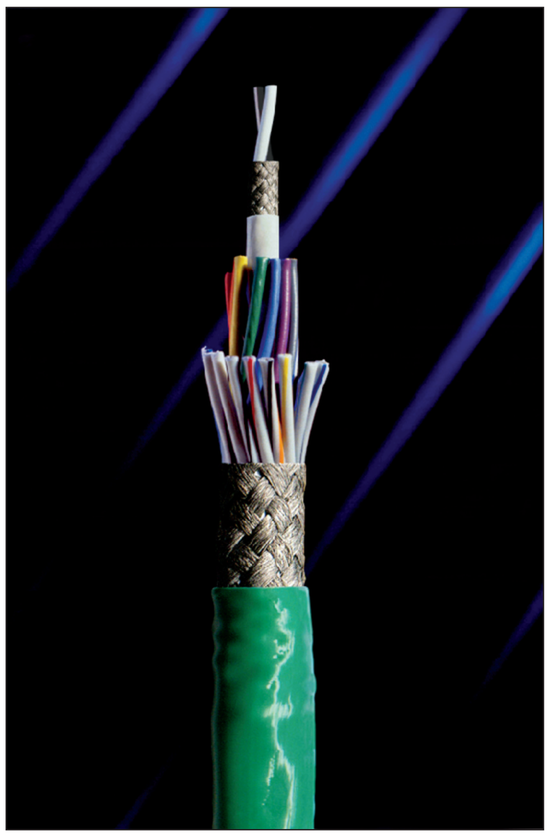

Figure 1. A cable with two Aracon shields. The inner shield, over a four-conductor group, keeps EMI from the control wires from interfering with the sensor signals.

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When the conductor size gets smaller than 30 AWG, consideration of moving to stainless steel as a conductor material needs to be reviewed. Often, for short conductor lengths, the increased resistance of stainless steel can be tolerated. If not, gold or silver plating can be done on the individual strands of a conductor to bring the resistance down to acceptable levels. For terminations, soldering to stainless steel is difficult, whereas the gold- or silver-plated wire can easily be soldered. Crimp contacts can easily be attached to stainless steel. Table 1 lists the strength and conductivity of alloys that can be considered when copper is not strong enough.

After the conductor has been determined, the insulation must be chosen. The environmental considerations determine the temperature rating, solvent resistance and physical characteristics. Many programs now prohibit the use of PVC. Thermoplastic elastomer's (TPEs) have taken the place of many PVC materials. Also, to replace PVC, companies such as GE Plastics have created flexible versions of NORYL that can be extruded to smaller wall thickness's and are tougher than the PVCs they replace.

After insulating the conductors they must be twisted into a cable core. Break strength

Base Material	Alloy Number (UNS)	Tensile Strength (PSI)		Elongation %	Conductivity % IACS	Density (pounds/cu. in)
		Annealed	Hard			
Copper						
ETP	C11000	35,000	68,000	25	100	0.322
Oxygen-free OF	C10200	35,000	68,000	25	100	0.322
OF w/silver	C10700	35,000	68,000	25	100	0.322
High Strength						
CS-95	-	95,000	130,000	6	63	0.319
Tensile flex	C18135	60,000	120,000	8	90	0.322
Zr copper	C15000	36,000	70,000	25	90	0.322
CT37	-	50,000	95,000	8	80	0.322
CC78		50,000	85,000	8	90	0.321
Cd copper	C16200	50,000	110,000	8	90	0.321
Cd copper	C16500	45,000	95,000	25	60	0.321
Copper Clad Steel						
Class 30	-	60000	127000	15	30	0.294
Class 40	-	55000	110000	15	40	0.294
Class 60	-	45000	90000	20	60	0.294
Class 70	-	40,000	80000	20	70	0.294
Brass						
70/30	C26000	60,000	130,000	30	27	0.308
80/20	C24000	55,000	125,000	30	32	0.313
85/15	C23000	48,000	105,000	30	36	0.316
87/13	C22600	45,000	97,000	30	40	0.317
90/10	C22000	45,000	90,000	30	43	0.318
95/5	C21000	45,000	65,000	30	56	0.320
Silicon Bronze						
Low (B) 1015	C65100	45000	105000	30	11	0.316
High (A) 1010	C65500	60000	145000	30	7	0.308
Phosphor Bronze						
95/5	C51000	57,000	140,000	35	15	0.32
97/3	C50900	53000	125000	35	16	0.321
92/8	C52100	70000	150000	50	12	0.318
Nickel Silver						
10%	C74500	70000	105000	25	8.4	0.31
12%	C75700	70000	93000	25	7.7	0.31
18%	C75200	70000	103000	25	6.2	0.316
Aluminum						
EC	-	15,000	25,000	15	62	0.098
5056	-	45,000	65,000	15	29	0.095
Other						
Nickel	200	65000	150000	25	18	0.321
CCAL	-	17000	23000	10	62	0.121
Silver	-	18000	55,000	30	108	0.379
Steel	LC	55000	110,000	20	13	0.284
Stainless steel	304	125000	250000	30	2.3	0.286
Stainless	316L	63000	137000	57	41.47	0.287

Table 1. Comparing conductor properties of myriad metals and alloys.

Material	Nom. Specific Gravity	Voltage Breakdown (volts/mil)	Abrasion Resistance	Nom. Dielec. Constant	Flame-Retardant Properties	Flexibility
Polyvinyl chloride (PVC)	1.37	500	Good	5-8	Excellent	Good
Polyethylene – solid	0.95	600	Good	2.1	Poor	Fair
Polyethylene – foam	0.50	n/a	Poor	1.5	Poor	Good
Teflon (FEP)	2.20	600	Excellent	2.1	Excellent	Fair
Teflon (PFA)	2.14	2,000	Excellent	2.0	Excellent	Fair
Tefzel	1.70	400	Excellent	2.7	Excellent	Fair
Nylon	1.07	450	Excellent	4.0	Poor	Poor
Polypropylene	0.91	650	Excellent	2.2	Poor	Poor
Polyurethane	1.10	500	Excellent	7.0	Poor	Excellent
Thermoplastic Elastomer (TPE)	1.00	650	Excellent	2.4	Good	Good
Hytrel	1.20	860	Excellent	6.0	Fair	Fair
Silicone	1.32	600	Fair	3.0	Fair	Excellent
Fluorosilicone	1.40	350	Excellent	7.0	Excellent	Excellent
Neoprene	1.30	250	Excellent	N/A	Excellent	Excellent

Table 2. Common properties of insulation and jacketing materials.

Electrical shields must have high effectiveness for the greater EMI-CBR fields present on the modern battlefield.

requirements now require the use of strength members in the center of the core. Kevlar and PPO fibers are common strength members. On occasion, steel wires may be used as the center core. Small aircraft stainless steel conductors can be placed in the core and are often insulated to keep them from abrading into the insulated conductors cabled around them. The strength members must be kept in the center of the cable. We have seen designs where attempts were made to put them in the "valleys" between the insulated conductors. When these cables are put in tension, the strength member must be pulled straight before it can bear the load. The motion inside the cable core of the conductors can and often leads to premature cable failure.

Shields to reduce electromagnetic interference (EMI) are placed over groups of the conductors or the total cable core. EMI can come from the cable or be introduced into the cable from adjacent equipment such as high-powered transmitters and radars. Shields are usually made from materials similar to the cable conductors, including alloys to maintain strength during flexing. Often, in the past, aluminumized mylar tapes were used for shields. They are suitable for fixed installations and should not be specified for flexing applications as the Mylar is notch sensitive and will disintegrate when subjected to continuous flexing.

Aracon, nickel or silver-plated Kevlar can be substituted for copper in shields with a 30% weight savings. For satellites, the weight savings can easily justify the high cost of Aracon. For ground-based units, the cost can sometimes be justified by combining the shield and strength members to reduce the cable size.

The cable jacket is chosen based on environmental conditions, i.e., temperature range, solvent presence, radiation and physical properties. Table 2 can be used for selection of the jacket material. Neoprene is an additional tough jacket material that can be "blown on" over the cable core.

Figure 1 shows a cable with two Aracon shields. The inner shield is over a four-conductor group used with a sensor. The first shield keeps EMI interference from the control wires from interfering with the sensor signals. The overall shield protects the cable from outside interference.

Terminating a cable

With the cable design completed we move on to the termination of these rugged cables.

Connectors must be designed with reinforcing to maintain ruggedness in smaller shapes. The use of newer high-strength materials and the use of conductive fillers allows connectors to be smaller and more robust.

Newer rugged cables now contain strength members such as Kevlar, which must be terminated in the connector. To use a strength member without terminating it, results in a "high-priced" filler. Often, one of the center pin locations can be replaced by a loop or hook to connect with the strength member if the insulation body can withstand the load placed between the strength member attachment and the connector housing. If not, a "spider" for the strength member must be fabricated so that the strength member can be attached to the "spider" and then the load will be transferred to the connector shell.

Cutting the cable to length starts the termination process. Sufficient length to include the lengths of the conductors and shields that will be inside the connector must be included in the length of the cable before cutting. Often, this step is forgotten, resulting in cable assemblies that are too short after assembly.

Jacket removal is the next step that must ensure that the shield, if present and conductor insulations, are not "nicked." Many of the tough jacket materials will dull the cutting blades faster than before. Blades must be kept sharp or replaced more often than in the past. Inspection of the shield and insulation should be performed to ensure that no "nicking" has occurred.

Electrical shields must have high effectiveness for the greater EMI-CBR fields present on the modern battlefield. Cables containing more than one shield, such as shielded pairs, must maintain isolation between the shields

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in the cable. This requires that additional pins must be assigned in the connector to allow for isolated shield terminations. Often, the overall shield is terminated to the connector shell. If the shell is a non-conductive material, then a pin needs to be assigned to the shield. The shield is often folded back over the jacket after removal of the jacket so the conductors can be terminated. For shielded jacketed groups within the cable, the jackets also need to be removed and the shields folded back.

The insulation on the conductors must be removed for application to the terminals. With the smaller conductor sizes used today, hot knife strippers are the preferred insulation-stripping tool. Mechanical strippers can easily damage or cut the small, fine strands of these smaller conductors. It is important to use temperature-controlled blades for the strippers to ensure clean, residue-free stripping. Pre tinning of the wires may be done if solder cup termination is used. For crimped contacts they can be crimped on at this time.

For solder cup terminations it is preferred that the soldering be started at the center of circular conductors or the bottom row of parallel conductors. Care must be taken to ensure that the proper wire is attached to each pin. For crimp contacts a similar insertion rotation is used.

Today, often all of a given wire gauge insulations are of the same color. One end of the cable is terminated and then placed on a continuity tester. There are testers that will show the wire number when a grounded finger is touched to a conductor on the other end of the cable. Then the identified conductor can be inserted or soldered to the correct location. Some testers even have audio that will speak the wire number when touched. This assembly method has resulted in far fewer miss-wired cable assemblies.

After the conductors are assembled into the connector, the shields must be terminated to their respective contacts. Some connectors call for the use of double crimp or solder sleeves over and under the braid and then a pigtail is used to terminate the shield to a contact. Other times, the shields are straightened out and the strands are twisted into a conductor that can be terminated.

After the shields and conductors are terminated it is common to pot the back of the connector to maintain the strength of the connections and to prevent moisture from entering the connector.

Final assembly of the connector with its back shell and cable grips can be completed. Some connectors will even have a second overmolding to keep moisture out of the back shell.

Continuity, high-pot and leakage testing is done to ensure that the cable assembly is properly assembled.

Part numbering and possibly serial numbering can be applied to the cable assembly. It may be sealed and stored in moisture-resistant packaging for shipment. DE

ABOUT THE AUTHOR

Donald Dodge is vice president of Research at Calmont Wire and Cable.