711 Lidgerwood Avenue
Elizabeth, NJ 07207-0711
1-800-52ALPHA

Technical Training Workshop
The Basics of Wire & Cable

A Technical Training workshop that will provide attendees with the necessary skills to be better able to communicate in today's ever changing field of Electrical & Electronic Wire & Cable Technology. This workshop will provide the technical skills necessary to blend our employees' skills with those of our customers.

Revised: 5/28/2010

Workshop Outline

Conductors

In this section, wire and cable conductors will be discussed. At the end of this section, the reader will understand the use and properties of the conductor, the variety of materials that may be used as conductors as well as the geometry of available conductors.

1. **Conductor:** Is an uninsulated wire designed to carry an electrical current.

2. **Conductor Materials:** There are several types of conductor materials widely used in the wire & cable industry, the most common ones being copper and aluminum.

- Copper is the most common because of its high electrical and thermal conductivity and its ability to convey electricity and heat coupled with relatively low cost compared to other conductor materials, such as gold or silver. Heat is a by-product that is typically not wanted.
- The copper used in the industry today is 99.9 % pure.
- Two common types of copper are ETP (electrolytic tough pitch) and OFHC (oxygen-free, high conductivity copper).

  - **ETP** is a refining (extraction) process that produces a 99.95% pure copper (see ASTM B115). This is done by extracting the copper out of the ore. There will still be some impurities left in the copper, such as dirt and scale but it is still considered pure. ETP usually contains between 0.02% to 0.05% oxygen.

  - **OFHC** has 99.95% minimum copper content and an average annealed conductivity[1] of 101%. This type of copper is more pure than ETP, since the impurities are kept out of the extraction process by using an inert gas blanket over the process. An inert substance is one that when used will not combine with the refining process.

The following materials are the most common conductor materials:

a) **Bare Copper (BC):** Is used in special applications since in an uncoated state, it easily oxidizes when exposed to air, heat and moisture. Some insulation materials, such as rubber, will also accelerate surface corrosion. Operating temperatures up to 200°C.

- Marries low cost with the best performance.
- Highly conductive, abundant and easily shaped or formed, bare copper is strong, yet flexible.
- Meets the minimum specified requirements of ASTM B-3.
- Commonly used in the Building Wire, Industrial and Sound & Security industries.

[1] Conductivity: The capability of a conductor material to carry an electrical current. The higher the conductivity, the greater the current carrying capacity. Silver and copper have higher current carrying capacity than aluminum. Silver and copper will not become as hot as aluminum when carrying the same amount of current.

b) **Tinned Copper (TC):** Most common coating used today. It yields corrosion protection while improving solderability. However, the Tin Coating restricts its operating temperature range to 120°C to 150°C, since higher temperatures may cause tin to oxidize, turn black, corrode or melt.

- Least expensive of the coated conductor materials.
- Highly conductive, abundant and easily shaped or formed and is strong, yet flexible.
- Meets the minimum specified requirements of ASTM B-33 and CID A-A-59551 (QQ-W-343).
- Commonly used in Electronics Industries.

c) **Heavy Tinned Copper:** Similar to tinned copper except with a heavier tin thickness. Typically 100 micro-inches for # 31 AWG[2] and smaller and 150 micro-inches on # 30 AWG and larger. This type of copper was primarily used for high frequency induction heaters. UL, CSA and the military permit this.

d) **Overcoated Copper:** Consist of an overall tin coating being applied over the top of a stranded conductor. Typically used in AWG sizes 28 through 18 AWG. This design is popular in hand soldering since the overcoat of tin precludes a splaying out of the individual conductor strands. This type of strand is somewhat less flexible than tinned copper. UL and CSA permit this design, but the military does not.

e) **Top Coated Copper:** Similar to overcoat copper, this design consists of bare copper strands twisted together and a tin coating applied overall. Stranded conductors come in sizes 28 to 18 AWG. It is less flexible than tinned copper and is less costly than overcoated copper. The use of this design may result in interior copper surface oxidation if used in an oxidizing atmosphere. It has many of the same uses as overcoated copper. UL and CSA permit this, but the military does not.

f) **Prefused (Prebond) Copper:** Consists of twisted strands of heavy tinned copper fused with heat along its entire length. Restricted to sizes 26 to 16 AWG in concentric or equilay constructions. This type of conductor is less flexible than other types of stranded conductors and the strands won't spray out. UL and CSA permit this, but the military may only accept it under MIL-W-16878D. Even then, it must be specifically requested.

g) **Silver Coated Copper:** This type of coated copper is more expensive than tinned copper, but can operate continuously at temperatures to 200°C. At temperatures above 250°C oxidation and corrosion rapidly occur. This type of copper is used in high frequency applications where the higher conductivity of silver is desired, due to its skin effect. It meets the minimum specified requirements of ASTM B-298.

h) **High Strength Copper Alloy (HSCA):** These are more expensive than copper-covered steel (CCS) but are specified since they permit size/weight reductions. They offer greater flex life, due to their high breaking strength. Operating temperatures can go up to 100°C. This type of copper is typically used in the Aerospace industry. It meets the minimum specified requirements of ASTM B-624.

[2] AWG: American Wire Gauge.

i) **Nickel Coated Copper:** This type of coated copper is less expensive than silver coated copper, and can withstand prolonged operating temperatures from 200°C to 260°C. The soft soldering of this type of conductor is problematic since soldering irons or solder pots must be run in excess of 357°C. It meets the minimum specified requirements of ASTM B-355.

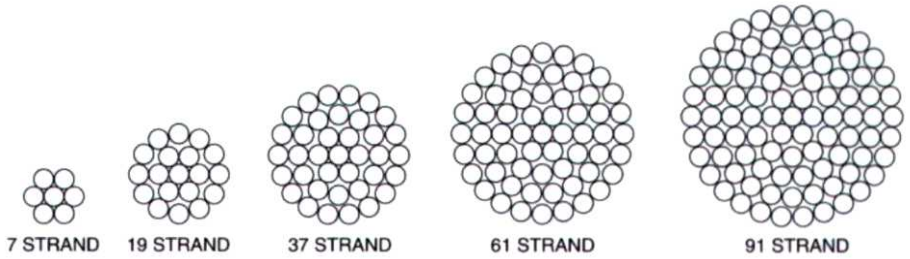
j) **Copper Covered Steel or Copper Clad Steel:** Is created by continuously fusing two different types of metals together. Some of the coatings are bare per ASTM B-869 (21% conductivity) or ASTM B-452 (30% & 40% conductivity), Tin per ASTM B-520 (30% & 40% conductivity), Silver per ASTM B-501 (30% & 40% conductivity) and Nickel per ASTM B-559 (30% & 40% conductivity). This type of conductor is usually found in coaxial cables. The benefit of a copper steel strand in coaxial cables is that it provides integral "messenger" ability; therefore, it is "self-supporting" over catenaries. Additionally, since at higher frequencies the center of the conductor does not carry any signal, the cost of the conductor is reduced by using steel rather than copper as the core of the conductor.

k) **Aluminum (Al):** It has some properties similar to copper, but is only used in very specific applications, such as service entrance cable. Aluminum conductors are no longer permitted as wiring inside commercial or residential buildings due to the galvanic interaction of aluminum and the brass connectors of electrical devices. Additionally, the equivalent gauge size of an aluminum conductor to carry equal levels of current as in a copper conductor is a difference of two gauge sizes larger.

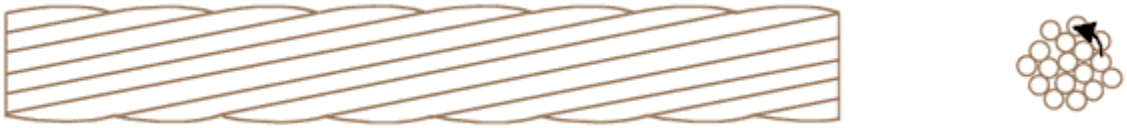
3. **Conductor Stranding:** There are several types of stranding commonly used in the wire and cable industry. These include:

a) **Solid conductor:** The cross-sectional area appears as a solid circle. It is the most economical, but is stiff and subject to breakage.

b) Stranded conductor: Where the cross-sectional area is not a solid circle. It is flexible and can withstand repeated bending. It is more expensive than solid and is made up of various individual gauge sizes to create the finished AWG size. For example a 22 AWG 7/30 consists of seven individual strands of 30 gauge wire with a circular mil area (CMA) of 100, twisted together to create the required circular mil area of 700 for a 22 AWG wire. A 20 AWG 10/30 has ten strands of 30 gauge (CMA = 100) twisted together to obtain an overall CMA = 1000. Examples of stranded conductors are as follows:



- **Bunched:** Individual strands twisted together with no specific geometric configuration. These types of conductors are usually used in static cable designs, such as the Alpha Xtra-Guard® Series.



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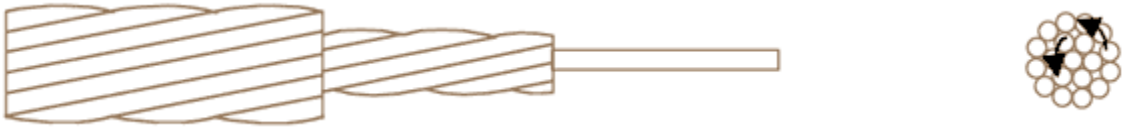
- **Unilay®:** Conductors are twisted together with the same lay direction and cable lay length and have a well-defined geometric configuration and defined cross-section. These types of conductors are usually used in static cable designs, such as the Alpha Xtra-Guard Series.



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- **Unidirectional Concentric**: Specific groupings of conductor strands into a circular pattern that are surrounded by one or more layers of helically laid conductors with the same direction or lay and increasing lay length in each layer. These types of conductors are usually used in torsional designs, such as the Alpha Xtra-Guard Series High-Flex Torsion Series for Robotics applications.

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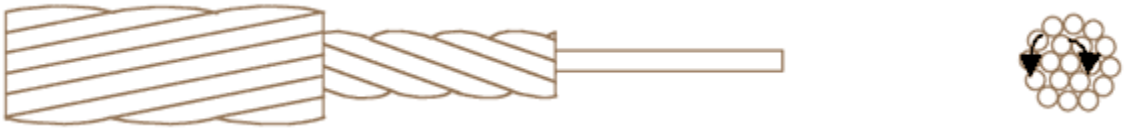
- **Concentric or True Concentric (Contra-helical):** Conductors that are surrounded by well-defined layers of helically laid conductors. Each layer has a reversed lay direction and an increasing lay length in each layer. These types of conductors are usually used in torsional designs, such as Alpha Xtra-Guard High-Flex Series Control Cables for continuous flexing.



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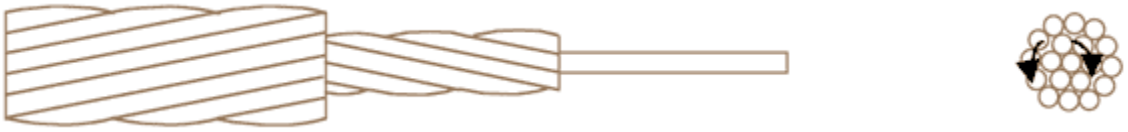
- **Equilay®:** Conductors that are surrounded by well-defined layers of helically laid conductors. Each layer has a reversed lay direction and an increasing lay length in each layer. These types of conductors are usually used in torsional designs, such as Alpha Xtra-Guard High-Flex Control Series Cables for continuous flexing.



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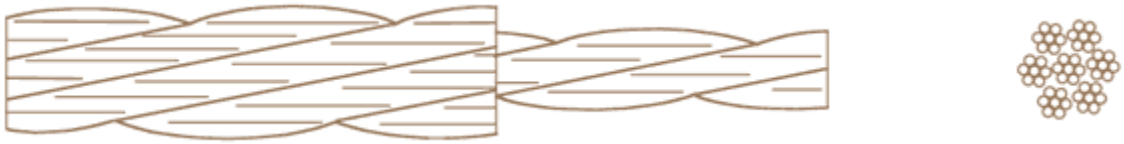
- **Rope:** Consists of several groups of either bunched or concentric combined into a circular pattern. The most common number of groups is usually 7 or 19.



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4. **Wire Gauge Sizes:** There are several systems used to define the size of conductors. Some of the more common ones are the American Wire Gauge (AWG), British Standard Wire Gauge (Imperial) and Metric Wire Gauge. The one commonly used in the United States is the American Wire Gauge (AWG); previously know as the Brown & Sharpe Wire Gauge. The AWG system consists of even numbered sizes ranging from 4/0 or No. 0000 (the largest) down to No. 36 (the smallest). In many of the AWG charts used today, the smallest size is #56 AWG. Gauges 45 through 56 were added in 1961 although the system itself was originally developed in 1912. The AWG system is based upon two gauges that were exact whole numbers with all intermediate gauges calculated from these two fixed values in terms of a geometric progression.

- Simple AWM system tools to include:

  - An increase of three gauge sizes (36 to 33) approximately doubles the cross section and weight and reduces the resistance by half.
  - An increase of six gauge sizes (36 to 30) approximately doubles the diameter.
  - An increase of ten gauge sizes (36 to 26) multiples the cross section and weight by approximately ten and divides the resistance by ten.

5. Although not a comprehensive chart of all AWG sizes and designs, the AWG Chart shown on the next page is representative of many of the common designs in frequent use today.

CONDUCTOR CHART

									BARE COPPER		TINNED COPPER	
				CIRCULAR			WEIGHT		D.C. RESISTANCE		D.C. RESISTANCE	
		APPROX. O.D.		MIL	SQUARE		LBS./		OHMS/	OHMS/	OHMS/	OHMS/
AWG	STRANDING	INCHES	MM	AREA	INCHES	MM	1000 FT.	KG/KM	1000 F.T.	KM	1000 F.T.	KM
36	Solid	0.005	0.127	25.0	0.00002	0.013	0.076	0.113	415	1361	445	1461
36	7/44	0.006	0.152	28.0	0.00002	0.014	0.086	0.129	378	1239	406	1330
34	Solid	0.006	0.160	39.7	0.00003	0.020	0.120	0.179	261	857	280	920
34	7/42	0.008	0.191	43.8	0.00003	0.022	0.135	0.201	242	793	260	851
32	Solid	0.008	0.203	64.0	0.00005	0.032	0.194	0.289	162	532	174	571
32	7/40	0.009	0.236	67.3	0.00005	0.034	0.208	0.309	157	516	169	554
32	19/44	0.010	0.254	76.0	0.00006	0.039	0.234	0.349	139	457	149	490
30	Solid	0.010	0.254	100	0.00008	0.051	0.303	0.451	104	340	111	365
30	7/38	0.012	0.305	112	0.00009	0.057	0.346	0.514	94.5	310	101	333
30	19/42	0.013	0.318	119	0.00009	0.060	0.366	0.545	89.1	292	95.6	314
28	Solid	0.013	0.320	159	0.00012	0.080	0.481	0.716	65.3	214	69.4	228
28	7/36	0.015	0.381	175	0.00014	0.089	0.540	0.804	60.4	198	64.9	213
28	19/40	0.016	0.394	183	0.00014	0.093	0.564	0.839	57.9	190	62.2	204
27	7/35	0.017	0.427	220	0.00017	0.111	0.678	1.01	48.2	158	51.7	170
26	Solid	0.016	0.404	253	0.00020	0.128	0.765	1.14	41.0	135	43.6	143
26	10/36	0.020	0.508	250	0.00020	0.127	0.772	1.15	42.3	139	45.4	149
26	19/38	0.020	0.508	304	0.00024	0.154	0.938	1.40	34.8	114	37.4	123
26	7/34	0.019	0.480	278	0.00022	0.141	0.857	1.28	38.1	125	40.9	134
24	Solid	0.020	0.511	404	0.00032	0.205	1.22	1.82	25.7	84.2	26.7	87.6
24	7/32	0.024	0.610	448	0.00035	0.227	1.39	2.06	23.6	77.4	25.3	83.1
24	10/34	0.025	0.640	397	0.00031	0.201	1.22	1.82	26.7	87.4	28.6	93.8
24	19/36	0.025	0.635	475	0.00037	0.241	1.47	2.18	22.3	73.0	23.9	78.4
24	41/40	0.023	0.583	394	0.00031	0.200	1.22	1.81	26.8	88.1	28.8	94.5
22	Solid	0.025	0.643	640	0.00050	0.324	1.94	2.88	16.2	53.1	16.8	55.3
22	7/30	0.030	0.762	700	0.00055	0.355	2.16	3.22	15.1	49.6	16.2	53.2
22	19/34	0.032	0.800	754	0.00059	0.382	2.33	3.46	14.0	46.0	15.1	49.4
22	26/36	0.029	0.737	650	0.00051	0.329	2.01	2.99	16.3	53.4	17.5	57.3
20	Solid	0.032	0.813	1024	0.00080	0.519	3.10	4.61	10.1	33.2	10.5	34.5
20	7/28	0.038	0.960	1111	0.00087	0.563	3.43	5.11	9.52	31.2	10.1	33.2
20	10/30	0.040	1.016	1000	0.00079	0.507	3.09	4.60	10.6	34.7	11.4	37.2
20	19/32	0.040	1.016	1216	0.0010	0.616	3.76	5.60	8.70	28.5	9.34	30.6
20	26/34	0.037	0.928	1032	0.0008	0.523	3.18	4.74	10.3	33.6	11.0	36.1
20	41/36	0.037	0.940	1025	0.0008	0.519	3.17	4.71	10.3	33.9	11.1	36.3
18	Solid	0.040	1.02	1624	0.0013	0.823	4.92	7.32	6.39	20.9	6.64	21.8
18	7/26	0.048	1.21	1770	0.0014	0.897	5.46	8.13	5.98	19.6	6.35	20.8
18	16/30	0.047	1.19	1600	0.0013	0.811	4.94	7.36	6.61	21.7	7.10	23.3
18	19/30	0.050	1.27	1900	0.0015	0.963	5.87	8.74	5.57	18.3	5.98	19.6
18	41/34	0.047	1.18	1627	0.0013	0.825	5.02	7.47	6.50	21.3	6.98	22.9
18	65/36	0.048	1.21	1625	0.0013	0.823	5.02	7.47	6.51	21.4	6.99	22.9
16	Solid	0.051	1.29	2581	0.0020	1.31	7.81	11.6	4.02	13.2	4.18	13.7
16	7/24	0.060	1.53	2828	0.0022	1.43	8.73	13.0	3.74	12.3	3.89	12.8
16	65/34	0.060	1.52	2580	0.0020	1.31	7.96	11.8	4.10	13.4	4.40	14.4

CONDUCTOR CHART

									BARE COPPER D.C. RESISTANCE		TINNED COPPER D.C. RESISTANCE	
		APPROX. O.D.		CIRCULAR MIL	SQUARE		WEIGHT LBS./		OHMS/	OHMS/	OHMS/	OHMS/
AWG	STRANDING	INCHES	MM	AREA	INCHES	MM	1000 FT.	KG/KM	1000 F.T.	KM	1000 F.T.	KM
16	26/30	0.058	1.47	2600	0.0020	1.32	8.04	12.0	4.07	13.3	4.37	14.3
16	19/29	0.057	1.44	2426	0.0019	1.23	7.50	11.2	4.36	14.3	4.63	15.2
16	105/36	0.058	1.47	2625	0.0021	1.33	8.11	12.1	4.03	13.2	4.33	14.2
14	Solid	0.064	1.63	4109	0.0032	2.08	12.4	18.5	2.52	8.28	2.63	8.61
14	7/22	0.076	1.93	4481	0.0035	2.27	13.8	20.6	2.36	7.74	2.46	8.05
14	19/27	0.071	1.80	3831	0.0030	1.94	11.8	17.6	2.76	9.06	2.93	9.6
14	41/30	0.074	1.88	4100	0.0032	2.08	12.7	18.9	2.58	8.46	2.77	9.08
14	105/34	0.073	1.86	4167	0.0033	2.11	12.9	19.1	2.54	8.33	2.72	8.94
12	Solid	0.081	2.05	6529	0.0051	3.31	19.8	29.4	1.59	5.21	1.65	5.42
12	7/20	0.096	2.44	7168	0.0056	3.63	22.1	32.9	1.48	4.84	1.53	5.03
12	19/25	0.090	2.27	6088	0.0048	3.08	18.8	28.0	1.74	5.70	1.85	6.05
12	65/30	0.095	2.41	6500	0.0051	3.29	20.1	29.9	1.63	5.34	1.75	5.73
12	165/34	0.095	2.42	6549	0.0051	3.32	20.6	30.6	1.65	5.40	1.77	5.80
10	Solid	0.102	2.59	10384	0.0082	5.26	31.4	46.8	0.999	3.28	1.04	3.41
10	37/26	0.111	2.83	9354	0.0073	4.74	28.9	43.0	1.13	3.71	1.20	3.94
10	49/27	0.116	2.96	9880	0.0078	5.01	30.5	45.4	1.07	3.51	1.14	3.73
10	105/30	0.116	2.95	10500	0.0082	5.32	32.5	48.3	1.01	3.30	1.08	3.55
8	49/25	0.147	3.73	15700	0.0123	7.96	48.5	72.1	0.674	2.21	0.72	2.35
8	133/29	0.166	4.22	16983	0.0133	8.61	53.5	79.7	0.635	2.08	0.67	2.21
8	655/36	0.166	4.22	16375	0.0129	8.30	52.1	77.5	0.665	2.18	0.71	2.34
6	133/27	0.209	5.30	26818	0.0211	13.6	84.4	126	0.402	1.32	0.427	1.40
6	259/30	0.210	5.33	25900	0.0203	13.1	81.6	121	0.416	1.37	0.447	1.47
6	1050/36	0.204	5.18	26250	0.0206	13.3	83.5	124	0.415	1.36	0.445	1.46
4	133/25	0.263	6.68	42615	0.0335	21.6	134	200	0.253	0.830	0.269	0.882
4	259/28	0.265	6.72	41119	0.0323	20.8	130	193	0.262	0.860	0.279	0.914
4	1666/36	0.290	7.37	41650	0.0327	21.1	132	197	0.261	0.858	0.281	0.921
2	133/23	0.332	8.44	67931	0.0534	34.4	214	318	0.159	0.521	0.165	0.542
2	259/26	0.334	8.48	65478	0.0514	33.2	206	307	0.165	0.540	0.175	0.574
2	665/30	0.335	8.51	66500	0.0522	33.7	212	315	0.164	0.537	0.176	0.577
2	2646/36	0.298	7.56	66150	0.0520	33.5	212	316	0.166	0.545	0.178	0.585
1	133/22	0.372	9.45	85132	0.0669	43.1	268	399	0.127	0.416	0.132	0.432
1	259/25	0.376	9.55	82986	0.0652	42.1	261	389	0.130	0.426	0.138	0.453
1	836/30	0.377	9.58	83600	0.0657	42.4	266	396	0.130	0.427	0.140	0.459
1	2107/34	0.375	9.52	83627	0.0657	42.4	268	399	0.131	0.431	0.141	0.463
1/0	133/21	0.419	10.6	108029	0.0849	54.7	340	506	0.100	0.327	0.104	0.341
1/0	259/24	0.422	10.7	104639	0.0822	53.0	329	490	0.103	0.338	0.107	0.352
2/0	133/20	0.470	11.9	136192	0.1070	69.0	429	638	0.079	0.260	0.082	0.270
2/0	259/23	0.475	12.1	132287	0.1039	67.0	416	620	0.082	0.267	0.085	0.278
3/0	259/22	0.531	13.5	165783	0.1302	84.0	522	777	0.065	0.213	0.068	0.222
3/0	427/24	0.539	13.7	172512	0.1355	87.4	548	816	0.063	0.207	0.066	0.215
4/0	259/21	0.599	15.2	210373	0.1652	107	662	986	0.051	0.168	0.053	0.175
4/0	427/23	0.606	15.4	218095	0.1713	111	693	1032	0.050	0.164	0.052	0.170

Insulation Compounds

In this section, wire and cable insulation will be discussed. At the end of this section, the reader will understand the use and types of insulation and the variety of materials that may be used as insulation.

A brief history of insulating materials:

At one point, there was no insulation material used over the conductors, which were usually made of iron and separated by ceramic spacers. As time progressed, it was determined that copper conductors covered with non-conducting materials would function better than the uninsulated iron ones. In 1846 and 1847 a substance called gutta percha was being experimented with as a possible insulation material over conductors. In the summer of 1848 the first underground telegraph line using gutta percha insulation was laid from Berlin to Gross Bersen. The next insulation material used was a cotton serve, which was soon followed by a woven braid, which was generally made of cambric (textile). As time progressed, it was determined that cambric impregnated with varnish would have better resistance against the elements. As technology moved forward, it was found that even the cambric impregnated with varnish didn't hold up well to the weather or to insects. It was at this point that the polymeric materials began to emerge as insulating material. The use of polymeric materials continues to grow and is still widely used today. Along with polymeric materials, elastomeric, or rubber materials, were also being developed and used as insulating materials. Today thermoplastics are widely used for insulation material, along with fluorocarbons and thermosets.

1. **Insulation:** A material having a good dielectric property that has a high resistance to the flow of electric current.

2. There are several types of insulating materials used in the industry today. The most common ones are listed below:

a) **Thermoplastic:** Material that can be repeatedly heated, softened and formed into any shape when hot. Once cooled, the material becomes firm or rigid and will hold its shape until reheated. Members of the Thermoplastic family are listed below:

- **Polyvinylchloride (PVC) or vinyl:** Vinyl resin must be blended with other ingredients to make it a useful insulation material. Vinyl resin alone is not suitable for use as insulation, since it is extremely rigid and can be subjected to degradation at processing temperatures. The ingredients added along with the vinyl resin determine the properties for the finished PVC formulation. PVC is a popular material for use as insulation or jackets. Most PVC compounds can be made flame retardant and UV resistant. PVC compounds can also be made to be oil resistant. PVC compounds will usually swell if exposed to chlorinated hydrocarbons, esters and ketones. PVC in general has some resistance to water and diluted acids. The dielectric properties of PVC will vary, depending on the specific finished compound. Compounds with temperatures ranging from –55°C to + 105°C are available. There is no single PVC compounds available that will cover the entire temperature range listed above.

  Temperature ratings ranging from –10°C to +105°C are the most common, such as used in our Xtra-Guard 1 Series. PVC is not recommended for applications where low dielectric loss is required. Over time, plasticizers will begin to migrate out of the

compound, which causes cracking or embrittlement that reduces its service life. The latest issue relative to vinyls is that they contain lead, which has been deemed environmentally damaging.

- **Semi-Rigid Polyvinylchloride (SR-PVC):** Commonly used for insulation walls ≤ 0.010" and temperature range of −10°C up to +105°C. See our Xtra-Guard 1 Series.

- **Polyethylene (PE):** Is a member of the polyolefin group polyethylene and copolymers of ethylene and propylene. Common use of these terms has made polyethylene and polyolefin synonymous. PE has a relatively low dielectric constant, which makes is useful for a wide array of applications. Temperature ratings ranging from −65°C to 90°C. PE offers good resistance to many acids, alkalis and organic solvents. The reason for using PE insulation is simply for better low level signal transmission properties.

  Here are a few types of PE compounds used:

  - **Foamed (cellular) PE:** Is used as an insulation material. It was found that by creating bubbles of air in the compound, resulted in better electrical properties and a cost savings, since less compound needed to be used to maintain electrical characteristics. Properties like these are important where high quality signals are to be transmitted, such as in coaxial and telephone circuits. However, conductors with cellular PE insulations are subject to a high degree of moisture ingress, since the open structure (bubbles) is weak and has very little tensile strength. This leaves them vulnerable to crushing and mechanical abuse. Dual wall extrusions help by providing a solid layer of PE over the foamed one.

  - **Solid PE:** Is available in a few forms, such as:
    - Linear low-density polyethylene (LLDPE)
    - Low density polyethylene (LDPE)
    - Medium density polyethylene (MDPE)
    - High-density polyethylene (HDPE).

  - **Cross-Linked or Irradiated Polyethylene (XLPE):** Is used as both an insulation and a jacket and has a maximum operating temperature rating of 125°C. Cross-linking is a process that transforms the thermoplastic material into a thermoset material. This transaction is done either chemically or by irradiation. Whichever method is used, the compound achieves the same basic characteristics. Cross-linked compounds usually have better chemical and thermal properties.

- **Polypropylene (PP):** Used mostly as an insulation material and has a maximum temperature rating of -55°C to 105°C in some cases. PP exhibits many of the same electrical properties as PE. PP offers good resistance to abrasion, chemicals, heat and moisture. It also offers good resistance to most acids, alkalis, salts and aliphatic. At elevated temperatures, chlorinated hydrocarbons and low molecular weight aliphatic compounds will cause some swelling, which softens the material. PP with carbon black, offers good UV resistance. PP can be foamed and in a foamed state exhibits better mechanical characteristics than does PE.

- **Cross-Linked or Irradiated Polyvinylchloride (XL-PVC):** Used as both an insulation and a jacket and has a maximum operating temperature rating of 105°C. Cross-linking is a process that transforms the thermoplastic material into a thermoset material. This transaction is done either chemically or by irradiation. Whichever method is used, the compound achieves the same basic characteristics. Cross-linked compounds usually have better chemical and thermal properties.

- **Nylon 6**: Typically used over PVC insulation to improve crush resistance and has a maximum operating temperature rating of 115°C.

- **Thermoplastic Elastomer (TPE) or Thermoplastic Rubber (TPR):** They have rubber-like attributes with the processability of thermoplastic materials. It has a temperature range of -60°C to 125°C. Resistant to fuels, oils, solvents and water. TPE's can be made highly flame resistant. These have low corrosive outgassing and are acid and alkali resistant. TPE's and TPR's remain flexible at low temperatures.

- **Polyester Elastomer:** Used as both an insulation and a jacket and has a maximum operating temperature rating of 90°C. It is a flexible thermoplastic that can be used in place of rubber and some urethanes. It has good chemical resistance properties and performs well under impact testing, with very thin walls.

- **Modified Polyphenylene Ether (mPPE):** This material is inherently lighter, tougher, more durable than PVC and easily recycled. It contains no halogens, phthalates, or heavy metals. The superior dielectric properties of mPPE enables reduced wall thickness while maintaining the same electrical properties as PVC. It offers a 10 times better abrasion and pinch resistance than PVC. This compound is used for Alpha Wire's EcoWire™ product line.

b) **Fluorocarbon:** These are compounds that contain fluorine in their molecular structure.

- **Tetrafluoroethylene (TFE)**: Used as both insulation and jacket and has a maximum continuous operating temperature rating of 260°C with a maximum intermittent operating temperature range of 316°C. TFE was first produced by DuPont Corporation in the late 1930's. Originally developed for military applications in the late 1940's it found its way into commercial markets. It offers excellent chemical resistance and good electrical properties. It can't be extruded using conventional extrusion equipment, like those used for thermoplastics. It requires special ram extrusion equipment which sets it apart from the more conventional heat extrusion models. A ram extruder uses high pressure as opposed to high heat. Since TFE can't be melt extruded, it is impossible to have long continuous lengths. The only way to fabricate relatively long lengths is to form the material into rolls of TFE tape. Once it is in the form of a tape, then it can be applied helically around a conductor and would have to pass through 600°C sintering towers to fuse the tape edge together. Due to the high heat needed for tape fusing, the conductor must be either silver or nickel coated, since tin coating would oxidize at best or melt at worst.

- **Fluorinated Ethylene-Propylene (FEP):** Used as both insulation and jacket and has a maximum continuous operating temperature rating of 200°C with a maximum intermittent operating temperature of 232°C. FEP was developed to offset some of the shortcomings of TFE. An advantage of FEP is that it can be heat extruded using conventional extrusion equipment.

- **Ethylene-Tetrafluoroethylene-Copolymer (ETFE):** Used as both insulation and jacket and has a maximum continuous operating temperature rating of 150°C and a maximum intermittent operating temperature of 199°C. It is a modified copolymer of tetrafluoroethylene and ethylene and provides excellent chemical and abrasion resistance as well as mechanical strength. It also has a low dielectric constant, so it has good electrical properties.

- **ECTFE:** Used mostly as an insulation. This is a copolymer of ethylene and chlorotrifluoroethylene that provides excellent chemical and abrasion resistance. It can be used for those applications where one requires better performance than offered by PVDF.

- **Polyvinylidene Fluoride (PVDF):** Has a temperature range of -40°C to 150°C and affords high resistance to acids and alkalis. It also has high impact resistance and tensile strength. It is a very stable and pure resin, which is used in several industries, such as electrical and electronic manufacturing, tubing, piping and those products used for handling fluids.

c) Thermosets:

- **Styrene-Butadiene Rubber (SBR):** This is a synthetic rubber that possesses excellent abrasion resistance and electrical characteristics. SBR decomposes when exposed to oil, ozone and weather. It has an operating temperature range of -55°C to 90°C. It is highly flammable, unless flame-retardants are added.

- **Polychloroprene:** Used mostly as a jacket material. It is basically a synthetic rubber and possesses better characteristics than SBR. It has an operating temperature range of -55°C to 90°C.

- **Chlorinated Polyethylene (CPE):** Typically used as a jacket material. Note: In our Fiber Optic cables we are using thermoplastic CPE as a jacket. It combines good LOI and good chemical resistance similar to polyethylene.

- **Chlorosulfonated Polyethylene (CSPE):** Is a chlorosulfonated polyethylene primarily used as a jacket material. It works well in harsh environments, such as those encountered in the industrial and mining industries. It provides good abrasion, heat, moisture and ozone resistance.

d) **Silicone:** Used as both insulation and a jacket, and it has an operating temperature range of -65°C to 200°C. It provides good abrasion, oil and heat resistance. It is commonly used as insulation on spark plug wires or as a jacket on power and control cables, where the cables need to be isolated from there surrounding environment.

3. **Insulation Properties:** The charts shown below are also located in the Alpha Wire Master Catalog in the Technical Data section.

Insulation-Materials Property Chart

PROPERTIES	PVC	PE	POLYPROPYLENE	TFE	FEP	PVDF	TPE
1 Abrasion Resistance	Good	Good	Fair	Fair	Good	Good	Good
2 Heat Resistance	Good	Good	Good	Excellent	Excellent	Excellent	Excellent
3 Weatherability	Good	Excellent	Excellent	Excellent	Excellent	Good	Excellent
4 Flame Retardancy	Excellent	Poor	Poor	Excellent	Excellent	Excellent	Excellent
5 Water Resistance	Good	Excellent	Excellent	Excellent	Good	Good	Good
6 Acid Resistance	Good	Good	Excellent	Excellent	Excellent	Excellent	Excellent
7 Alkali Resistance	Good	Good	Excellent	Excellent	Excellent	Excellent	Excellent
8 Aliphatic Hydro. Resis.	Good	Poor	Fair	Excellent	Excellent	Excellent	Poor
9 Aromatic Hydro. Resis.	Poor	Poor	Fair	Excellent	Excellent	Excellent	Poor

PROPERTIES	ASTM METHOD	PVC	PE	POLY-PROPYLENE	TFE	FEP	PVDF	TPE
1 Specific Gravity	D-792-66	1.16-1.70	0.91-1.26	0.890-0.905	2.13-2.20	2.12-2.17	1.75-1.78	1.16-1.20
2 Tensile Strength, psi	D-638-77	1500-4500	1500-2200	2900-4500	1000-3500	2700-3100	5200-7500	2300
3 Elongation, %	D-412-75	40-400	180-600	700	275	250-330	500	500
4 Volume Resistivity, ohm-cm	D-257-78	10^4-10^{16}	$>10^{15}$	1.5×10^{15} 2.8×10^{15}	$>10^{18}$	2.0×10^{18}	2×10^{14}	2.2×10^{18}
5 Dielectric Strength, volts/mil	D-149-75	250-500	230-1420	450-850	500	500-600	260	625
6 Dielectric Constant @ 60 Hz	D-150-78	3.2-9.0	2.28-2.50	2.50-2.75	2.0-2.1	2.1	8.40	2.8
7 Dielectric Constant @ 1 kHz	D-150-78	3.0-8.0	2.27-2.50	2.50-2.65	2.0-2.1	2.1	7.9	2.8
8 Power Factor (Dissipation) @ 60 Hz	D-150-78	.007-0.15	0.003-0.044	0.0054-0.0070	0.0004	0.0002	0.049	0.002
9 Power Factor Dissipation) @ 1 kHz	D-150-78	.009-0.16	.00048-.00049	.0036-.0050	0.0001	0.0007	0.019	0.002

The above chart reflects a qualitative comparison of insulating properties and should be used as a general guide only.
For specific compound information, consult Alpha's Engineering Staff.
Note: All values shown are nominal.

3. **Insulation Properties:** The charts shown below are also located in the Alpha Wire Master Catalog in the Technical Data section.

Insulation-Materials Property Chart

PROPERTIES	ETFE	NATURAL RUBBER	CSPE	POLYCHLOROPRENE	SILICONE	POLYURETHANE
1 Abrasion Resistance	Good	Excellent	Good	Excellent	Fair	Excellent
2 Heat Resistance	Excellent	Fair	Excellent	Good	Excellent	Good
3 Weatherability	Good	Fair	Excellent	Good	Excellent	Good
4 Flame Retardancy	Excellent	Poor	Good	Good	Good	Good
5 Water Resistance	Excellent	Good	Good	Excellent	Excellent	Good
6 Acid Resistance	Excellent	Fair	Excellent	Good	Good	Fair
7 Alkali Resistance	Excellent	Fair	Excellent	Good	Good	Fair
8 Aliphatic Hydro. Resis.	Excellent	Poor	Fair	Good	Poor	Good
9 Aromatic Hydro. Resis.	Excellent	Poor	Fair	Fair	Poor	Poor

PROPERTIES	ASTM METHOD	ETFE	NATURAL RUBBER	CSPE	POLYCHLOROPRENE	SILICONE	POLY-URETHANE
1 Specific Gravity	D-792-66	1.70-1.86	1.3-1.7	1.35-1.7	1.23-1.65	1.1-1.6	1.30
2 Tensile Strength, psi	D-638-77	6500	1500-4000	1200-2200	1200-2700	1000	>3500
3 Elongation, %	D-412-75	200	300-700	300-600	300-700	100-500	540-750
4 Volume Resistivity, ohm-cm	D-257-78	$>10^{16}$	10^{13}-10^{16}	10^{12}-10^{14}	10^{11}-10^{13}	2×10^{14} 8×10^{13}	11×10^{14}
5 Dielectric Strength, volts/mil	D-149-75	500	---	500	600	100-700	330-630
6 Dielectric Constant @ 60 Hz	D-150-78	2.6	---	---	---	---	5.4-7.6
7 Dielectric Constant @ 1 kHz	D-150-78	2.6	2.3-3.0	9.0-11.0	5.0-7.0	3.0-3.5	5.6-7.6
8 Power Factor (Dissipation) @ 60 Hz	D-150-78	---	---	---	---	---	0.015-0.046
9 Power Factor (Dissipation) @ 1 kHz	D-150-78	0.0006	.00023-.00030	0.05-0.07	3.5	0.001-0.010	0.043-0.060

The above chart reflects a qualitative comparison of insulating properties and should be used as a general guide only.
For specific compound information, consult Alpha's Engineering Staff.
Note: All values shown are nominal.

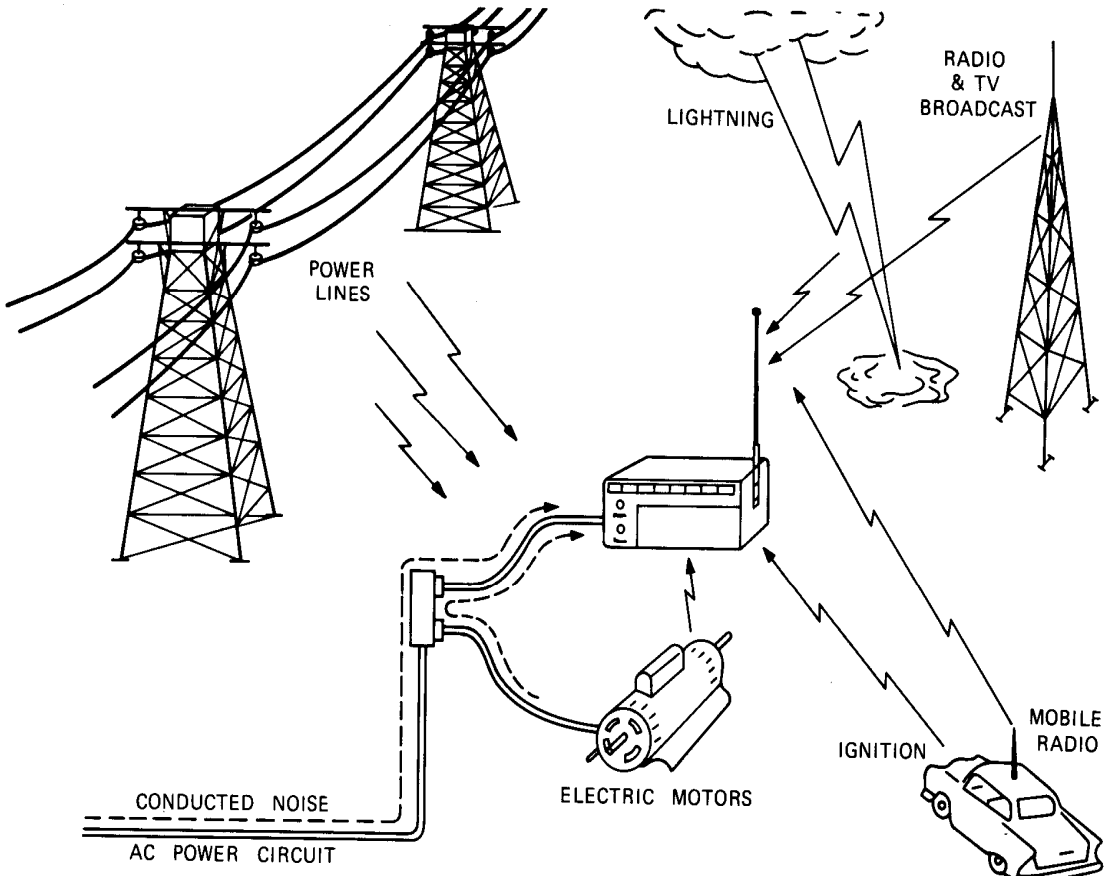
Shielding and Armoring Materials

In this section you will learn about the various types of cable shielding and armoring options, their use and the types of materials commonly used in shielding cables.

Shield: Is a material that is electrically conductive and surrounds a wire or cable. The shield's primary function is to limit any signal trying to escape from the wire or cable. It also inhibits external signals or interference from flowing into the wire or cable. Braids, armor and corrugated metal can also provide mechanical protection for the cable.

Now that you know what a shield is, we will discuss the various types of interference:

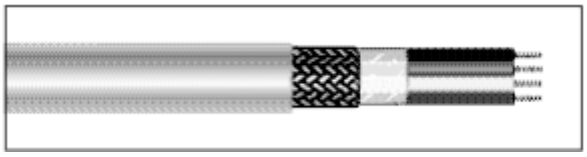
- **Electromagnetic interference (EMI):** Any electromagnetic disturbance that interrupts or limits the performance of electrical or electronic devices. Examples of electromagnetic interference: Electric Motors or Ballasts in fluorescent light fixtures.
- **Electrostatic interference:** Any electrostatic interference such as motor spiking.



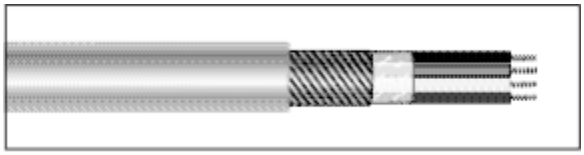
Henry W. Ott, Noise Reduction Techniques in Electronic Systems

There are a few basic types of shields used in the wire and cable industry today. The most popular ones are listed below:

1. **Braid shields:** This is the oldest form of shielding still used today. Braids can be traced back to the shoelace industry since the machines used to make the laces were later used to make metal braids. A braid shield is a woven pattern made up of small gauge wires. Most braids are made up of either bare copper, tinned copper, silver plated copper, aluminum or steel. Rayon and fiberglass are also used in some instances as strength members but not for shielding, since these materials are non-conductive. There are other types of braiding material, but they are less popular in our industry. Braid shields typically have a nominal coverage of 55% to 95%. Braids are typically more expensive than a tape shield, due to the slow speed of the braider, the percent coverage desired and the material used to construct the braid. They are also more difficult to terminate.



2. **Spiral shields:** This is similar to a braid except that it is made up of single strands of wires spirally wrapped around a conductor or cable core. This type of braid is more flexible than a woven braid. It is also easier to terminate than the woven braid. Spiral shields typically have a nominal coverage of 95% to 98%. Spiral shields are most effective in the audio frequency range and are typically found in microphone and audio cables.



3. **Tape shields:** These are made from various materials. They normally consist of a laminate of aluminum and polyester layers joined together by adhesive. These types of shields are fragile and provide little in the way of mechanical strength. The adhesive is typically a pressure sensitive solvent release adhesive. Listed below are some of the more popular ones used today:
    - Aluminum/Polyester
    - Aluminum/Polypropylene (AP)
    - Aluminum/Polyester/Aluminum (APA)
    - Foil Free Edge
    - Bonded

    Some examples of the various types of tapes are shown on the next page.

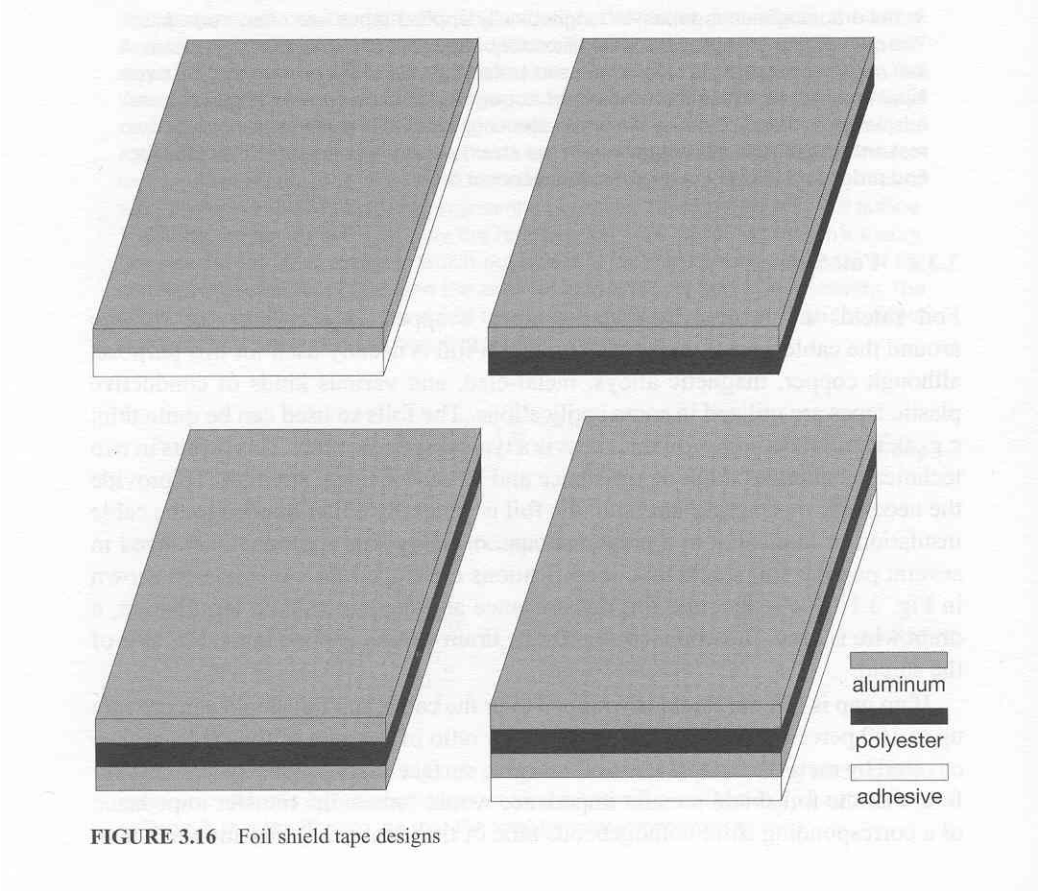


FIGURE 3.16 Foil shield tape designs

Anatoly Tsaliovich, Cable Shielding for Electromagnetic Compatibility, Chapman & Hall, 1995, page176.

Terms typically used in conjunction with foil shields are:

- **Longitudinal** or pull in is some times referred to as a cigarette wrap. This is where the tape is applied longitudinally and folded over its self to form a typical 25% overlap. This can be applied either with the foil side facing inward or outward, relative to the cable core.

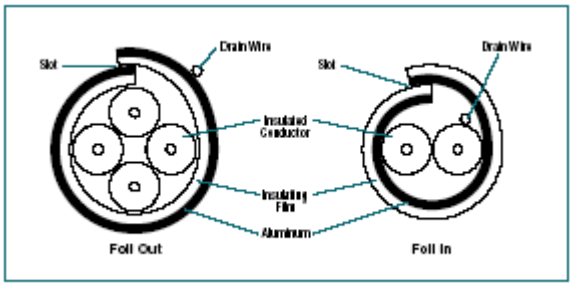


Figure 1: Foil shield configurations without shorting tabs.

Belden Catalog MCAT-2003, page 16.11

- **J-Fold:** This type of fold allows for a metal-to-metal contact. Without metal-to-metal contact the signal could escape and cause interference.

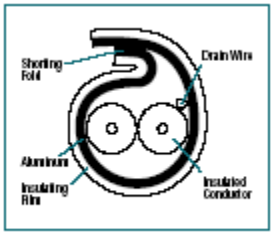


Figure 2: Foil shield configuration with shorting fold.

Belden Catalog MCAT-2003, page 16.11

- **Z-Fold:** Is a combination of a metal-to-metal contact with the addition of an isolation fold. This type of design is typically used in individually shielded pair cables where total shield isolation is required between the pairs.

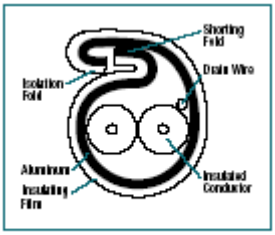
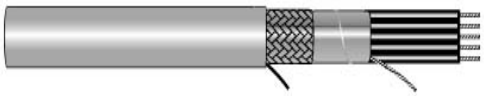


Figure 3: Foil shield with Z-Fold reduces crosstalk in multi-pair applications.

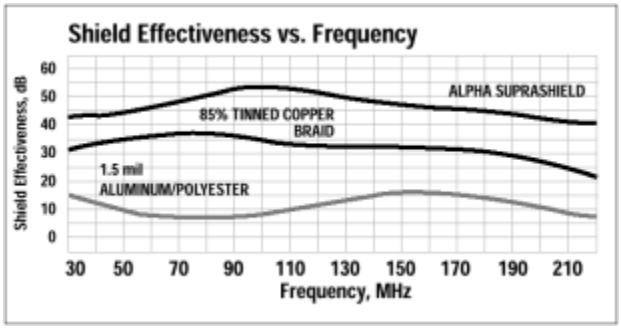
Belden Catalog MCAT-2003, page 16.11

- **Spiral wrap:** This is where a tape is spirally wrapped around the core.

4. SUPRA-SHIELD®**:** This is a term used by Alpha Wire to describe a combination of an aluminum/polyester/aluminum foil shield and a 70% tinned copper braid shield. This provides the **best** combination for shielding and makes the cable suitable for a wide array of applications where good EMI shielding is required.

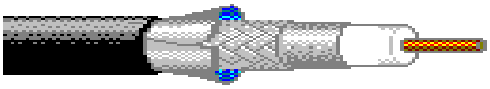


The following graph shows the measured Shield Effectiveness verses Frequency for a aluminum/polyester tape (1.5 mils thick), 85% Tinned Copper Braid and the Alpha SUPRA-SHIELD. This graph is also located in the Technical Data section of the master catalog.



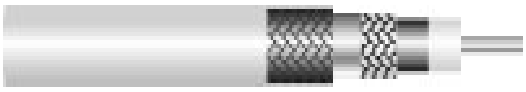
5. There are various other types of shielding used:

   - **Tri-Shield**: Which is a foil/braid/foil



Belden Catalog MCAT-2003, Page 14.12

   - **Quad Shield:** Which is a foil/braid/foil/braid. These types are typically found in coaxial cables.

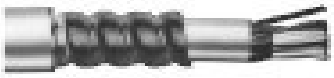


6. **Armors:** Metallic outer covering that protects the cable from mechanical damage. There are a few types of armors used today. The most common is the "Interlock" type of armor.

    - **Longitudinal:** A relatively thick (6 to 12 mils) "tape" is longitudinally formed and wrapped around the cable and covered by a jacket. The tape may be made of steel, aluminum, bronze or copper. The choice of material is a function of the frequency range of the signal that is being kept in or kept out of the cable as well as the degree of mechanical protection that is desired for the cable. This type of shield may be applied smooth or corrugated if somewhat improved flexibility is desired. The aluminum and steel materials may be coated with a thin plastic coating that thermally bonds to the jacket, improving the mechanical characteristics of the sheath and also improving chemical resistance. The seam may simply be overlapped or continuously corrugated and welded (CCW).

Picture is from Tamaqua Cable Products Corp.

    - **Interlock:** A heavy steel, copper or aluminum strip (20 to 25 mils) is spirally wrapped around the cable core. As it is wrapped, the edges are formed and shaped so that each wrap is interlocked with the preceding wrap. The result is a very strong and robust product. For this reason, interlocking is most often thought of as an armoring rather than a shielding, though it does both. Copper strips provide excellent low frequency noise mitigation.



Jacket Compounds

In this section, wire and cable jackets will be discussed. At the end of this section, the reader will understand the use and types of jackets and the variety of materials that may be used as jackets.

1. **Jacket:** An outer covering that is typically placed around a group of insulated conductors, pairs, triads or other cable core components to provide mechanical protection as well as to aid in cable installations.

2. There are several types of jacket materials used in the industry today. The most common ones are listed below:

a) **Thermoplastic:** Material that can be repeatedly softened and is formable into any shape when hot. Once cooled, the material becomes firm or rigid and will hold its shape. Members of this family are as follows:

- **Polyvinylchloride (PVC) or vinyl:** Vinyl resin must be blended with other ingredients to make it a useful jacket material. Vinyl resin alone is not suitable for use as a jacket material, since it is extremely rigid and can be subjected to degradation at processing temperatures. The ingredients added along with the vinyl resin determine the properties for the finished PVC formulation. PVC is a popular material for use as insulation or jackets. Most PVC compounds can be made flame retardant and UV resistant. PVC compounds can also be made to be oil resistant. PVC compounds will usually swell if exposed to chlorinated hydrocarbons, esters and ketones. PVC in general has some resistance to water and dilute acids. The dielectric properties of PVC will vary, depending on the specific finished compound. Compounds with temperatures ranging from –65°C to + 105°C are available. There is no single PVC compound available that will cover the entire temperature range listed above. Temperature ratings ranging from –10°C to +105°C are the most common, as used in our Xtra-Guard 1 Series. Over time, plasticizers will begin to migrate out of the compound. This may cause cracking or embrittlement and reduces its service life.

- **Polyethylene (PE):** Solid PE is good in wet locations, such as direct burial applications. PE is available in several types, including linear low-density polyethylene (LLDPE), low density polyethylene (LDPE), medium density polyethylene (MDPE) and high-density polyethylene (HDPE). Temperature ratings ranging from 75°C to 90°C. Xtra-Guard 3 uses solid LDPE jacket.

Chlorinated Polyethylene (CPE): It combines most of the toughness and chemical resistance of PE with the flame retardance of PVC, except CPE doesn't outgas[3] by-products that would damage switching equipment. This is a major reason why pulp and paper manufacturing sites prefer CPE. CPE compounds are also available in thermoset formulations.

- **Cross-Linked or Irradiated Polyvinylchloride (XL-PVC):** Cross-linking is a process by which thermoplastic material is transformed into a thermoset by either beam irradiation or by a chemical action. XL-PVC has a maximum operating temperature rating of 105°C.

[3] Outgas: Percentage of gas released during the combustion of a material.

- **Cross-Linked or Irradiated Polyethylene (XLPE):** Cross-linking is a process by which thermoplastic material is transformed into a thermoset by either beam irradiation or by a chemical action. XLPE has a maximum operating temperature rating of 125°C.

- **Thermoplastic Elastomer (TPE) or Thermoplastic Rubber (TPR):** Has a temperature range of -60°C to 125°C. It is resistant to fuels, oils, solvents and water and can be made highly flame resistant. These have low corrosive outgassing by-products and are acid and alkali resistant and offer low temperature flexibility in the range of –50ºC.

- **Thermoplastic Polyurethane (TPU) or Polyurethane (PU):** Has a temperature range of -20°C to 90°C. It is resistant to fuels, oils, solvents and water. It has twice the tensile strength and three times the tear and abrasion resistance of PVC. The benefits of TPU or PU are its very good mechanical and physical properties, such as abrasion resistance, good weatherability and low temperature flexibility in the range of -50ºC or better for special blends. TPU is either polyether-based or polyester-based. Polyether-based TPU is recommended for low temperature flexing and fungus resistance. Polyester-based TPU are generally used when mechanical strength, heat and chemical attack is a concern. Xtra-Guard 2 is polyether-based.

- **Polyester Elastomer:** Used as both an insulation and jacket. It has a maximum operating temperature rating of 90°C. It is a flexible thermoplastic that can be used in place of rubber and some urethanes. It has good chemical resistance properties and performs well under impact testing and flexing.

- **Low Smoke Zero Halogen (LSZH):** The designation for materials that emit little or no smoke. If burned they do not contain any chemicals from the "halogen" group (chlorine, fluorine, etc). They are based on olefinic chemistry. They are frequently required in military and in mass transit applications.

b) Fluorocarbon: Resins that contain fluorine in their molecular structure.

- **Tetrafluoroethylene (TFE):** Used as both insulation and jacket, TFE has a maximum continuous operating temperature rating of 260°C and a maximum intermittent operating temperature range of 316°C. TFE was first produced by Dupont Corporation in the late 1930's for military applications. In the late 1940's it found its way into commercial markets. TFE Teflon offers excellent chemical resistance and good electrical properties, but its high cost, coupled with the fact that it can't be extruded using conventional extrusion equipment, such as those used for thermoplastics. The type of extruder used for TFE is called a "ram extruder", which uses high pressure as opposed to high heat. Since TFE can't be melt-processed, it is not possible to have long continuous lengths. The only way to fabricate relatively long lengths is to form the material into rolls of TFE tape. Once it is in the form of a tape, then it may be applied helically around a conductor and the overlap sealed by passing through 600°C sintering towers. Due to the high heat needed for tape fusing, the conductor must be either silver or nickel coated, to avoid melting the tin coating.

- **Fluorinated Ethylene-Propylene (FEP):** Used as both insulation and jacket, FEP has a maximum continuous operating temperature rating of 200°C and a maximum intermittent operating temperature range of 232°C. FEP was developed to offset some of the high costs associated with TFE. An added advantage of FEP is that it can be extruded using conventional extrusion equipment.

- **Ethylene-Tetrafluoroethylene-Copolymer (ETFE):** Used as both insulation and jacket and has a maximum continuous operating temperature rating of 150°C and a maximum intermittent operating temperature range of 199°C. It is a modified copolymer that provides excellent chemical resistance, mechanical strength and abrasion resistance. It also has a low dielectric constant, so it has good electrical properties.
- **Polyvinylidene Fluoride (PVDF):** Has a maximum continuous operating temperature rating of 135°C and a maximum intermittent operating temperature range of 150°C.

c) Thermosets: Materials that harden when heat is applied and can not be reshaped by reapplying heat.

- **Styrene-Butadiene Rubber (SBR):** It is a synthetic rubber with excellent abrasion resistance and reasonably good electrical characteristics. SBR does begin to decompose if exposed to oil, ozone and weathering. It has an operating temperature rating of -55°C to 90°C and it is highly flammable, unless flame retardants are added.

- **Polychloroprene:** Used mostly as a jacket. It is basically a synthetic rubber and possesses better characteristics than natural rubber or SBR. It has an operating temperature rating of -55°C to 90°C.

- **Chlorosulfonated Polyethylene (CSPE):** Is a chlorosulfonated polyethylene that is used mainly as a jacket. It works well in harsh environments and is often used in hard service cords and mining and power cables.

d) **Silicone:** Has an operating temperature rating of –65°C to 200°C. It is often used for primary wiring insulation and jackets for automotive ignition wire and other high temperature applications.

3. **Jacket Properties:** The charts shown on the next page are also located in the Alpha Wire Master Catalog in the Technical Data section.

Jacket-Materials Property Chart

PROPERTIES	PVC	PE	TFE	FEP	PVDF	TPE
1 Abrasion Resistance	Good	Good	Fair	Good	Good	Good
2 Heat Resistance	Good	Good	Excellent	Excellent	Excellent	Excellent
3 Weatherability	Good	Excellent	Excellent	Excellent	Good	Excellent
4 Flame Retardancy	Excellent	Poor	Excellent	Excellent	Excellent	Excellent
5 Water Resistance	Good	Excellent	Excellent	Good	Good	Good
6 Acid Resistance	Good	Good	Excellent	Excellent	Excellent	Excellent
7 Alkali Resistance	Good	Good	Excellent	Excellent	Excellent	Excellent
8 Aliphatic Hydro. Resis.	Good	Poor	Excellent	Excellent	Excellent	Poor
9 Aromatic Hydro. Resis.	Poor	Poor	Excellent	Excellent	Excellent	Poor

PROPERTIES	ASTM METHOD	PVC	PE	TFE	FEP	PVDF	TPE
1 Specific Gravity	D-792-66	1.16-1.70	0.91-1.26	2.13-2.20	2.12-2.17	1.75-1.78	1.16-1.20
2 Tensile Strength, psi	D-638-77	1500-4500	1500-2200	1000-3500	2700-3100	5200-7500	2300
3 Elongation, %	D-412-75	40-400	180-600	275	250-330	500	500
4 Volume Resistivity , ohm-cm	D-257-78	10^4-10^{16}	$>10^{15}$	$>10^{18}$	2.0 x 10^{18}	2 x 10^{14}	2.2 x 10^{18}
5 Dielectric Strength, volts/mil	D-149-75	250-500	230-1420	500	500-600	260	625
6 Dielectric Constant @ 60 Hz	D-150-78	3.2-9.0	2.28-2.50	2.0-2.1	2.1	8.40	2.8
7 Dielectric Constant @ 1 kHz	D-150-78	3.0-8.0	2.27-2.50	2.0-2.1	2.1	7.9	2.8
8 Power Factor (Dissipation) @ 60 Hz	D-150-78	.007-0.15	0.003-0.044	0.0004	0.0002	0.049	0.002
9 Power Factor (Dissipation) @ 1 kHz	D-150-78	.009-0.16	.00048-.00049	0.0001	0.0007	0.019	0.002

The above chart reflects a qualitative comparison of insulating properties and should be used as a general guide only.
For specific compound information, consult Alpha's Engineering Staff.
Note: All values shown are nominal.

4. **Jacket Properties:** The charts shown on the next page are also located in the Alpha Wire Master Catalog in the Technical Data section.

Jacket-Materials Property Chart

PROPERTIES	NATURAL RUBBER	CSPE	POLYCHLOROPRENE	SILICONE	POLYURETHANE
1 Abrasion Resistance	Excellent	Good	Excellent	Fair	Excellent
2 Heat Resistance	Fair	Excellent	Good	Excellent	Good
3 Weatherability	Fair	Excellent	Good	Excellent	Good
4 Flame Retardancy	Poor	Good	Good	Good	Good
5 Water Resistance	Good	Good	Excellent	Excellent	Good
6 Acid Resistance	Fair	Excellent	Good	Good	Fair
7 Alkali Resistance	Fair	Excellent	Good	Good	Fair
8 Aliphatic Hydro. Resis.	Poor	Fair	Good	Poor	Good
9 Aromatic Hydro. Resis.	Poor	Fair	Fair	Poor	Poor

PROPERTIES	ASTM METHOD	NATURAL RUBBER	CSPE	POLYCHLOROPRENE	SILICONE	POLY-URETHANE
1 Specific Gravity	D-792-66	1.3-1.7	1.35-1.7	1.23-1.65	1.1-1.6	1.30
2 Tensile Strength, psi	D-638-77	1500-4000	1200-2200	1200-2700	1000	>3500
3 Elongation, %	D-412-75	300-700	300-600	300-700	100-500	540-750
4 Volume Resistivity , ohm-cm	D-257-78	10^{13}-10^{16}	10^{12}-10^{14}	10^{11}-10^{13}	2×10^{14} 8×10^{13}	11×10^{14}
5 Dielectric Strength, volts/mil	D-149-75	---	500	600	100-700	330-630
6 Dielectric Constant @ 60 Hz	D-150-78	---	---	---	---	5.4-7.6
7 Dielectric Constant @ 1 kHz	D-150-78	2.3-3.0	9.0-11.0	5.0-7.0	3.0-3.5	5.6-7.6
8 Power Factor (Dissipation) @ 60 Hz	D-150-78	---	---	---	---	0.015-0.046
9 Power Factor (Dissipation) @ 1 kHz	D-150-78	.00023-.00030	0.05-0.07	3.5	0.001-0.010	0.043-0.060

The above chart reflects a qualitative comparison of insulating properties and should be used as a general guide only.
For specific compound information, consult Alpha's Engineering Staff.
Note: All values shown are nominal.

Design Considerations

There are several factors that need to be considered when designing a cable for a specific application. The most common factors are as follows:

1. **Electrical requirements:**

- **Ampacity (Current Carrying Capacity):** The amount of current (electrical flow) a conductor can carry. The larger the wire size, the greater the amount of current. Current is expressed in amperes (Amp).
  - *Memory trick*: Think of a garden hose. It is the amount of water that the hose can carry. The larger the hose, the more water it can carry.

- **Capacitance:** The storage of electrically separated charges between two conductor surfaces having different potentials. The value depends upon the surface area of the conductors and the distance between them. Capacitance is expressed in Pico farad per foot (pF/ft).
  - *Memory trick*: Think of a storage tank. The larger the tank, the more room for storage and the smaller the tank, the less room for storage.

    - **Direct Capacitance:** Measured directly between conductors.

    - **Mutual Capacitance:** Measured between two conductors with all other conductors and shield tied to ground.

    - **Ground Capacitance:** Capacitance between one conductor and all other conductors tied together and to the grounded shield.

- **Inductance:** The property of a circuit or circuit element that opposes a change in current flow, causing current changes to lag behind voltage changes. This is expressed in micro henries per foot (μH/Ft).
  - *Memory trick*: Think of a river. When there is no blockage the water flows without any problem; however, if a beaver has built a dam then the water isn't able to flow past it, it starts backing up and therefore it is more difficult for the water to flow.

- **Impedance:** The total opposition (reactance[4], X & resistance, R) that a circuit offers to the flow of alternating current (AC) at any given frequency. Impedance is expressed in Ohms (Ω). Impedance is not length related.

    - **Characteristic Impedance:** The ratio of voltage to current at each point along a transmission line on which there are no standing waves.

- **Resistance**: A measurement of the difficulty in moving electrical current through a medium when voltage is applied. Resistance is expressed in Ohms (Ω).

[4] Reactance: The opposition offered to the flow of alternating current (AC) by capacitance or inductance of a circuit.

- *Memory trick*: Think of a highway. When there is a traffic jam it is more difficult to get through than when there is no traffic.

    - In DC circuits, resistance is the opposition that a material offers to the current flow.
    - In AC circuits, resistance is a component of impedance, which is normally higher than the actual measured DC resistance value.

- **Velocity of Propagation (Vp):** The speed a signal travels down a length of cable as compared to the speed in free air and is directly dependent upon the dielectric material properties. Vp is the reciprocal of the square root (√) of the dielectric constant (ε) of the insulation material ($1/\sqrt{\varepsilon}$) and is expressed as a percentage (%).

    - *Memory trick*: Think of a faucet. If you open your bath tub faucet all the way the tub will fill quicker than if you just barely turn the faucet on.

- **Voltage (Volt):** A measurement of electrical pressure along a conductor. The voltage rating depends primarily on the insulation thickness. The thicker the insulation, the higher the voltage rating.

    - 0.010" nominal insulation wall = 600 volts (Military Specifications)
    - 0.016" nominal insulation wall = 1000 volts (Military Specifications)
    - 0.016" nominal insulation wall = 300 volts (UL)
    - 0.032" nominal insulation wall = 600 volts (UL)

2. **Environmental requirements:** Environmental requirements are critical since a cable built of materials that cannot stand up to the environment is of no use to anyone since it will fail.

    - **Chemical Resistance:** Refer to the Oil and Chemical Chart in the Master Catalog.

    - **Moisture Resistance:** Ability of a material to resist moisture absorption.

    - **Outgassing:** The percentage of gas released during combustion of a material. Outgassing of by-products can damage sensitive electronic equipment.

    - **Temperature Requirement:** This would involve both the upper and low end temperatures required for the product or environment.

    - **UV resistance:** Jacketing materials may lose some of their physical properties when exposed to UV radiation (sunlight) unless they have been specifically designed to be UV resistant or UV stable.
    - **California Proposition 65:** Is currently in effect and requires that the outer surfaces of goods must not contain greater than 300 parts per million (ppm) of lead (Pb) for goods entering California. The current status of Alpha Wire products appear on the Alpha Wire web site. Other states appear to taking similar actions.

- **RoHS:** Is the abbreviation for Restriction of certain Hazardous Substances. RoHS falls under Directives 2002/95/EC and 2002/96/EC and will become law by July 2006. It forbids any products entering the EU that contain lead (Pb), hexavalent Chromium (Cr+6), cadmium (Cd), other heavy metals, Deca-BDE, PBB and PBDE (chemicals used as flame retardants in compounds). However, naturally occurring trace amounts are acceptable.
- **WEEE:** Is the abbreviation for Waste Electrical & Electronic Equipment. WEEE falls under Directive 2002/96/EC and it became law around June 2004. It makes the manufacturer responsible for disposal of products that have reached end-of-life status. The manufacturer is viewed as being the producer of the final product. So far, wire manufacturers have not been involved with this directive.

3. Mechanical requirements:

- **Abrasion Resistance:** Ability of the material to resist surface wear.
- **Cut-Through Resistance:** Ability to withstand mechanical pressure without separation.
- **Elongation:** The increase in length as the material is placed under tension.
- **Flexibility:** The quality of a cable that allows for bending under normal conditions.
- **Flex Life:** The ability of a cable to withstand repeated flexing without damage.
- **Tensile strength:** The pulling stress required to break a given specimen.

4. **Regulatory Agencies and other Conformity Certification Programs:** These will be discussed in depth in the Section 6.

- Underwriters Laboratory, Inc. (UL)
- Canadian Standards Organization International (CSA)
- Conformitè Europèenne CE
- China Compulsory Certification (CCC)
- Harmonized (HAR)
- International Electrotechnical Commission (IEC)
- Saudi Arabian Standards Organization (SASO)
- International Organization for Standardization (ISO) or (OIN) in French for *Organisation internationale de normalisation*
- *Technischer Überwachungsverein* and the English translation is Technical Inspection Association (TUV)
- Telecommunications Industry Association/Electronics Industry Association (TIA/EIA)
- European Committee for Electrotechnical Standardization (CENELEC)
- Rural Electrification Administration (REA)
- International Municipal Signal Association (IMSA)
- Pennsylvania Bureau of Deep Mine Safety (P-MWMS)
- Military Specifications

5. **Military Specifications:** A group of specifications developed by various U.S. Government organizations, such as the Army and Navy.

    - **MIL-W-76B**: This specification is inactive for new designs and is only used for replacement. The latest revision level is MIL-W-76D. This specification covers single-conductor, synthetic-resin insulated, electrical hookup wire and cable for use, at temperatures from -55° C to +90° C, in the internal wiring of electrical and electronic equipment. For the purpose of this specification, single-conductor hookup wire and cable are hereinafter referred to as wire.

        - Type LW (Light Wall): 0.010" insulation wall, 80°C and rated 600 volts
        - Type MW (Medium Wall): 0.016" insulation wall, 80°C and rated 1000 volts
        - Type HW (Heavy Wall): 0.032" insulation wall, 80°C and rated 2500 volts

    - **MIL-W-16878D**: This specification covers unshielded wire for hookup and lead wiring of electrical and electronic components and equipment so that minimum size and weight are consistent with service requirements. The temperature rating of wire included in this specification ranges to a maximum of 260 degrees Celsius (°C); with potential rating from 250 to 5000 volts root mean square (Vrms). The single conductor wire covered in this specification is intended for use in lead wire and internal wiring of electrical and electronic equipment and switchboards.

        - Type B: 0.010" PVC insulation wall, 105°C and rated 600 volts
        - Type C: 0.016" PVC insulation wall, 105°C and rated 1000 volts
        - Type D: 0.030" PVC insulation wall, 105°C and rated 3000 volts
        - Type E: 0.010" TFE insulation wall, 200°C and rated 600 volts
        - Type EE: 0.014" TFE insulation wall, 200°C and rated 1000 volts
        - Type ET: 0.007" TFE insulation wall, 200°C and rated 250 volts

There are several other Military Standards. For more information please see the websites listed below:

http://www.dscc.dla.mil/Programs/MilSpec/

http://assist2.daps.dla.mil/quicksearch/

http://www.dscc.dla.mil/Programs/MilSpec/OtherSites.html

Regulatory Agencies and other Certifying Bodies

There are several Regulatory Agencies in existence today, but several do not involve the wire and cable industry. The most common ones used in our industry are as follows:

1. **Underwriters Laboratories, Inc. (UL):** Underwriters Laboratories Inc. (UL) is an independent, not-for-profit product safety testing and certification organization."

   - Website Address: www.ul.com
   - Types of Approvals:

     - **Communications Cable:**
       - UL Standard 444 (CCN[5]: DUZX), CSA C22.2 No. 214-02
       - National Electrical Code (NEC) Article 800 of NFPA 70
       - CMX, CM, CMG, CMR, CMP[6], CMUC[7]
       - CMD[8] may be added to the NEC in 2005
       - MP, MPG, MPR and MPP: Are no longer permitted after 7/1/2003
     - **Power-Limited Circuit Cable:**
       - UL Standard 13 (CCN: QPTZ)
       - National Electrical Code (NEC) Article 725 of NFPA 70
       - PLTC, CL2X, CL2, CL2R, CL2P, CL3X, CL3, CL3R, CL3P
       - CL2D[9] and CL3D may be added to the NEC in 2005

       Note: The designation "Open Wiring" will be changed to "Exposed Runs" in the 2005 National Electrical Code.
     - **Fire Alarm Cable:**
       - UL Standard 1424 (CCN: HNIR)
       - National Electrical Code (NEC) Article 760 of NFPA 70
       - FPL, FPLR, FPLP
       - FPLD[10] may be added to the NEC in 2005
     - **Non-Power Limited Fire Alarm:**
       - UL Standard 1425 (CCN: HNHT)
       - National Electrical Code (NEC) Article 760 of NFPA 70
       - NPLF, NPLFR, NPLFP
       - NPLFD[11] may be added to the NEC in 2005
     - **Wind Turbine Tray Cable:**
       - UL Standard 2277 (CCN: ZGZN)
       - National Electrical Code (NEC) Article 336 of NFPA 70
       - WTTC

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[5]CCN: Category Control Number
[6] CMP: These cables may be re-defined as "being suitable for use in ceiling cavity plenums and raised floor plenums."
[7] CMUC: Indicates cable for undercarpet use in accordance with section 800.53(E)(6) of the NEC.
[8] CMD: The D stands for Limited Combustible for use in ducts, plenums and other spaces used for environmental air.
[9] CL2D and CL3D: The D stands for Limited Combustible for use in other spaces used for environmental air (not in ducts and plenums).
[10] FPLD: The D stands for Limited Combustible for use in ducts, plenums and other spaces used for environmental air.
[11] NPLFD: The D stands for Limited Combustible for use in other spaces used for environmental air (not in ducts and plenums).
Note: Footnotes 2 thru 7 are taken from the UL Wiretalk Volume 11 No. 3.

- **Tray Cable:**
  - UL Standard 1277 (CCN: QPOR)
  - National Electrical Code (NEC) Article 336 of NFPA 70
  - TC

  Note: The designation "Open Wiring" will be changed to "Exposed Runs" in the 2005 National Electrical Code.
- **Instrumentation Tray Cable:**
  - UL Standard 2250 (CCN: NYTT)
  - National Electrical Code (NEC) Article 727 of NFPA 70
  - ITC
- **Optical Fiber Cable:**
  - UL Standard 1651 (CCN: QAYK)
  - National Electrical Code (NEC) Article 770 of NFPA 70
  - OFC, OFN, OFCG, OFNG, OFCR, OFNR, OFCP, OFNP
  - OFNG and OFCG may be getting removed from the NEC in 2005
  - OFND[12] and OFCD may be added to the NEC in 2005
- **Community Antenna Television Cable:**
  - UL Standard 1655 (CCN: DVCS)
  - National Electrical Code (NEC) Article 820 of NFPA 70
  - CATVX, CATV, CTVR, CATVP
  - CATVD[13] may be added to the NEC in 2005
- **Flexible Cord:**
  - UL Standard 62 (CCN: ZJCZ), CSA C22.2 No. 49
  - National Electrical Code (NEC) Article 400 of NFPA 70
  - S, SO, SOO, SOW, SOOW, ST, STO, STOO, STW, STOW, STOOW, SE, SEO, SEOO, SEW, SEOW, SEOOW and etc.
- **Fixture Wire:**
  - UL Standard 66 (CCN: ZIPR)
  - National Electrical Code (NEC) Article 402 of NFPA 70
  - TFN, TFFN, TFF, RFH-2, FFH-2, SFF-1, SFF-2, RFF, PGFF, XF, XFF, KF-1, PTF and etc.
- **Thermoplastic – Insulated Wire:**
  - UL Standard 83 (CCN: ZLGR)
  - National Electrical Code (NEC) Article 310 of NFPA 70
  - TW, THHN, THHW, THWN, PFA, PFAH, Z, ZW and etc.
- **Data Processing Cable:**
  - UL Standard 1690 (CCN: EMRB)
  - National Electrical Code (NEC) Article 645 of NFPA 70
  - DP-1, DP-1P, DP-2, DP-2P, DP-3, DP-2P.
- **Appliance Wiring Material:**
  - UL Subject 758 (CCN: AVLV2)
  - See the following link: http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/cawmsrch.html

[12] OFND and OFCD: The D stands for Limited Combustible for use in ducts, plenums and other spaces used for environmental air.
[13] CATVD: The D stands for Limited Combustible for use in ducts, plenums and other spaces used for environmental air.
Note: Footnotes 7 & 8 were taken from the UL Wiretalk Volume 11 No. 3.

- **Note: There are several others, please see either the UL Wire & Cable Marking Guide included at the back of this section or http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/ccnsrch.html.**
- **Alpha Wire UL File Numbers:** See the List at the website listed: http://www.ul.com

2. **Canadian Standards Association International (CSA): "Test products** for compliance to national and international standards, and **issue certification marks** for qualified products. Certification marks tell potential customers and users that a product has been evaluated by a formal process-involving examination, testing and follow-up inspection-and that it complies with applicable standards for safety and performance."

   - Website Address: www.csa-international.org
   - Types of Approvals:

     - **Communications Cable:** This has been harmonized with UL Standard 444
       - CSA Standard C22.2 No. 214-02
       - CSA Standard C22.2 No. 0
       - CMH, CMG, CMR, CMP
     - **Appliance Wiring Material Products:**
       - CSA Standard C22.2 No. 210.2
       - CSA Standard C22.2 No. 0
       - Canadian Electrical Code, Part II
     - **Cord Sets and Power Supply Cords:**
       - CSA Standard C22.2 No. 21
       - CSA Standard C22.2 No. 0
       - Canadian Electrical Code, Part II
     - **Thermoset Insulated Wires and Cables:**
       - CSA Standard C22.2 No. 38-95
       - Canadian Electrical Code, Part II
     - **Flexible Cords and Cables:** This has been harmonized with UL Standard 62
       - CSA Standard C22.2 No. 49
       - Canadian Electrical Code, Part I
     - **Thermoplastic Insulated Wires and Cables:**
       - CSA Standard C22.2 No. 75-M1983
       - Canadian Electrical Code, Part II
     - **Fire Alarm and Signal Cable:**
       - CSA Standard C22.2 No. 208
       - Canadian Electrical Code, Part II
     - **Tray Cables:**
       - CSA Standard C22.2 No. 230-M1988
       - Canadian Electrical Code, Part I
     - **Control and Instrumentation Cables:**
       - CSA Standard C22.2 No. 239-97
       - Canadian Electrical Code, Part II

- **There are several others, please see the website listed:** http://directories.csa-international.org/

- **Alpha Wire CSA File Numbers:** See the List at the website: http://directories.csa-international.org/cert_rec_srch.asp?txtDir=*&Submit=Search&txtCustomer=Alpha+Wire&txtProvState=&txtCountry=&txtFile=&txtMajorClass=&txtMinorClass=&txtClassDesc=&txtKeyword=

3. **Conformitè Europèenne (CE):** Indicates that a product complies with a European Directive. See **XTRA□GUARD® 1**, **2**, **4**, **5** Series, **XTRA●GUARD® Flexible Cables** Series and the **INDUSTRIAL SERIES** for products that carry the CE Mark**.** See page 78 of the Alpha Wire Master Catalog for more information on the CE mark.

4. **China Compulsory Certification (CCC):** The **CCC Mark** will be required for products being exported to or sold to the Peoples Republic of China market. This is being handled through the UK office but I will provide, under separate cover, a simple write-up regarding the CCC Mark. For more information see the website listed below:
http://www.ccc-mark.com/china-compulsory-certification.html

5. **Harmonized (HAR):** These are products intended for use in Europe that fall under the Harmonization Documents. These items must be manufactured within a member country there are no exceptions. For this reason these carry the name and/or file numbers of the producing party. Products that comply with this are P/N Series 1900 through 1906 and P/N Series 1915 through 1925.

6. **International Electrotechnical Commission (IEC):** Prepares and publishes International Standards for electrical, electronic and other related technologies. For more information, see the website listed: http://www.iec.ch/

7. **Saudi Arabian Standards Organization (SASO):** For standardization in the Kingdom. See the website listed below for more information. Alpha has many of her products registered with SASO Authorities.
For more information, see the website listed: **http://www.saso.org/about/about.html**

8. **International Organization for Standardization (ISO) or (OIN) in French for** *Organisation internationale de normalization*: Is intended to establish, document and maintain a system for ensuring quality in both products and service. For more information, refer to Alpha's Quality Policy and the website listed below:
http://www.iso.ch/iso/en/ISOOnline.frontpage

9. ***Technischer Überwachungsverein*, English translation: Technical Inspection Association (TÜV):** For more information see the website listed:
http://www.tuvamerica.com/
"TÜV America Inc., a subsidiary of Group TÜV Süddeutschland, is a business-to-business engineering services firm providing international safety testing and certification services."

10. **Telecommunications Industry Association/Electronics Industry Association (TIA/EIA):** For more information, see the websites listed: http://www.tiaonline.org/ or http://www.eia.org/
"The Technical Committee has overall responsibility for establishing the broad technical policy of the Association, including the organization and operating policies of the Standards and Technology Department and Engineering Committees."

11. **CENELEC:** Prepares Electrotechnical Standards. For more information, see the website: http://www.cenelec.org/Cenelec/Homepage.htm
"CENELEC, the **European Committee for Electrotechnical Standardization**, was created in 1973 as a result of the merger of two previous European organizations: CENELCOM and CENEL. Today, CENELEC is a non-profit technical organization set up under Belgian law and composed of the National Electrotechnical Committees of 23 European countries. In addition, 12 National Committees from Central and Eastern Europe are participating in CENELEC work with an Affiliate status. Their ultimate goal as affiliates is gaining full membership to CENELEC Standardization activities."

12. **Rural Electrification Administration (REA):** Provided loan programs for electric and telephone service in rural areas, to provide farms with inexpensive electric lighting and power and telephone improvements. For more information, see the website: http://www.infoplease.com/ce6/history/A0842689.html

13. **International Municipal Signal Association (IMSA):** For more information, see the websites listed: http://www.imsasafety.org/ or http://www.imsasafety.org/descrip.htm
"IMSA is a non-profit organization founded in 1896 by signal engineers. IMSA offers various levels of certification to assist the participant in becoming more proficient in their field and to acknowledge their commitment to public safety."

14. **Pennsylvania Bureau of Deep Mine Safety (P-MWMS):** Responsible for the health and safety of underground mines, caves and other commercial operations. The **Xtra•**Guard® 4 Series has carries this approval. Alpha also has select products registered with IMSA. For more information, see the websites listed: http://www.dep.state.pa.us/dep/deputate/minres/dms/dms.htm

15. **Military Specifications:** A group of specifications developed by various U.S. Government organizations, such as the Army, Navy and etc. Many of their specifications have been converted into NEMA Standards or Commercial Specs. For specific information on a specific spec, see the websites listed: http://www.dscc.dla.mil or http://assist2.daps.dla.mil/quicksearch

Alpha Wire

Part 1 Exam

1. What is the most common conductor material used today?
   a) Aluminum
   b) Copper
   c) Silver
   d) Both a and b

2. What is the most common conductor coating used today?
   a) Nickel
   b) Silver
   c) Tin
   d) None of the above

3. What conductor construction is typically used in high flex designs?
   a) Bunched
   b) Concentric
   c) Concentric Contra-Helical
   d) None of the above

4. What term is used to define the refining process that produces a 99.95% pure copper?
   a) ASTM
   b) ETP
   c) OFHC
   d) None of the above

5. What conductor coating can withstand continuous operating temperatures up to 200°C?
   a) Tin
   b) Silver
   c) Both of the above
   d) None of the above
   e)

6. Which of the polymers are thermoplastic?
   a) FEP
   b) PVC
   c) TPE
   d) All of the above

7. Which of the following is the most chemical resistant?
   a) FEP
   b) PVC
   c) TPE
   d) XLPE

8. Which of the following is the most abrasion resistant?
   a) PU
   b) PVC
   c) SR-PVC
   d) TPE
   e)

9. What compound would you recommend for direct burial applications?
    a) FEP
    b) PE
    c) TPE
    d) None of the above

10. What material would be the least costly?
    a) FEP
    b) PVC
    c) TPE
    d) XLPVC

11. What is the primary purpose of the shield?
    a) Limits signal trying to escape the cable
    b) Inhibits external signals or interference from getting into the cable
    c) Eliminates crosstalk
    d) Both a and b

12. Which type of shield provides better flexibility?
    a) Braid
    b) Spiral
    c) Tape
    d) Both a and b

13. What shielding method is typically used for individually shielded pairs?
    a) J-Fold
    b) Longitudinal
    c) Z-Fold
    d) All of the above

14. What terminology is used to describe a combination of APA and 70% braid shield?
    a) SUPRA-SHIELD
    b) Tri-Shield
    c) Quad-Shield
    d) All of the above

15. What type of braid material is used as strength members?
    a) Fiberglass
    b) Kevlar
    c) Rayon
    d) All of the above

16. What is the primary purpose of the cable jacket?
    a) Color code
    b) Protection from external interference
    c) Protection of the cable
    d) All of the above

17. What materials are considered thermosets?
    a) CPE
    b) SBR
    c) TFE
    d) Both a and b

18. Why is vinyl resin alone not suitable for use as a cable jacket?
    a) Subject to degradation at processing temperatures
    b) Extremely rigid
    c) None of the above
    d) All of the above

19. What is the most common temperature range for most PVC compounds?
    a) −10°C to +105°C
    b) −60°C to +125°C
    c) −40°C to +105°C
    d) None of the above

20. What jacket compound has low corrosive outgassing and is acid and alkali resistant?
    a) PVC
    b) CPE
    c) TPE
    d) Both a and b

21. Which term is used to describe current carrying capacity?
    a) Ampacity
    b) Capacitance
    c) Both a and b
    d) None of the above

22. Which value is expressed in ohms?
    a) Inductance
    b) Impedance
    c) Resistance
    d) Both b and c

23. If someone is asking for the picofarads per foot, what electrical parameter do they want to know?
    a) Ampacity
    b) Capacitance
    c) Inductance
    d) None of the above

24. What requirements must be taken into consideration when designing a cable?
    a) Electrical
    b) Environmental
    c) Regulatory requirements
    d) All of the above

25. What term best describes the speed at which a signal travels down a length of cable?
    a) Impedance
    b) Velocity of Propagation
    c) Voltage
    d) None of the above

26. What is the purpose for using nylon coating over PVC singles?
    a) Improves flexibility
    b) Improves crush resistance
    c) Both a and b
    d) None of the above