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ENGINEERING DESIGN HANDBOOK

ELECTRICAL WIRE AND CABLE

HEADQUARTERS, U.S. ARMY MATERIEL COMMAND SEPTEMBER 1969

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UNITED STATES ARMY MATERIEL COMMAND
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PREFACE

This Engineering Design Handbook, ***Electrical Wire and Cable,*** contains basic information and fundamental data in the design, usage, and development of wire and cable used in Army materiel and systems. The handbook contains a wide variety of useful information and quantitative facts as well as authoritative references helpful in the design, development, usage, and maintenance, of wires and cables used in modern Army electronic and electrical systems. The information contained herein will enable the systems engineer, technician, buying agency, and user, to meet the tactical and technical needs of the Armed Forces.

The highly technical nature of today's Army, together with the demands placed upon it, have greatly enhanced the need for a wire and cable handbook of this scope. Information which has been amassed through wide experiences of both manufacturer and user has been systematically recorded so as to expedite the search for the necessary technical data.

The objective of this handbook is to provide a practical guide to correct design of equipment to meet the exacting transmission requirements of the many and varied aspects of today's electronic and electrical systems. The designer who considers the proper technology of wire and cable design can alleviate many problems in proper transmission and installation techniques; whereas, the designer who ignores this technology can and does greatly multiply the problems.

This handbook contains information on the structure, application, usage, and installation of most of the wires and cables utilized by the Army. Also included are a glossary of terms; a listing of equations for quick reference; and an appendix which presents the applicable Military Specifications, Standards, and Publications.

This handbook was prepared by International Telephone and Telegraph Corporation Wire and Cable Division under subcontract to the Engineering Handbook Office of Duke University, prime contractor to the Army Research Office–Durham for the Engineering Handbook Series.

The Handbooks are readily available to all elements of AMC including personnel and contractors having a need and/or requirement. The Army Materiel Command policy is to release these Engineering Design Handbooks to other DOD activities and their contractors, and other Government agencies in accordance with current Army Regulation 70-31, dated 9 September 1966. Procedures for acquiring these Handbooks follow:

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Washington, D. C. 20310

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Comments and suggestions on this handbook are encouraged, and should be addressed to Army Research Office–Durham, Box CM, Duke Station, Durham, N. C. 27706.

CHAPTER 1
CONDUCTORS

1–1 MATERIAL ELEMENTS

Conductors have the function of getting electricity from one point to another in an electrical circuit. For this handbook, copper and aluminum will be the main materials discussed because of their balance between high conductivity and reasonable price.

1–1.1 COPPER (ETP and OFHC)

There are two main divisions of copper used for conductor purposes, electrolytic tough pitch (ETP) copper, and oxygen-free high conductivity (OFHC)* copper which is similar, except that the molten copper is protected by an inert gas cover from melt to casting in OFHC.

Both varieties have similar properties (tensile strength, elongation, melt point, etc.) except that with ETP when exposed to reducing gases (illuminating gas and hydrogen) at high temperatures (1000°F and above) embrittlement takes place. The manufacture of OFHC within an inert atmosphere adds to its cost and only imparts resistance to embrittlement way above operating temperature of wire and cable. Therefore, the premium price paid for OFHC is wasted in most wire and cable applications except where copper wire has to be welded.

1–1.2 COPPER (HOT ROLLED)

Hot rolled copper rod used for drawing into wire usually has embedded in its surface, oxides, scale, and dirt. When fine gage strands (0.025 in. or less) are to be drawn from such rod, the rod should be processed by pickling and die shaved to insure round rod and remove troublesome rolled-in oxides, particles, and scales.

* **Registered Trademark American Metals Climax**

1–2 WIRE SIZE (SOLID)

1–2.1 GAGING SYSTEMS

While there are several gage systems for classifying wire size, the American Wire Gage (AWG) or Brown and Sharpe series of size designations is used for conductor materials in the United States. Table 1–4 is arranged by AWG size and shows diameters, areas, weights, and resistances.

This gage system is a geometric progression whereby each gage size represents a 20% reduction in area or roughly a 10% reduction in diameter. On this basis every **3** gage sizes approximately doubles the area and every 6 gage sizes approximately doubles the diameter.

1–2.2 CIRCULAR MIL AREA (CMA)

The area of round conductors is usually expressed in circular mils. A circular mil is the area of a circle 1 mil in diameter or $\frac{\pi}{4}$ times a square mil. Therefore, the area of any circle is simply the square of the diameter (in mils) expressed in circular mils.

There is an easy rule of thumb which may be used to obtain approximate sizes of wire if one remembers that #10 AWG wire is approximately 1/10 in. in diameter and has approximately 10,000 circular mils and approximately 1 ohm/1000 ft of length. Example: What is approximate size, weight, area, and resistance of #22 AWG wire?

#22 is 12 sizes smaller than #10, therefore, the area has been halved 4 times (#13, #16, #19, #22) making the area approximately 625 circular mils.

The diameter has been halved twice (#16, #22) and is approximately 0.025 in. Since resistance is inversely proportional to area, it has been doubled 4 times and is approximately 16 ohm/1000 ft.

1–2.3 COPPER WIRE DIMENSIONS

The dimensions of soft drawn bare copper wire are normally controlled by Federal, Military, and ASTM* Specifications, and Handbook 100 – National Bureau of Standards, to ±1% of the diameter for sizes larger than 0.010 in. and to ±0.0001 in. for sizes 0.010 in. and smaller.

1–2.4 DC RESISTANCE

The maximum resistance figures shown in Table 1–4 were calculated using minimum diameter values. For other alloys, resistance may be calculated, if % conductivity is known.

1–3 COATINGS

Copper is rarely used on specialized applications in its bare state because of the oxidation that takes place on exposure to air. Oxidation or other corrosion is accelerated by the presence of heat, moisture, and some insulation materials such as rubber. To prevent corrosion and enhance terminating, bare copper is coated with a metal less susceptible to oxidation and corrosion.

1–3.1 METHODS OF COATING

Coatings may be applied by one of several methods. The more common are:

a. Electroplating: an electrolytic anodic coating over the base metal.

b. Hot dipping: the process of running the wire through a molten bath of the coating material.

c. Cladding: the process of welding under heat and pressure, producing a heavy outer coating over a base metal which is then formed into a wire in the usual fashion.

1–3.1.1 Tin

For ordinary usage the least expensive coating is tin. In addition to its corrosion protection, tin facilitates the application of solder. However, tin is limited to 120° to 135°C in its usage because at higher temperatures tin rapidly oxidizes, turning black, and corrodes.

Historically, tin was applied to copper first by the hot dip method. With this technique, impurities of the molten tin bath remain in the coating deposited on the surface of the wire. The control of the thickness of tin coating by this method is relatively poor, varying from 10 to 100 pin. even on wires running through the same molten tin bath on adjacent spools.

A more accurate method of applying a tin coating to a conductor is by the electroplating method. Here a concentric, high purity, uniform layer of tin deposit on the copper is assured. The plating should be done at rod or intermediate size and redrawn to compact and reflow the relatively porous coating formed by plating.

The electroplating method of tin coating wire is chosen so that very accurate control of the deposit can be maintained after final redraw, and the resulting plating thickness will be suitable for the required application. This method allows the same diameter tolerance as bare copper (±0.0001 in. on 0.010 in. or smaller strand, and ±1% for larger strand) on tin-coated wire. The ASTM, Federal, and Military Specifications permit a +0.0003 in. -0.0001 in. and +3% -1% tolerance to allow for added tin when processed by the hot tin dip method. This tolerance difference can become a significant factor in applications in aircraft and space craft where weight is critical. Example: Nineteen strands of #38 AWG (#26 equivalent) is a common large usage item in such vehicles. The maximum strand diameter with such a wire, and the ±0.0001 in. tolerance would be 0.0041 in.; with the 0.0003 in. tolerance, 0.0043 in. The weight is proportional to area, and therefore, to the diameter squared as depicted in Eq. 1–1.

$$\frac{d_1 W^2 + d_2 \left[(W + x_2)^2 - w^2\right]}{d_1 W^2 + d^2 \left[(W + x_1)^2 - w^2\right]} \times 100 = \%\ \text{weight increase of } x_2 \text{ over } x_1 \quad (x_1 = 100\%) \tag{1-1}$$

where W = wire diameter, nominal in.
d_1 = density of copper, 8.9
d_2 = density of tin, 7.3
x_1 = smaller diameter tolerance, in.
x_2 = larger diameter tolerance, in.

* American Society for Testing and Materials

Note

Eq. 1–1, is used for **#30** AWG strands and smaller. To cite an example, and using the **#38** AWG stranding as above, we would determine the weight proportion as follows:

$$\frac{\quad}{\quad} \times 100 = \frac{\quad}{\quad} \times 100 = \mathbf{108.26\%}$$

We now see that the maximum weight with the looser, or larger, tolerance is **8.26%** greater than the maximum weight of the lighter, or smaller, tolerance. In addition, the size is larger, hence more insulation is needed.

Tin-coated wire is normally tested for tensile strength and elongation, resistivity, continuity of coating, and adherence of coating and finish. ASTM Standard **B-33** specifies parameters for these tests.

Tin thickness for normal applications is **25–30** pin. on the finished wire. For special applications, heavy coatings of from **125** to **175** pin. are applied. Testing for continuity and adhesion of coating should be done prior to stranding because, due to the softness of the coating, minor scratches are inevitable during future operations. Tests should be made to insure that the coating is applied evenly and adheres firmly to the base metal.*

There is some evidence that pure tin can transform to a grey tin powdery structure when subjected to a sub-zero environment for prolonged periods. The addition of small amounts of antimony and/or bismuth will inhibit this transformation. Antimony and bismuth can be added to both the hot dip and electroplating process. This phenomenon has been thoro'ughly investigated by experts and transformation of tin has been observed on tin-coated wire in laboratory studies; however, there is not sufficient evidence that there is a generally serious problem.**

* **ASTM Standard B-33 (tin)**
ASTM Standard B-298 (silver)
ASTM Standard B-355 (nickel)

1–3.1.2 Silver

Silver-coated conductors are reliable for continuous temperature applications through 200°C. At temperatures in the order **of 350°C** silver will rapidly tarnish and corrode. The silver and copper tend to migrate through the boundary layer and form an alloy with copper, which rises to the surface.

Silver is applied by the electrodeposit method which allows a ±0.0001 in. and +1% tolerance on final wire size. In this case ASTM, Federal, etc., Specifications require these tolerances. Silver-coated wire has the same tests applied to it as to tin-coated wire with the addition of a thickness measurement. The parameters of these tests are specified in ASTM Standard **B-298.**

Many specifications require a minimum thickness of 40 pin. of silver coating on the finished strand while others call for 50. ASTM **B-298** specifies several classes of plating thickness by % weight of silver to that of total wire weight and only recommends by note that a minimum of 40 pin. be used. This does not help the end user who is only concerned that sufficient thickness be required to prevent corrosion.

Example:

Class B ASTM **B-298** requires 2.50% silver.

On a 0.010 in. **(#30)** wire this yields **53** pin. of silver.

On a 0.004 in. **(#38)** wire this yields only 21 pin. of silver.

** **ASTM Special Technical Publication** #319

This Class B wire is totally inadequate for #38 wire.

Example:

Class D ASTM B-298 requires 6.10% silver.

On a 0.010 in. (#30) wire this yields 129 pin. of silver.

On a 0.004 in. (#38) wire this yields 52 pin. of silver.

Obviously far too much silver is present on the #30 wire, resulting in excess cost.

The various classes of ASTM, therefore, are only academic since in practical use sufficient silver must be applied so that after redraw the required amount is present.

In spite of its large usage, silver-coated copper has some limitations as follows:

a. Silver tarnishes, giving poor appearance and frequently causes misunderstandings with inspectors expecting a brilliant finish.

b. Silver wets very easily with molten solder, and solder will wick up into the strands by capillary action to form a solid conductor at the soldered joint where flexibility and flex life are most needed. This has caused conductors to break under conditions of repeated flexing or vibration. It can be overcome by controlled soldering techniques – controlling such parameters as solder pot temperature, time and amount of immersion during dip, use of heat sinks, and soldering iron temperature. A much more satisfactory solution is found in the use of nickel coating which reduces wicking.

c. With silver, in proximity to copper and moisture being present, electrolytic corrosion can take place with the copper protecting the silver. Copper is electropositive to silver so that the corrosion can be progressive if conditions remain conducive. A red cuprous oxide formation, sometimes referred to as "red plague", has occurred. Usually this is the result of poor manufacturing procedures, where either insufficient silver was applied or excessive heating has caused the copper to migrate to the surface and form sites for electrolysis. Fifty microinches of silver is very much more effective than forty in minimizing this problem. An effective way of eliminating this oxidation is dual coating (see par. 1–3.2).

1–3.1.3 Nickel

Nickel plating was developed for continuous service up to 300°C. The nickel does not tarnish at elevated temperatures as does silver. Nickel is electropositive to copper, therefore, nickel does not exhibit the oxides that are sometimes found when using silver. In a phenomenon of electrolytic action, a flaw in the nickel coating will actually heal, preventing the cuprous oxide from forming. Nickel is much harder than silver, and therefore, passes through stranding machinery with less surface scratching.

Again, as in the case of tin coatings, the electrodeposit method of nickel coating gives assurance of a high purity, concentric, uniform layer of deposit. The tolerance on finished nickel-coated wire strands in ASTM B-355 are +0.0003 in.–0.0001 in. and +3%–1% for tin-coated copper. Since nickel-coated wire is redrawn through dies after coating, this extra tolerance is not needed and normal manufacturing controls can hold this to 20.0001 in. and ±1%. This smaller tolerance should be specified to save weight as illustrated in par. 1–3.1.1 for tin-coated strands.

Nickel coating solders readily with approved noncorrosive solders but requires higher temperatures. Solder pots and irons should be run in excess of **675°F** for adequate wetting.

Testing of nickel-coated copper wire includes tensile strength, resistivity, continuity, coating adherence, weight, and finish. The parameters of these tests are specified in ASTM B-355. The normal thickness applied is 50 pin. minimum. The plating of nickel is more difficult to accomplish than silver or tin, therefore, the nickel-coated wire has the additional coating adhesion test and resistence check. This adhesion test consists of heat cycling which, because of the differences in coefficients of thermal expansion of nickel and copper, causes the nickel and copper to separate if not thoroughly bonded. This is a very useful and revealing test, and should be part of every specification requiring the use of nickel plating. The resistivity test is utilized to assure that excessive amounts of nickel are not present on the wire.

1–3.2 DUAL COATING

In order to provide silver coating with the corrosion protection of nickel, a corrosion-resistant coating with excellent solderability has been developed consisting of thin layer of nickel, and over that a coating of silver. These combine to give the advantages of both materials. This coating is usually applied with 10 pin. of nickel and 40 pin. of silver (minimum).

This construction should include testing for resistance, thickness of coating, continuity of coating, adhesion of coating, tensile strength, and elongation.

1-3.3 CLADDINGS

Copper-clad steel consists of a steel core surrounded by a copper cylinder, the two metals continuously fused or bonded together under heat and pressure. Nickel-clad copper is similarly formed. When being drawn to fine wire, it is important that the cladding process be accomplished at a small wire size instead of at the billet stage. When the cladding is done in billet size (4 in. to 6 in. diameter) and drawn to 0.003 in.–0.010 in. diameter range, the coating will no longer be uniform and, in fact, the core material may even be exposed. Resistances will vary along the length of the wire and the product is unsatisfactory. Table 1–1 shows data of copper-clad steel conductors.

Nickel is normally applied by the electrodeposit method, but may be clad. When applied by cladding, the nickel coating must be heavier than a plated coating. This normally runs 15% or greater by weight which is undesirable since the conductivity of nickel is much lower than that of copper.

1-4 ALUMINUM

1-4.1 USES

Aluminum is frequently used as a conductor material because of its good conductivity and light weight. Large diameter transmission lines made of aluminum with a steel reinforcement are the main uses of aluminum conductors.

High purity (99.45%) EC grade aluminum is used, however, it is necessary to use a conductor two gage sizes larger, where aluminum is substituted for copper, to have equal current-carrying capacity because of the increase in resistivity over that of copper (see Table 1–4). Therefore, because the aluminum conductor is larger, more insulation has to be provided to assure equivalent protection. Even though the size of the aluminum configuration is from 20% to 50% larger than that of copper, the breaking strength is less due to the much lower tensile strength of aluminum.

1-4.2 COATINGS

Aluminum should not be coated by any other metals even though the techniques exist to do it. Aluminum is very active, high in the EMF series, and positive, so that electrolytic corrosion between aluminum and other metals such as, copper, tin, silver, or nickel is very rapid and destructive at the interface in the presence of moisture, especially if polar salts are involved.

1-5 ALLOYS

1-5.1 GENERAL PROPERTIES

Alloying of copper with small amounts of other metals can increase the hardness, tensile strength, flex endurance, and resistance to elevated temperatures, with only a small sacrifice of electrical conductivity (see Table 1–7).

Reduction of conductor size offers the greatest opportunity for weight and size reductions where current and voltage drops permit. In small gages (#26 AWG or smaller) copper does not have sufficient physical strength to be completely reliable. The substituion of hard drawn materials is an unsatisfactory method of increasing strength because they have little or no elongation which would make breakage due to high stress a very serious problem. Obviously, hard drawn conductors with no elongation, bound into harnesses of cable, must break if the cable is bent since there is no stretch available. This rules out the use of cadmium copper, beryllium copper, or hard drawn copper to increase the strength of fine wire since in the annealed state they offer little or no improvement in physical properties over soft copper.

1-5.2 HIGH CONDUCTIVITY TYPES

Flex-life is improved vastly with the use of high conductivity copper alloy conductors as compared to similar soft copper constructions. It is possible to select a conductor #2 AWG sizes smaller in an alloy construction, for weight saving designs, while retaining the breaking strength, elongation, and flex-life characteristics of the larger and heavier soft copper conductor. See Table 1–4 for flex-life comparisons.

These alloys can be acquired with the same protective coatings as described for copper.

TABLE 1—1

DATA—COWER-CLAD STEEL CONDUCTORS"

AWG#	Dia, in.	Max DC Resistance, ohm/ 1000 ft @20°C, Conductivity		AWG#	Dia, in.	Max DC Resistance, ohm/ 1000 ft @20°C, Conductivity	
		40%	30%			40%	30%
40	0.003 145	2978.0	3955.0	18	0.04030	17.58	24.10
39	0.003531	2324.0	3135.0	17	0.04526	13.96	19.10
38	0.003965	1787.0	2490.0	16	0.05082	11.06	15.15
37	0.004453	1408.0	1974.0	15	0.05707	8.77	12.02
36	0.006000	1143.0	1566.0	14	0.06408	6.96	9.53
35	0.005614	910.0	1242.0	13	0.07196	5.52	7.56
34	0.006304	720.0	984.0	12	0.08081	4.37	6.00
33	0.007080	567.0	780.0	11	0.09074	3.47	4.76
32	0.007950	447.0	619.0	10	0.1019	2.75	3.77
31	0.008928	361.0	491.0	9	0.1 144	2.18	2.99
30	0.0 1003	286.0	392.0	8	0.1285	1.73	2.37
29	0.01126	224.0	308.0	7	0.1443	1.372	1.88
28'	0.0 1264	180.0	245.0	6	0.1620	1.088	1.492
27	0.01419	142.0	194.0	5	0.1819	0.864	1.183
26	0.01590	113.5	154.0	4	0.2043	0.684	0.938
25	0.01790	89.2	122.2	3	0.2294	0.542	0.744
24	0.02010	70.7	97.0	2	0.2576	0.43 1	0.590
23	0.02257	56.0	76.8	1	0.2893	0.34 1	0.467
22	0.02535	44.7	60.8	0	0.3249	0.271	0.371
21	0.02846	35.2	48.4	00	0.3648	0.215	0.294
20	0.03 196	27.9	38.3	000	0.4096	0.170	0.233
19	0.03589	22.2	30.4	0000	0.4600	0.135	0.185

Material	Conductivity IACS** Based on DC Resistivity	Tensile Strength, psi		Elongation, % in 10 in.	
		Min	Max	Min	Nom
Copper-Covered Steel 40% Hard Drawn	40%	110,000	120,000	1	2
40% Hard Drawn	40%	55,000	60,000	8	12
30% Hard Drawn	30%	127,000	135,000	1	2
30% Soft	30%	60,000	65,000	8	12

* Copper-covered Steel or Copperweld are other common names.
** International Annealed Copper Standard.

1—5.3 HIGH CONDUCTIVITY-HIGH STRENGTH TYPES

The high conductivity-high strength alloys can be subjected to much higher temperatures than can copper, either in processing or in use, without effect on breaking strength or flex-life. Copper, cadmium bronze, etc., anneal at temperatures as low as 450°F, whereas the alloys can be exposed to 750°F with no change in properties.

1—6 STRANDING

The majority of high quality, specialized wire is stranded in order to give it flexibility, long flex-life, and to improve its reliability.

Nonstandard strand sizes may be selected so that the finished wire will have a certain cross-sectional area as defined by a standard wire gage, or a standard strand size may be selected so that the finished wire, with a specified number of strands, does not match the standard wire gage exactly, but is a close approximation. Table 1–6 shows a typical comparison of strandings specified in Specification QQ-W-343 and ASTM B-286. The ASTM Specification calls for the measurements of resistivity as a control of the finished size of a conductor. This is more realistic and is more readily measured on an insulated conductor than circular mil area. These values may be controlled more closely by careful wire processing techniques to cut down on the amount of cold working of the conductor during stranding, and stretching in subsequent operations.

Table 1–6 shows typical wire resistance values for stranded and solid wires of various materials. **ASTM** B-286 furnishes Eq. 1–2 for calculating the maximum D–C resistance of coated and uncoated electrical conductors. Eq. 1–2 applies to 0.010 in. and larger strand sizes. **Eq.** 1–3 is used for computation of maximum resistance for 0.0099 in. and smaller strand size.

$$\frac{R \times 105.35 \times f \times m}{d^2 \times N \times 0.98 \times S.G.} = \text{ohm (max)/1000 ft @ 20°C} \qquad (1\text{-}2)$$

$$\frac{R \times 105.35 \times f \times m}{(d_{min})^2 \times N \times S.G.} = \text{ohm (max)/1000 ft @ 20°C} \qquad (1\text{-}3)$$

R = resistivity, ohm-lb/mi^2 @ 20°C

R = 875.20 for bare copper

R = 939.51 for tinned copper 0.0111 in. to 0.0030 in. diameter

R = 929.52 for tinned copper 0.0201 in. to 0.0111 in. diameter

R = 910.15 for tinned copper 0.103 in. to 0.0201 in. diameter

R = 875.20 for silver-coated copper

R = 875.20 for nickel-coated copper (50μin.)

105.35 = constant conversion factor

f = stranding lay factor

f = 1.02 for bunch or concentric stranding through 27 strands

f = 1.03 for bunch or concentric stranding through 28 or more strands

f = 1.04 for rope lay conductors with 7 members

f = 1.05 for rope lay conductors with 19 members

m = stretch allowance factor to compensate for stretching of conductor during processing

m = 1.02

d = nominal strand diameter, mils (i.e., 0.001 in. = 1 mil)

d_{min} = minimum allowable strand diameter, mils (same as above).

Note

For nickel-coated strands use 0.0002 in. less than minimum allowable strand diameter.

0.98 = cross-sectional area factor for minus tolerance allowance in single end wire.

$S.G.$ = specific gravity

8.89 for copper and Alloy 63

2.7 for aluminum

7.9 for steel

N = number of strands

In the stranding of conductors there are specific numbers of strands which lend themselves to round configurations. These round configurations may be made up with 7, 12, 19, 27, or 37 and larger numbers of strands. Normally the 37 grouping is the largest one utilized without making up a rope out of 7 or 19 groups of stranded conductors. When insulating conductors, it is extremely desirable to use these configurations which yield round conductors because the insulation is extruded from a circular die and is in itself round. If the conductor is not round, then excessive insulation requiring additional space and weight must be utilized, or there will be insufficient insulation on the thin spots to properly carry the rated voltage without breakdown.

Wire is stranded in 3 basic configurations – bunched, concentric, and rope.

1–6.1 BUNCHED STRANDING

Bunched stranding consists of twisting a group of wires of any number together, all at once – in the bunching machine, with the same length of lay for all strands – without regard to roundness or geometric arrangement. When configurations – such as 7, 12, 19, etc., which may be round – are twisted in this manner, the bunch stranding has been called "Unilay". "Unilay" stranding is still a bunched stranding with all its inherent problems, such as strands popping out and sliding from layer to layer. In order to attempt to minimize this strand migration, bunched stranding is sometimes passed through a closing die too small for the conductors and "mashed" into shape. During this process the round strands are pressed into polygons. This results in excessive work hardening, loss of flex life, and scraped coating.

1–6.2 CONCENTRIC STRANDING

Concentric stranding consists of a central core surrounded by distinct layers of strands. The only way such a stranding can be guaranteed to stay round is to either reverse the direction of the successive layers of strands, or have a different length of lay for eachlayer, so that the inner layer will support the outer layer and prevent the strand migration encountered in a bunched configuration. When the lay in each layer is reversed, concentric stranding is called true concentric, and when the layers are in the same direction, each with a different lay length, it is called unidirectional concentric. Unidirectional concentric has an advantage of much greater flexibility and flex life than the true concentric. Lay lengths close to, but not greater than, those specified in Table 1–8 are important for flexibility and flex life. Concentric stranding is preferred to bunched to achieve more uniform wall thickness of insulation.

1–6.3 ROPE STRANDING

Rope stranding consists of twisted groups of stranded conductors. Each group may be either bunched or concentrically stranded. In rope stranding it is standard to use a number of groups that lead to round constructions (7, 12, 19, 27, etc.) – 7 and 19 being most common. These groups may be twisted in the same direction in all layers (unidirectional) or in alternate directions for each successive layer (true concentric). As with concentric stranding, each layer in a unidirectional construction must have a different lay length if the roundness is to be maintained. Unidirectional lay is preferred to true concentric because of better flexibility and greater flex life. The lay lengths for each lay should be between 8 and 14 times the pitch diameter of that layer for best compromise between flexibility and flex life. See Table 1–8 for stranded conductor lay lengths.

1–7 SOLDERING

Since soldering is a mutual union involving an action between two metals, it is essential that the metal being soldered be as hot as the molten solder for proper alloying to transpire. If hot solder is dropped on a cold metal, the solder will only freeze to produce a "cold joint", and no alloying action will take place – the result is a poor electrical connection. Therefore, the soldering iron or other source of heat that is employed must be of adequate capacity to heat the metal being soldered to a temperature that will melt and alloy the solder.

For successful, effective soldering, the soldering iron must be "tinned" before use. The purpose of this is to provide a completely metallic surface through which the heat may flow readily from the iron to the metal being soldered. If tinning is not present, the hot iron will oxidize and the heat will not flow readily through the surface oxide film to the work.

Even the metals – tin, silver, and nickel – which are added to enhance solderability, will form an oxide surface which must be removed before a good joint can be achieved. This is accomplished by chemical fluxes which must be noncorrosive at the operating temperature of the finished product. The flux may be applied by brush, dipping, or most commonly by incorporating as a core in the solder.

When using flux-core solder, it is important to remember that this product consists of two substances (solder and flux) that are physically and chemically dissimilar. For instance, the flux in most cases is liquid or semi-liquid at room temperatures with a tendency to volatilize at 100°C (212°F), while the solder does not become liquid below 183°C (361°F) to 327°C (620°F). For this reason the soldering flux, which is contained within the solder core, has a tendency to volatilize or decompose while the solder is being melted. Flux-core solder must, therefore, be applied not on the top or side of the hot iron where it will volatilize and lose its effectiveness, but rather at the exact junction between the metal assembly and the soldering iron in order that solder and flux may be liberated simultaneously at the specific joint where solder is desired and where it is needed.

The primary purpose of soldering is not to secure mechanical strength, but to secure a permanently sound, nonporous, and continuously metallic connection that is not affected by temperature change; that lends itself to minor torsional strain and stress without rupture; and that has a constant and permanent electrical value. A joint must be mechanically secure before soldering, and allowed to remain undisturbed until it is completely solid. It is of no value to add solder to a joint after adequate alloy action has taken place. The alloy attachment lies in the thin film of solder between the two metals that are joined together. This film of solder is preferably in the order of 0.004 in. in thickness.

Some metals solder' readily, some solder with difficulty, and some will not solder. The type of solder and flux depends on the particular metal being soldered.

1–7.1 SOLDERING STRANDED WIRE

There have been many problems in connection with the soldering of stranded wire. The conventional procedure has been to cut and strip conductors, either by hand or mechanized equipment, twist the stripped ends together and dip in a solder pot to tin the conductors and hold the strands together. This being a hand operation, it becomes very costly and presents problems such as melting of the insulation and the wicking of solder up into the strands. An attempt to avoid this may be made by running tinned stranded wire through a hot tin dip in order to fuse all the strands together continuously throughout the length of the wire prior to insulating. This approach is costly and results in a stiff stranded conductor similar to a solid conductor.

A second approach is to lightly tack the strands together so that, on flexing, these strands will break away on the first bend and will then act as stranded conductors. However, this has the disadvantage that, when it is bent with tools to insert into lugs or wrap around terminals, the strands will break open defeating the purpose of fusing. Neither of these methods is approved under the governing specifications for hookup wire, MIL-W-76 or **MIL-W-16878D**, because of the obvious implications of reduced flex life compared to the stranded conductor specified.

1–7.2 HEAVY TINNED STRANDING

The most practical solution to enable this tinning to be done without sacrifice to wire characteristics is by the use of stranded wire made with heavy tinned strands utilizing 100-150 pin. of tin. Heavy tinned, insulated, stranded wire utilizing such a conductor may be passed through a coil on a radio frequency induction heater, and if the correct amount of radio frequency current is passed through the coil, it will heat the conductor through the insulation and fuse together the heavy tinned strands in a section approximately equal to the coil length. The coil length should be such that when the fused section is cut in the center and stripped, a tinned and fused section of conductor will be exposed where the insulation is stripped off, with the remainder of the conductor unfused. This technique may be utilized with either heavy tin or silver coating to eliminate the tedious hand dipping operation.

In practice the coil is located an integral number of cutting lengths from the cutting and stripping machine so that when the wire stops for cutting a pulse of current is passed through the coil fusing a spot which will later be cut and stripped. Example: A run of 9 in. pieces are to be made with 1/2 in. stripped length at each end. A coil will be chosen to fuse 3/4 in. of conductor and the machine set so that the center of the coil is 18 in., 27 in., *36* in., or other convenient multiple of 9 in. from the cutter. As the machine operates, the cut will be made in the center of the fused portion and stripped, leaving **3/8** in. of fused and 1/8 in. of unfused conductor exposed.

1–7.3 SILVER-COATED STRANDING

Considerable breakage has been experienced by equipment manufacturers utilizing silver-coated strandings, particularly with Teflon insulation. In most instances, the breakage was due to careless soldering operations which caused the solder to wick up into the strands, yielding a solid conductor where the insulation is stripped and the 'flexibility is needed most. This probably occurred for the following reasons: (1) Teflon being resistant to the heat of soldering causes operators to become extremely careless and actually dip the Teflon itself into the solder pot, and (2) silver has a great affinity for solder, and as long as the temperature of the silver-coated wire is hot enough to keep the solder melted, it will continue to wick up by capillary action higher and higher into the stranded wire under the insulation. This condition can be controlled by exercising extremely careful regulation of solder pot temperature, immersion time, immersion depth, solder iron temperature, and use of heat sinks.

1–7.4 NICKEL-COATED STRANDING

A more satisfactory solution is to avoid the problem completely by using nickel-plated wire in place of silver. While nickel does not have the great affinity for solder that silver does, it will solder nicely with ordinary approved noncorrosive fluxes. It does require slightly higher temperatures for the solder pot, in the order of 320°C (608°F) to 360°C (680°F).

Experience has shown, both in production and the laboratory, that the flex life of nickel-plated, stranded conductor terminations is superior to those of silver-plated terminations. This can be traced to the greatly reduced amount of solder wicking which occurs with a nickel-plated strand.

1–7.5 COMPOSITE STRANDING

An unsatisfactory attempt at a solution to wire breakage was offered several years ago – before adequate alloy materials were available. Strandings made of composite materials – such as copper mixed with stainless steel, copper-covered steel strands, or other reinforcement – were tried. If composite strands are stretched or jerked in some manner, the copper will elongate, and the more springy, harder materials will retract more readily, causing basket effects and kinking of the adjacent copper strands. When materials such as stainless steel are used, they do not solder; and, therefore, are useless in adding strength at the solder joint where the strength is most needed. Also, they can become a source of electrical noise since they are free to move within the solder joint under conditions of vibration or stress. These composite strandings were formerly permitted in MIL-W-16878C without regard for their solderability. In MIL-W-16878D this was modified, and if composite strandings are used, the steel or other material must be coated with a solderable surface similar to the copper coating for the particular wire in question.

1–8 TERMINATIONS

1–8.1 CRIMP TERMINATION

A crimp termination can be definied as the joining together of conductor and terminal through the proper mechanical displacement of the materials by squeezing the connector sleeves onto the conductor. The process is realized through a mechanical bond in lieu of thermal alloying. The primary concern in the selection of this termination method is proper execution of the crimp. This can only be realized through selection of proper tools and terminals, including contacts, lugs, etc., and wire sizes. Tools are now available which will properly execute the termination by means of ratchet, preset, positive cycle mechanisms. These tools will function properly over extended periods of time, with the augmentation of thorough test sampling cycles. This method lends itself well to semi- and fully-automated production methods. Crimp terminations offer the advantages of the selection of wire, insulation, and terminals without concern for thermal characteristics. This method also permits miniaturization and subminiaturization of circuitry with excellent mechanical and environmental parameters. The greatest single advantage of crimping, compared to soldering, is elimination of the human element always present in soldering. When proper tooling is used, crimps are as consistent as the tolerances that can be maintained on the joined parts.

1–8.2 WIRE WRAP TERMINATION

A relatively recent method of making a reliable solderless termination, rapidly and adaptable to automation, is the wire wrapping technique. The principle of this method involves the wrapping of a solid wire under tension, 4 to 8 complete turns in the form of a closed helix, around a rectangular termination pin made from a relatively harder material than the wire being used. The wire is bent sharply around the corners of the pin under enough tension that the corners displace metal in the wire and form an increased area of contact. For this reason, the wire used for wire wrapping must be very ductile and resistant to notch sensitivity, and is usually controlled by raising the minimum elongation values of copper wire 5% above the normal. In some cases an added restriction of maximum tensile strength is desirable. Present usage involves #22 through #30 AWG. Stranded wire cannot be used for wrap terminations.

1–9 SHIELDING

1–9.1 GENERAL

Shielding is used to prevent electrical interference, whether from the protected circuit to other circuits, or from other circuits into the protected circuit.

Shielding is also helpful in reducing damage to wire insulations from electrical discharges, due to lightning, built up on the outside of the insulation and serves as a safety measure to prevent injury if the insulation is accidentally pierced or otherwise penetrated or broken. A shield is applied over the insulated conductor and is usually grounded while the wire or cable is in operation. An external shield or armor may be applied over the jacket and primarily serves the function of protecting the wire or cable from external physical damage.

For low frequency electrostatic shielding, semiconductive coatings, either extruded or tape wrapped, have been used. Usually this semiconductive coating is applied over an uninsulated drain wire which is used for termination purposes. The electrical effectiveness of those semiconductors leaves much to be desired, and in fact, the drain wire alone will furnish the major portion by capacitive coupling.

Shielding may be provided by metallic (usually copper or aluminum) sheaths in various forms. The metal may be either spirally or longitudinally applied in tape form. When sufficient thickness is applied to furnish effective electrical shielding, the construction is very stiff – the spirally wrapped version being slightly more flexible because the layers can slide as the cable is bent.

The most effective shield, electrically, is a solid metal tube applied either by drawing down over the conductor or by wrapping a sheet of material around the conductor and welding the seam. This construction, of course, is very stiff and will only stand limited bending. It is utilized a great deal for permanent installations of coaxial cable.

Thin solid metal coatings may be applied by electroplating directly to the dielectric. These are unsatisfactory, because, if sufficient plating is applied to give an electrically .effective shield, the resulting metal is so brittle it will fracture under bending around small radii.

Thin metal foils applied by tape wrapping suffer the same lack of electrical shielding capability as thin plating. This is especially true at low frequencies where current penetration is greater. This would apply particularly to metal-backed plastic films where the metal is especially thin. Again, as with semi-conductors, most of the shielding would result from capacitive coupling to a drain wire wrapped under the foil.

Flat wire has been applied by braiding over the insulated wire in an attempt to reduce costs through weight saving and labor, and improve coverage. One end of wire per carrier is used. It has been found that coverage measurements average about the same as round wire braids and the flat wire adds considerably to the stiffness of the cable. On sharp bends the flat wire has a tendency to kink with the relatively sharp edges cutting into the insulation.

The most satisfactory shield technique is the use of braided wires. This yields a high conductivity, flexible, mechanically sound structure giving an effective electrostatic and electromagnetic shield at the price of a weight increase. The size of wire used depends on the diameter to be shielded, and is chosen on the basis of machine limitations and mechanical structures.

A typical shield is pictured in Fig. 1–1.

1–9.2 BRAID TERMINOLOGY

In braid terminology the number of ends refers to the number of parallel wires in a group (C in Fig. 1–1 in this case). The number of carriers refers to the total number of groups of wires in the braid (total number of spools on the braiding machine). The number of picks refers to the number of group cross-overs measured longitudinally along the cable in any distance, usually 1 in., (*P*, Fig. 1–1 in this case). The ends/carrier is shown as *N* in Fig. 1–1. An indication (although not mathematically proportional) of the shield effectiveness is given by the % of optical coverage of the shield. It is usual to specify a braid by the degree of angle, % coverage, and shield wire gage size; and leave the actual design up to the manufacturer.

In order to facilitate terminations, a shielded conductor or complex must have good push back qualities. The use of a 20" to 40" angle, angle *a* in Fig. 1–1, with the axis of the conductor will assure these

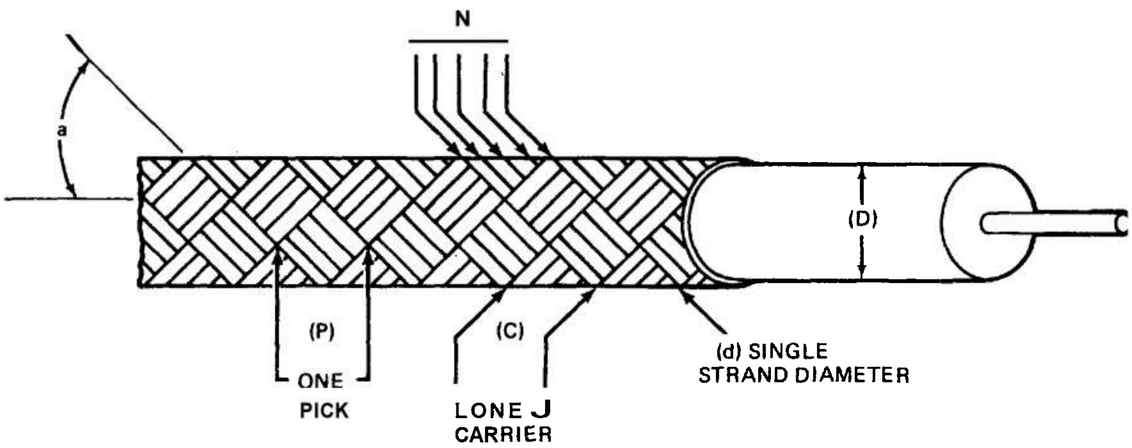

Figure 1–1. Shield–Constructional Details

qualities. It is not always possible to maintain this angle range however, particularly where the cable OD is in excess of 0.400 in.; on such cables the shield angle shall be the best possible. For a high coverage, tightly adhering shield, an angle of between 40° and 60° is preferable. This is sometimes used to assure good attenuation characteristics.

1–9.3 COMPUTATION OF BRAID ANGLE AND COVERAGE

The percent coverage of the shield may be computed by

$$K = (2F - F^2)\,100 \qquad (1\text{-}4)$$

where

K = coverage, %

$F = \dfrac{NPd}{\sin a}$

N = number of strands per carrier (ends)

P = picks per in.

d = diameter, carrier, single end, in.

a = angle of shield with axis of conductor, deg

$$\tan a = \frac{2\pi(D + 2d)P}{C}$$

C = number of carriers

π = 3.1416

D = diameter of core under shield, in.

Wire gage generally used for shielding is #36 AWG or #34 AWG for single conductors and up to #30 AWG for overall cable shield depending on size.

The percent coverage range is usually between 85% and 95% by specification requirement, and is dependent on the number of carriers, number of ends per carrier, and the picks per inch as shown by **Eq. 1–4.** Table 1–2 is a guide to good design for shield wire diameter.

TABLE 1–2

DESIGN GUIDE —SHIELD WIRE SIZE

Diameter of Core Under Shield, in.	Shield Wire Size
Up to 0.048	#38 AWG
0.049 to 0.300	#36 AWG
0.300 to 0.500	#34 AWG
0.500 to 1.00	#32 AWG
1.000 and over	#30 AWG

1–9.4 SERVED SHIELDS

In order to save weight, shield wires are sometimes served in one direction. This cuts down considerably on electrical effectiveness due to the inductance introduced as currents spiral around the core. It also presents some minor problems in fraying if the outer plastic jacket is removed.

1–9.5 SHIELDING EFFECTIVENESS

Table 1–3 gives measured values of typical shields utilizing the method of U.S. Army Electronics Command Technical Requirement SCL-1476. In this table the shielding effectiveness number is nondimensional: 0 = perfect shielding 1 = No shielding. The values listed in Table 1–3 for shield effectiveness K_e at 5 MHz are those obtained experimentally.

TABLE 1–3

SHIELDING EFFECTIVENESS—VARIOUS MATERIALS AND CONSTRUCTIONS

Shield Description	Relative Shield Effectiveness K_e @ 5 MHz*
1. #36 AWG Tinned Copper Braid 50% Coverage	2.9×10^{-3}
2. #36 AWG Tinned Copper Braid 75% Coverage	1.06×10^{-3}
3. #36 AWG Tinned Copper Braid 85% Coverage	0.850×10^{-3}
4. #36 AWG Tinned Copper Braid 95% Coverage	0.636×10^{-3}
5. #36 AWG Tinned Copper Served Shield 100% Coverage	7.65×10^{-3}
6. Flat Wire Braid—0.002 in. Thick 48% Coverage	11.90×10^{-3}
7. #36 AWG Tinned Copper Braid 85% Coverage (2 conductors twisted together – overall shield)	0.0352×10^{-3}
8. Extruded Semiconductive Thermoplastic (with no drain wire)	No Apparent Shielding
9. Extruded Semiconductive Thermoplastic (with drain wire)	No Apparent Shielding
10. Double-faced Aluminum on Mylar Backing. Spirally Wrapped Tape – 50% Overlap	5.2×10^{-3}
11. 1/4 in. Alcoa Aluminum Foil 0.005 in. Thick	24.0×10^{-3}
12. Impregnated Semiconductive Cloth Tape (no drain wire)	0.353 (very poor shield)
13. Semiconductive Black Cloth Tape with #30 Drain Wire	0.900 (no shield effectiveness)

TABLE 1–3 (CONT.)

Shield Description	Relative Shield Effectiveness K_e @ 5 MHz*
14. Semiconductive Yarn 40 Denier With No Drain Wire	0.350 (very poor shield)
15. Semiconductive Yarn 40 Denier With #30 Drain Wire	0.291 (very poor shield)

* K_e is the shielding effectiveness factor derived from using cylindrical testers to obtain an absolute measurement of the shielding effectiveness. Therefore:

0 = perfect shielding
1 = no shielding

TABLE 1–4

WIRE CHART—SOLID CONDUCTORS

AWG#	Nominal Dia, in.	Circular Mil Area	Material	Weight, lb/1000 ft	Maximum D-C Resistance, ohm/1000 ft @ 20°C			
					Bare	Tinned	Silver-coated	Nickel-coated
10	0.1019	10384	Copper	31.43	1.018	1.059	1.018	1.023
			Aluminum	9.55	1.669	------	------	------
11	0.0908	8238	Copper	24.92	1.283	1.334	1.283	1.289
			Aluminum	7.57	2.108	------	------	------
12	0.0808	6528	Copper	19.77	1.621	1.686	1.621	1.629
			Aluminum	6.00	2.669	------	------	------
13	0.0720	5184	Copper	15.68	2.041	2.123	2.041	2.053
			Aluminum	4.76	3.373	------	------	------
14	0.0641	4109	Copper	12.43	2.575	2.675	2.575	2.591
			Aluminum	3.78	4.269	------	------	------
15	0.0571	3260	Copper	9.858	3.245	3.380	3.245	3.268
			Aluminum	2.99	5.402	------	------	------
16	0.0508	2581	Copper	7.818	4.101	4.255	4.101	4.134
			Aluminum	2.37	6.856	------	------	------
17	0.0453	2052	Copper	6.200	5.154	5.375	5.154	5.201
			Aluminum	1.88	8.666	------	------	------
18	0.0403	1624	Copper	4.917	6.514	6.770	6.514	6.581
			Aluminum	1.49	11.012	------	------	------
19	0.0359	1289	Copper	3.899	8.211	8.539	8.211	8.573
			Aluminum	1.18	13.569	------	------	------
20	0.0320	1024	Copper	3.092	10.319	10.731	10.319	10.455
			Aluminum	0.939	17.138	------	------	------
			Chrome Copper	3.09	12.284	------	------	------
			Alloy 63**	3.09	11.465	------	------	------
21	0.0285	812	Copper	2.452	13.028	13.549	13.029	13.210
			Aluminum	0.745	21.686	------	------	------
			Chrome Copper	2.45	15.510	------	------	------
			Alloy 63**	2.45	14.476	------	------	------
22	0.0254	645	Copper	1.945	16.5	17.1	16.5	16.7
			Aluminum	0.591	28.6	------	------	------
			Chrome Copper	1.940	19.6	------	19.6	19.9
			Alloy 63**	1.940	18.3	------	18.3	18.6

TABLE 1–4 (CONT.)

AWG#	Nominal Dia, in.	Circular Mil Area	Material	Weight, lb/1000 ft	Maximum D-C Resistance, ohm/1000 ft @ 20°C			
					Bare	Tinned	Silver-coated	Nickel-coated
23	0.0226	511	Copper	1.542	20.7	21.5	20.7	21.0
			Aluminum	0.468	37.2	------	------	------
			Chrome Copper	1.540	24.6	------	24.6	25.0
			Alloy 63**	1.540	23.0	------	23.0	23.4
24	0.0201	404	Copper	1.223	26.2	27.2	26.2	26.8
			Aluminum	0.371	46.6	------	------	------
			Chrome Copper	1.220	31.4	------	31.4	31.9
			Alloy 63**	1.220	29.2	------	29.2	29.8
25	0.0179	320	Copper	0.970	33.1	35.2	33.1	33.9
			Aluminum	0.295	59.4	------	------	------
			Chrome Copper	0.969	39.4	------	39.4	40.3
			Alloy 63**	0.969	36.8	------	36.8	37.7
26	0.0159	253	Copper	0.769	42.1	44.7	42.1	43.2
			Aluminum	0.234	76.6	------	------	------
			Chrome Copper	0.769	50.1	------	50.1	51.5
			Alloy 63**	0.769	46.7	------	46.7	48.0
27	0.0142	202	Copper	0.610	52.2	55.3	52.2	53.7
			Aluminum	0.185	97.4	------	------	------
			Chrome Copper	0.610	62.2	------	62.2	64.0
			Alloy 63**	0.610	58.0	------	58.0	59.7
28	0.0126	159	Copper	0.484	66.4	70.0	66.4	68.5
			Aluminum	0.147	126.0	------	------	------
			Chrome Copper	0.483	79.0	------	79.0	81.5
			Alloy 63**	0.483	73.7	------	73.7	76.1
29	0.0113	128	Copper	0.384	82.7	87.7	82.7	85.6
			Aluminum	0.117	160.2	------	------	------
			Chrome Copper	0.383	98.5	------	98.5	101.9
			Alloy 63**	0.383	91.9	------	91.9	95.1
30	0.0100	100	Copper	0.304	105.8	113.7	105.8	110.3
			Aluminum	0.092	210.0	------	------	------
			Chrome Copper	0.304	126.0	------	126.0	131.3
			Alloy 63**	0.304	117.4	------	117.4	122.7

TABLE 1-4 (CONT.)

AWG#	Nominal Dia, in.	Circular Mil Area	Material	Weight, lb/1000 ft	Maximum D-C Resistance, ohm/1000 ft @ 20°C			
					Bare	Tinned	Silver-coated	Nickel-coated
31	0.0089	79.2	Copper	0.241	133.8	144	134	140
			Aluminum	0.073	225	------	------	------
			Chrome Copper	0.241	159	------	159	167
			Alloy 63**	0.241	149	------	149	156
32	0.0080	64.0	Copper	0.191	166.2	178	166	175
			Aluminum	0.058	279	------	------	------
			Chrome Copper	0.191	198	------	198	208
			Alloy 63**	0.191	185	------	185	194
33	0.0071	50.4	Copper	0.152	211.6	227	212	224
			Aluminum	0.046	357	------	------	------
			Chrome Copper	0.151	252	------	252	267
			Alloy 63**	0.151	235	------	235	249
34	0.0063	39.7	Copper	0.120	270.0	290	270	288
			Aluminum	0.037	457	------	------	------
			Chrome Copper	0.120	322	------	322	343
			Alloy 63**	0.120	300	------	300	320
35	0.0056	31.4	Copper	0.095	343.0	368	343	369
			Aluminum	0.029	582	------	------	------
			Chrome Copper	0.095	408	------	408	440
			Alloy 63**	0.095	381	------	381	410
36	0.0050	25.0	Copper	0.076	431.9	464	432	470
			Aluminum	0.023	738	------	------	------
			Chrome Copper	0.076	514	------	514	560
			Alloy 63**	0.076	480	------	480	522
37	0.0045	20.3	Copper	0.060	535.7	576	536	588
			Aluminum	0.018"	------	------	------	------
			Chrome Copper	0.060	639	------	639	700
			Alloy 63**	0.060	596	------	596	654
38	0.0040	16.0	Copper	0.048	681.8	733	682	757
			Aluminum	0.015*	------	------	------	------
			Chrome Copper	0.048	812	------	812	902
			Alloy 63**	0.048	758	------	758	841

TABLE 1–4 (CONT.)

AWG#	Nominal Dia, in.	Circular Mil Area	Material	Weight, lb/1000 ft	Maximum D-C Resistance, ohm/ 1000 ft @ 20°C			
					Bare	Tinned	Silver-coated	Nickel-coated
39	0.0035	12.25	Copper	0.038	897.1	964	898	1011
			Aluminum	0.012*	-----	-----	-----	-----
			Chrome Copper	0.038	1068	-----	1068	1202
			Alloy 63**	0.038	997	-----	997	1122
40	0.0031	9.61	Copper	0.030	1152	1237	1152	1323
			Aluminum	0.009*	-----	-----	-----	-----
			Chrome Copper	0.030	1372	-----	1372	1578
			Alloy 63**	0.030	1270	-----	1270	1470

Method of Calculation (Eq. 1–3)

$$\frac{R \times 105.35}{(d_{min})^2 \times S.G.} = \text{ohm/1000 ft}$$

where R = resistivity, ohm-lb/mi² @ 20°C
- bare copper: 875.20
- aluminum EC Grade: 436.24
- chrome copper (84% IACS): 1041.9
- Alloy 63 (30% IACS): 972.44
- tinned copper: 910.15 (0.103 in. to 0.0201 in. dia inclusive)
  - 929.52 (0.0201 in. to 0.0111 in. dia inclusive)
  - 939.51 (0.0111 in. to 0.0030 in. dia inclusive)
- silver-coated: Same as base materials
- nickel-coated: Use base metal values and subtract 0.2 mils from min diameters.

105.35 = conversion factor (constant)

d_{min} = minimum allowable diameter, in mils (1 mil = 0.001 in.)

S.G. = specific gravity
- for copper, chrome-copper, Alloy 63: 8.89
- for aluminum EC Grade: 2.703

* EC Grade aluminum is not available in sizes smaller than #36 AWG, however, other grades are available with the same weights.

** High strength copper alloy, manufactured by I.T.T.

1–10 FLEX-LIFE COMPARISON — COPPER VS ALLOY 63

1–10.1 TEST METHOD

Wire is flexed through an arc of 120" (± 60" from vertical) between parallel horizontal mandrels – having a diameter 4 x the wire diameter and set 90" to the plane of flexure. One complete cycle represents the swing of the wire from vertical to 60" one way, 120" the opposite way, and 60" back to vertical. The load is attached to the bottom of the wire.

1–10.2 COMPARATIVE DATA:

Table 1–5 shows comparative figures.

TABLE 1–5

FLEX-LIFE OF COPPER VS ALLOY 63

Load Material*, psi	Soft Copper	Alloy 63
1500	160 cycles	2000 + cycles
5000	36 cycles	249 cycles
10,000	16 cycles	30 cycles
15,000	1* cycle	14 cycles

* Load psi exceeds material yield strength

TABLE 1–6

WIRE CHART — STRANDED CONDUCTORS

	Conductor Construction					Maximum D-C Resistance, ohm/1000 ft @ 20°C				
AWG#	No. of Wires	Nominal Dia, each strand, in.	Circular Mil Area	Nominal Dia, in.	Weight, lb/1000 ft	Bare & Silver-coated copper	Tin-coated copper	Nickel-coated copper	Bare & Silver-coated chrome copper	Nickel-coated chrome copper
0000	2109	0.0100	210900	0.595	674	0.0537	0.0577	0.0559	-----	-----
000	1672	0.0100	167200	0.535	534	0.0678	0.0720	0.0726	-----	-----
00	1330	0.0100	133000	0.455	425	0.0852	0.0915	0.0888	-----	-----
0	1045	0.0100	104500	0.410	334	0.108	0.116	0.113	-----	-----
	1064	0.0100	106400	0.420	340	0.107	0.114	0.111	-----	-----
1	817	0.0100	81700	0.380	261	0.138	0.149	0.144	-----	-----
	836	0.0100	83600	0.385	267	0.136	0.146	0.141	-----	-----
2	665	0.0100	66500	0.315	212	0.169	0.181	0.177	-----	-----
4	133	0.0179	42615	0.269	136	0.263	0.280	0.272	-----	-----
	420	0.0100	42000	0.255	134	0.267	0.287	0.281	-----	-----
6	133	0.0142	26818	0.213	85.2	0.419	0.445	0.441	-----	-----
	266	0.0100	26600	0.220	85.0	0.422	0.453	0.439	-----	-----
8	133	0.0113	16983	0.169	53.6	0.661	0.702	0.693	-----	-----
	168	0.0100	16800	0.172	53.1	0.668	0.717	0.696	-----	-----
10	37	0.0159	9354	0.111	29.1	1.18	1.25	1.23	-----	-----
	49	0.0142	9880	0.128	30.5	1.14	1.21	1.17	-----	-----
	105	0.0100	10500	0.120	32.6	1.07	1.15	1.13	-----	-----
12	19	0.0179	6088	0.091	18.8	1.81	1.92	1.85	-----	-----
	37	0.0126	5874	0.089	18.8	1.87	1.99	1.95	-----	-----
	65	0.0100	6500	0.093	20.2	1.69	1.82	1.72	-----	-----

TABLE 1–6 (CONT.)

AWG	Conductor Construction					Maximum D-C Resistance, ohm/ 1000 ft @ 20°C				
	No. of Wires	Nominal Dia, each strand, in	Circular Mil Area	Nominal Dia, in.	Weight? lb/1000 ft	Bare & Silver-coated copper	Tin-coated copper	Nickel-coated copper	Bare & Silver-coated chrome copper	Nickel-coated chrome copper
14	19	0.0142	3831	0.072	11.9	2.87	3.05	2.95		-----
	41	0.0100	4100	0.076	12.7	2.69	2.88	2.79	-----	-----
16	19	0.0113	2426	0.057	7.44	4.54	4.82	4.70	-----	-----
	26	0.0100	2600	0.060	8.06	4.23	4.55	4.41	-----	-----
18	7	0.0159	1770	0.048	5.49	6.22	6.61	6.37	-----	-----
	19	0.0100	1900	0.050	5.89	5.80	6.22	6.03	-----	-----
	26	0.0080	1667	0.047	5.07	6.62	7.10	6.95	-----	-----
20	7	0.0126	1111	0.038	3.45	9.90	10.5	10.2	11.8	12.2
	10	0.0100	1000	0.038	3.10	11.0	11.8	11.5	13.1	13.7
	19	0.0080	1216	0.040	3.70	9.05	9.72	9.52	10.8	11.4
22	7	0.0100	700	0.030	2.17	15.7	16.9	16.4	18.7	19.5
	19	0.0063	754	0.032	2.32	14.6	15.7	15.6	17.4	18.6
24	7	0.0080	448	0.024	1.36	24.6	26.4	25.8	29.3	30.9
	19	0.0050	475	0.025	1.47	23.2	24.9	25.1	27.6	30.0
26	7	0.0063	278	0.019	0.856	39.6	42.5	42.2	47.2	50.3
	19	0.0040	304	0.020	0.930	36.2	38.8	40.1	43.2	48.0
28	7	0.0050	175	0.015	0.514	62.9	67.5	68.2	74.9	81.4
	19	0.0031	183	0.016	0.581	60.3	64.7	69.0	71.8	82.0
30	7	0.0040	112	0.012	0.343	98.0	106	108	117	130.0
32	7	0.0031	67	0.010	0.214	164	176	173	196	224.0

TABLE 1-7

GENERAL PROPERTIES OF CONDUCTOR MATERIALS

Material	Specific Gravity	Tensile Strength, 10^{-3} psi		Elongation, % in 10%		Conductivity, % IACS	Max Resistivity, ohm-lb/mi² @ 20°C	Comment
		Hard Drawn	Annealed	Min	Nom			
1. Copper	8.89	60	---	*	1**	96	910.15	Poor flex-life
2. Copper			35		20	100	875.20	Best all around-low tensile in fine gages.
3. Silver	10.5		30		35	105	984.46	Expensive
4. Cadmium Copper	8.89	90	---	1	1.5**	90	972.22	Poor flex-life. No elongation
5. Cadmium Copper			35		20	90	972.22	No mechanical advantage over copper.
6. Alloy 63	8.89		60	6	8	90	972.22	Best all around for finer AWG
7. Chrome Copper	8.89		58	6	8	84	1042.8	Good properties for fine AWG
8. Aluminum EC	2.7	25	--	1	1.5**	61	436.24	Light weight; poor flex-life and corrosion resistance.
9. Aluminum EC			12		15	61	436.24	Light, poor strength and corrosion resistance.
10. Nickel-clad Copper	8.89		42	--	15	73	1232.7	Heavy nickel coating not needed for ordinary corrosion resistance.
11. Beryllium Copper	8.23	185	--	1	1.5**	15	----	Conductivity degrades with flexing.
12. Beryllium Copper		---	60	6	8	50	----	Poor conductivity. No advantage over Alloy 63.
13. Copper-covered Steel	8.15	11o	--	1*	1.5""	40	2218.1	Poor flex-life/conductivity.
14. Copper-covered Steel	---		50		15	40	2218.1	Poor conductivity.
15. Copper-covered Steel	8.15	127	--	1*	1.5""	30	3108.4	Poor flex-life/conductivity.
16. Copper-covered Steel			55		15	30	3108.4	Poor conductivity
17. Aluminum 5056	2.64	60	--	1	1.5""	27	----	Poor flex-life/conductivity
18. Aluminum 5056		--	40	--	15	29		Poor conductivity-lt. wt.
19. Nickel	8.89	120	--	1	1.5""	18	----	Poor flex-life/conductivity, corrosion-resistant.

TABLE 1–7 (CONT.)

Material	Specific Gravity	Tensile Strength, 10^{-3} psi		Elongation, % in 10%		Conductivity, % IACS	Max Resistivity, ohm-lb/mi^2 @ 20°C	Comment
		Hard Drawn	Annealed	Min	Nom			
20. Nickel		--	60	--	20	18	----	Poor conductivity-weldable.
21. Tin	7.3	3	2	30	60	15	----	Poor conductivity/strength. Corrosion-resistant @low temps.
22. Steel Low Carbon	7.8	120		1	1.5**	15	----	Poor flex-life/conductivity. Magnetic
23. Steel Low Carbon	7.8	---	60	---	20	15	----	Poor conductivity Magnetic
24. Stainless Steel 302	7.9	325		1	1.5**	2.5	----	Poor flex-life/conductivity. Magnetic
25. Stainless Steel 302		---	125	---	30	2.5	----	Poor conductivity. Non-magnetic

* See applicable ASTM Specifications for minimum values.
** It is not recommended that hard wire be used in constructions for electronic purposes.

TABLE 1-8

STRANDING LAY LENGTHS—STRANDED CONDUCTORS

AWG #	No. of Wires	Strand Diameter Each Strand, in.	Stranded Diameter, in.		Length of Lay, in.	
			Min	Max	Min	Max
0000	2109	0.0100	0.580	0.605	*5.24	8.47
000	1665	0.0100	0.515	0.540	*4.32	7.56
00	1330	0.0100	0.455	0.480	*3.84	6.72
0	1045	0.0100	0.405	0.425	*3.40	5.95
1	817	0.0100	0.360	0.380	*3.04	5.32
2	665	0.0100	0.320	0.340	*2.72	4.76
4	133	0.0179	0.250	0.274	*2.19	3.84
6	133	0.0142	0.192	0.217	*1.74	3.04
8	133	0.0113	0.157	0.173	*1.38	2.42
10	37	0.0159	0.103	0.114	0.91	1.82
	49	0.0142	0.118	0.128	*1.02	1.79
12	37	0.0142	0.090	0.100	0.80	1.60
	19	0.0179	0.083	0.092	0.74	1.47
	37	0.0126	0.082	0.090	0.72	1.44
14	19	0.0142	0.066	0.073	0.58	1.17
16	19	0.0113	0.052	0.058	0.46	0.93
18	19	0.0100	0.046	0.051	0.41	0.82
	16	0.0100	0.045	0.048	0.38	0.77
20	19	0.0080	0.037	0.041	0.33	0.66
	7	0.0126	0.037	0.039	0.31	0.62
22	19	0.0063	0.029	0.033	0.26	0.54
	7	0.0100	0.029	0.031	0.25	0.50
24	19	0.0050	0.023	0.026	0.21	0.42
	7	0.0080	0.023	0.025	0.20	0.40
26	19	0.0040	0.019	0.021	0.17	0.34
	7	0.0063	0.018	0.020	0.16	0.32
28	7	0.0050	0.0147	0.016	0.13	0.26
30	7	0.0040	0.0117	0.013	0.10	0.23

* Rope Strandings - Lay Lengths are a minimum of 8 times, and a maximum of 14 times, the maximum stranded diameter. All other stranding lay lengths are 8 times minimum and 16 times maximum stranded diameter.

REFERENCES

1. **ASTM Reference, Special Technical Publication # 319.**

2. **ASTM-STD-B33,** *Tinned Soft or Annealed Copper Wire for Electrical Purposes.*

3. **ASTM-STD-B286,** *Specification for Copper Conductors for Use in Hook-up Wire for Electronic Equipment (Tentative).*

4. **ASTM-STD-B298,** *Specification for Silver Coated Soft or Annealed Copper Wire.*

5. **ASTM-STD-B355,** *Specification for Nickel Coated Soft or Annealed Copper Wire (Tentative).*

6. **MIL-W-76,** *Wire and Cable Hook-up Electrical, Insulated,*

7. **MIL-W-16878D,** *Wire, Electrical, Insulated, High Temperature (Navy).*

8. **QQ-W-343,** *Wire, Electrical and Nonelectrical, Copper, Uninsulated.*

9. *Final Report on Extra Flexible Tactical Cable,* **USAECOM Contract No. DA-28-043-AMC-00043(E) with Martin-Marietta Corp., November 1967.**

CHAPTER 2

INSULATION MATERIALS

2–1 INTRODUCTION

Over the past thirty years or so, the complexity of materials available for use as primary insulations and as jackets or sheaths for wire and cable constructions has vastly increased. The technology associated with the application of these materials to wire and cable has also become more sophisticated. This chapter, however, is a presentation of only the salient characteristics of the most prominent classes of insulation materials.

The thermal ratings and other characteristics assigned to the materials hereinafter discussed are those generally accepted by the military. Throughout the chapter, tables and figures will be found which list typical properties of the various insulating materials under consideration. (Table **2–9** indicates the relative costs of insulating materials.) The data herein should not be utilized for specification limiting values because appreciable variation from the given values may result from varying wall thicknesses, conditions of processing, and methods of testing.

2–2 THERMOPLASTIC INSULATION MATERIALS

The term "thermoplastic" is applied to those materials which repeatedly soften and become formable or plastic with the application of heat. In the application of thermoplastic materials as wire and cable insulation and jacketing, advantage is taken of their semi-fluid nature at elevated temperature to form them around conductors or cable cores by means of extrusion, without the need for curing.

Simply stated, the extrusion process consists of feeding solid resin into a heated barrel in which turns a worm or screw which forces the resin along the barrel. As the resin picks up heat it melts into a viscous fluid. The screw forces the molten plastic into the "head" on the end of the barrel where it is formed into a tube. The item to be covered is also introduced through the head where it contacts the molten resin, and both are drawn through a sizing die simultaneously. The coated wire or cable is then drawn through a water bath which returns the plastic to its solid state. The coated wire is wound on reels.

The thermoplastic resins most commonly used as insulation and jacketing for wire and cable are discussed in the paragraphs which follow. See Table 2–2.

2–2.1 POLYVINYLCHLORIDE

The terms "vinyl" or "PVC" are commonly applied to polyvinylchloride resins.

Polyvinylchloride resins alone would be useless as wire insulations even if they could be applied to wire. They are extremely hard and rigid, and are subject to autocatalytic degradation at temperatures required for processing. Therefore, the resins must be compounded with various ingredients in order to prepare useful products. The compounding ingredients thus become controlling factors in determining material properties for the finished vinyl formulation.

Compounds having temperature ratings from a low of -65°C to a high of 105°C are available, although unfortunately, no single compound is known which can cover this range. Therefore, five typical compounds have been selected which cover a wide range of applications. Their typical properties are listed in Table 2–2.

With reference to the compounds shown in Table 2–2:

a. Compound 1 is a high-grade compound capable of being used at temperatures up to 105°C as a primary insulation for wires made to **MIL-W-16878D** and **NAS-702.** It can also be used as a sheath over shielded single and multiconductor cable configurations not exceeding **0.250** in. in diameter.

b. Compound 2 is a "semi-rigid" compound utilized as the primary insulation over small size conductors (approximately #20 AWG) and in thin walls (approximately 0.010 in.) for application as appliance wire or instrument wire where small diameter combined with insulation toughness is required.

c. Compound 3 is a typical 80°C compound which finds application as a primary insulation and jacketing compound in wires and cables to such specifications as MIL-W-76, MIL-C-11311, and MIL-C-915.

d. Compound 4 is a typical extreme low temperature compound utilized as a jacketing material for -65°C environments. Its electrical properties are generally considered to be insufficient for its use in primary insulations.

e. Compound 5 is the material widely used as a "noncontaminating" jacket for MIL-C-17 cable constructions. It is compounded with a special nonliquid (nitrile rubber polymer) plasticizer which will not migrate into the cable dielectric and thereby affect its electrical parameters.

Vinyl compounds can be made which are fairly resistant to embrittlement in hot oils, but all vinyls are subject to swelling in ketones, chlorinated hydrocarbons, and esters. They are generally resistant to water and dilute acids and bases.

Nearly all vinyl compounds can be made to be flame retardant. The dielectric properties of vinyl compounds vary considerably with temperature and signal frequency. They are not considered adequate for use as primary insulations in applications requiring the use of low loss dielectric materials.

2-2.2 POLYOLEFINS

The term "polyolefin" relates to polymers similar to paraffinic oils and waxes in their basic chemical structure. The most important of the thermoplastic polyolefins as regards insulating and jacketing materials are polyethylene and polypropylene.

Polyethylene resins are generally classified by density and are roughly grouped into three types: low-density resins having a density of 0.910 to 0.925 g/cc, medium-density resins having a density of 0.926 to 0.940 g/cc, and high-density resins having a density of 0.941 to 0.965 g/cc.

In general, such properties as stiffness, hardness, tensile strength, abrasion resistance, dielectric constant, and softening temperature increase with increasing resin density; while such properties as elongation, impact strength, and cold temperature flexibility decrease with increasing resin density. Some of the established applications for the polyolefins, together with pertinent governing specifications, are listed in Table 2-1.

Where the polyolefins are to be used in applications which require exposure to sunlight, it has been found necessary to add small amounts of carbon black to protect the resin against ultraviolet degradation. These compounds quite naturally have higher dielectric constants and dissipation factors than the natural resins. Indeed, it is generally true that the addition of fillers to any of these resins, as for example, to impart flame retardance or to reduce stress cracking, will result in the sacrifice of some physical properties and electrical parameters.

2-2.2.1 Lowdensity Polyethylene

Low density polyethylene exhibits good fluid resistance at room temperature. It also has very low water absorption. Its general temperature rating is on the order of -65° to 75°C. The upper temperature limit is dictated by the softening of the resin as it approaches its melting point of 97° to 110°C. Low-density polyethylene is flammable, but it can be compounded so as to be "flame-retardant" at some sacrifice of physical and electrical properties.

The mechanical properties of low-density polyethylene are not outstanding. Generally, where mechanical abuse is anticipated on relatively thin-walled hook-up wire constructions, a nylon jacket or some other suitable outer covering is usually recommended to improve abrasion and cut-through resistance.

The electrical properties of low-density polyethylene are outstanding. It is a low loss material and is used as the dielectric for many coaxial cables involving high frequency applications. It exhibits good resistance to breakdown under corona and is often used in high voltage applications.

2-2.2.2 High-density Polyethylene

High-density polyethylene has chemical and electrical properties similar to the low-density resins. Its fluid resistance is somewhat better. Its melting

TABLE 2—1

TYPICAL APPLICATION FOR POLYOLEFIN RESINS

Resin	Application	Specification
Polyethylene, Low-density	Coaxial Cable Dielectric (WF-8 and CX-4245/G)	MIL€-1 7; L-P-390
	Hook-up Wire	MIL-W-76
	Multiconductor Cable	MIL-C-13777; MIL-C-915
	Field Wire (WD-I/TT)	MIL€-1 3294
Polyethylene, Medium-density	Telephone Wire	L-P-390
Polyethylene, High-density	Telephone Singles (WM-130A/U)	MIL€-55036
Polypropylene	Telephone Wire (CX-11230( )/G)	Pending

point is generally in the range of 121" to 135°C. The major difference between the two types lies in the mechanical area. High-density resins are harder, stiffer, and better in abrasion and cut-through resistance than the low-density resins. These resins are suitable for jackets or sheaths since they have good resistance to environmental degradation. Although the electrical properties of high-density polyethylene are similar to those of the low-density resins, the fact that its dielectric constant is higher than that of low-density polyethylene combined with the added stiffness of the high-density resin generally results in making it impractical for use in coaxial cables involving heavy insulation walls.

The chemical, physical, and electrical properties of medium-density resins, in general, can be regarded as compromises between those of the high- and low-density polyethylenes.

2—2.2.3 Polypropylene

Polypropylene has the lowest density of the polyolefin resins, approximately 0.905 g/cc. The chemical and electrical properties of these resins are similar to those of the polyethylenes. Its fluid resistance is somewhat superior to the polyethylenes. It is flammable, but flame-retardant grades have been made available. Its melting point is on the order of 155° to 168°C. Its dielectric constant is somewhat lower than that of low density polyethylene. The primary difference between polypropylene and polyethylene lies in their mechanical properties. Polypropylene is even harder and stiffer than high-density polyethylene. For this reason, its abrasion and cut-through resistance is superior to the high-density polyethylene resins. However, its use in heavy-walled coaxial cable or sheathing material is decidedly limited by its high degree of stiffness. One other major drawback to the use of polypropylene is its relatively poor low-temperature flexibility.

2—2.3 CROSS-LINKED POLYOLEFINS

Cross-linking is a term used to describe the process wherein individual polymer molecules are tied together to form a network structure. There are two ways to cross-link polyolefins: (1) by irradiation, and (2) by chemical means. The end effect of either method is the creation of a three-dimensional network, or "gel", of the resin molecules. The cross-linked material no longer has a true melting point. The effects of this cross-linkage on the properties of the resins are:

a. The electrical properties are essentially unchanged.

TABLE 2—2

TYPICAL PROPERTIES OF THERMOPLASTIC MATERIALS

Resin Type Compound	PVC *					Polyethylene (Unfilled)		
	1	2	3	4	5	Low-density	Medium-density	Highdensity
Specific Gravity	1.35	1.38	1.37	1.21	1.20	0.920	0.935	0.947
Ultimate Tensile Strength, psi	3000	4000	2400	2000	1800	2200	2500	3400
Ultimate Elongation, %	200	150	250	375	400	625	350	250
Volume Resistivity, ohm-cm	8×10^{15}	8×10^{15}	4×10^{15}	1×10^{12}	1×10^{11}	1×10^{17}	1×10^{17}	1×10^{17}
Dielectric Constant, 1kHz	5.0	4.8	5.7	6.0	6.0	2.25	2.29	2.32
Dissipation Factor, 1kHz	0.10	0.08	0.12	0.15	0.15	0.0002	0.0002	0.0002
Rated Max Temp, °C	105	80	80	60	60	75	——	——
Rated Min Temp, °C	−40	−10	−40	−65	−55	−65	−65	−65

* Refer to par. 2-2.1 for Detailed Compound Descriptions.

TABLE 2–2 (CONT.)

Resin Type Compound	Polypropylene (Unfilled)	Nylon 610	Fluorocarbon				Polyurethane Jacketing (Ether Type)
			TFE	FEP	CTFE	VF-2	
Specific Gravity	0.902	1.08	2.18	2.16	2.16	1.76	1.25
Ultimate Tensile Strength, psi	5000	8000	3500	3000	5000	7000	6000
Ultimate Elongation, %	200	200	300	250	150	300	600
Volume Resistivity, ohm-cm	1×10^{17}	1×10^{14}	1×10^{18}	1×10^{18}	1×10^{18}	1×10^{14}	2×10^{11}
Dielectric Constant, 1 kHz	2.22	4.5	2.0	2.1	2.3	8.0	7.5
Dissipation Factor, 1 kHz	0.0003	0.04	0.0002	0.0003	0.0023	0.019	0.060
Rated Max Temp, °C	—	105	260	175	135	135	75
Rated Min Temp, °C	10	-40	-65	-65	-65	-65	-55

b. The chemical properties are enhanced as regards oil resistance at elevated temperatures.

c. Certain mechanical properties are markedly improved. The resins will not melt or drip even at solder-iron temperatures. This does not mean that it does not soften at these temperatures, only that the gel structure introduced by cross-linking is such that the resin will not melt or drip away.

The polyolefins cross-linked by irradiation may be compounded to improve heat aging characteristics, therefore, taking advantage of the increased flow resistance so as to be rated at 110° to 135°C. The low temperature properties are essentially unaffected by cross-linking, so that the **−65°C** rating for polyethylene still applies.

In general, only the polyethylene resins have been successfully cross-linked commercially. Polypropylene resins tend to embrittle when subjected to the cross-linking processes.

As to the relative merits of chemical cross-linking versus irradiation, it might be stated that although irradiation is the more expensive process, it has the advantages of:

a. Processing thin walls of insulation without danger of deformation

h. Versatility

c. Better process control

d. Freedom from contamination from peroxide residues

Chemical cross-linking has been confined generally to applications involving relatively heavy walls of insulation in which electrical parameters, such as dielectric constant and power factor, are not critical.

2–2.4 NYLON

The term "nylon" is applied to polyamide resins. In wire and cable construction nylon is used almost exclusively as a jacketing material. Its electrical properties are generally adequate for 60-cycle service at low voltages but it does absorb appreciable moisture, even from the atmosphere, and for this reason it is not suitable for primary insulation in critical applications.

Nylon is used in wire applications because of its resistance to abrasion and cut-through and its excellent resistance to hydraulic fluids including Skydrol. It is the most inert to fungus of the thermoplastics. It finds wide use as a protective jacket over polyvinylchloride primary insulations in wire constructions, such as those of MIL-W-5086 and MIL-W-16878D and over polyethylene in constructions as typified in MIL-C-13777E, MIL-W-76, and MIL-C-13294. Although nylon is listed in the literature as "slow burning", or even as "self-extinguishing", the fact remains that in the relatively thin walls in which it is used as a jacketing for wire, it must be considered flammable.

Nylon generally carries a high temperature rating of 105°C for continuous service. Its low temperature limit is dependent upon the wall thickness and the diameter of the construction. As both of these parameters increase, the susceptibility to cracking or flexing at low temperatures also increases. For this reason, nylon fiber braid is substituted for extruded nylon on the larger conductor sizes of most wire constructions. In general, in order to achieve a −55°C rating, extruded nylon jacketing is utilized in wall thicknesses less than 6 mils over construction, less than 0.150 in. in diameter.

Although nylon has been utilized as a jacketing material over small shielded wire constructions, it should be pointed out that there is a tendency for cracking of the nylon to occur when such constructions are exposed to temperatures near the upper rated limit of 105°C. The combination of the drying effect, which reduces the elongation of the nylon, together with the presence of the braided metallic shield which provides points of stress concentrations due to its relatively uneven surface, is believed to be the cause for the development of cracks, The use of a heat-sealed, tape-wrapped, polyester/polyethylene jacket (see par. 2–6) to replace extruded nylon is often recommended for this type of construction.

Where nylon is to be exposed to considerable outdoor weathering and sunlight, the addition of a small amount of carbon black is recommended for stabilization against embrittlement.

Table 2–2 shows some typical properties for the most widely used nylon resin, a "610" polymer described by Type III Grade E of MIL-M-20693. Other nylon polymers and copolymers are utilized in wire jacketing for specialty applications, but the 610 polymer is by far the most popular resin for electrical applications because it absorbs appreciably less moisture than other types.

2–3 FLUOROCARBONS

There are presently four fluorocarbon resins which are of importance as insulating and jacketing materials for wire and cable: (1) polytetrafluoroethylene or "TFE", (2) a copolymer of tetrafluoroethylene and perfluoropropylene or "FEP", (3) a resin based upon polychlorotrifluoroethylene or "CTFE", and (4) polyvinylidenefluoride or "VF-2". All of these resins are nonflammable in the sense that they will not support combustion. They are considered to be inert to fungus. However, in many other properties these resins are significantly different from each other as will be noted in the ensuing discussion.

2–3.1 POLYTETRAFLUOROETHYLENE (TFE)

TFE is probably the most widely utilized fluorocarbon resin. It possesses unexcelled fluid resistance and is attacked only by alkali metals and by fluorine at high temperatures and pressures. TFE has excellent thermal stability and a wide range of operating temperatures, being rated for continuous operation from -65° to +260°C. It is useful at temperatures as low as -265°C and also for short time exposures to temperatures as high as 320°C.

TFE does not possess particularly good mechanical properties at room tempeature with regard to abrasion resistance or cut-through resistance. However, TFE at elevated temperatures, even up to 200°C, retains a significant degree of mechanical strength. Even above its melting point of 327°C, TFE exists as a remarkably tough, form-stable gel which imparts to the resin the ability to withstand contact with a hot solder iron without damage.

The electrical properties of TFE are also outstanding. The dielectric constant is low and remains stable over a wide range of temperatures and frequencies. It is an extremely low loss material. It is not suitable for high voltage applications because of its poor corona resistance in the presence of air or oxygen, which limits its use to about 100-volt rms constructions.

As might be expected, TFE finds wide application in hook-up wire as specified in MIL-W-16878D and MIL-W-22759, and in coaxial cable dielectrics and jackets per MIL-C-17.

2–3.2 COPOLYMER OF TETRAFLUOROETHYLENE AND PERFLUOROPROPYLENE (FEP)

The copolymer of tetrafluoroethylene and perfluoropropylene (FEP) has fluid resistance properties similar to those of TFE up to about 200°C. It possesses excellent thermal aging properties. However, because it does soften at lower temperatures than TFE, becoming a melt at approximately 290°C, the maximum temperature rating is generally accepted to be 175°C. The low temperature properties of FEP are similar to TFE and result in a-65°C rating.

The mechanical properties of FEP are similar to TFE, but fall off with increasing temperature at a faster rate than TFE. FEP will, of course, melt and flow on contact with a hot solder iron.

The electrical properties of FEP are nearly identical with TFE and remain constant over a wide range of temperatures and frequencies. However, at frequencies of around 2000 MHz and higher, FEP starts to exhibit higher losses than TFE.

The primary differences between TFE and FEP lie in the melting point phenomena. The fact that FEP will melt into a fluid state permits its extrusion in a manner similar to that employed for many thermoplastic materials. TFE, since it "melts" into a tough gel, cannot be melt-extruded and must be paste-extruded and subsequently sintered at 327°C using techniques approaching those of powder metallurgy. Therefore, FEP becomes a somewhat more versatile resin to process than TFE.

FEP finds application as primary insulation on hook-up wires, typically specified in MIL-W-16878D, and as jacketing over many shielded high-temperature coaxial cables similar to those of MIL-C-17.

2—3.3 POLYCHLOROTRIFLUOROETHYLENE (CTFE)

There is a series of polymers based upon monochlorotrifluoroethylene. This resin, which is most commonly utilized as primary insulations and jacketing for wire and cable, has a melting point of approximately 210°C. This CTFE resin is generally rated for continuous service over a temperature range of -65° to 135°C. Its useful life falls off rapidly at temperatures exceeding 135°C however, resulting in a short term rating of 96 hours at 150°C.

The chemical resistance of CTFE is very good, but not as universally excellent as TFE and FEP. CTFE exhibits excellent resistance to a wide variety of acids, bases, oils, and alcohols at room temperature. It is swollen somewhat by halogenated solvents and some oxygenated solvents (ketones, esters, ethers) and is severely attacked by the hydrazines at mildly elevated temperatures, by alkali metals, and by liquid halogens.

CTFE is a hard, tough material which imparts excellent cut-through resistance and good abrasion resistance to insulations fabricated from it.

The electrical properties of CTFE are excellent. It has a high volume resistivity, a low dielectric constant, and a good dissipation factor over a wide frequency range. Like FEP and TFE, CTFE is not generally useful as a high voltage insulation because it is degraded under corona conditions.

CTFE is used as a jacketing material over small size coaxial cables and as primary insulation on hook-up wire made to MIL-W-12349. It also finds application as primary insulation for hook-up wire in automatic wire wrapping equipment.

2—3.4 POLYVINYLIDENEFLUORIDE (VF-2)

VF-2 is a relatively new polymer. The present resin has a melting point of 171°C and is tentatively rated for continuous use over a temperature range .of from -65" to 135°C. The relatively high temperature rating, with relation to the melting point of VF-2, is made possible by the unique retention of its physical properties at elevated temperatures.

The chemical resistance of VF-2 is such that the resin is resistant to attack or penetration by most corrosive chemicals and organic solvents including inorganic acids, oxidants, alkalies, halogens, and hydrocarbons. Strongly polar solvents, such as dimethylacetamide, tend to react with and embrittle the resin.

VF-2 is a very hard material with high tensile strength which results in insulations having excellent cut-through resistance and good abrasion resistance. The material is notch-sensitive, however, and some drawbacks result when it is extruded over large, rope-stranded conductors, in that a sharp blow will cause the insulation to shatter. However, when used on solid conductors, over other extruded insulations, or on small gage, concentrically stranded conductors; the notch-sensitivity of VF-2 does not appear to be a handicap. VF-2 has the lowest specific gravity of the fluorocarbon polymers.

The dielectric strength of VF-2 is excellent. However, its dielectric constant and power factor are quite high, and it is not to be recommended for high frequency, low loss applications.

VF-2 can be cross-linked by irradiation so as to impart a degree of resistance to flow at temperatures above its normal melting point. In this form, it is used as a jacketing for hook-up and air frame wire specified in MIL-W-81044. The regular polymer is also adaptable to uses as primary insulation for hook-up wire, and for wire utilized in automatic wire-wrapping equipment.

Table 2--2 gives some typical properties of the fluorocarbon polymers discussed above.

2—4 POLYURETHANES

2—4.1 PHYSICAL PROPERTIES

The thermoplastic polyurethane resins are unique in that at room temperature they have the physical properties of a very tough rubber, although they are essentially true thermoplastic materials. These resins have excellent tensile and elongation properties and provide the toughest, most abrasion-resistant, jacketing material presently available,

Polyurethanes possess good resistance to most liquid fuels and oils, but are attacked, and swollen or dissolved, by halogenated solvents and a variety of ketones, esters, and polar solvents. Some ester types are subject to hydrolysis on water immersion, and, although properly compounded polymers will be useful for many years of continuous immersion in water at or below room temperature, any potential application involving continuous immersion in water at temperatures exceeding 50°C should be carefully evaluated.

2—4.2 THERMAL PROPERTIES

Polyurethane thermoplastics have not been assigned specific thermal ratings, but indications are that a continuous operating range of from -55° to 75°C is realistic. The upper temperature limit is dictated by the thermoplastic nature of these resins which soften appreciably at temperatures of 100° to 120°C.

These resins have outstanding ozone resistance and resistance to radiation damage. The electrical properties of the polyurethane formulations are entirely adequate for jacketing applications, but marginal for primary insulations.

2—4.3 USES

The polyurethane thermoplastics are used almost exclusively as jacketing, typified by the requirements specified in MIL-C-23020 for RG 264B/U.

In general, ether type urethanes have superior fungus and freeze resistance and hydrolytic stability to ester types.

Some typical properties of a polyurethane thermoplastic formulation are given in Table 2—2.

2—5 RUBBER

Rubbers are thermoset elastomers. This means that the application of heat results in the formation of a material which cannot be reformed or melted; it is "set". Hence, although these materials are extruded, they are extruded cold, or only mildly heated, and later subjected to a heating cycle which causes them to "cross-link" or "vulcanize" into their familiar form. Elastomers differ from other thermosetting polymers – such as phenolics, epoxies, etc. – in that they have the properties of being able to stretch and retract rapidly, exhibit high strength and modules while stretched, and recover on release of the stress.

As in the case with PVC insulating and jacketing application, the basic polymer is extensively compounded to impart specific properties pertinent to the end-use of the finished product. The additives to the elastomer itself include fillers, plasticizers, extrusion aids, vulcanizing agents, accelerators, activators, antioxidants, and antiozonants. Finished rubber compounds for wire and cable, then, may contain as little as perhaps 20% actual elastomer to perhaps as much as 90% elastomer, depending upon desired properties and cost factors. It is obvious that a considerable number of compounds having a wide range of chemical, electrical, and physical properties can be made from any given elastomer. Since this handbook is not intended to be a treatise on the compounding of elastomers, it will be confined to a very general discussion of the salient properties of the elastomeric polymers, together with some typical properties of some of the compounds which find use as wire and cable insulation or jacketing materials.

2—5.1 NATURAL RUBBER (POLYISOPRENE)

The physical properties of natural rubber are excellent and offer a wide range of compounding possibilities. Compounds with thermal ratings of from −55° to 75°C can be prepared. The electrical properties of specifically compounded natural rubber are good. It is generally resistant to water, but its resistance to liquid fuels and oils is inferior to some of the synthetic elastomers. The heat aging, resistance to oxidation, and ozone resistance are only fair. The current trends appear to be toward using natural rubber only when it offers price advantage over SBR elastomers, or when some special end use seems to require its exceptional high strength and resiliency.

Typical properties for natural rubber compounds are shown in Table 2—3.

Natural rubber compounds have application as primary insulations for power cables, portable cords, multiconductor field cable, tinsel wire, and building wire. It is used as jacketing over flexible cords and in some heavy duty applications. The use of natural rubber as insulation material is becoming obsolete, especially in military applications, since synthetic polyisoprenes can replace the natural polymer.

2—5.2 STYRENE-BUTADIENE RUBBERS

These copolymers are also known by the designations GR-S, Buna S, and SBR. The most common monomer ratio is approximately 75/25 butadiene/styrene, but some copolymers of lower styrene content (10-15%) are used for special low-temperature compounds. Compounds with thermal ratings of from -55" to 90°C can be prepared. The electrical properties of specifically compounded SBR are good. It is superior to natural rubber in resistance to aging, but somewhat inferior in general physical properties. Its water and solvent resistance is generally comparable to natural rubber.

Typical properties for SBR compounds are shown in Table 2–3.

SBR compounds are used as primary insulation and as jacketing in much the same areas as natural rubber. The deciding factors as to which is used are in the majority of cases material cost and processing considerations.

2–5.3 CHLOROPRENE RUBBER

These elastomers are better known under their commercial name of "Neoprene" (duPont). Compounds made from these rubbers are generally characterized by poorer electrical properties than natural rubber, SBR, and butyl compounds; and, therefore, their use as primary electrical insulations is confined to noncritical applications.

However, the neoprenes have good weathering properties, oil resistance, flame resistance, ozone resistance, arid good mechanical toughness. This combination of properties has led to its being currently the most widely used jacketing material within its temperature limitations. Specially compounded neoprene formulations can be prepared which will permit thermal ratings as low as -55°C, while other formulations can be made which will permit thermal ratings as high as 90°C.

Typical properties for neoprene compounds are shown in Table *2–3,*

The so called "arctic" (-55°C) neoprene compounds are used specifically in multiconductor cable jackets to MIL-C-13777, MIL-C-3432, and telephone drop wires.

2–5.4 BUTYL RUBBER

Butyl elastomers are copolymers of isobutylene and small amounts of isoprene. Specifically compounded formulations have excellent electrical properties and can be used as primary insulations on high-voltage power cables having voltage ratings in excess of 25,000 volts.

Butyl rubbers are characterized by generally superior weathering and ozone resistance, low water absorption, and good resistance to heat aging. They are considerably inferior to neoprene in oil resistance. Specific compounds can be prepared which can be thermally rated as low as -55°C, and some others with thermal ratings as high as 90°C. The mechanical properties of butyl are not as good as neoprene or natural rubber, but can be made to be adequate for many jacketing applications in which its excellent ozone resistance and resistance to water absorption are important factors. Butyl rubber is also utilized as a multiconductor cable jacket on some ground support cables for missiles fueled with nitrogen tetroxide and the hydrazines because of its superiority to other elastomers in its resistance to these chemicals.

Typical properties of butyl rubber compounds are listed in Table 2–3.

2–5.5 SILICONE RUBBER

The silicone elastomers can be broadly divided into three classifications. The first two are based upon polymer differences which result in notable differences in low-temperature properties. Hence, one might be designated as "standard" and the second as "extreme low temperature", for want of better designations. The third class would be the fluorinated silicones. Silicones have the widest thermal operating range of the elastomers.

The "standard" elastomers are capable of being compounded into formulations having thermal ratings from a low of about -55°C to a high of 200°C.

The "extreme low temperature" elastomers remain flexible at temperatures of -90°C, and possibly somewhat lower without sacrifice of other properties, but are more expensive.

The fluorinated silicone differs from the other two grades primarily in its improved resistance to oils and liquid fuels in which the other types are severely swollen. Its thermal ratings would be about the same as the "standard" elastomers.

TABLE 2–3

TYPICAL PROPERTIES OF ELASTOMERIC COMPOSITIONS

Base Polymer	Natural	SBR	Neoprene	Butyl	Silicone
Specific Gravity	1.3 to 1.7	1.15 to 1.55	1.4 to 1.65	1.15 to 1.5	1.10 to 1.55
Ultimate Tensile Strength, psi	1500 to 4000	800 to 2500	1200 to 2700	500 to 1500	500 to 1500
Ultimate Elongation, %	300 to 700	350 to 650	300 to 700	300 to 800	100 to 600
Rated Max Use Temp, °C	75	90	90	90	200
Rated Min Use Temp, °C	-55	-55	-55	-55	-55 to -100
Volume Resistivity, ohm-cm	10^{13} to 10^{15}	10^{12} to 10^{15}	10^{11} to 10^{13}	10^{13} to 10^{16}	10^{13} to 10^{16}
Dielectric Constant, 1 kHz	3.3 to 5	3.5 to 5	5 to 7	3.2 to 5	2.9 to 3.5
Dissipation Factor, 1 kHz	0.01 to 0.035	0.006 to 0.035	0.02 to 0.05	0.008 to 0.035	0.002 to 0.02
Resistance to:					
Water Absorption	excellent	excellent	good	excellent	good
Oil and Gasoline	poor	poor	good	poor	poor
Chlorinated Hydrocarbon	poor	poor	poor	poor	poor
Weathering	poor	poor	good	excellent	excellent
Ozone	poor	fair	good	excellent	excellent
Flame	poor	poor	good	poor	fair
Radiation	fair	fair	poor	poor	good

Notes

With the exception of the electrical properties, Table 2–3 shows typical properties of both insulating and jacketing compounds. The electrical properties shown are typical of insulating compounds containing little or no carbon black, but are not typical of many jacketing compounds which may contain varying amounts of black as reinforcing filler which can produce considerable variation of electrical properties.

TABLE 2–3 (CONT.)

Base Polymer	Fluorinated Silicone	Hypalon (du Pont)	EPR	Fluorocarbon
Specific Gravity	1.4 to 1.8	1.35 to 1.7	1.25 to 1.45	1.9 to 2.0
Ultimate Tensile Strength, psi	500 to 1000	1200 to 2200	1000 to 2500	1000 to 2000
Ultimate Elongation, %	100 to 250	300 to 600	350 to 600	200 to 400
Rated Max Use Temp, °C	200	90	90	200
Rated Min Use Temp, °C	-55	-55	-55	-30
Volume Resistivity, ohm-cm	10^{12} to 10^{14}	10^{12} to 10^{14}	10^{13} to 10^{16}	10^{12} to 10^{14}
Dielectric Constant, 1 kHz	6 to 7.5	9 to 11	3.2 to 5	7 to 9
Dissipation Factor, 1 kHz	0.03 to 0.06	0.05 to 0.08	0.007 to 0.035	0.02 to 0.05
Resistance to:				
Water Absorption	good	good	good	good
Oil and Gasoline	excellent	good	poor	excellent
Chlorinated Hydrocarbon	good	poor	poor	excellent
Weathering	excellent	excellent	excellent	excellent
Ozone	excellent	excellent	excellent	excellent
Flame	fair	good	poor	good
Radiation	good	fair	fair	fair

Notes

With the exception of the electrical properties, Table 2–3 shows typical properties of both insulating and jacketing compounds. The electrical properties shown are typical of insulating compounds containing little or no carbon black, but are not typical of many jacketing compounds which may contain varying amounts of black as reinforcing filler which can produce considerable variation of electrical properties.

All silicone elastomers are flammable, but their unique structure is such that a nonconductive ash remains after burning. If this ash is contained by a glass braid, it will function as an insulator for short time emergency use. This property has facilitated its use in many military applications.

The mechanical properties of silicone elastomers are not exceptional. Its abrasion resistance and cut-through resistance is inferior to that of many of the other elastomers.

The electrical properties of silicone rubber compounds are very good. They can be compounded to have a relatively low dielectric constant and dissipation factor. Their ability to resist corona and ozone is excellent. These properties make silicone rubber a useful high-voltage insulation where temperature or flexibility requirements rule out the use of butyl rubber or polyethylene.

Silicone rubber also possesses good ability to resist radiation damage.

Properly compounded silicone rubbers have been utilized in hook-up and interconnecting wires made to MIL-W-8777 and MIL-W-16878D. They are also used as primary insulation and jacketing to MIL-(2-2194 and MIL-C-23206, power, control, and thermocouple cables aboard nuclear-powered naval vessels. Another application is that of primary insulation and jacketing for ignition cable made in accordance with MIL-C-3702.

Typical properties of silicone rubber compounds are shown in Table 2–3.

2–5.6 CHLOROSULFONATED POLYETHYLENE

These elastomers are better known under the trade-name, "Hypalon" (duPont). Compounds formulated from these elastomers are characterized by their excellent resistance to ozone, common oils, liquid fuels, weathering, flame, and corona. Properly compounded formulas have been prepared which indicate a probable thermal range for continuous usage from a low of -40°C to a high of 90°C, and possibly to 105°C, in wire and cable applications. Special compounding can reduce the low-temperature rating to perhaps **-55°C** at some sacrifice in the high-temperature rating.

Hypalon vulcanizates have reasonably good physical properties, but are not particularly resilient. Their electrical properties are adequate for low frequency applications, but their high dielectric constant and dissipation factor make them unsuitable for use as high frequency dielectrics.

Hypalon compounds are finding application in mining cable, power cable, motor lead and appliance wiring, automotive ignition wire, and cord jacketing.

Typical properties of chlorosulfonated polyethylene compounds are shown in Table 2–3.

2–5.7 ETHYLENE PROPYLENE RUBBER

These elastomers are copolymers of ethylene and propylene, or more recently, terpolymers of ethylene, propylene, and a diene. The latter offers vulcanization with more conventional curing systems.

Compounds made from these elastomers offer excellent resistance to ozone and weathering, good heat resistance, good low-temperature properties, and good resilience. Specific compounds can be made which appear to offer wire and cable applications having thermal ratings from a low of about -55°C to a high of 90°C.

Chemical resistance is generally good, but oil resistance is poor. Electrical properties of specific compounds are very good. It is expected that compounds based on ethylene propylene rubber may find application as primary insulation and sheathing for power cables and flexible cords, in place of butyl rubber.

Typical properties of ethylene propylene rubber compounds are given in Table 2–3.

2–5.8 FLUOROCARBON RUBBER

The outstanding properties of properly compounded fluorocarbon elastomers are its high temperature resistance and its excellent oil resistance. Temperature ratings for continuous service would appear to be approximately -30°C to a high of 200°C.

The physical characteristics of compounds based upon these elastomers are good. They have good resistance to ozone and weathering.

The electrical properties are generally poor. The compounds have a high dielectric constant and dissipation factor.

The high cost of the fluorocarbon elastomers has limited their use to specialty jacketing applications requiring a combination of high temperature resistance, good chemical resistance, and good mechanical properties.

Typical properties of compounds based on fluorocarbon elastomers are listed in Table *2–3*.

2–6 FILMS

Film can be defined as sheeting less than 10 mils in thickness. In this paragraph only those films which are used as primary insulations or as jacketing will be considered. Normally, film insulations are used only when processing factors make extruded insulation impractical, as in the attainment of extremely thin insulation walls, or in the instances where the film material cannot be obtained in a form suitable for extrusion. The principal reason for the use of films as insulations is the reduction in size and weight where the end-use requirements, in combination with the film properties, permit the utilization of thinner walls than can be achieved by extrusion.

The application of films, as wire insulation and jacketing, is done by either spiral wrapping or longitudinal wrapping of the film as a tape, followed by some subsequent operation designed to hold the wrap in place. Such an operation might consist of the application of a coating from solution of dispersion, an overbraid of some suitable fiber, a thermoplastic or elastomeric extruded jacket, or by heat-sealing. The most desirable holding method, from the standpoint of maintaining thin walls together with dielectric integrity, is that of heat sealing.

In the paragraphs which follow, typical properties of those films most commonly considered suitable for application as insulating materials for wire and cable are presented. Typical properties of these films are listed in Table 2–4.

2–6.1 CELLULOSICS

There are three principal types of film – cellulose acetate, cellulose acetate butyrate, and cellulose triacetate – made from cellulose derivatives that have had some use as wire insulation in low voltage, noncritical applications when high humidity is not encountered.

a. Cellulose Acetate is one of the first plastic films to be used as an electrical insulating tape. It has good electrical properties and good physical properties. Its resistance to aging makes it useful for continuous operation over a temperature range of -30° to 60°C. It is flammable. Cellulose acetate has been used as a film insulation for lead wire and switchboard wiring.

b. Cellulose Acetate Butyrate has somewhat lower water absorption than cellulose acetate. It has good electrical properties and good physical properties. It has good aging properties and can be considered useful over a temperature range of -40° to 60°C. It is somewhat softer and more flexible than cellulose acetate. It is flammable. Cellulose acetate butyrate films have been used as insulation for switchboard hook-up wire.

c. Cellulose Triacetate also has good electrical and physical properties. It is the most resistant to heat distortion of this group of cellulosics and can be considered to have a thermal operating range of -30° to 75°C. It is flammable. Cellulose triacetate film has been used as insulation for range wire and lead wire.

2–6.2 POLYESTERS

The polyester films utilized in the wire and cable industry are based upon terephthalic ester resins. All of these products are characterized by excellent physical properties, good chemical resistance, good electrical properties, and a wide range of service temperatures (-60°C to 150°C).

The most useful polyester film, as regards applications for primary insulation and insulation over shields, is a heat-sealable composite film of polyethylene and polyester. The composite, made from 1 mil polyester and 0.5 mil polyethylene, when properly double-wrapped and heat-sealed (6-mil nominal wall) results in an insulation of exceptional mechanical toughness, abrasion resistance, cut-through resistance, and puncture resistance. Long lengths of both insulated conductors and shields have been made and subjected to the "tank test" dielectric requirement of MIL-W-16878D without failure.

TABLE 2–4

TYPICAL PROPERTIES OF FILMS

General Type	Cellulosic			Polyester	
Specific Compound	Cellulose Acetate	Cellulose Acetate-Butyrate	Cellulose Triacetate	Polyester	Polyester/Polyethylene, 1/0.5 mil
Specific Gravity	1.30	1.20	1.29	1.39	1.20
Ultimate Tensile Strength, psi	10,000	8,000	14,000	25,000	17,000
Ultimate Elongation, %	25	80	25	75	125
Volume Resistivity, ohm-cm	1×10^{14}	1×10^{15}	1×10^{15}	1×10^{17}	2×10^{17}
Dielectric Constant, 1 kHz	3.8	2.9	3.2	3.25	2.7
Dissipation Factor, 1 kHz	0.020	0.015	0.016	0.005	0.003

TABLE 2-4 (CONT.)

General Type	Fluorocarbon		Polyimide
Specific Compound	**TFE**	FEP	Kapton (du Pont)
Specific Gravity	2.2	2.15	1.42
Ultimate Tensile Strength, psi	3300	3000	20,000
Ultimate Elongation, %	300	300	70
Volume Resistivity, ohm-cm	1×10^{18}	1×10^{18}	1×10^{17}
Dielectric Constant, 1 kHz	2.1	2.1	3.5
Dissipation Factor, 1 kHz	0.0003	0.0003	0.003

2–6.3 FLUOROCARBONS

The fluorocarbon resins described in the paragraphs on Thermoplastic Insulation Materials (pars. 2–2 through 2–2.4) are also available in tape form and have properties essentially the same as those given in those paragraphs.

Of the group of fluorocarbons, polytetrafluoroethylene (TFE) is the resin most used in tape form for insulating purposes. TFE tape is available in several forms:

a. Cast Tape: This tape is usually required where thicknesses from 0.25 mil to about 3 mils are involved. These tapes are used for extremely thin-walled, wrapped insulations where resistance to mechanical damage is not a consideration in the end use of the wire.

b. Skived Tape: This tape (literally shaved or skived continuously from the surface of a cylindrical block of molded TFE) is generally used where 5- to 10-mil tape thicknesses are useful, as in the wrapped dielectric for some large size coaxial cables.

c. Unsintered Tape: This is a tape which can be wrapped into place and sintered or fused at temperatures in excess of the resin melting point of 327°C. Unsintered tapes are most commonly used in thicknesses of from 3 to 7 mils. They find wide use as both primary wire insulation and as jacketing over shields in a variety of applications and constructions.

2–6.4 POLYIMIDE

A new film, trade-named "Kapton" (duPont), made from an aromatic polyimide resin has recently become available. The film has good physical properties, excellent thermal properties, and good electrical properties over a very wide temperature range. In an aging test the film has an extrapolated life of 10 years at 250°C, 1 year at 275°C, 1 month at 300°C, and about 1 day at 400°C. It exhibits excellent cut-through resistance at temperatures in excess of 250°C and maintains its electrical properties at elevated temperatures. It has excellent solvent resistance. It is degraded by concentrated acids and alkalies, and has relatively poor sunlight resistance in its present form.

For purposes of its use as primary insulation, heat sealability would be required. The polyimide film itself cannot be heat-sealed. However, composite films of "polyimide" and FEP fluorocarbon resin are available which can be heat-sealed. The resulting composite insulation, combining properties of FEP and polyimide, can properly be rated for service over 200°C, while maintaining and even enhancing the electrical, physical, and chemical resistance properties of the polyimide film alone.

Properties of the composite films are dependent upon the relative amounts of polyimide and FEP, and can be approximated by calculating a weighted average of the respective properties of each.

2–7 FIBERS

The principal uses of fibers in the wire and cable industry are in the form of protective coverings, reinforcements, and fillers. They are usually applied by serving or braiding, followed by a lacquer coating or possibly by an extruded jacket of some material either subsequent to, or in place of, the lacquer coating. See MIL-E-572 for data on fibers.

Although extruded jackets offer far better protection against fluid penetration and a greater contribution to the overall dielectric strength of a wire construction than do fiber braids, there are good reasons for using the latter. First, fiber braids provide wire constructions with a more flexible covering than extruded jacketing, particularly on the larger wire sizes. Second, in the case of braids utilizing glass yarns, some degree of physical separation of adjacent conductors is provided should the insulation be burned out in a fire, thereby permitting low-voltage circuits to continue functioning in critical situations. Finally, fiber braids do mechanically reinforce and strengthen overall constructions, particularly heavy-duty elastomeric cable jackets, but also to some degree, even on small size, jacketed hook-up wires such as type 3 of MIL-W-5086.

The characteristics of braided coverings are dependent upon the combination of the properties of the fiber and the lacquer or saturant. The contribution of the fiber is one primarily of mechanical strength. The function of the saturant is the impregnation of the braided fibers in order to bond them together for effective abrasion resistance and to minimize fraying and wicking.

A brief description of some of the most commonly used fibers and lacquers is given in the paragraphs which follow. Typical properties of the fibers to be discussed are given in Table 2-5.

2–7.1 COTTON

Cotton is a relatively strong and flexible fiber with good abrasion resistance and resiliency. It is highly water absorbent, and has poor fungus resistance unless treated. It is flammable. It has moderate heat resistance. Cotton finds its principal application as a reinforcement for elastomeric jacketing typified in MIL€-1 3777E.

2–7.2 RAYON

Rayon is a regenerated cellulose. It is somewhat lower in tensile strength than cotton, but has abrasion resistance and resiliency similar to that of cotton. It is not fungus-resistant unless treated. It is flammable. It is less water absorbent than cotton. It has moderate thermal capabilities, on the order of 80°C. Saponified acetate rayon is commonly used.

2–7.3 NYLON

Nylon is a strong, tough fiber which has excellent abrasion resistance. In fact, in combination with nylon lacquer, it forms probably the best braid lacquer team in this respect. Nylon is inert to fungus. Nylon is flammable, but much slower burning than other organic fibers. It has thermal properties which permit its continuous use at 105°C. Nylon is widely used both as a reinforcement for elastomeric jacketed cables and as outer coverings for many wire constructions, such as those specified in MIL-W-5086.

2–7.4 POLYESTER

The polyester most commonly utilized is a polyethylene terephthalate resin. It possesses good strength and abrasion resistance. It is flammable. It is fungus-resistant. Its thermal properties are sufficient to permit its use as an outer covering in wire constructions rated at 200°C, such as those of MIL-W-8777.

2–7.5 GLASS

Glass fibers are very strong but brittle. Hence, their abrasion resistance is relatively poor. The nonflammability of glass is one of its major characteristics. It is fungus inert. The thermal capabilities of glass are'excelled only by those of some of the ceramic fibers and asbestos. Glass is useful at temperatures up to about 320°C. Glass braids are utilized in a number of wire constructions including MIL-W-5086, MIL-W-16878D, MIL-W-8777, and many others too numerous to list.

2–7.6 CERAMIC

There is a growing number of ceramic fibers some of which are reputed to have heat resistance to temperatures of 1500° to 1700°C. However, only one of these, a quartz fiber, has seen much application in the wire and cable field. This quartz fiber is characterized by being weak and brittle, thus requiring relatively bulky yarns to obtain sufficient strength for braiding. This fiber finds its principal application in the so-called "fire-wall" wire of MIL-C-25038 where its resistance to an 1100°C flame is required.

2–7.7 ASBESTOS

The asbestos fiber commonly used for electrical applications is derived from the mineral, chrysotile, principally composed of hydrous silicates of magnesia. Individual fibers have extremely high tensile strength, but are not amenable to a spinning process. Hence, pure asbestos yarns are relatively weak and must be quite bulky in order to be adaptable to braiding and serving operations. Asbestos yarn is characterized by poor mechanical properties, but excellent thermal properties, making it useful at temperatures up to about 480°C. It is nonflammable. It is used for low voltage applications in lead wire, range wire, appliance wires and cords, apparatus cable, and thermocouple leads.

2–7.8 FIBER COMBINATIONS

Of the many combinations of fibers that are possible, only a few are commonly used. One example is the combination of cotton with rayon, or nylon with asbestos. The obvious reason for this latter combination of fibers is to increase the physical strength of the asbestos. Such combinations must be derated thermally. Industrial practice relates the thermal use, temperature to type and quantity, of nonasbestos content. A second example is the combination of polyester and glass. The obvious compromise of properties is that of the abrasion resistance of the polyester with the nonflammability of glass.

2–7.9 COATED FIBERS

Of the many possible coated yarns, those of glass coated with polytetrafluoroethyiene (TFE) are probably the most widely used. The fact the TFE completely surrounds the fiber results in a finished braid having improved abrasion resistance over that resulting from applying TFE dispersion to a regular glass braid. To obtain the ultimate properties of this braid, it must be heated to the sintering temperature of TFE to cause the resin particles to fuse together. This, of course, limits its use to those constructions capable of withstanding this processing temperature, generally, TFE of the insulating resins. This fiber has been widely used in hook-up wire constructions made to MIL-W-7139.

2–8 LACQUERS

Lacquers are generally solutions of soluble polymers or dispersions of insoluble polymers. Thus they are applied to braids as liquids, dried, and in some cases baked or fused, to form a polymer film. The characteristics of some of the most commonly used lacquers or braid saturants are briefly discussed.

2–8.1 CELLULOSE ACETATE BUTYRATE

Lacquers made from solutions of this polymer are generally compounded with additives to impart fungus resistance. They form good-looking films with good abrasion resistance and good oil resistance. The thermal capabilities of these films are limited to about 80°C. The film is affected by solvents, particularly those in which it was originally dissolved to form the lacquer. Cellulose acetate butyrate lacquers are used over cotton, rayon, and glass braids. A typical construction in which this lacquer is often used is MIL-W-76.

2–8.2 NYLON

Solutions of nylon make excellent lacquers. Nylon adheres well to all fibers and forms films which have excellent abrasion resistance. It is fungus inert. It is resistant to oils and solvents with the exception of the alcohols. Its thermal use limit is about 105°C. Nylon lacquers or braid saturants are widely used over many fibers. Typical of the wire constructions in which it is used are those of MIL-W-5086.

TABLE 2–6

TYPICAL PROPERTIES OF FIBERS

Type	Cotton	Rayon	Nylon	Polyester	Glass	Asbestos
Specific Gravity	1.54	1.3 to 1.5	1.14	1.38	2.54	2.4 to 2.6
Tensile Strength, psi	90,000	40,000	100,000	90,000	210,000	500,000
Elongation, %	5	25	25	20	2	———
Resistance to:						
Fungus	poor	poor	inert	inert	inert	inert
Flame	poor	poor	fair	poor	excellent	excellent
Abrasion	fair	fair	excellent	good	poor	poor

2–8.3 FLUOROCARBONS

There are several fluorocarbon resins which have been utilized as lacquer coatings in the form of solutions or dispersions. The two most widely used are a solution of a specific fluorocarbon resin and a dispersion of TFE.

The fluorocarbon resin solution is generally applied over polyester braids and glass braids. It has fair abrasion resistance and is flame-retardant. It has good thermal resistance and is used in wire constructions rated at 200°C, typical of those specified in MIL-W-8777.

The TFE dispersion results in a coating which must be heated to the sintering temperature of the resin (327°C) to form a film. This fact imposes a limitation in its use to materials which will withstand this processing temperature – such as glass or ceramic fiber and TFE primary insulation. The thermal, mechanical, and chemical resistance capabilities of the film are typical of the resin. As previously noted, this coating is used in wire constructions typical of those specified in MIL-W-7139.

2–8.4 SILICONES

Solutions of silicone resins are available for use as high temperature braid saturants having thermal use capabilities up to 250°C. To achieve their optimum properties, however, they must be baked at high temperatures. As a result, their applications are generally confined to glass braids and high temperature primary insulation material. There are some so-called "silicone" lacquers which do not require this extreme baking cycle. However, these coating solutions can contain considerable proportions of nonsilicone resins and are not capable of the high temperature usage of the straight silicones. These solutions must be derated to perhaps 135° to 180°C, depending upon their silicone resin content.

2–8.5 SPECIALIZED COATINGS

In addition to the braid saturants or lacquer coatings described above, there are some specialized coatings which are designed for use specifically with wires insulated with extruded polytetrafluoroethylene (TFE) and polyfluorinated ethylene propylene (FEP) resins. These can be categorized as bondable coatings and polyimide coatings.

2–8.6 BONDABLE COATINGS

Both TFE and FEP resins are characterized by having surfaces which are extremely inert and nonwettable. Normally this is an advantageous feature for an electrical insulation, because it results in a high degree of surface resistivity. However, it becomes a distinct disadvantage when it becomes desirable to obtain an adhesive bond to the surface as, for example, in potting connector assemblies.

There are two ʻways to obtain a bondable surface. One is the sodium etching process. This process results in excellent bondability, but has the disadvantage of blackening the. surface, particularly of TFE, and rendering any color coding indiscernible. Additionally, it is a rather hazardous operation requiring strict safety precautions.

A number of manufacturers have developed proprietary bondable coatings applied over TFE and FEP insulated wires capable of providing adequate adhesive bonds to common potting compounds. These coatings do not mask printed, striped, or solid color identifications and can be procured with a thermal endurance equivalent to that of the potting compounds themselves.

2–8.7 POLYIMIDE COATINGS

The development of a polyimide resin solution and the process for applying it in thin films (about 1 mil thick) to wires insulated with relatively thin walls (5-6 mils thick) of extruded FEP have resulted in a vast improvement of mechanical properties, such as cut-through resistance over the uncoated insulation. The polyimide coating, when properly applied and processed, has properites similar to that of the polyimide film listed in par. 2-6, "Films", of this chapter. The presence of the film permits the use of thinner walls of FEP in areas subject to more mechanical abuse, without reducing its thermal rating, than the fluorocarbon resin could be expected to withstand by itself.

Currently, techniques for the application of the polyimide resin to TFE insulated wires have not been developed to the point where a consistently satisfactory product can be manufactured on a commercial scale.

Wires having this coating are expected to be especially valuable in space application where reduced size and weight are vital considerations.

2–9 POTTING COMPOUNDS

Potting compounds are usually low viscosity liquids which cure to a thermoset polymer at room, or moderately elevated, temperatures. Their major function is to provide a moisture-tight seal around the embedded components; however, an important secondary function is one of providing mechanical protection and reinforcement.

2–9.1 TYPES OF POTTING COMPOUNDS

There are three major types of potting compounds: epoxy resin formulations, polyurethane formulations, and room temperature vulcanizing (RTV) silicone rubber compounds; also some less frequently used types, such as polystyrene and unsaturated polyester formulations. There are literally hundreds, and perhaps thousands, of possible formulations of potting compounds commercially available with a resulting wide range of physical, thermal, and electrical properties. Table 2–6, which lists properties of some typical potting compounds, should be utilized therefore only in a very general way, particularly in the case of the epoxy resin compounds.

It is usually a relatively simple matter to select a potting compound having the required thermal and electrical properties for a potting application. The major problems involved in achieving a satisfactory potted connection are those which can be classified as problems of adhesion. The problems can be narrowed even further by considering that adhesion to the metallic components of the connection are relatively easily resolved, thus leaving the adhesive bonds between the potting compound and wire or cable insulation or jacket materials as the most critical.

2–9.2 POTTING – DESIGN CRITERIA

Some suggestions which should be considered in the design of potted wire and cable terminations are the following:

2–9.2.1 Surface Preparation

a. Rely upon the advice of the potting compound supplier with regard to surface preparation and priming.

b. In the case of bonding TFE or FEP, either sodium-etch the area to be bonded or use wires having a bondable coating.

c. In the case of polyethylene, some method of oxidizing the surface is usually required. The simplest method is that of "flame-treating".

d. Once having prepared the surfaces to be bonded, keep them clean.

2–9.2.2 Mechanical Factors

a. Utilize a potting compound having as low a volume shrinkage on curing as possible.

b. Ideally, the moduli of elasticity of the potting compound and the surface to which it is bonded should be equal. In actual wire and cable applications, however, this is rarely possible and the best rule of thumb to follow is that the potting compound, when cured, should have a lower elastic modulus than that of the insulation to which it is adhered.

c. If possible, fillet the potting compound around the wire or cable to help distribute stresses.

2–9.2.3 Chemical Factors

a. Be aware of the fact that those potting compounds which are exothermic (generate heat) during cure should be used in sufficiently small quantities so that the heat generated does not exceed the thermal capabilities of the insulation.

b. Check with the supplier of the potting compound to be sure that none of the compound components will affect components of the potted connection.

c. Select compositions which do not readily volatilize or change composition ratio during vacuum degassing.

2–10 INORGANIC INSULATIONS

In addition to the inorganic fibers, such as glass, asbestos, and quartz discussed in par. 2-7 "Fibers", other inorganic materials are utilized as insulations in the form of compressed powders which may or may not be fused. Cables and wires using this form of insulation consist of one or more conductors surrounded by the preformed insulation and enclosed

TABLE 2–6

PROPERTIES OF TYPICAL POTTING COMPOUNDS

Compound Type	Epoxy	Polysulfide	Polyurethane	RTV Silicone
Specific Gravity	1.2	1.2	1.1	1.4
Tensile Strength, psi	8000	200	5000	700
Elongation, %	4	200	500	150
Volume Resistivity, ohm-cm	10^{15} to 10^{16}	10^{10} to 10^{1}	10^{12} to 10^{13}	10^{14} to 10^{15}
Dielectric Constant, 1 kHz	4	9.5	6.5	3.8
Dissipation Factor, 1 kHz	0.04	0.05	0.03	0.01

in a liquid and gas tight metallic sheath. Such constructions, being completely inorganic, are very heat-resistant, inert to most environments, and fireproof.

Although such wires and cables can be bent, it is obvious that they are not truly flexible. Further, their lengths are limited, because the application of the insulation is not amenable to a continuous process.

2–10.1 MAGNESIUM OXIDE INSULATION

The most common inorganic insulation is magnesium oxide. It finds use in "mineral insulated" cables as a compressed powder. Such cables are used at voltages up to 600 volts rms under continuous operating temperatures of 250°C. Short time overloads, or higher operating temperatures at lower voltage ratings, are possible depending upon the melt temperature of the sheath or conductor (copper melts at 1080°C). The insulation is physically stable to 2800°C, although its insulation resistance is very low at that temperature.

Other inorganic materials which have found some use as wire and cable insulations are aluminum oxide and boron nitride.

Some of the properties of these materials are given in Table 2–7.

2–10.2 MAGNESIUM OXIDE BEADS

Double-sheathed, multiconductor cables for unusual applications may be fabricated by threading the conductors through preformed magnesium oxide beads which in turn are placed inside a sheath of the appropriate diameter and length. The assembly is then subjected to a process which compresses the magnesium oxide. The cable is built up by repeating the operation of "stringing" and compression.

2–11 SPECIAL ENVIRONMENTS

2–11.1 FUNGUS RESISTANCE

Fungi are defined as being saprophytic and parasitic lower plants which lack chlorophyll.

Certain insulating materials, notably cellulose derivatives and some rubber and plastic compounding ingredients, are fungus nutrients. Therefore, these materials are subject to fungus attack when ambient conditions are favorable for fungus growth. This attack can ultimately severely deteriorate or even destroy the insulating material. Mildew is an example of one type of fungus. Generally, warm, damp, and shaded areas provide the most ideal conditions for fungus growth.

The obvious way to avoid insulation deterioration arising from fungus attack is to utilize materials which are non-nutrient, or "inert", to fungus. It is possible, however, to utilize fungus nutrient materials if adequate concentrations of additives which are poisons for fungi (fungicides) are incorporated to render the insulation fungus-resistant.

A typical test method for determining fungus resistance is that given in MIL-STD-454 and MIL-STD-810.

2–11.2 RADIATION RESISTANCE

The effect of nuclear radiation upon insulating and jacketing materials is of concern where wires and cables must operate in environments which may expose them to such radiation.

All polymeric insulation materials are adversely affected by exposure to radiation. The mechanics of the attack upon polymer structure are either cross-linking or chain scission. The former results in eventual embrittlement, the latter results in loss of physical properties. In general, radiation in a vacuum or in an inert atmosphere is less severe in its effects than radiation in air. The inorganic insulations are quite resistant to radiation damage, and high exposures are required to effect significant changes in physical properties. Materials containing boron are an exception. They are not resistant to thermal-neutron bombardment, although they are resistant to damage by high energy electrons. Conversely, thermal-neutrons have not been found to contribute significantly to the degradation of organic polymers.

Table 2–8 shows the approximate, relative gamma radiation resistance in air of the materials commonly used as wire and cable insulations and jackets. The table is only indicative of the relative service life of the materials listed and should not be interpreted as actual service life. Factors such as dose rates, temperatures, wall thicknesses, compounding variables, and ventilation conditions will combine to affect actual service life.

TABLE 2–7

PROPERTIES* OF TYPICAL INORGANIC INSULATING MATERIALS

Material	Magnesium Oxide	Aluminum Oxide	Boron Nitride
Melting Point, "C	2800	2015	2730
Volume Resistivity, ohm-cm			
@ 300°C	10^{14}	10^{9}	10^{11}
@ 1000°C	10^{9}	10^{6}	10^{7}
@ 1500°C	10^{7}	-----	-----
Specific Gravity	3.6	3.8	2.2
Dielectric Constant, 1 MHz	9.7	9.5	4.2
Dissipation Factor, 1 MHz	0.002	0.008	0.001

* The properties listed are those expected of a void free construction, and in the case of compressed powders, would vary appreciably with the degree of compaction, particularly with regard to dielectric constant.

TABLE 2–8

RELATIVE RADIATION RESISTANCE OF INSULATING MATERIALS IN AIR

Material	Radiation Resistance, Gamma Exposure, rad
Thermoplastic	
Polyvinylchloride	10^7 - 10^8
Polyethylene, Low-density	10^8 - 10^9
Polyethylene, High-density	10^7 - 10^8
Polypropylene	10^6 - 10^7
Nylon	10^6 - 10^7
Fluorocarbon, TFE	10^4 - 10^5
Fluorocarbon, FEP	10^5 - 10^6
Fluorocarbon, CTFE	10^6 - 10^7
Fluorocarbon, VF-2	10^6 - 10^7
Polyurethane	10^8 - 10^9
Elastomeric	
Natural Rubber	10^7 - 10^8
SBR	10^7 - 10^8
Chloroprene	10^6 - 10^7
Butyl	10^5 - 10^6
Silicone Rubber	10^7 - 10^8
Chlorosulfonated Polyethylene	10^6 - 10^7
EPR	10^6 - 10^7
Fluorocarbon Rubber	10^6 - 10^7
Films	
Cellulosic	10^5 - 10^7
Polyester	10^6 - 10^8
Polyimide	10^8 - 10^{10}

TABLE 2–9

RELATIVE COSTS OF INSULATING MATERIALS

Material	Cost = Weight x Specific Gravity *
PVC	0.4
Polyolefin	0.4
Nylon	1.2
TFE	10.0
FEP	12.0
CTFE	12.9
VF-2	9.0
Polyurethane	1.8
Natural Rubber	0.6
SBR Rubber	0.5
Neoprene Rubber	0.9
Butyl Rubber	0.5
Silicone Rubber	3.8
Silicone Rubber, Fluorinated	25.0
Hypalon Rubber	0.8
EPR Rubber	0.5
Fluorocarbon Rubber	19.0
Cellulosics	0.3
Polyester Films	1.7
Polyimide Films	40.0

* Since wire and cable are sold by length rather than by weight, it is necessary to multiply weight by specific gravity to reflect the true cost relationship of insulating materials. This table does not include costs imparted by processing characteristics of the various materials which, in some cases, are a major factor in the cost of finished wire and cable.

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19. MIL-C-23206, *Cable, Electric, Thermocouple.*

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CHAPTER 3

DESIGN FACTORS – HOOK-UP AND INTERCONNECTING WIRE

3–1 SCOPE

Conductor materials, coatings, and configurations were presented in Chapter 1. Insulating materials, their ratings, properties, and limitations, were presented in Chapter 2. This chapter proceeds with the choice of materials and design criteria to meet requirements of application for single conductor insulated wires.

3–2 FACTORS INFLUENCING DESIGN

3–2.1 ENVIRONMENTAL FACTORS

3–2.1.1 High Temperature

One of the chief factors contributing to the degradation of electrical insulation in service is that of temperature. Temperature degradation is a function of time, so that the maximum permissible temperature is higher for a short time than that permissible for continuous service.

The total temperature of a system determines the rate of aging and establishes its thermal endurance. This total temperature is based on two prime factors; ambient operating temperature and temperature rise due to internal conductor heatings. The conductor "hot spot" (the temperature of the conductor at the hottest spot in the system) should be used as the total temperature for insulation selection. Chapter 2 should be referenced for the selection of insulating materials for continuous upper limit thermal ratings.

3–2.1.2 Low Temperature

As discussed in Chapter 2, the low temperature characteristics of the many insulation systems – and even different compounds of the same system – differ greatly, depending on the ingredients, method of processing, and method of testing to verify suitability for handling at extreme temperatures.

Insulations, both primary and jacketing types, will withstand extreme low temperatures well below their "rating", usually down to absolute zero, provided they are not disturbed or flexed in any manner. Such being the case, storage at temperatures below the specified limits will present no problems if the wire or cable is returned to a safe handling temperature before unreeling, flexing, or installation.

Low-temperature ratings or limitations should be specified in terms of the actual usage expected, and where applicable should include: (1) mechanical and electrical performance expected at the temperatures to be encountered in service, (2) temperature of installation and maintenance, (3) maximum permissible variation of properties under temperature cycling throughout the entire operating range, and (4) vibration and operational flexing expected within the operating range.

Specifying only a general low-temperature rating can be dangerous due to the many adverse conditions and environments that cannot be duplicated or simulated by test in the laboratory. Present test methods employed for low temperature rating define controlled test conditions, including mandrel sizes for bending or wrapping, motor driven sheaves at constant speeds, specific load weight, and controlled temperature duration. These methods should only be utilized for comparison in selection of materials, and as a quality control measure on the material. Chapter 2 lists the low-temperature ratings of the more commonly used insulating materials.

3–2.1.3 Flammability

Flame-retardant properties, as discussed in Chapter 2, will vary greatly depending on the ingredients, the compounding, the construction, and method of test. Most insulations, except for the fluorocarbons, will support combustion and convey flame if extensive flame is present or applied continuously This is particularly true if the wire or bundle of wires run vertically. Again, all adverse conditions and environments cannot be duplicated in the laboratory, and the test method should be utilized only as a guide to determine and compare the flame-retardant properties of the materials and construction of the wire. Self-extinguishing properties, and flame travel and burning rate in air at sea level can be entirely different from those in oxygen at zero gravity.

3–2.1.4 Moisture and Fungus

Fungus-resistant materials should be utilized for wire and cables that are to be used in warm, damp, or wet installations. This is especially true for use in tropical or semitropical areas. The materials that are fungus inert are fluorocarbons, nylon, and some vinyls (see MIL-STD-454). For further information refer to Chapter 2.

3–2.2 CHEMICAL FACTORS

3–2.2.1 Liauid

The mutual compatibility of the basic insulations with chemicals should be evaluated to the extent that they will be encountered. Immersion in, or contact with, fluids, solvents, oils, fuels, acids, salt water, and moisture, that may result in mechanical or electrical degradation should be examined throughout the entire temperature range to be encountered in operation. It is, however, not necessary to boil the wire in tests when only occasional splashing may be encountered at room temperature. Some of the degrading effects of immersion are swelling, cracking, splitting, protrusion, dielectric breakdown, and iqsulation resistance loss.

3–2.2.2 Ultraviolet

Ultraviolet produces (1) ozone, causing degradation, usually on the surface and, (2) attacks most plastic materials directly. The materials may be protected by inhibitors for direct exposure to sunlight. Plastics should be pigmented (black preferred) to exclude penetration. Infrared raises the temperature of dark materials above that of the atmosphere.

3–2.2.3 Gaseous

Oxidation is a predominant cause for deterioration in plastic materials and can lead to deterioration of properties – such as stiffening and loss of elongation, loss of dielectric strength, and discoloration resulting in loss of identity.

Ozone concentration must also be considered, particularly with vulcanized rubber and rubber-like materials. Conditions affecting insulating materials are the concentration of ozone together with temperature, stress, additives, sunshine, and rainfall.

3–2.2.4 Corrosion

Corrosion problems, for the most part, are concerned with the basic conductor, but some rubber insulating materials (particularly those having sulfur in the curing system) can accelerate this condition. Heat and moisture also contribute. Corrosive atmospheres should be evaluated to the extent that they may be encountered by both insulating materials and basic conductor metals.

3–2.2.5 Outgassinq

Insulation systems containing volatiles (particularly plasticizers) can outgas, at low pressures in airborne equipment and space vacuum, to form condensible film or fog on critical optical and electrical surfaces. PVC, polyethylenes, irradiated polyolefins, and compounds containing additives – with the exception of the fluorocarbons TFE and FEP, and polyimides – are known to outgas the additives, such as flame retardants or thermal stabilizers, that are frequently used in these materials. Some plasticizers, such as used in 60°C PVC compounds, can form a conductive gas in a closed (unvented) system.

3–2.3 MECHANICAL FACTORS

3–2.3.1 Flex-life

Flex-life refers primarily to the conductor, relating to its ability to withstand specific bending or flexing without breakage. Flex-life is very dependent on installation techniques – such as type of lug or termination, whether soldered or crimped, whether the insulation is supported by the termination, and how the wire is fastened and secured within the equipment. The insulation system can contribute greatly as a strain relief, particularly when utilized with insulation grip type terminations. Some plastics, particularly the polycarbonates, exhibit poor flex-life.

3–2.3.2 Abrasion Resistance

As with low temperature and flammability, abrasion resistance characteristics are difficult to assess with laboratory methods because of the many forms of abrasion encountered in practice. Abrasion is a very important problem and a control must be established, again on a comparative basis, even though the tests do not always simulate practice. Even a change in the brand (manufacturer) of the abrasive, although supposedly the same material and grit size, can change the results.

3–2.3.3 Penetration

Mechanical problems of penetration, cut-through, slow compression, cold flow, or deformation are really one and the same, i.e., amounting to stress under load. These again are dependent on conditions of installation and mechanical abuse during service. It is important, however, to specify cut-through testing to simulate use conditions at the maximum use temperature where the insulation material is softer than at room temperature. Specific test methods and test equipment again determine only the relative capabilities of the insulation system.

3–2.3.4 Tensile Strength

Tensile strength per se has no real importance to the finished wire except to serve as a control of the material chosen.

3–2.3.5 Elongation

Elongation is also used as a control of material but differs from tensile strength in that a certain minimum value *must* be retained for adequate performance. Conductor materials should always have greater than 6% elongation at rupture (while maintaining a yield point of 0.5% at elongation) to prevent conductor breakage. Insulation should have greater than 50% elongation to eliminate possible cracking on flexure. For specific material control however, values in excess of these may be specified as minimum.

3–2.4 ELECTRICAL FACTORS

3–2.4.1 Dielectric Constant

Factors affecting the dielectric constant of a given material are signal frequency, temperature, voltage, moisture absorption, weathering, deterioration, and electrical history. Dielectric constant is of utmost importance in a shielded construction (coaxial) for radio frequency application. It is generally desirable to have the capacitance, and hence the dielectric constant, as small as possible.

3–2.4.2 Dielectric Strength

The fundamental requirement of insulation is to confine the electrical field as close to the conductor as possible under all applied voltages required by the end use. The dielectric strength test is necessary to prove performance as a quality measure. In service there may be many deteriorating influences – such as heat, mechanical stress, manufacturing defects, corona and its products, contaminants, etc. – which may reduce the breakdown voltage of the insulation below the value as originally installed. Some of these effects can be simulated in the laboratory, and followed by a dielectric test, to obtain an estimate of material performance under adverse conditions. In dielectric testing it is important that the voltage be raised from zero at a uniform rate to prevent transients (500 volts per second is usually specified).

3–2.4.3 Gradient (Electrical)

Gradient is generally expressed as the quotient of the applied voltage divided by the insulation thickness between two oppositely charged conducting members. The electrical stress of a single core cable with a conducting cylindrical outer surface may be calculated at any point in the insulation in terms of the applied voltage and cable dimensions by Eq. 3-1.

$$S = \frac{E}{x \log_e (R/r)} \qquad (3\text{–}1)$$

S = electrical stress, volt/mil

x = distance from center of the conductor to point of stress calculation, mil

r = radius of center conductor, mil

R = radius of core (or inner radius of outer conductor), mil

E = voltage between inner conductor and outer conductor, volt

Gradient calculations are important in the design of high voltage cables.

3–2.4.4 Insulation Resistance

Insulation resistance is a measure of volume resistivity of insulation and depends on the length of time of electrification and on the value of the applied voltage (in addition to the usual material and environmental variables). This is due to a combination of polar migration, linear resistance, and displacement current. It is usual to use the value achieved after one minute of electrification.

Insulation resistance is lower at high temperature because of increased molecular activity.

The insulation resistance required can be accurately determined from circuit considerations and should be specified at the highest operating temperature to be encountered.

3–2.4.5 Loss Factor

The loss factor is an indication of the power loss in the insulation system and should be small to reduce insulation heating and signal degradation.

It is usually of importance only in audio and radio frequency cables.

Factors affecting loss characteristics are identical to those affecting the dielectric constant.

3–2.4.6 Current-carrying Capacity

Reliable current ratings are one of the prerequisites for the design of any electrical system. There are two general criteria by which the current-carrying capacity of a cable is determined: (1) the maximum permissible voltage drop in the conductor, and (2) the maximum insulation temperature of the conductor. Since the maximum conductor temperature is limited by the insulation, the maximum current will depend upon the maximum operating, or "hot spot", temperature and ambient temperature. The higher the ambient, the lower the allowable temperature rise will be. Under conditions of thermal equilibrium, the rate at which heat is produced in the conductor is equal to the rate at which the heat is removed from the insulation and dissipated to the surroundings by conduction, convection, and radiation.

Inasmuch as there are many factors involved in the determination of current-carrying capacity and its technical prerequisites, no attempt will be made to define all the parameters involved in the selection and ratings of single conductors here. The current-carrying capacity can be determined experimentally, and can be accurately calculated using formulas on current and temperature rise in cables in Refs. 1-3. These techniques have been verified experimentally in several laboratories, and are accurate and usable. (For bundling see Chapter 4.)

3–2.4.7 Voltage Drop

Another criterion that influences the selection of conductor size is the voltage drop under operating conditions. This condition is often found in aircraft cable installations containing low voltage, high current, and long wiring runs. This factor may be more important than current-carrying capacity. Voltage drop, when excessive, can be reduced to a practical value by resorting to a conductor larger than necessary to carry the necessary circuit current.

For direct current and **60-Hz** circuits (except long interstate power circuits) the voltage drop may be calculated from Ohm's Law. For 400-Hz and high-voltage systems, particularly 3-phase, the calculations become involved beyond the scope of this handbook. Skin effect must also be taken into consideration. Techniques for these calculations may be found in Ref. 4. Cognizance must be taken of the increase in resistance with operating temperature according to the fundamental relation:

$$R_T = R_{20}\left[1 + a_{20}(T - 20)\right] \quad (3-2)$$

where

R_T = resistance at measurement temperature, ohm

R_{20} = resistance @ 20°C the reference temperature, ohm

T = measurement temperature, "C

a_{20} = temperature coefficient of resistivity per "C @ 20°C

The value of temperature coefficient of resistivity will depend on the conductivity of the conductor as well as the temperature and may be obtained from the equation

$$a = \frac{1}{\dfrac{1}{n(0.00393)} + (T - 20)} \quad (3-3)$$

where

a = coefficient of resistivity

n = percent conductivity of conductor expressed decimally (99% = 0.99)

0.00393 = copper (100%conductivity)

3–2.5 IDENTIFICATION

Basically there are three requisites for identification: manufacturer, temperature, and circuit identification.

Manufacturer identification may be accomplished by the use of color-coded threads placed either within the strands or under the insulation, braid, or jacket, and surface printing or Federal Code designation.

Temperature identification may also be accomplished by a color-coded thread system or by surface printing.

Circuit identification is accomplished by the use of color coding or printed numbers. Color coding includes solid colored insulation, helical striping, continuous or broken horizontal striping, "hash-mark" or slash striping, and, in some instances, a series of dashes. Color coding by spiral striping is the most common and least expensive.

Circuit identification may also be accomplished by the surface printing method utilizing a color code number system.

3–3 DESIGN CONSIDERATIONS

3–3.1 CONDUCTOR CHOICES

The selection of the basic conductor involves many factors which are essential to the satisfactory operation of an electrical system. The following is a discussion of the most important of these factors.

3–3.1.1 Mechanical Factors

From the engineering information available, the tensile strength and elongation of the basic conductor should be specified.

For applications involving wire sizes #24 AWG and smaller, consideration should be given to the use of alloy materials for improved strength and flex-life.

Flex-life is primarily a function of the number and size of the individual strands, the strength of the conductor material, and the length and direction of stranding lay employed. A greater number of smaller size strands will increase the flex-life considerably. The use of a solid conductor should not be considered when flex-life or flexibility is important. Cold working due to mechanical vibration, physical abuse in installation and service, and uncontrolled manufacturing processes can lead to premature breakage of solid conductors. See Chapter 1 for details and particulars affecting construction and design of the basic conductor.

3–3.1.2 Thermal Factors

Following the requirements of tensile strength, elongation, and flex-life of the basic conductor, consideration must be given to its thermal operating environment. Selection of a coating, if required, must be made. Many factors are involved in the selection of the coating material, i.e., tin, silver, nickel, or dual coatings. Reference to Chapter 1 will aid in the selection and determination of the proper coating.

The following examples are typical of conductor selection:

EXAMPLE NO. 1:

	Required
Tensile Strength	39,000 psi (max)
Elongation	20% (min)
Flex-life	Essential
Wire Size	#20 AWG
Maximum Conductor Temperature	105°C
Coating	Tin
DC Resistance	10.5 ohm/1000 ft @ 20°C
Conductivity	99%
Corrosion	No problem

The following selection would be more than adequate for Example No. 1: 19 strands of #32 AWG tin copper, or 27 of #34, or 37 of #36, depending on the degree of flexibility. (As opposed to a solid or 7 strands of #28 AWG.) Each stranding has a tensile strength of approximately 37,000 psi, an elongation of approximately 25%, a coating thickness of approximately 40 pin., and a DC resistance of less than the maximum 10.5 ohm/1000 ft @ 20°C specified.

EXAMPLE NO. 2:

	Required
Tensile Strength	50,000 psi (min)
Yield Strength (at 0.5% strain)	45,000 psi
Elongation	8% (min)
Flex-life	Essential
Wire Size	#26 AWG
Maximum Conductor Temperature	260°C
Coating	High Temperature
DC Resistance	49.00 ohm/1000 ft @ 20°C
Conductivity	85% - 90%
Corrosion	Possibility

The following selection would be more than adequate for Example No. 2: 19 strands of #38 AWG high strength, nickel-coated copper alloy, with a tensile strength of approximately 63,000 psi, a yield strength of 55,000 psi (at 0.5% strain), an elongation of approximately 10% at rupture, a nickel coating thickness of 50 pin. minimum, a conductivity of 90% minimum, and a DC resistance of approximately 47.8 ohm/1000 ft @ 20°C.

3—3.2 INSULATION CHOICES

The following factors govern the choice of the correct insulating material for the prescribed installation.

a. Temperature (high): Refer to par. 3-2.1.1

b. Temperature (low): Refer to par. 3-2.1.2

c. Chemical Factors: Refer to par. 3-2.2

d. Electrical Factors: Refer to par. 3-2.4

3—3.2.1 Mechanical Considerations

Factors affecting the mechanical performance of an insulation are elongation, flexibility, abrasion, resistance to penetration, cold flow, and deformation. All of these properties are desirable, but the cost factors involved usually dictate an acceptable compromise. A careful evaluation of the necessary properties required for satisfactory operation should be made and applicable test methods should be specified to insure sufficient wall thickness for the mechanical abuse that may be encountered, or exist, under normal operating conditions.

3—3.2.2 Electrical Considerations

The primary function of wall thickness, in relation to the electrical properties of a single wire, is to provide a capability of withstanding the electrical stress imposed upon it during the application of the nominal operating voltages and frequencies.

The dielectric stress at any point is a function of the applied voltage, conductor size, and insulation thickness. It will be maximum at the surface of the conductor and will progressively decrease towards the outer surface of the insulation, and will vary with the size of the conductor. From this it is obvious that for a given voltage rating the wall thickness will be dependent on the physical size of the conductor. When the wall thickness is increased, for mechanical reasons or special service conditions, the test voltage and frequency should be determined by the size of the conductor and the rated voltage, not the apparent thickness of the insulation. Minimum wall thicknesses may be limited by permissible interference due to capacitive coupling. Reference to Chapter 7 should be made for details involved in voltage ratings vs insulation thickness.

3—4 TESTING TO PROVE DESIGN

The culmination of all engineering work is in the practicable application of the materials selected. The most expert and knowledgeable selection is only one step toward the final objective. Another step is the establishment *of* suitable test methods which insure that the end product will perform in accordance with the requirements to be encountered under operating conditions for the service life expected.

A general outline of specific tests is presented that may be utilized in the writing of specifications for control of production processes, quality control, and acceptance test procedures. This listing does not include special test methods applicable to certain wire and cable that may be described in appropriate detail specifications, nor does it include all the test methods for wire and cable used in the industry.

Reference to established Military Specifications, ASTM Standards, and Federal Test Specifications should be made for detailed descriptions of the indicated tests. For additional information refer to the Appendix.

3—4.1 ELECTRICAL TESTS:

Dielectric Strength Test AC/DC/RF	DC Resistance
Spark Test, Insulation Defect	Conductivity
Corona Level	Capacitance
Insulation Resistance	Surface Resistance
Power Factor	Volume Resistance
Dielectric Constant (capacitive coupling in multiconductor cable)	Electrical Stress
	Smoke

3—4.2 PHYSICAL TESTS

Tensile Strength	Accelerated Aging
Elongation	Thickness of Insulation
Tension Set	Concentricity
Tear Test	Specific Gravity
Tensile Stress	Wicking
Solder	

3—4.3 AGING TESTS

Air Oven	Oxygen Test
Life Cycle	Air Pressure Test
Accelerated Aging	Humidity Resistance

3—4.4 THERMAL TESTS

Heat Shock	Deformation
Heat Distortion	Melt Point
Flammability	Shrinkage (insulation)
Brittleness	

3—4.5 MECHANICAL TESTS

Cold Bend	Penetration
Flexibility	Slow Compression
Flex-life	Flow Under Stress
Abrasion Resistance	

3—4.6 CHEMICAL TESTS

Water Absorption	Coating (continuity conductor)
Ozone Resistance	Sodium Polysulfide
Resistance to Oils and Solvents	
Resistance to Acids and Alkalies	

3—5 HOOK-UP VS INTERCONNECTING WIRE

3—5.1 HOOK-UP WIRE

Major uses of hook-up include internal wiring of meters, panels, electronic computers, aircraft and instrumentation wiring, military ground support wire, industrial and domestic appliances, automotive industry, telephone equipment, "black boxes" for aircraft and missile components, and other automated equipment. As opposed to interconnecting wire, most hook-up wire is utilized in (1) mechanically protected areas such as chassis wiring, or (2) as basic components in multiconductor cables protected by either individual shields or overall shields and outer protective coverings such as extruded jackets or sheaths and armor braids.

Most hook-up wires manufactured in accordance with individual specifications are suitable as component parts of milticonductor cables. However, it should be noted that the test requirements of the individual hook-up wire do not necessarily cover the performance requirements if those wires are incorporated in multiconductor cables. Tests required for completed cable constructions, to assure suitability for operating conditions, should be agreed upon between the purchaser and manufacturer.

Thin-wall insulations below 10 mils, usually rated at 250-300 volts rms, are relatively fragile and easily damaged, and, therefore, should not be used where subjected to mechanical stress or abrasive environment. Conductors employing thin-wall insulations are very susceptible to damage and, consequently, may not be suitable for circuits requiring the highest degree of reliability. This problem can be minimized by employing high strength copper alloy conductors in sizes #24 AWG and smaller in order to insure greater tensile strength, elongation, and flexibility. In order to appear consistent, thin-wall insulations are assigned the same rated values as those rated values assigned to heavier walls of the same dielectric material. Care must be taken with these thin-wall insulations during installation to avoid damage to the dielectric – e.g., the use of hot soldering irons or leaving residual strain on the dielectric wall – that may cause thermoplastic flow and subsequent failures. Thin-wall insulations should be used only where space and weight limitations preclude the use of more substantial and reliable insulation thickness.

Most hook-up wire specifications allow, or make provisions for, alternate strandings and additional outer coverings such as braids, shields, and jackets that may be specified by the purchaser for mechanical protection from abrasives, oils, fluids, and moisture environments.

3–5.2 INTERCONNECTING WIRE AND CABLE

The term "interconnecting" indicates wire or cable utilized as harnesses between "black boxes", electrical equipment, and operational units where they are exposed to mechanical abuse. This means that a more rugged construction is necessary than for hook-up wire. There are innumerable types and designations of interconnecting wire or cable, both in the commercial and military fields.

Major uses of interconnecting wire include aircraft, aerospace and missile wire, mining and refinery installations, grounded transportation equipment, communications, and electronic computers. Other uses are for the interconnection of various interior units of space vehicles, and exterior ground network systems in multiconductor configurations.

Due to the rapid increase and growth of electronic equipment and automation, it was necessary that specifications for more rugged and compatible constructions and insulation systems be designed to meet both the new mechanical and the environmental service conditions to be encountered. These conditions necessitated the 105°C temperature range. It was imperative that more rugged constructions be designed to meet the mechanical and installation problems that could not be handled by the more fragile types of hook-up wire.

3–6 COMPARISON OF HOOK-UP WIRE TYPES

Characteristics and ratings of hook-up wire are usually given in detailed specifications, applicable individual design data sheets, or Military Standards. See Table 3-1 for comparison of wire types per various Specifications. Specifications are subject to frequent revision and their citation in this handbook are for reference only. Latest issue should be consulted.

3–6.1 MIL-W-76

MIL-W-76 covers synthetic resin insulated hook-up wire for temperatures of 80°C for internal wiring of electrical and electronic equipment. Specifications have been made for five basic types of 80°C hook-up wire, including provisions for jackets, shields, braids, outer jackets, or combinations thereof.

The wire covered by this specification is not intended for high-temperature applications. The 80°C rating is approximate, applies to the insulated wire without covering, and may be raised slightly when the construction includes a covering over the insulation. The rating is ambient temperature plus temperature rise due to conductor current. When a nylon jacket is used, the temperature rating may be raised to 90°C. This is possible because the extruded nylon jacket will prevent the escape of plasticizer, allowing the basic material to maintain its properties and characteristics for a much greater service life. In direct current circuits the wire covered by this specification may be used at voltages 1.4 times the rms voltage rating specified.

TABLE 3–1

EXISTING MILITARY SPECIFICATIONS FOR GENERAL PURPOSE WIRE (HOOK-UP)

Military Specifications	Military Designations	Temperature Rating, °C	Voltage Rating, rms	Wire Size Range, AWG	Copper Conductor Coating	Primary Insulation	APPLICATION AND USE
MIL-W-16878D	Type B	-54 to 105	600	#32 - #14	Tin	PVC	General purpose, excellent resistance to moisture, oils, and solvents.
MIL-W-16878D	Type C	-54 to 105	1000	#26 - #12	Tin	PVC	General purpose, excellent resistance to moisture, oils, and solvents.
MIL-W-16878D	Type D	-54 to 105	3000	#24 - #1/0	Tin	PVC	General purpose, excellent resistance to moisture, oils, and solvents, high-voltage.
MIL-W-16878D	Type E	-65 to 200/260	600	#32 - #10	Silver Nickel	TFE	High-temperature, ultra-high frequency use, good resistance to hot solder irons, general purpose.
MIL-W-16878D	Type EE	-65 to 200/260	1000	#32 - #8	Silver Nickel	TFE	High-temperature, ultra-high frequency use, good resistance to hot solder irons, high-voltage.
MIL-W-16878D	Type ET	-65 to 200/260	250	#32 - #20	Silver Nickel	TFE	High-temperature, ultra-high frequency use, low voltage. Note: thin-wall precautions.
MIL-W-16878D	Type F	-54 to 200	600	#24 - #12	Silver Nickel	SE	High-temperature, medium frequency range, solder-iron-resistant, contained during fire, will serve as dielectric.
MIL-W-16878D	Type FF	-54 to 200	1000	#24 - #4/0	Silver Nickel	SE	High-temperature, medium frequency range, solder-iron-resistant, high-voltage.
MIL-W-16878D	Type FFW	-54 to 200	1000	#24 - #8	Silver Nickel	SE	High-temperature, encapsulated coil lead wire, water-blocked stranding, high-voltage.
MIL-W-16878D	Type J	-65 to 75	600	#24 - #4/0	Tin	HF	Ultra-high frequency, relatively poor resistance to environmental cracking, protect with polyamide jacket.
MIL-W-16878D	Type K	-65 to 200	600	#32 - #10	Silver	FEP	High-temperature, ultra-high frequency, does not resist hot solder irons, general purpose.
MIL-W-16878D	Type KK	-65 to 200	1000	#32 - #8	Silver	FEP	High-temperature, ultra-high frequency, does not resist hot solder irons, high-voltage.
MIL-W-16878D	Type KT	-65 to 200	250	#32 - #20	Silver	FEP	High-temperature, ultra-high frequency, does not resist hot solder irons, low-voltage.
MIL-W-76	Type LW	-40 to 80	300	#30 - #20	Tin	PVC	General purpose, internal wiring of electrical and electronic wiring.
MIL-W-76	Type MW	-40 to 80	1000	#24 - #12	Tin	PVC	General purpose, internal wiring of electrical and electronic wiring, high-voltage.
MIL-W-76	Type HW	-40 to 80	2500	#22 - #16	Tin	PVC	General purpose, internal wiring of electrical and electronic wiring, high-voltage (#14 - #6 AWG).
			600	#14 - #6			
MIL-W-76	Type FX	-54 to 80	500	#30 - #00	Tin	PVC	Special purpose, internal wiring of electrical and electronic wiring.
MIL-W-76	Type HF	-40 to 80	1000	#24 - #16	Tin	HF	Radio frequency, internal wiring of electrical and electronic wiring, high-voltage.
MIL-W-27300	MS-24284	-65 to 260	600	#26 - #12	Nickel	TFE	Aircraft and missiles, min size, min weight, smooth outer surface for use with grommet-type seals.
MIL-W-81044	M81044/1	-65 to 135	600	#24 - #4	Silver	PE/PVF-2	Aerospace electrical systems, general purpose.
MIL-W-81044	M81044/2	-65 to 135	600	#24 - #4	Tin	PE/PVF-2	Aerospace electrical systems, general purpose.
MIL-W-81044	M81044/3	-65 to 135	600	#30 - #12	Silver	PE/PVF-2	Aerospace electrical systems, general purpose.
MIL-W-81044	M81044/4	-65 to 135	600	#30 - #12	Tin	PE/PVF-2	Aerospace electrical systems, general purpose.
MIL-W-22759	MS-21985	-65 to 200	600	#28 - #12	Silver	TFE	Aerospace electrical systems, general purpose, high-temperature.
MIL-W-22759	MS-21986	-65 to 260	600	#28 - #12	Nickel	TFE	Aerospace electrical systems, general purpose, high-temperature.
MIL-W-22759	MS-18113	-65 to 200	1000	#28 - #8	Silver	TFE	Aerospace electrical systems, general purpose, high-temperature, high-voltage.
MIL-W-22759	MS-18114	-65 to 260	1000	#28 - #8	Nickel	TFE	Aerospace electrical systems, general purpose, high-temperature, high-voltage.
MIL-W-22759	MS-18104	-65 to 200	600	#28 - #8	Silver	TFE/ML	Aerospace electrical systems, general purpose, high-temperature, polyimide-coated.
			1000	#12 - #14			
MIL-W-22759	MS-18105	-65 to 260	600	#28 - #10	Nickel	TFE/ML	Aerospace electrical systems, general purpose, high-temperature, polyimide-coated.
			1000	#12 - #14			
MIL-W-22759	MS-18032	-65 to 200	600	#30 - #2	Silver	TFE/Tape	Aerospace electrical systems, general purpose, high-temperature, fused, laminated insulation.
MIL-W-22759	MS-18033	-65 to 260	600	#30 - #2	Nickel	TFE/Tape	Aerospace electrical systems, general purpose, high-temperature, fused, laminated insulation.

3–6.2 MIL-W-16878D

MIL-W-16878D at the present time covers hook-up wire employing several types of primary insulation systems. Provisions are made for jackets, shields, and outer covering such as polyimide (nylon), glass braid or synthetic: yarns, polyvinyl, FEP-fluorocarbon and TFE-fluorocarbon jackets.

3–6.3 MIL-W-81044

MIL-W-81044 is a new specification with temperature rating in the mid-temperature range (135°C), utilizing a combination of two cross-linked materials and offers to the industry four designs, two of which are sufficiently rugged to be used as aircraft interconnecting wire and are suitable replacements for MIL-W-5086 type wire with improved properties and high temperature rating.

3–6.4 MIL-W-27300

MIL-W-27300 covers extruded polytetrafluoroethylene primary insulation only. This Specification covers nickel-coated copper conductor and incorporates features of minimum size, weight, and smooth outer surface suitable for use in grommet-type seals. Care should be exercised in harnessing and outing of this wire. Mechanical abuse, abrasion, and concentrated loads should be avoided.

3–6.5 MIL-W-22759

MIL-W-22759 covers both TFE- and FEP-fluorocarbon insulation systems, alone, or in combination with outer insulating materials. It covers both hook-up and interconnecting or airframe wires.

3–7 COMPARISON OF INTERCONNECTING WIRE TYPES

Characteristics and ratings of interconnecting, or "airframe", wire types are given in detailed specifications, individual applicable design date sheets, or Military Standard Sheets (see Table 3-2).

3–7.1 MIL-W-5086

MIL-W-5086 was drawn up primarily for use as airframe and missile interconnecting wire. This specification at the present time consists of four types of PVC insulation covered by MS-25190.

3–7.2 MIL-W-81044

MIL-W-81044 a relatively new specification issued in 1964, has made available to the industry two new "interconnecting" wire types sufficiently rugged for replacement of MIL-W-5086.

These constructions provide a long-needed improvement in the MIL-W-5086 type wires. They offer improved resistance to fluids, higher temperature rating, much improved resistance to flow due to momentary overloading of conductors or short term heat aging, physical stability at elevated temperatures, and improved abrasion resistance (both scrape and sandpaper tests) which is maintained at maximum rated temperatures.

Of all the aircraft types, it offers the lightest weight for interconnecting service.

3–7.3 MIL-W-7139

MIL-W-7139 covers two classes: Class 1, silver copper conductor with polytetrafluoroethylene primary insulation, rated at 200°C, 600 volt rms, and Class 2, rated at 260°C, 600 volt rms, with nickel-copper conductor. This specification allows the use of polytetrafluoroethylene tapes or extruded polytetrafluoroethylene, glass tapes impregnated with polytetrafluoroethylene, or glass braids which are impregnated. This particular type of construction has presented many problems, due to wicking of the outer glass braid, causing electrical surface arcs and termination failures. In addition, the irregular surface makes sealing in grommet-type connections, such as those described in MIL-C-26500, difficult.

3–7.4 MIL-W-8777

MIL-W-8777 employs silicone rubber primary insulation in two constructions. These are covered by MS-25471 and MS-27110. Both MS types are rated for 600 volts rms, 200°C, with the basic difference being the outer jackets. MS-25471 employs a double braid jacket, glass inner braid, and a polyester outer braid. Both braids are impregnated with high temperature finishes. MS-27110 employs a tan glass braid impregnated with an extruded fluorinated-ethylenepropylene jacket to make it more fluid-and moisture-resistant. Basic problems with these types have been with the glass braid construction.

TABLE 3–2

EXISTING MILITARY SPECIFICATIONS FOR INTERCONNECTING WIRE

Military Specifications	Military Designations	Temperature Rating, °C	Voltage Rating, (rms)	Wire Size Range, (AWG)	Copper Conductor Material	Primary Insulation	APPLICATION AND USE
MIL-W-5086	Type 1 (MS-25190-A)	-55 to 105	600	#22 - #12	Tin	PVC	Aircraft electrical systems per MIL-W-5088, MIL-C-27500, and general purpose within specification limits.
MIL-W-5086	Type 2 (MS-25190-B)	-55 to 105	600	#22 - #0000	Tin	PVC	Aircraft electrical systems per MIL-W-5088, MIL-C-27500, and general purpose, employing glass braid for overload protection.
MIL-W-5086	Type 3 (MS-25190-C)	-55 to 105	600	#22 - #0000	Tin	PVC	Aircraft electrical systems per MIL-W-5088, MIL-C-27500, and general purpose, employing glass braid for overload protection and vinyl jacket with nylon or nylon braid for mechanical protection.
MIL-W-5086	Type 4 (MS-25190-D)	-55 to 105	3000	#22 - #16	Tin	PVC	Aircraft electrical systems per MIL-W-5088, MIL-C-27500, and general purpose, heavy wall, high-voltage.
MIL-W-7139	Class 1	-65 to 200	600	#22 - #0000	Silver	TFE	Aircraft and missile wiring and general purpose, within specification limits, not fire-resistant.
MIL-W-7139	Class 2	-65 to 260	600	#22 - #0000	Nickel	TFE	Aircraft and missile wiring and general purpose, within specification limits, not fire-resistant.
MIL-W-8777	MS-25471	-55 to 200	600	#22 - #00	Silver	SE	Aircraft and missile wiring and general purpose, within specification limits, not fire-resistant, polyester jacket.
MIL-W-8777	MS-27110	-55 to 200	600	#22 - #4	Silver	SE	Aircraft and missile wiring and general purpose, within specification limits, not fire-resistant, FEP jacket.
MIL-W-22759	MS-17410	-65 to 200	600	#22 - #00	Silver	TFE	Aerospace vehicles and general purpose, within specification limits, TFE, FEP, and fibrous glass combination.
MIL-W-22759	MS-17411	-65 to 200	600	#26 - #4	Silver	TFE	Aerospace vehicles and general purpose, within specification limits, homogeneous, extruded TFE, abrasion-resistant.
MIL-W-22759	MS-17412	-65 to 260	600	#26 - #4	Nickel	TFE	Aerospace vehicles and general purpose, within specification limits, homogeneous, extruded TFE, abrasion-resistant.
MIL-W-22759	MS-17331	-65 to 200	600	#22 - #8	Silver	TFE	Aerospace vehicles and general purpose, within specification limits, abrasion-resistant, asbestos reinforced, combination.
MIL-W-22759	MS-17332	-65 to 260	600	#22 - #8	Nickel	TFE	Aerospace vehicles and general purpose, within specification limits, abrasion-resistant, asbestos reinforced, combination.
MIL-W-22759	MS-18000	-65 to 200	600	#24 - #4	Silver	TFE	Aerospace vehicles and general purpose, within specification limits, homogeneous, extruded TFE, abrasion-resistant, medium weight.
MIL-W-22759	MS-18001	-65 to 260	600	#24 - #4	Nickel	TFE	Aerospace vehicles and general purpose, within specification limits, homogeneous, extruded TFE, abrasion-resistant, medium weight.
MIL-W-81044	M81044/1	-65 to 135	600	#24 - #4	Silver	PE/PVF 2	Aerospace electrical systems, general purpose.
MIL-W-81044	M81044/2	-65 to 135	600	#24 - #4	Tin	PE/PVF 2	Aerospace electrical systems, general purpose.

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5. *Method for Calculation of Current Rating of Hook-up Wire,* EIA Standard RS-214, November 1958.

6. MIL-C-27500, *Cable, Electrical, Shielded and Unshielded, Aircraft and Missile.*

7. MIL-W-76, *Wire and Cable, Hook-up, Electrical, Insulated.*

8. MIL-W-5086, *Wire, Electrical,* 600 *Volt, Copper, Aircraft.*

9. MIL-W-5088, *Wiring Aircraft, Installation Of.*

10. MIL-W-7139, *Wire, Electrical, Polytetrafluoroethylene Insulated, Copper, 600 Volt.*

11. MIL-W-8777, *Wire, Electrical, Silicone Insulated, Copper, 600 Volt.*

12. MIL-W-16878D, *Wire, Electrical, Insulated, High Temperature (Navy).*

13. MIL-W-22759, *Wire, Electrical, Fluorocarbon Insulated, Copper.*

14. MIL-W-27300, *Wire, Electrical, Polytetrafluoroethylene Insulated, Copper, 600 Volt.*

15. MIL-W-81044, *Wire, Electric, Crosslinked Polyalkene Insulated, Copper.*

16. MIL-STD-454, *General Requirements for Electronic Equipment.*

CHAPTER 4
BUNDLED WIRES

4–1 LACED BUNDLES

4–1.1 LACING

Bundled and laced cables referred to in this chapter will be two or more single, insulated conductors, laid parallel, held by a lacing cord, wrapped and tied intermittently along the bundle. In lacing, it is very difficult to control the tension applied to the cord; this is of major concern in the fabrication of these cable types. A too tight tension during application causes cut-through and insulation flattening, while a too loose tension will not hold the bundled conductors in place after repeated flexing. Usually nylon cordage is used because it is fungus inert, strong, and resists the usual fluids found in aircraft and other vehicles. When nylon lacing is applied under tension it stretches, and when heated, due either to increased ambient temperature or current flow, it will tend to relax. This constant tensing and relaxing will apply a great deal of force to the bundled wires tending to cut-through the insulation. For this reason, especially when used with a PVC-insulated wire, and particularly with thin-wall insulation on the order of 0.015 in. or less, the nylon cordage used should be a flat braid rather than a round monofilament. This flat braid should be between 1/16 in. and 3/16 in. wide.

Also available, as alternate bundling ties, are blown-on or shrinkable plastics tubes, metal or plastic clamps, and various types of tie wraps made of various materials.

4–1.2 USAGE – LACED BUNDLES

The major reason for employing a laced, bundled cable of this type is that a great many breakouts may be permitted. These cables are normally used for relatively short run assemblies where numerous breakouts of one or more conductors from the main bundle occur at frequent intervals. Where fewer breakouts occur, a much more satisfactory assembly would be factory assembled cables, as discussed under prefabricated bundles later in this chapter and the chapter on multiconductor cables. Laced bundles frequently contain, within a given harness, a multiplicity of wire sizes and frequently more than one wire type; e.g., coaxial cable intermixed with interconnecting wires. Laced bundles are utilized for either hook-up or interconnecting applications, dependent upon whether the assembly is to be enclosed within the chassis or exposed. Laced bundles utilizing hook-up wire within "black boxes" have been largely replaced by the printed circuit. Laced bundles are used in aircraft or missile applications where size and weight are of major concern.

4–2 PREFABRICATED BUNDLES

Within modern large aircraft there are several relatively long runs of interconnecting wire without breakouts. Here a much more satisfactory assembly results from factory constructed bundles or cables terminated in juction boxes at either end of the run. These cables are usually confined to 7 or less conductors and consist of the assembled, insulated conductors twisted on a planetary twisting machine to insure smooth, even component lay-up within the cable. Conductors are usually twisted with a left hand lay, and the individual conductor lay ranges between not less than 16 nor more than 28 times the diameter of the individual basic cable component.

These preassembled bundles, or cables, have an advantage in that they are more flexible due to the twisted construction; are less costly because the hand labor of lacing is eliminated; the danger of cut-through is eliminated; and they are more rugged and substantial because of the outer protective jacket. The Military Specifications covering this type of cable are MIL€-7078 and MIL€-27500, both of which are similar in the latest revision.

4–2.1 CONSTRUCTION

These cables are fabricated in four general catagories:

(1) Two or more spirally laid, coded wires – unshielded, unjacketed.

(2) Two or more spirally laid, coded wires — jacketed.

(3) Two or more spira ly laid, coded wires — shielded.

(4) Two or more spira ly laid, coded wires — shielded and jacketed.

4—2.2 COMPONENTS

The cable components are all constructed from the specified insulated wires as described in Chapter 2.

4—2.3 COLOR CODE

Color coding should be performed, where possible, using a colored ink, spiral stripe on the individual conductor insulation.

4—2.4 SHIELD

A metallic braid over the bundle should be employed, where shielding is required, to reduce electrical interference. This shield may be fabricated from bare copper, silver-plated copper, nickel-plated or nickel-clad copper, or stainless steel dependent on the temperature environment and corrosion resistance needed. The metallic braid should be so applied that a 20" to 40" angle occurs between the braid carriers and the bundle axis; this is desirable in order to give a push back quality to the shield for greater flexibility and easier termination characteristics. Table 4—1 will aid in the selection of a correct shield wire material for a particular environment.

4—2.5 JACKET

The jackets provided for these cable types are as follows:

(1) Extruded, clear nylon for cables not over 0.25 in. diameter under the jacket. Braided, saturated nylon where temperature is not a major factor and good abrasive qualities are desired.

(2) Braided, saturated Fiberglas is used where temperature and abrasion factors are encountered.

(3) Extruded PVC is used, where possible, because of the cost savings incurred over the other type jackets.

(4) Extruded or taped TFE is used where extreme temperatures or acid environments are of major concern. Extruded FEP would be used at slightly lower temperature environments and for added flexibility over TFE.

(5) Extruded materials, based on monochlorotrifluoroethylene (CTFE), would be used where extreme abrasion factors are encountered.

These specifications allow freedom of design to optimize cost and performance.

Table 4—2 will aid in the selection of the proper jacketing material for each cable and environment. It must be emphasized that the minimum temperature indicated refers only to bundled wire which remains in a relatively stationary position.

4—3 DERATING FACTORS FOR BUNDLED WIRES

4—3.1 INTRODUCTION

A great deal of information has been compiled on the current-carrying capacity of bundled insulated wires, but it has had very little use. This is true because the calcuations are complex and differ for each particular assembly or circumstance. The following describes the most accurate method of determining current ratings of bundled wires.

This method should not be used in calculating wire size for signal circuits since mechanical strength is usually the determining factor in this type circuit.

The basic document referenced for many of the procedures is *Current Rating For Bundled Wire — A Step by Step Procedure,* A.M. Samborsky, U.S. Navy Electronics Lab., San Diego, Calif.

4—3.2 BASIC CONSIDERATIONS

The limiting factor for current-carrying capacity is the maximum allowable wire temperature. Current rating is, therefore, dependent on the ability of the bundled wire, or wire configuration, to dissipate internal heat losses emanating from the current being transmitted. These losses are determined by cabling design parameters, physical size of conductor. or bundle, and thermal limits and properties of 'the insulation. A heat balance is calculated for the configuration in question.

TABLE 4-1

BUNDLE SHIELD MATERIAL SELECTION CHART

Shield Material	Continuous Operating Temp (Air) Max, °C	Corrosion Resistance		Shielding Effectiveness
		Air Atmosphere	Liquid Atmosphere	
Bare Annealed Copper	105	Poor	Poor	Excellent
Tinned Copper	150	Good	Fair	Good
Silver-plated Copper	200	Good	Good	Excellent
Nickel-plated Copper	350	Excellent	Very Good	Good at audio frequency. Poor at radio frequency.
Nickel-clad Copper	500	Excellent	Very Good	Good at audio frequency. Poor at radio frequency,
Stainless Steel	550	Excellent	Excellent	Poor

TABLE 4–2

CORE AND/OR SHEATH MATERIAL SELECTION FOR BUNDLED WIRES

Material	Temperature Limits, °C		Limitations	Applications
	Maximum	Minimum		
Extruded PVC (Polyvinylchloride)	105	–55	Relatively short temperature span.	Relatively inexpensive. Does not support combustion.
Extruded Nylon	120	–40	Use only where cable core does not exceed 0.250 in. Relatively inflexible. Poor moisture resistance.	Good solvent resistance. Good physical properties. Good abrasion resistance. Good fungus resistance.
Braided Nylon	120	–55	Material wicks moisture. Frays badly when cut or abraded.	Use where flexibility is needed.
Extruded CTFE (Monochlorotrifluoro-ethylene)	135	–55	Relatively inflexible. High cost.	Good solvent resistance. Good physical properties. Does not support combustion. Good abrasion resistance. Good fungus resistance.
Heat-sealed Mylar	135	–55	Flammable.	Good flexibility. Good physical properties. Use where thin walls are required.
Kynar * (Polyvinyladene Fluoride)	135	–55	Poor flexibility. Use only where cable core does not exceed 0.250 in.	Does not support combustion. Good physical properties.

* RTM - Pennsalt *Co.*

TABLE 4–2(CONT.)

Material	Temperature Limits, °C		Limitations	Applications
	Maximum	Minimum		
Extruded FEP (Fluorinatedethylene-propylene)	200	−260	Fair physical properties. Apply only over TFE or FEP. High cost. Only fair abrasion resistance.	Excellent in extreme solvent or temperature environment. Applied over 0.350 in. diameter where extruded fluorocarbon is desired.
Extruded TFE (Tetrafluoroethylene)	260	−260	Apply only over TFE components. Maximum 0.350 in. diameter. High cost.	Excellent in extreme solvent or temperature environment.
TFE Tape Wrap	260	−260	Apply only over TFE components. High cost material. High cost application.	Use over 0.350 in. diameter. Excellent solvent and temperature environment. Particularly good over irregularly shaped core where TFE is needed.
Braided Fiberglas	300	−80	Poor abrasion qualities. Braid will fray when cut. Braid will wick moisture slightly. Poor in solvent environment.	Excellent temperature span.

Note

As more data become accumulated it is suggested that the polyimides, polysulfones and urethanes be investigated for bundled wire sheathing material.

Certain basic qualities of cabled wires have been assumed, as follows, and verified experimentally to be true:

a. The difference in temperature between the ambient and the cabled wires is very large in comparison with the temperature difference between the highest and lowest wire temperature within the bundle. This being true, nominal heat transfer equations apply — heat in equals heat out.

b. The heat transfer is calculated as a combination of free convection and radiation. Conduction will assist in cooling, but is not considered in the calculations because of the variation in parameters along the run throughout, giving a conservative result.

c. The insulating material is important to determine the temperature level above which the insulation will degrade. Calculations, verified by test, show that a 100% change in insulation thermal resistance can result in as low as 5% change in maximum current rating of any given conductor over the entire operating temperature span.

d. The cabling lay-up, or configuration, greatly affects the efficiency of the heat dissipation within the cable.

4—4 DERATING CALCULATIONS

4—4.1 SYMBOLS AND THEIR DEFINITIONS

A = surface area per unit length of a cylinder with diameter equal to D_b, in.^{2}/ft

a = temperature coefficient of resistance per °C @ 25°C

D_b = bundle diameter, in.

D_w = internal diameter of sheath, wrap, or other covering, in.

d = individual wire diameter over insulatidn, in.

F_b = bundling factor, ratio of the allowable heat dissipation of an unsheathed or unwrapped cable, of a given physical size, to the heat dissipation of a cylinder, of equal physical size, under ideal conditions

F_t = temperature factor. Ratio of resistance at temperature t_s to temperature at 25°C

F_w = wrapping factor, ratio of the allowable heat dissipation of a sheathed or wrapped cable, of a given physical size, to the heat dissipation of a cylinder, of the same physical size, under the same environmental conditions

I = maximum allowable current, amp

N = number of conductors of diameter d which can be contained in a bundle of diameter D_b (if all conductors are of diameter d)

n = actual number of conductors of diameter d in the cable

p = absolute air pressure, in. Hg

Q = heat dissipation ability of bundled conductor per unit length, watt/ft

4 = heat dissipation under ideal conditions, watt/in.^{2}

q_c = free convective heat dissipation under ideal conditions, watt/in.^{2}

q_r = radiant heat dissipation under ideal conditions, watt/in.^{2}

R = resistance per unit length @ 25°C, ohm/ft

S = sum of the series resistances per unit length of N cabled conductors @ t_s, ohm/ft

t_a = maximum anticipated ambient temperature, "C

t_s = maximum specified wire temperature, "C

W = ratio of unwrapped cross-sectional area to wrapped cross-sectional area

4—4.2 RATING. PROCEDURE

Following is a general case procedure for current-rating cabled conductors.

a. Ascertain maximum ambient temperature t_a wire will encounter.

b. Specify maximum allowable temperature t_s of cabled conductors; value should be lowest rated maximum temperature for any component.

c. Specify nominal wire diameter d. If more than one size wire, use d_1, d_2, etc.

d. Specify number n of size d conductors used in cable. If more than one wire size, use n_1, n_2, etc.

e. Calculate bundle diameter:

$$D_b = 1.15\sqrt{\sum_{i=1}^{j} n_i(d_i)^2}$$

f. Determine the heat dissipation under ideal conditions:

$$q = q_c + q_r$$

where q_c and q_r are obtained from Fig. 4–1 and Fig. 4–2, respectively.

For common values of the variables, a table such as Table 4–3 may be derived.

g. Calculate the surface area per foot length of cylinder of diameter D_b:

$$A = 37.7\, D_b, \text{ in.}^2/\text{ft}$$

h. Calculate the heat dissipation ability of the bundled conductors:

$$Q = A \times q, \text{ watt/ft}$$

i. Calculate the number of conductors of size d that could be circumscribed by a circle of diameter D_b:

$$N = 0.75\left(\frac{D_b}{d}\right)^2 \quad \text{(round to the nearest integer)}$$

j. Calculate the temperature factor:

$$F_t = 1 + a(t_s - 25)$$

For often used values of t_s and a, a table such as Table 4–4 may be calculated.

k. Specify the resistance per foot length @ 25°C R for each wire type and size.

l. Calculate the sum of the resistance per foot length for each wire type and size, as if the cable contained only that type, from:

$$S = N \times F_t \times R$$

m. Determine the bundling factor F_{b_n} from Fig. 4–4. For often used values of t_s, a simpler figure such as Fig. 4–2 may be constructed.

(1) Where the bundled or cabled conductors are properly sheathed, using a close fitting extruded sheath or tightly applied wrap, use the sheath outside diameter for D_b in steps f and g, and F_w = 1.

(2) For unsheathed bundles F_w = 1, also.

(3) When the sheath is loose fitting, such as a rigid pipe or zipper tubing, the current must be further derated with the use of a calculated F_w.

n. For loosely wrapped or sheathed cables, calculate the cross-sectional area ratio of unwrapped to wrapped cable.

$$W = \frac{D_b^2}{D_w^2}$$

where D_w is the inner diameter of the wrap, or outer diameter of the cabled conductors.

o. Determine the wrapping factor F_w from Fig. 4–3 (F_w = 1 for unwrapped cables).

p. Compute the current rating for each wire size.

$$I = \sqrt{(F_w)(F_b)(Q/S)}$$

4–4.3 USAGE – CURRENT RATING PROCEDURE

The two more common uses of this current rating procedure are:

1. Calculating a safe current rating for any given bundle of conductors.

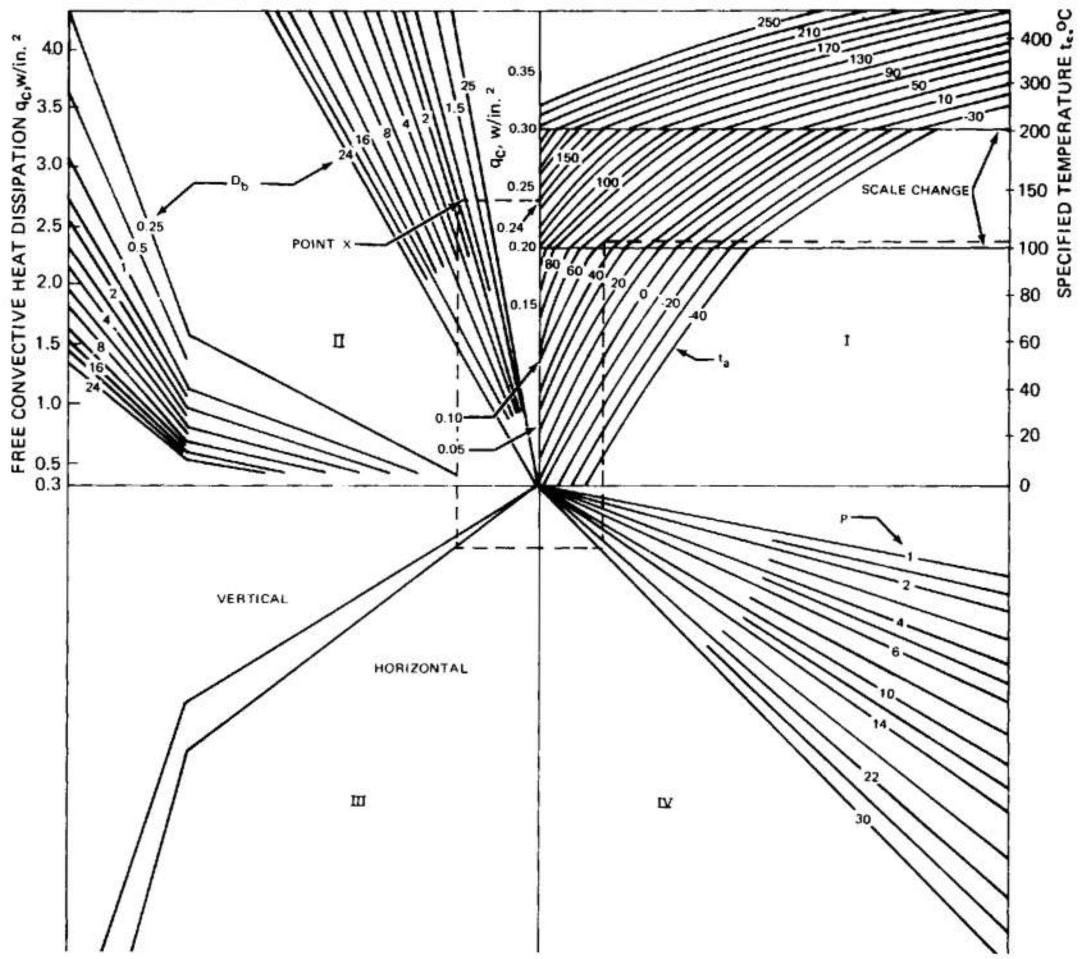
2. Determining the minimum wire size for the required current ratings.

The following examples typify these applications and illustrate the use of the procedure and graphs.

EXAMPLE NO. 1: Determine the current ratings for each of three wire types in a single bundle.

1. Given:

a. 55 conductors, cabled and sheathed.



Point X may be in the left or right family of curves in quadrant. The value of q_c is read from the left or right hand scales, respectively. Dashed lines indicate sample calculation for Table 4–5.

Figure 4–7. Calculation of Free Convective Heat Dissipation

b. Bundled core diameter is **1.79** in., and the bundle is enclosed in a zipper tubing having an ID of 2 in.

c. Bundle is placed in horizontal attitude.

d. Ambient temperature is 50°C

e. The three types of wire involved are:

(1) Ten (10) SHFS – 9 per MIL-C-915

(2) Fifteen (15) D – 6 per MIL-W-16878

(3) Thirty (30) E – 10 per MIL-W-16878

2. Data:

a. The three wires and jackets have the following maximum temperature ratings:

(1) Type SHFS Wire – 125°C

(2) Type D Wire – 105°C

(3) Type E Wire – 200°C

(4) Jacket Type – 105°C

b. Since 105°C is maximum for type D and jacket, this is the maximum temperature the bundle is allowed to reach. Therefore, t_s = 105°C.

c. The maximum DC resistances for the three wire types at 25°C are:

(1) Type SHFS – 9 = 1.25 x 10^{-3} ohm/ft

(2) Type D – 6 = 0.444 x 10^{-3} ohm/ft

(3) Type E – 10 = 1.24 x 10^{-3} ohm/ft

d. The nominal diameters for the three wire types are:

(1) Type SHFS – 9 = 0.240 in.

(2) Type D – 6 = 0.290 in.

(3) Type E – 10 = 0.137 in.

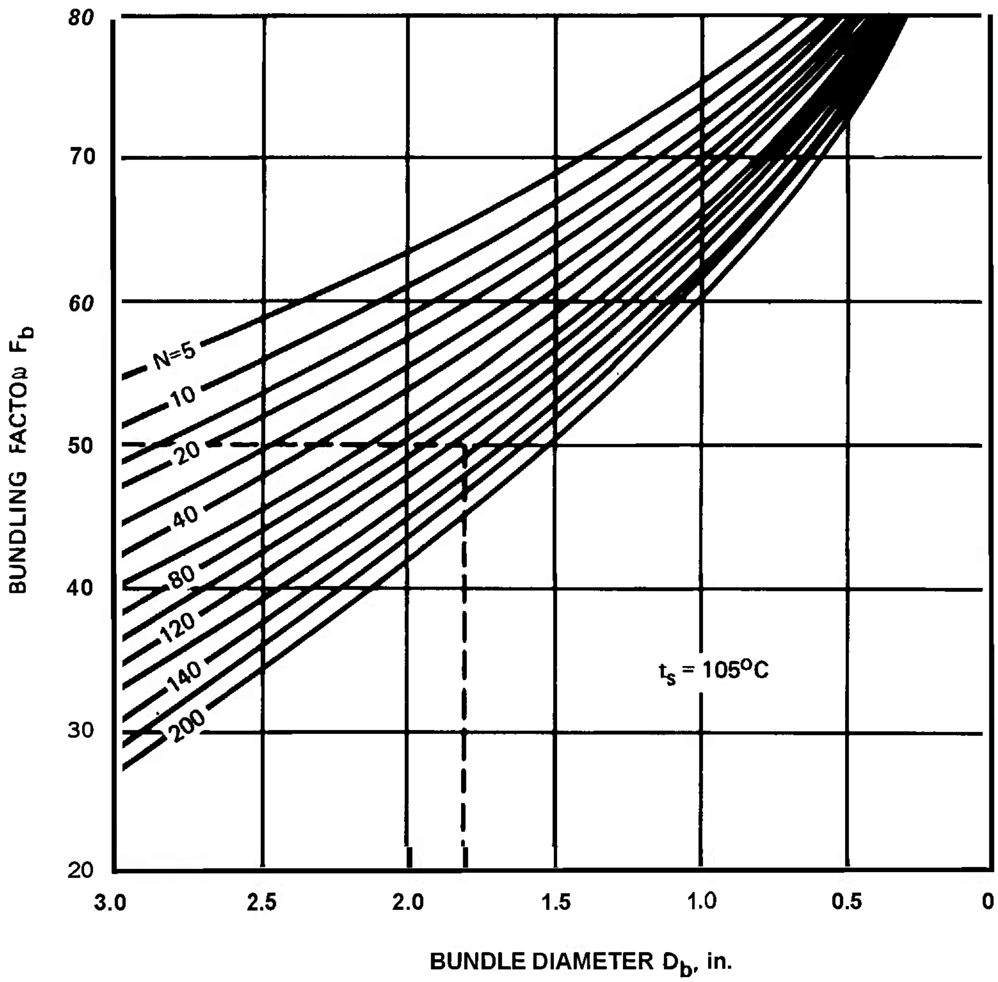


Figure 4–2. Calculation of Bundling Factor for 105° C. Dashed lines indicate sample calculation for Table 4–5.

TABLE 4-3

VALUES OF IDEAL HEAT DISSIPATION FOR HORIZONTAL CABLE AT STANDARD ATMOSPHERIC AIR PRESSURE

Bundle Diameter D_b, in.	Heat Dissipation q, watt/in.^{2}					
	t_s = 105°C		t_s = 125°C		t_s = 200°C	
	t_a = 50°C	t_a = 70°C	t_a = 50°C	t_a = 70°C	t_a = 50°C	t_a = 70°C
0.25	0.73	0.44	1.10	0.80	2.75	2.42
0.50	0.67	0.41	1.01	0.74	2.55	2.26
1.00	0.62	0.38	0.93	0.69	2.37	2.10
1.50	0.60	0.37	0.89	0.67	2.29	2.03
2.00	0.58	0.36	0.87	0.65	2.22	1.98
3.00	0.56	0.35	0.84	0.63	2.15	1.92

Note

Values obtained using Figs. 4-1 and 4-2.

TABLE 4–4

TEMPERATURE FACTORS (DERATING)

Specified Temperature	Temperature Factor F_t	
t_s, °C	Copper a = 0.00385	Aluminum a = 0.00396
105	1.308	1.317
125	1.385	1.396
200	1.674	1.693

3. Solution: Ratings are worked out in Table 4–5.

a. Steps a through e are accomplished by reference to data and given information.

b. Step f may be obtained either from Figs.4–1 and 4–5 or from Table 4–3. The value of q_c is obtained in 5 steps, as shown by the dashed lines in Fig. 4–1 as follows:

(1) Quadrant I: Follow the 105°C abscissa left to the curve representing an ambient of 50°C.

(2) Quadrant IV: Proceed down to the line representing 30 in. Hg absolute air pressure.

(3) Quadrant III: Proceed left to the line representing horizontal attitude.

(4) Quadrant II:

(a) Proceed up to an interpolated line representing a 1.79 in. bundled diameter.

(b) Then, read $q_c = 0.24$ watt/in.^{2}, from the right hand scale.

c. Step j may be either calculated or interpolated from Table 4–4.

d. Step m may be obtained from either Fig. 4–3 or Fig. 4–4. The value of F_b is obtained in 4 steps, as shown by the dashed lines in Fig. 4–4, as follows (the 127 conductor case is used to illustrate the procedure):

(1) Follow the 105°C ordinate up to an interpolated curve for 127 conductors.

(2) Proceed to the right to the reference line representing a 2-in. cabled diameter (Note: Chart is based on this 2-in. ID).

(3) Draw a curve parallel to the 105°C curve, to a diameter of 1.79 in.

(4) Read the value of the bundle factor, $F_b = 0.50$, from the vertical scale.

The calculation of the current rating for given wire sizes, but using a close fitting sheath or wrapping of 2.20 in. overall diameter, is now performed. From Table 4–6, it can easily be seen that the use of a close fitting sheath will noticeably increase the current-carrying capabilities of a given conductor or conductor group over that same conductor or conductor group utilizing a loose fitting sheath such as zipper tubing.

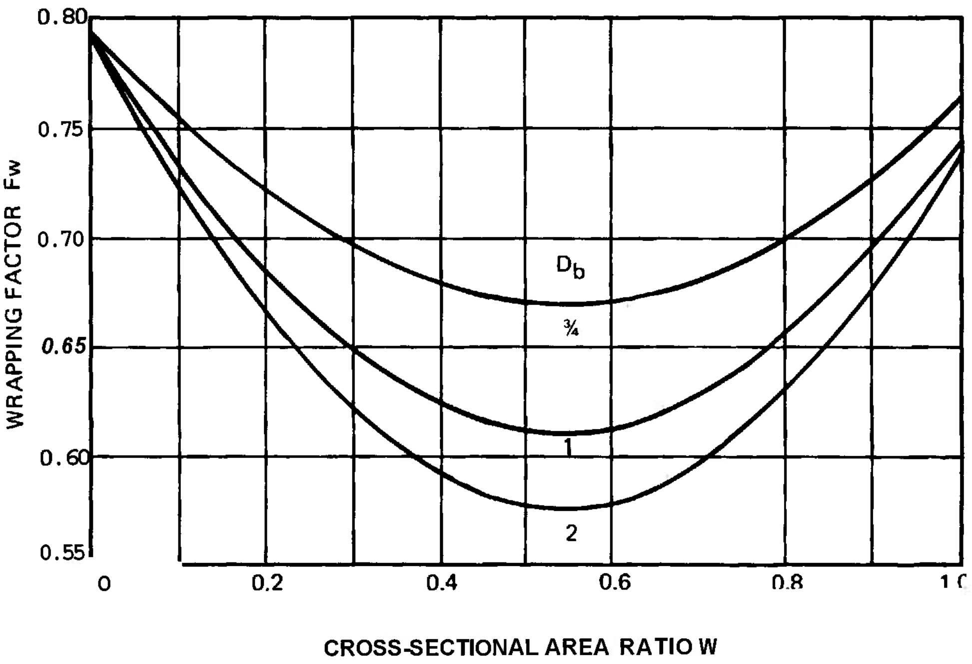


Figure 4–3. Wrapping Factor vs Ratio of Unwrapped to Wrapped Cross-sectional Area for Typical Bundle Diameters.

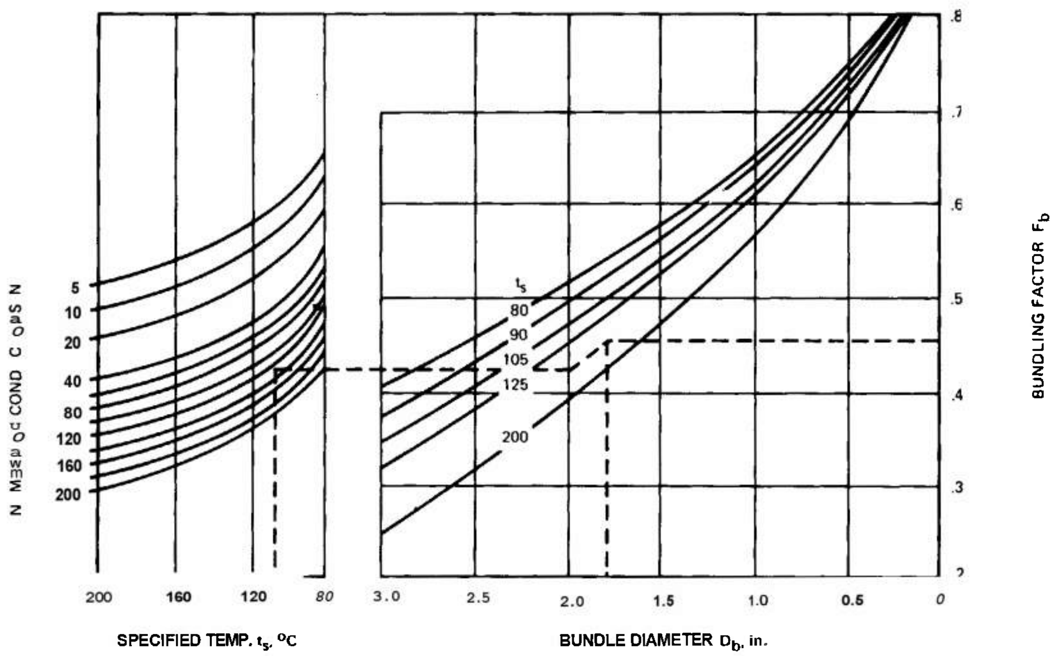


Figure 4–4. Calculation of Bundling Factor. Dashed lines indicate sample calculation for Table 4–5.

TABLE 4-5

CABLED WIRE CURRENT RATING—EXAMPLE NO. 1

a. $t_a = 50^\circ\text{C}$

b. $t_s = 105^\circ\text{C}$

c. $d_1 = 0.24$ in. $\quad d_2 = 0.29$ in. $\quad d_3 = 0.137$ in.

d. $n_1 = 10 \quad n_2 = 15 \quad n_3 = 30$

e. $D_b = 1.15\sqrt{\sum_{i=1}^{n} n_i(d_i)^2} = 1.15\sqrt{10(0.24)^2 + 15(0.29)^2 + 30(0.137)^2}$

$= 1.15\sqrt{0.576 + 1.2615 \text{ t } 0.5631} = 1.15\sqrt{2.4006} = 1.15\,(1.5494)$

$= 1.782$ in.

f. $4 = q_c \text{ t } q_r = 0.24 + 0.35 = 0.59$ watt/in.^{2}

g. $A = 37.7\,(D_b) = 37.7\,(1.782) = 67.18$ in.^{2}/ft

h. $Q = A(q) = 67.18\,(0.59) = 39.64$ watt/ft

i. $N_1 = 0.75\,(D_b/d_1)^2 = 0.75\,(1.782/0.24)^2 = 41$ (to nearest integer)

$N_2 = 0.75\,(D_b/d_2)^2 = 0.75\,(1.782/0.29)^2 = 28$ (to nearest integer)

$N_3 = 0.75\,(D_b/d_3)^2 = 0.75\,(1.782/0.137)^2 = 127$ (to nearest integer)

j. $F_t = 1 + a(t_s - 25) = 1 + 0.00385\,(105 - 25) = 1 + 0.3080 = 1.308$

k. $R_1 = 1.25 \times 10^{-3}$ ohm/ft $\quad R_2 = 0.444 \times 10^{-3}$ ohm/ft

$R_3 = 1.24 \times 10^{-3}$ ohm/ft

1. $S_1 = N_1(F_t)(R_1) = 41\,(1.308)\,(1.25 \times 10^{-3}) = 0.067$ ohm/ft

$S_2 = N_2(F_t)(R_2) = 28\,(1.308)\,(0.444 \times 10^{-3}) = 0.01626$ ohm/ft

$S_3 = N_3(F_t)(R_3) = 127\,(1.308)\,(1.24 \times 10^{-3}) = 0.206$ ohm/ft

m. $F_{b_1} = 0.56 \quad F_{b_2} = 0.59 \quad F_{b_3} = 0.50$

n. $W = (D_b/D_w)^2 = (1.782/2.0)^2 = 0.794$

o. $F_w = 0.63$

TABLE 4-5 (CONT.)

p. $I_1 = \sqrt{(F_w)(F_{b_1})(Q/S_1)} = \sqrt{(0.63)(0.56)(39.64/0.067)}$

$= \sqrt{(0.63)(0.56)(591.642)} = \sqrt{208.731} = 14.45$ amp

$I_2 = \sqrt{(F_w)(F_{b_2})(Q/S_2)} = \sqrt{(0.63)(0.59)(39.64/0.01626)}$

$= \sqrt{(0.63)(0.59)(2439.884)} = \sqrt{906.162} = 30.10$ amp

$I_3 = \sqrt{(F_w)(F_{b_3})(Q/S_3)} = \sqrt{(0.63)(0.50)(39.64/0.206)}$

$= \sqrt{(0.63)(0.50)(192.427)} = \sqrt{60.615} = 7.78$ amp

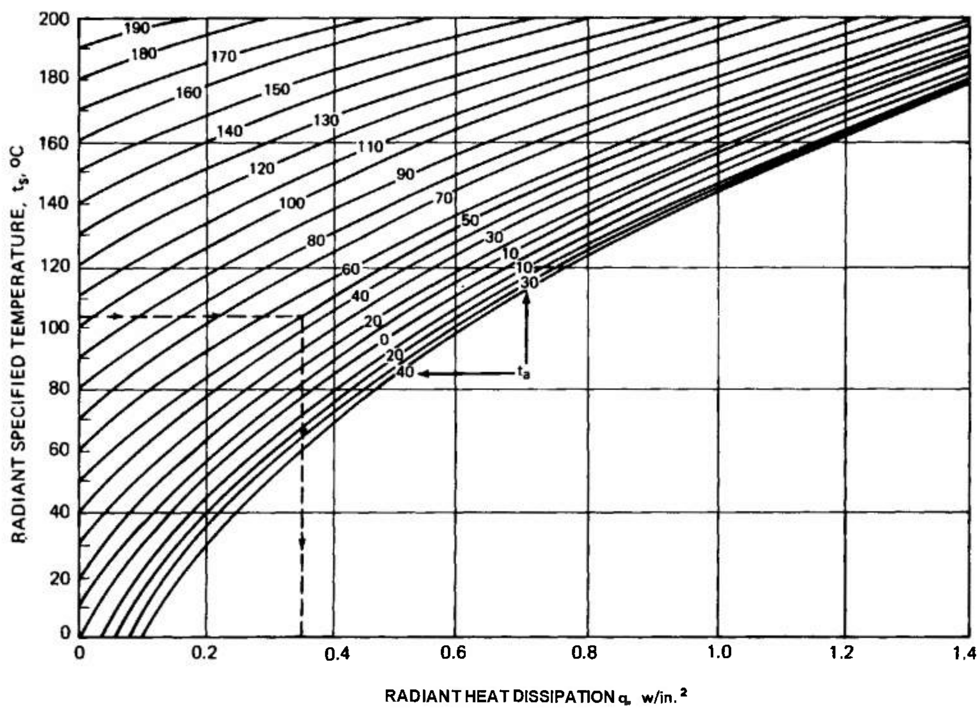


Figure 4-5. Calculation of Radiant Heat Dissipation. Dashed lines indicate sample calculation for Table 4-5.

TABLE 4–6

BUNDLED WIRE CURRENT RATING

a. t_a = 50°C

b. t_s = 105°C

c. d_1 = 0.24 in. d_2 = 0.29 in. d_3 = 0.137 in.

d. n_1 = 10 n_2 = 15 n_3 = 30

e. $D_b = 1.15\sqrt{\sum_{i=1}^{j} n_i(d_i)^2} = 1.15\sqrt{10(0.24)^2 + 15(0.29)^2 + 30(0.137)^2}$

$= 1.15\sqrt{0.576 + 1.2615 + 0.5631} = 1.15\sqrt{2.4006} = 1.15(1.5494)$

$= 1.782$ in.

f. $q = q_c + q_r = 0.22 + 0.35 = 0.57$ watt/in.²

g. $A = 37.7\,(D_b) = 37.7\,(2.2) = 82.94$ in.²/ft

h. $Q = A(q) = (82.94)\,(0.57) = 47.276$ watt/ft

i. $N_1 = 0.75\,(D_b/d_1)^2 = 0.75\,(1.782/0.24)^2 = 0.75\,(55.13) = 41$ (to nearest integer)

$N_2 = 0.75\,(D_b/d_2)^2 = 0.75\,(1.782/0.29)^2 = 0.75\,(37.759) = 28$ (to nearest integer)

$N_3 = 0.75\,(D_b/d_3)^2 = 0.75\,(1.782/0.137)^2 = 0.75\,(169.182) = 127$ (to nearest integer)

j. $F_t = 1 + a(t_s - 25) = 1 + 0.00385\,(105 - 25) = 1 + 0.3080 = 1.308$

k. $R_1 = 1.25 \times 10^{-3}$ ohm/ft $R_2 = 0.444 \times 10^{-3}$ ohm/ft

$R_3 = 1.24 \times 10^{-3}$ ohm/ft

l. $S_1 = N_1\,(F_t)\,(R_1) = (41)\,(1.308)\,(1.25 \times 10^{-3}) = 0.067$ ohm/ft

$S_2 = N_2\,(F_t)\,(R_2) = (28)\,(1.308)\,(0.444 \times 10^{-3}) = 0.0163$ ohm/ft

$S_3 = N_3\,(F_t)\,(R_3) = (127)\,(1.308)\,(1.24 \times 10^{-3}) = 0.206$ ohm/ft

m. F_{b_1} = 0.56 F_{b_2} = 0.59 F_{b_3} = 0.50

n. W (unnecessary for tight sheathing)

o. F_w = **1.0**

TABLE 4–6 (CONT.)

p. $I_1 = \sqrt{(F_w)(F_{b_1})(Q/S_1)} = \sqrt{(1)(0.56)(47.276/0.067)}$

$= \sqrt{(1)(0.56)(705.612)} = \sqrt{395.143} = 19.88$ amp

$I_2 = \sqrt{(F_w)(F_{b_2})(Q/S_2)} = \sqrt{(1)(0.59)(47.276/0.0163)}$

$= \sqrt{(1)(0.59)(2900.368)} = \sqrt{1711.217} = 41.37$ amp

$I_3 = \sqrt{(F_w)(F_{b_3})(Q/S_3)} = \sqrt{(1)(0.50)(47.276/0.206)}$

$= \sqrt{(1)(0.50)(229.495)} = \sqrt{114.748} = 10.71$ amp

EXAMPLE NO. 2: Determine a minimum wire size for three different current ratings.

1. Given:

a. Current Ratings:

(1) Twelve (12) currents of six (6) amperes each.

(2) Seven (7) currents of fifteen (15) amperes each.

(3) Ten (10) currents of nine (9) amperes each.

b. Ambient temperature of 70°C.

c. Conductors are tightly tape wrapped.

d. Minimum voltage ratings of 600 volts rms.

e. Type E wire per MIL-W-16878, silver-plated copper (t_s = 200°C).

2. Solution:

a. Use an inverse current density of 300 circular mils per ampere for initial conditions. Therefore:

(1) For a 6-ampere current, a conductor with 1800 circular mils is needed; try Type E, #16 AWG.

(2) For a 15-amyere current a conductor with 4500 circular mils is required; try Type E, #12 AWG.

(3) For a 9-ampere current, a conductor with 2700 circular mils is required; try Type E, #14 AWG.

Observe from Table 4–7 that the current ratings are significantly higher than the requirements. We must change the conductor sizes accordingly.

b. Therefore, try:

(1) Type E, #18 AWG (for 6 amp)

(2) Type E, #14 AWG (for 15 amp)

(3) Type E, #16 AWG (for 9 amp).

Observe from Table 4–8 that these are satisfactory sizes from the performance figures obtained.

c. Observe from Table 4–9 that wire size is too small using Type E wire sizes #20 AWG (6 amp), #14 AWG (15 amp), and #16 AWG (9 amp).

TABLE 4–7

CABLED WIRE CURRENT RATING — EXAMPLE NO. 2 (FIRST CALCULATION) (#16 AWG FOR 6 AMP, #12 AWG FOR 15 AMP, #14 AWG FOR 9 AMP)

a. t_a = 70°C

b. t_s = 200°C

c. d_1 = 0.080 in. d_2 = 0.113 in. d_3 = 0.094 in.

d. n_1 = 12 n_2 = 7 n_3 = 10

e. $D_b = 1.15\sqrt{\sum_{i=1}^{j} n_i(d_i)^2} = 1.15\sqrt{12\,(0.080)^2 + 7\,(0.113)^2 + 10\,(0.094)^2}$

$= 1.15\sqrt{0.0768 + 0.0894 + 0.0884} = 1.15\sqrt{0.2546}$

$= 1.15\,(0.5046) = 0.5803$ in.

f. $q = q_c + q_r = 0.90 + 1.33 = 2.23$ watt/in.^{2}

g. $A = 37.7\,(D_b) = 37.7\,(0.5803) = 21.877$ in.^{2}/ft

h. $Q = A(q) = 21.877\,(2.23) = 48.786$ watt/ft

i. $N_1 = 0.75\,(D_b/d_1)^2 = 0.75\,(0.5803/0.080)^2 = 0.75\,(52.618) = 39$ (to nearest integer)

$N_2 = 0.75\,(D_b/d_2)^2 = 0.75\,(0.5803/0.113)^2 = 0.75\,(26.372) = 20$ (to nearest integer)

$N_3 = 0.75\,(D_b/d_3)^2 = 0.75\,(0.5803/0.094)^2 = 0.75\,(38.111) = 29$ (to nearest integer)

j. $F_t = 1 + a(t_s - 25) = 1 + 0.00385\,(200 - 25) = 1.674$

k. $R_1 = 4.85 \times 10^{-3}$ ohm/ft $R_2 = 1.92 \times 10^{-3}$ ohm/ft

$R_3 = 3.05 \times 10^{-3}$ ohm/ft

l. $S_1 = N_1\,(F_t)\,(R_1) = (39)\,(1.674)\,(4.85 \times 10^{-3}) = 0.317$ ohm/ft

$S_2 = N_2\,(F_t)\,(R_2) = (20)\,(1.674)\,(1.92 \times 10^{-3}) = 0.064$ ohm/ft

$S_3 = N_3\,(F_t)\,(R_3) = (29)\,(1.674)\,(3.05 \times 10^{-3}) = 0.148$ ohm/ft

m. F_{b_1} = 0.73 F_{b_2} = 0.74 F_{b_3} = 0.73

n. W (Not Applicable)

o. F_w = 1.0

TABLE 4–7 (CONT.)

p. $I_1 = \sqrt{(F_w)(F_{b_1})(Q/S_1)} = \sqrt{(1.0)(0.73)(48.786/0.317)}$

$= \sqrt{(1.0)(0.73)(153.899)} = \sqrt{112.346} = 10.60$ amp

$I_2 = \sqrt{(F_w)(F_{b_2})(Q/S_2)} = \sqrt{(1.0)(0.74)(48.786/0.064)}$

$= \sqrt{(1.0)(0.74)(762.281)} = \sqrt{564.088} = 23.75$ amp

$I_3 = \sqrt{(F_w)(F_{b_3})(Q/S_3)} = \sqrt{(1.0)(0.73)(48.786/0.148)}$

$= \sqrt{(1.0)(0.73)(329.635)} = \sqrt{240.634} = 15.51$ amp

TABLE 4–8

CABLED WIRE CURRENT RATING – EXAMPLE NO. 2 (SECOND CALCULATION) (#18 AWG FOR 6 AMP, #14 AWG FOR 15 AMP, #16 AWG FOR 9 AMP)

a. $t_a = 70°\text{C}$

b. $t_s = 200°\text{C}$

c. $d_1 = 0.068$ in. $d_2 = 0.094$ in. $d_3 = 0.080$ in.

d. $n_1 = 12$ $n_2 = 7$ $n_3 = 10$

e. $D_b = 1.15\sqrt{\sum_{i=1}^{i} n_i(d_i)^2} = 1.15\sqrt{12(0.068)^2 + 7(0.094)^2 + 10(0.080)^2}$

$= 1.15\sqrt{(0.055) + (0.062) + (0.064)} = 1.15\sqrt{0.181}$

$= 1.15(0.4254) = 0.489$ in.

f. $4 = q_c + q_r = 0.90 + 1.36 = 2.26$ watt/in.^{2}

g. $A = 37.7(D_b) = 37.7(0.489) = 18.435$ in.^{2}/ft

h. $Q = A(4) = 18.435(2.26) = 41.663$ watt/ft

i. $N_1 = 0.75(D_b/d_1)^2 = 0.75(0.489/0.068)^2 = 0.75(51.713) = 39$ (to nearest integer)

$N_2 = 0.75(D_b/d_2)^2 = 0.75(0.489/0.094)^2 = 0.75(27.062) = 20$ (to nearest integer)

$N_3 = 0.75(D_b/d_3)^2 = 0.75(0.489/0.080)^2 = 0.75(37.363) = 28$ (to nearest integer)

j. $F_t = 1 + a(t_s - 25) = 1 + 0.00385(200 - 25) = 1.674$

k. $R_1 = 6.57 \times 10^{-3}$ ohm/ft $R_2 = 3.05 \times 10^{-3}$ ohm/ft

$R_3 = 4.85 \times 10^{-3}$ ohm/ft

TABLE 4–8 (CONT.)

l. $S_1 = N_1 (F_t)(R_1) = (39)(1.674)(6.57 \times 10^{-3}) = 0.429$ ohm/ft

$S_2 = N_2 (F_t)(R_2) = (20)(1.674)(3.05 \times 10^{-3}) = 0.102$ ohm/ft

$S_3 = N_3 (F_t)(R_3) = (28)(1.674)(4.85 \times 10^{-3}) = 0.227$ ohm/ft

m. $F_{b_1} = 0.75 \qquad F_{b_2} = 0.75 \qquad F_{b_3} = 0.75$

n. W (Not Applicable)

o. $F_w = 1.0$

p. $I_1 = \sqrt{(F_w)(F_{b_1})(Q/S_1)} = \sqrt{(1.0)(0.75)(41.663/0.429)}$

$= \sqrt{(1.0)(0.75)(97.117)} = \sqrt{72.838} = 8.53$ amp

$I_2 = \sqrt{(F_w)(F_{b_2})(Q/S_2)} = \sqrt{(1.0)(0.75)(41.663/0.102)}$

$= \sqrt{(1.0)(0.75)(408.461)} = \sqrt{306.346} = 17.5$ amp

$I_3 = \sqrt{(F_w)(F_{b_3})(Q/S_3)} = \sqrt{(1.0)(0.75)(41.663/0.227)}$

$= \sqrt{(1.0)(0.75)(183.537)} = \sqrt{137.653} = 11.73$ amp

TABLE 4–9

CABLED WIRE CURRENT RATING – EXAMPLE NO. 2 (THIRD CALCULATION) (#20 AWG FOR 6 AMP, #14 AWG FOR 15 AMP, #16 AWG FOR 9 AMP)

a. $t_a = 70°C$

b. $t_s = 200°C$

c. $d_1 = 0.058$ in. $\qquad d_2 = 0.094$ in. $\qquad d_3 = 0.080$ in.

d. $n_1 = 12 \qquad n_2 = 7 \qquad n_3 = 10$

e. $D_b = 1.15\sqrt{\sum_{i=1}^{j} n_i (d_i)^2} = 1.15\sqrt{12(0.058)^2 + 7(0.094)^2 + 10(0.080)^2}$

$= 1.15\sqrt{0.040 + 0.062 + 0.064} = 1.15\sqrt{0.166} = 1.15(0.4075)$

$= 0.469$ in.

TABLE 4–9 (CONT.)

f. $q = q_c + q_r = 0.94 + 1.34 = 2.28$ watt/in.^{2}

g. $A = 37.7\ (D_b) = 37.7\ (0.469) = 17.681$ in.^{2}/ft

h. $Q = A(q) = 17.681\ (2.28) = 40.313$ watt/ft

i. $N_1 = 0.75\ (D_b/d_1)^2 = 0.75\ (0.469/0.058)^2 = 0.75\ (65.387) = 49$ (to nearest integer)

$N_2 = 0.75\ (D_b/d_2)^2 = 0.75\ (0.469/0.094)^2 = 0.75\ (24.894) = 19$ (to nearest integer)

$N_3 = 0.75\ (D_b d_3)^2 = 0.75\ (0.469/0.080)^2 = 0.75\ (34.369) = 26$ (to nearest integer)

j. $F_t = 1 + a(t_s - 25) = 1 + 0.00385\ (200 - 25) = 1.674$

k. $R_1 = 10.5 \times 10^{-3}$ ohm/ft $\qquad R_2 = 3.05 \times 10^{-3}$ ohm/ft

$R_3 = 4.85 \times 10^{-3}$ ohm/ft

l. $S_1 = (N_1)\ (F_t)\ (R_1) = (49)\ (1.674)\ (10.5 \times 10^{-3}) = 0.861$ ohm/ft

$S_2 = (N_2)\ (F_t)\ (R_2) = (19)\ (1.674)\ (3.05 \times 10^{-3}) = 0.097$ ohm/ft

$S_3 = (N_3)\ (F_t)(R_3) = (26)\ (1.674)\ (4.85 \times 10^{-3}) = 0.211$ ohm/ft

m. $F_{b_1} = 0.74 \qquad F_{b_2} = 0.84 \qquad F_{b_3} = 0.82$

n. $W = (D_b/D_w)^2$ = Not Applicable

o. $F_w = 1.0$

p. $I_1 = \sqrt{(F_w)\ (F_{b_1})\ (Q/S_1)} = \sqrt{(1)\ (0.74)\ (40.313/0.861)}$

$= \sqrt{(1)\ (0.74)\ (46.821)} = \sqrt{34.648} = 5.89$ amp

$I_2 = \sqrt{(F_w)\ (F_{b_2})\ (Q/S_2)} = \sqrt{(1)\ (0.84)\ (40.313/0.097)}$

$= \sqrt{(1)\ (0.84)\ (415.598)} = \sqrt{349.102} = 18.68$ amp

$I_3 = \sqrt{(F_w)\ (F_{b_3})\ (Q/S_3)} = \sqrt{(1)\ (0.82)\ (40.313/0.211)}$

$= \sqrt{(1)\ (0.82)\ (191.057)} = \sqrt{156.666} = 12.51$ amp

4–5 RIBBON CABLE

4–5.1 INTRODUCTION

Ribbon cable is a construction where a number of individually insulated conductors are bonded together in a flat parallel cable. This construction can be seen in Fig. 4–6.

Numbers of individual constructions – including single insulated wires, and shielded and jacketed wires – may be manufactured into a ribbon-type construction. The only criterion is that the two materials to be joined must be bondable.

4–5.2 USAGE

A ribbon-type construction is generally designed when a multiconductor construction is to be located in a limited space or where great flexibility in one plane is needed and no flexibility is needed in the perpendicular plane. A good example is in the "drawer" or accessible front of a rack panel where the "drawer" must be continually opened and closed for repair and adjustment. A ribbon cable is ideal for a loop connection from drawer to complex because of its flexibility and flatness.

4–5.3 CONSTRUCTION

There are five basic ways to construct a ribbon-type cable after the individual constructions, or insulated conductors, have been selected.

4–5.3.1 Adhesive Bonding

Using individually insulated conductors, an adhesive is applied to the bonding area of the insulation and the two insulations glued together within a guide or closing die. The most common materials used in this type construction are polyvinylchloride or nylon. Extreme care must be used in the selection of the adhesive because most adhesives are solvents which leech out the plasticizer, thus greatly lowering the electrical properties and tending to make the insulation brittle.

4–5.3.2 Thermal Fusina

Thermal fusing also uses individually insulated conductors, and by the application of heat to the insulation' the components are bonded. The bonding edges of the insulation are heated and the wires are passed through a closing die which fuses the insulation together under pressure. The most common materials used in this type construction are polyvinylchloride and polyethylene. Care must be exercised here to not overheat the insulation – allowing the conductors to cut-through the soft, heated material and short circuit. Insufficient heat will cause poor bonding with resultant separation.

4–5.3.3 Direct Extrusion

By use of a number of bare conductors and the use of a multi-die, the ribbon cable may be actually extruded as one integral unit. Nearly any type insulation may be used for this type construction. This is by far the best way to produce ribbon cable, but the tooling is very expensive. This method, therefore, allows a smaller flexibility in the selection of conductors without retooling, while still maintaining a reasonable cost.

4–5.3.4 Envelope

With Teflon*, an "envelope" type construction is usually employed since it cannot be cemented or melted. A number of individual Teflon insulated wires are run parallel through a very carefully matched roll calendar which encloses them in a thin Teflon film, or "envelope", formed from two Teflon tapes introduced onto the rolls, between the rolls and the conductors. This technique is also very costly and inflexible because of the tooling involved, but is the only way of producing a high quality Teflon ribbon cable.

4–5.3.5 Braided or Woven

By modifying conventional braiding machines, a flat fabric braid may be woven about parallel conductors to hold them in place. While the product, as manufactured, can be made to be presentable, it is very difficult to install without severe fraying and resultant poor appearance. The fabric braids will also wick moisture and other fluids. Fabrics used include cotton, nylon, glass, and Dacron*.

4–6 COMPARISON – RIBBON CABLE VS ROUND MULTICONDUCTOR CABLE

4–6.1 ADVANTAGES – RIBBON CABLE

a. Can be placed through narrow, rectangular openings where round cable might not fit.

* RTM duPont.

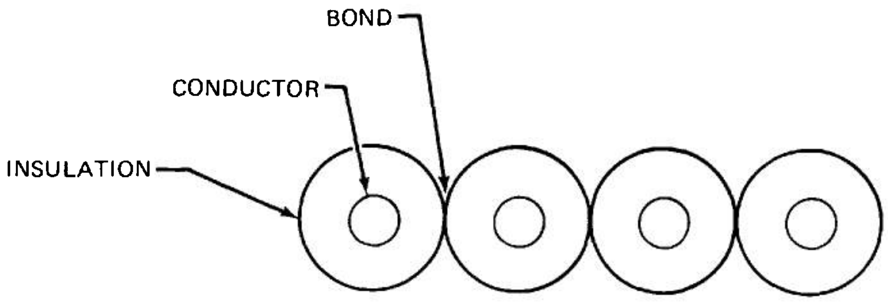


Figure 4–6. Bonded Ribbon Cable Configuration

b. Greater flexibility in one plane.

c. High current rating.

d. More precise and fixed capacitance between conductors.

4–6.2 DISADVANTAGES – RIBBON CABLE

a. Flexible in only one plane.

b. More delicate. Careful handling is required to prevent separations, and other inherent problems.

c. Much less flexible for design. To be practical, conductors used in a given cable must be nearly the same physical size. There are practical limitations to the number of conductors in a given cable (approximately 3 in. in width in a single layer).

d. For the same mechanical protection the ribbon cable may be larger and heavier. All shielded constructions must be jacketed, except woven types.

e. Adhesive bonding may degrade insulation.

f. Heat bonding may reduce dielectric strength.

g. The direct extrusion and envelope techniques are inflexible and expensive for short runs.

4–7 TAPE CABLE

4–7.1 INTRODUCTION

Tape cable is similar to ribbon cable, except the conductors are usually flat, metallic strips covered with a thin wall of insulating material. The conductors are not individually insulated first.

4–7.2 USAGE

The usage is for the same applications as ribbon cable, except the tape cable is much lighter in weight for the same current ratings as compared to conventional cables.

4–7.3 FLAT WIRE

An increasing demand for smaller and lighter electronic component systems has resulted in the development of a cable utilizing a flat flexible copper conductor sandwiched between plastic film. The flat wire cable possesses some unique qualities; among them are:

a. Two-dimensional cable harnessing can be achieved with flat wire, parallel conductor, cables which are compatible with some of the newly developed microminiaturized systems and techniques.

b. A flat wire cable construction can be bonded to the equipment chassis or wall to secure the cable harness. This, in effect, achieves efficient shielding and/or heat dissipation at the expense of high capacitance per foot.

c. The precise geometry of flat wire cable requires greater circuit design accuracy due to the specifically established capacitance between conductors and/or ground.

d. Corrugating a flat conductor cable can provide an extremely flexible harness for drawer-type applications.

4—7.3.1 Constructional Factors

The laminated, flat conductor cable has parallel, flat, metallic, specifically spaced, conductors, laminated between two sheets of insulating material, which are either heat-sealable or bondable to each other by adhesive. This configuration is shown in Fig. 4—7.

4—7.3.2 Construction

Flat copper, or plated metallic, ribbons varying from 0.001 in. to 0.003 in. in thickness and 0.010 in. to 0.050 in. in width, are laid parallel between two sheets of plastic film, usually between 0.002 in. and 0.005 in. thick, the plastic film being heat-sealed or cemented together around and between the conductors. Insulation material may be polyethyleneteraphthalate (Mylar*), polyimide (Kapton*), Teflon", FEP, or polychlorotrifluoroethylene(CTFE).

These cables have the same advantages as ribbon cable plus being smaller in size, lighter in weight, and more flexible.

4—7.3.3 Disadvantages—Flat Wire

a. Flexible in only one plane.

b. Solid conductor is susceptible to nicks and breakage.

c. For some methods of termination special precision tooling is required to strip the chosen configuration, making field repairs difficult.

d. Shielded flat cables lose a great deal of their flex characteristics, due to shield breakage and shield penetration of insulation, after repeated flexing. This is particularly true in the straight flexure rather than the roll flexure.

e. The difficulty in manufacturing to maintain the stringent conductor spacing tolerances required.

4—7.4 CONSTRUCTIONAL CONSIDERATIONS

The cable can be fabricated as described in any desired width and reasonably long lengths, utilizing as many conductors as is physically feasible. The cable is normally manufactured in one-half inch increments, with conductor center-to-center spacing in increments of 25 mils (i.e., 25-50-75-100-150-etc.). This spacing controls the number of conductors contained within a specified cable width.

Of major concern in the manufacture of flat laminated cables is the physical dimensional stability of the conductor spacing throughout any given length of wire, and/or wire taken from different manufacturing runs. There are many reasons for this concern, among them are:

a. Connector designs demand a high degree of dimensional integrity.

b. Electrical parameters depend on equal spacings for repeated values.

Flat laminated cables may also be of a shielded construction. The shielding normally consists of a spirally served wire, or group of wires; a spirally wrapped metallic foil; or two foils laid parallel, one on each side of the cable core. An overall jacket is applied using the extrusion process, or the same lamination construction used in the cable core, sealing the edges in an "envelope" type configuration.

4—7.5 TESTING

Most of the tests performed on flat laminated cable are common to any cable configuration, such as:

a. Dielectric strength

b. Insulation resistance

c. Conductor resistance

d. Moisture resistance

e. Shrinkage

f. Accelerated aging

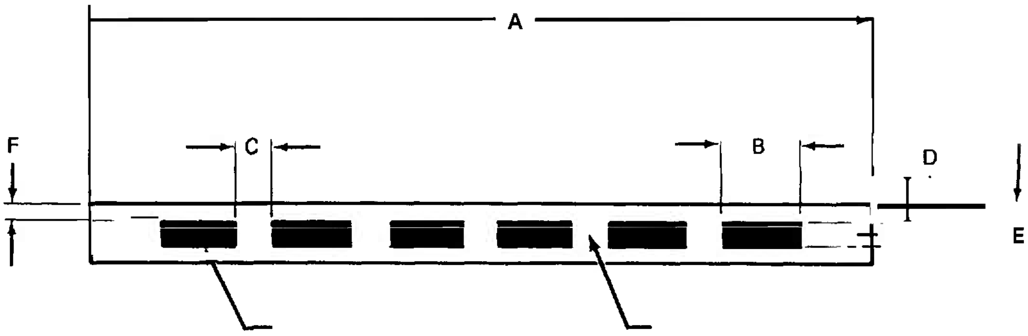
g. Thermal shock

h. Tensile strength and elongation

i. Vibration tests

j. Noise tests

* RTM duPont



where:

A = total width
B = conductor width
C = conductor spacing
D = conductor thickness
E = total thickness
F = insulation thickness

Figure 4–7. Laminated Flat Conductor Cable

There are, however, some very important tests performed which are more or less unique to flat cable due to the nature of the job expected from the installation for which these cables were designed. These tests are presented in the paragraphs which follow.

4–7.5.1 Folding Test

This test is designed primarily to ascertain the physical and/or electrical degradation of a tape cable construction at a point of extreme bend. The test is performed as follows: A length of cable, approximately two feet in length, is folded 180" transversely and a pressure of **30** psi applied to the folded specimen for 15 minutes. After the 15-minute interval the specimen is unfolded, laid flat, and the pressure reapplied for 15 minutes. This series constitutes one complete cycle. A total of two to three cycles is normally applied to a specimen. The specimen is then subjected to the insulation resistance and dielectric strength (conductor-to-conductor and conductor-to-ground) tests.

4–7.5.2 Roll Flexure Tests

This test is designed primarily to determine the amount of opening and shutting action a cable can absorb before failure in a panel mounted "drawer" type installation. The test is performed as shown in Fig. 4–8.

The rate of flexure is approximately **30** cycles per minute, and the tests performed at room temperature. These two factors will, of course, vary with the cable construction and installation environment to be encountered. All conductors in the cable are series connected and monitored to detect short circuits or breaks.

4–7.5.3 Straight Flexure Test

This test is designed primarily to determine the normal flex-life of a tape cable construction under conditions where the cable is continuously bent at a fixed point. The test is performed as shown in Fig. 4–9.

This being a much more stringent test than the roll flexure test, the flexure rate will necessarily be reduced to approximately **1/3** as many cycles per minute. Here again, all conductors are series connected and monitored for conductor breakage or short circuits.

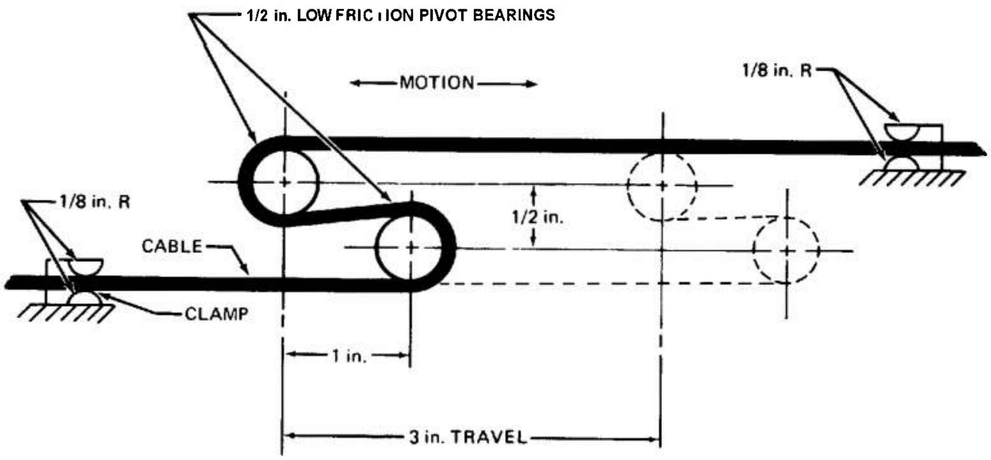


Figure 4–8. Rolled Flex Test

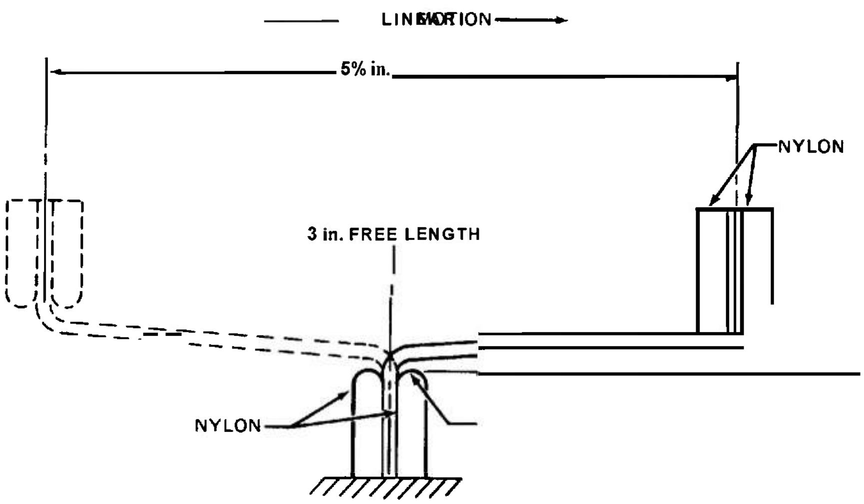


Figure 4–9. Straight Flex Test

4–7.6 INSTALLATION

It would appear that flat tape cables may have a value in certain specifically designed military installations. If installed and used properly, they have some advantages over conventional designs, specifically in the savings of space and weight. If improperly used or installed, the troubles encountered can quickly overcome these advantages and highly unsatisfactory performances will result. Highly selective cable design and equipment design is a must when flat cables are to be utilized.

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CHAPTER 5

COAXIAL CABLES

5–1 INTRODUCTION

The term "coaxial cable" usually implies that the cable is to be used to transmit radio frequency energy (500 kHz to 10,000 MHz). Coaxial cables are often used at frequencies lower than 0.5 MHz, and have many applications in the audio frequency range. However, at frequencies lower than 0.5 MHz, coaxial cable is normally designated as merely shielded and jacketed wire. A more accurate distinction between shielded wires and coaxial cable is that a coaxial cable is an RF transmission line for propagation of electromagnetic energy in the transverse electrical magnetic (TEM) mode. In shielded wire, the outer conductor serves only as a screening ground plane to minimize electrical interference.

In most applications, for the types of coaxial and triaxial cable described, the outer shields are covered with an insulating sheath which is often referred to as the outer jacket. This sheath serves to isolate the shield from adjacent metallic surfaces and to repel moisture, solvents, and other contaminants.

5–2 TYPES OF COAXIAL CABLE

5–2.1 DEFINITIONS

5–2.1.1. Coaxial

A *coaxial cable* may be defined as two concentric wires, cylindrical in shape, separated by some type of dielectric material; one wire being the center conductor and the other wire the outer conductor. See Fig. 5–1.

5–2.1.2 Twin Coaxial

A *twin coaxial* cable consists of two individually insulated conductors, within a common shield. These insulated conductors are either laid parallel to one another or twisted around each other, and placed concentrically within an additional cylindrical cable core or dielectric. The shield, or ground, is placed over this cable dielectric. See Figs 5–2 and 5–3.

5–2.1.3 Dual Coaxial

A *dual coaxial* cable is two individual coaxial cables, either laid parallel tu one another or twisted around one another, and placed concentrically within a common sheath or an additional cylindrical shield and sheath. See Figs 5–4 and 5–5.

5–2.1.4 Double Shielded

A *double shielded* coaxial cable is sometimes specified when small improvements over single shielding are required. This type of cable has one shield braided over the other with no insulating barrier between them. See Fig. 5–6.

5–2.1.5 Triaxial

A *triaxial cable* is very similar to a coaxial cable and is used in place of the coaxial cable when further shielding effectiveness is required. This cable is cylindrical in shape, having a center conductor located concentrically within the cable core or dielectric, but having two shields separated by a nonconducting material such as polyethylene (PE), or polytetrafluoroethylene (TFE) tape or extrusion. See Fig. 5–7.

5–3 MATERIALS

Conductor materials are defined in Chapter 1, dielectric materials in Chapter 2. The important electrical parameters required of these materials will be evident from the required electrical characteristics of the cable.

5–4 ELECTRICAL PROPERTIES OF COAXIAL CABLE

5–4.1 BASIC PARAMETERS

A transmission line has four line parameters, which consist of (1) shunt capacitance C between wires, (2) shunt conductance G, (3) series resistance R, (4) and series or self-inductance *L*. Any uniform line, regardless of length, has these parameters uniformly distributed along the entire length. The line or cable may be represented as in Fig. 5–8, where an infinite number of infinitesimally small sections are connected end to end.

These parameters depend upon the materials used arid their physical configurations, which in turn regulate the electrical performance of the cable.

5–4.1.1 Capacitance

Capacitance is that property of two electrodes which builds up charges caused by a difference in potential. The amount of charge built up by a given voltage, and hence the capacitance, is directly proportional tu a property of the dielectric called the "dielectric constant" ε. When a potential (voltage) is placed across a dielectric, a certain amount of current will flow between center conductor and shield.

Part of this "cuirent" charges up the electrodes through which the potential is applied, and part is pure current flow inversely proportional to the resistance of the dielectric, or directly proportional to its conductance.

The series resistance *R* is the loop resistance of the center and outer conductors, and the inductance *L* is due to the magnetic flux linkages set up by current flow in these conductors. The resistance *R* is inversely proportional to the area of copper through which the current flows. The behavior of both the resistance arid inductance is influenced by "skin effect". At high frequencies the current is crowded into an area nearer the outer perimeter of the conductor; this is due to the internal magnetic field. The magnetic flux determines the inductance; therefore, when current penetration is large, some of the flux is within the conductor and the inductance is at a maximum. As the frequency increases, the flux forces the current toward the outer perimeter of the conductor, and the inductance decreases somewhat. Inductance may be considered to have a constant value (maximum) at lower frequencies, varying as "skin effect" takes over, and again returning to a constant value when "skin effect" no longer varies the value of inductance. In other words, the "skin effect" has reached its maximum value and no longer changes the value of inductance. This constant value is approximately 20 percent less than that of the constant value before the influence of "skin effect". The frequency range in which inductance varies from maximum to minimum is nominally between 100 kHz and 10 MHz. Variations of inductance will depend largely on the type of cable, its size, and conductor configuration.

Since the depth of current penetration into the conductor is reduced, the effective area of conductor is reduced, therefore, the conductor resistance has increased with frequency. The resistance becomes approximately proportional to the square root of the frequency when skin effect depth becomes very small. The use of stranded conductors will not eliminate "skin effect", but will reduce it and will increase the upper limit of the inductance change region. The high frequency resistance is influenced by the type and composition of conductor, thickness, size, type, and quality of conductor plating.

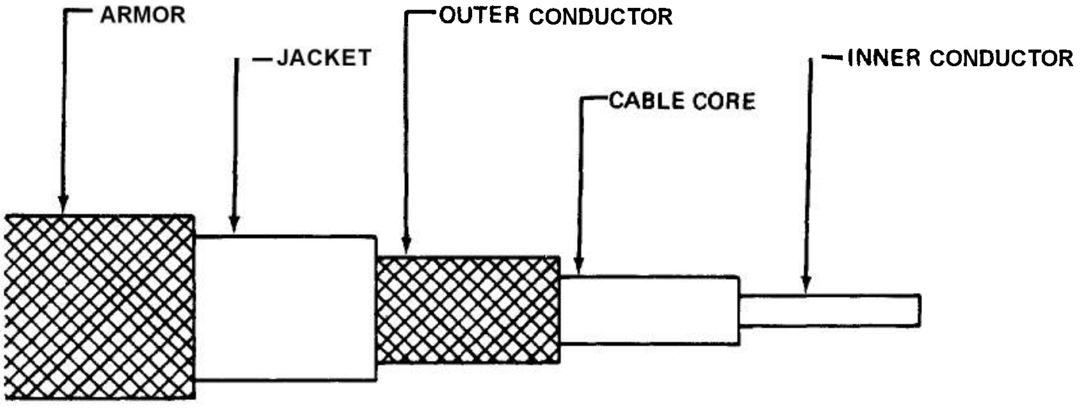

Figure 5–1. Coaxial Cable

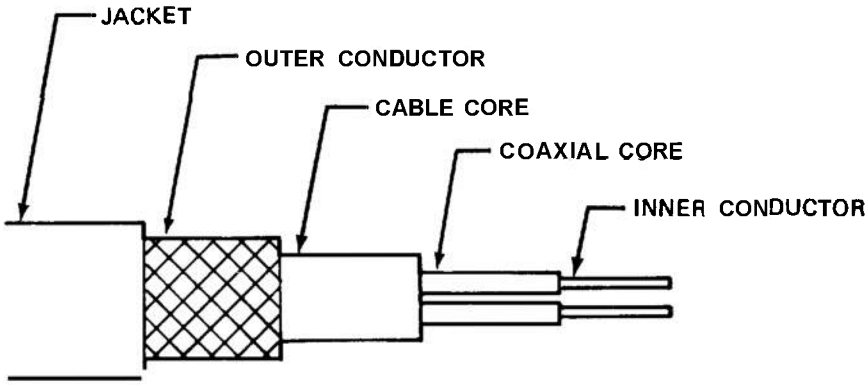

Figure 5–2. Twin Coaxial (Parallel)

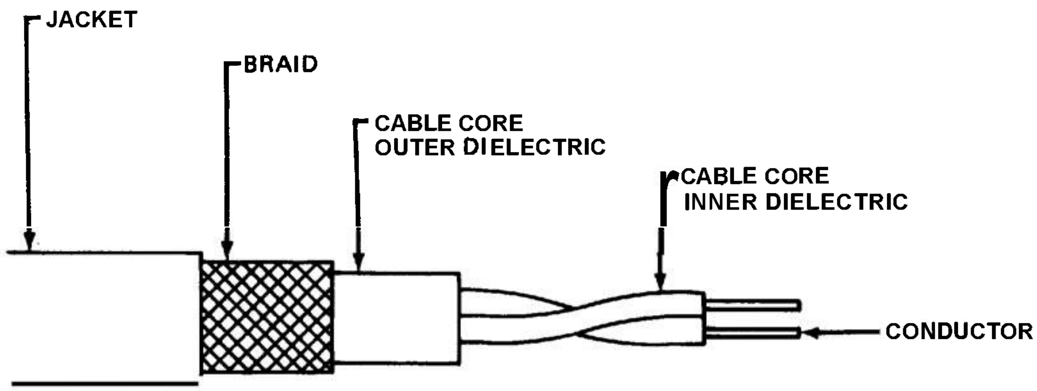

Figure 5–3. Twin Coaxial (Twisted)

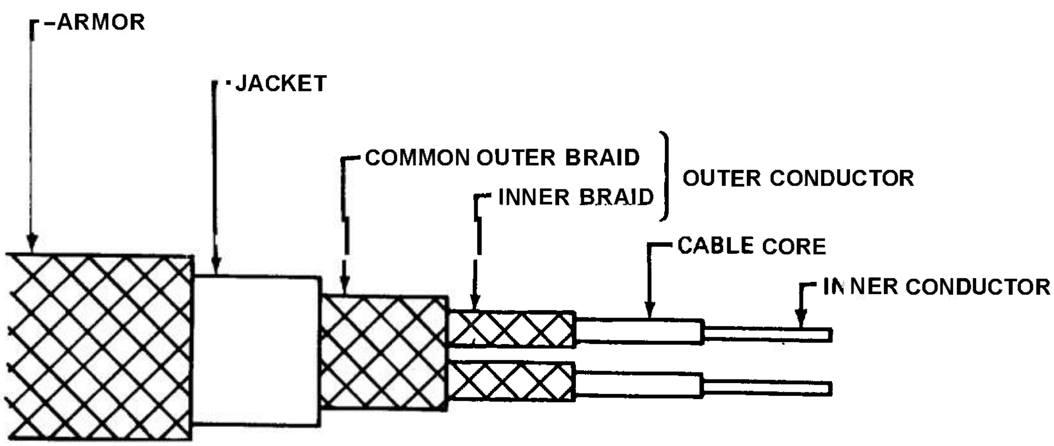

Figure 5–4. Dual Coaxial (Parallel)

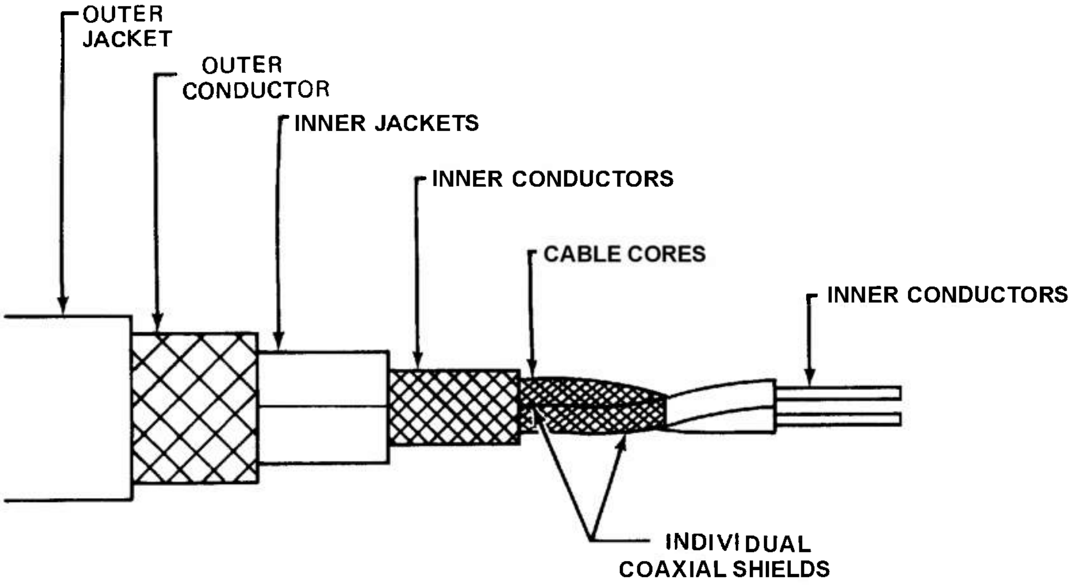

Figure 5–5. Dual Coaxial (Twisted)

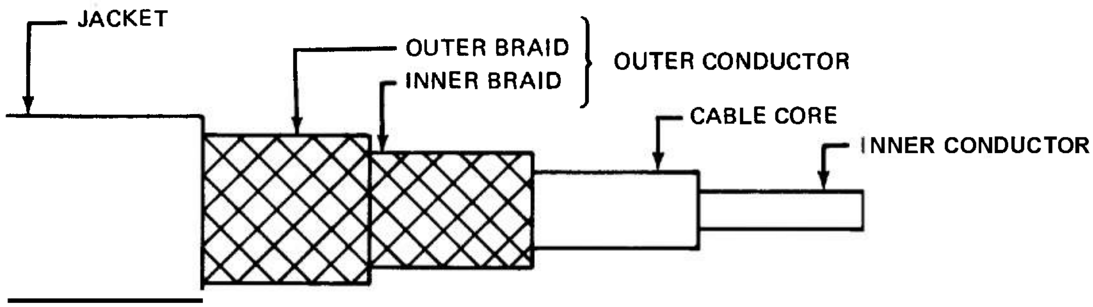

Figure 5–6. Double Shielded Coaxial

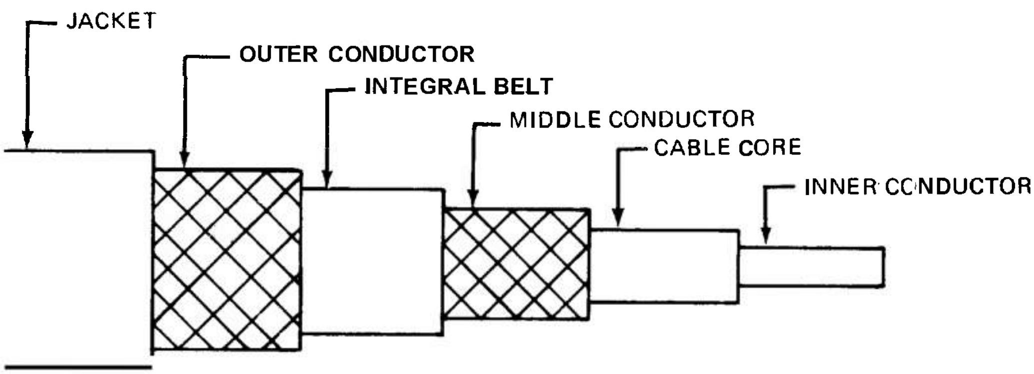

Figure 5–7. Triaxial Cable

5–4.1.2 Phase Angle

The dielectric phase angle ϕ of a dielectric material is the time difference between the sinusoidal alternating voltage applied to a dielectric and the resulting alternating current, as referred to one cycle or *360"*.

5–4.1.3 Power Factor

The power factor P is the cosine of the dielectric phase angle and the dissipation factor is defined as the cotangent of the phase angle of the dielectric material. Therefore, when the phase angle approaches 90" the power factor and the dissipation factor are both small. Coaxial cables for radio frequency RF transmission require a dielectric material which has a dielectric constant e and a low dissipation factor, both of which are essentially constant from audio frequencies to microwave frequencies. Three such dielectrics are polyethylene (PE), tetrafluoroethylene (TFE), and fluorinatedethylenepropylene (FEP). In these materials the shunt capacitance and the dissipation factor are constant, except that with FEP-type insulation the dissipation factor increases above 2000 MHz. Rubber- and PVC-type insulations have a high loss, and the value of capacitance is not constant with frequencies. Because of their high attenuation, or loss characteristics, these latter materials are not normally used for radio frequency transmissions.

5–4.1.4 Dielectric Constant

The dielectric constant of air, as a dielectric, is one (1); this value yields the theoretical limitation in coaxial cable design. The closer the dielectric constant is brought to one, the higher the velocity of propagation (and lower the capacitance). It is possible to introduce air into the dielectric space and further reduce the effective dielectric constant. This may be done by supporting the conductor on beads of dielectric material spaced intermittently along the conductor, or by a spirally applied, round monofilament of dielectric material separating the center conductor from the outer conductor. A foamed dielectric material may also be formed by introducing unicellular gas pockets into the solid insulating material. This may be done with polyethylene, polypropylene, and Teflon FEP. With any of these foams a dielectric constant as low as 1.40 may be achieved. However, mechanical and electrical strength is sacrificed. Table 5–1 lists some of the more common dielectric materials, and shows comparisons of dielectric constant and velocity of propagation.

5–4.1.5 Velocity of Propagation

The velocity of propagation of electrical energy through a cable is a function of dielectric constant only; therefore, the value of velocity would remain the same regardless of size or configuration of the dielectric material being used. The dielectric constant of insulating material is generally a known factor. An accurate method of determining the dielectric constant of any insulating material is the method described in ASTM-D-150-59T. The velocity of propagation may be directly measured per MIL-C-17, or calculated from one of the following equations:

$$V = \frac{1}{\sqrt{e}} \qquad (5\text{–}1)$$

$$V = \frac{1}{\sqrt{LC}} \qquad (5\text{–}2)$$

where

V = ratio of velocity of propagation to speed of light

e = dielectric constant

L = inductance, μH/ft

C = capacitance, μF/ft

5–4.1.6 Characteristic Impedance

Assume that a line composed of the basic parameters $R, L, C,$ and G is infinitely long so that factors at the receiving end of the line cannot be measured at the sending end. Obviously, this line has an input impedance of some definite value due to the distributed $R, L,$ C, and G. If a short section of line is cut off the sending end, the remaining infinite length still has the same input impedance since it is still infinitely long. If the piece cut off the front end is now terminated in the impedance of the infinite line, the sending end must have the same impedance it did originally. Since this short piece is made up of a series of $R, L,$ C, and G elements, any other termination would reflect a different input value. This value of impedance, when used as a termination to a transmission line, yields the same value of input impedance. This is called the "characteristic impedance" of the cable. When a cable is terminated in its characteristic impedance all energy transmitted down the line is absorbed in the termination. Any other termination causes energy to be reflected. A line terminated in its characteristic impedance is said to be matched.

The characteristic impedance may be determined by the following equation used at any frequency, high or low:

$$Z_o = \sqrt{\frac{R + j\,\omega L}{G + j\,\omega C}} \qquad (5\text{–}3)$$

where

Z_o = characteristic impedance, ohm

R = resistance, ohm/unit length

L = inductance, H/unit length

C = capacitance, F/unit length

G = conductance, mhos/unit length

ω = $2\pi f$, rad/sec

f = frequency, **Hz**

j = $\sqrt{-1}$

Obviously the characteristic impedance varies with frequency and must be ascertained at the frequency of application. At frequencies where L is much greater than R, and C much greater than G (approximately 1 MHz) Eq. **5–3** reduces to the following:

$$Z_o = \sqrt{\frac{0 + j\,\omega L}{0 + j\,\omega C}} = \sqrt{\frac{L}{C}} \qquad (5\text{–}4)$$

Since the parameters L and C are a function of the electrode geometry, the following equations apply to concentric cylinders, as in coaxial cable.

$$\text{Capacitance } C = \frac{7.36\,(\epsilon)}{\log_{10}\frac{D}{d}},\ pF/\text{ft} \qquad (5\text{–}5)$$

$$\text{Inductance } l = 0.140\,\log_{10}\frac{D}{d},\ \mu H/\text{ft} \qquad (5\text{–}6)$$

$$\text{Characteristic Impedance } Z_o = \frac{138}{\sqrt{\epsilon}}\log_{10}\frac{D}{d},\ \text{ohm} \qquad (5\text{–}7)$$

where

D = inner diameter of the outer conductor

d = diameter of inner conductor

ϵ = dielectric constant

The characteristic impedance of a coaxial line in the radio frequency range is primarily determined by its physical dimensions and the dielectric constant of the insulating material used. Fig. 5–10 is a representation of the changes in the characteristic impedance when the ratio ***D/d*** was varied from **3.33** to **33.33.** Plots for the three most commonly used insulating materials used for coaxial cable were derived from **Eq. 5–7.**

From Eqs. **5–1** and 5–5 the characteristic impedence may be expressed as

$$Z_o = \frac{101600}{\nu C},\ \text{ohm} \qquad (5\text{–}8)$$

where

ν = velocity of propagation, % (See Table **5–1**)

C = capacitance, pF/ft

This leads to a simple experimental determination of the high frequency characteristic impedance. The capacitance is measured on a bridge, and the velocity either measured or calculated from the dielectric constant.

Fig. 5–11 may **be used** for approximations of Z_o, C, and L of a twin coaxial cable where the conductor insulation and cable core dielectric are of the same insulating material.

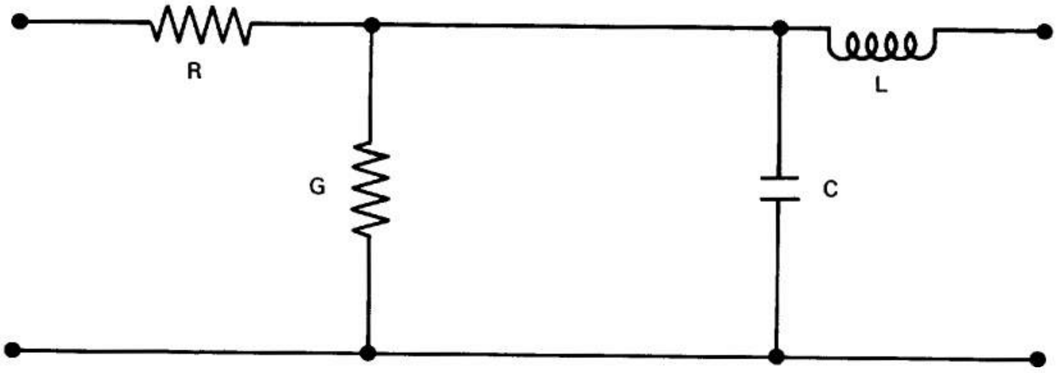

Figure 5–8. Basic Parameters of a Transmission Line

Dielectric Material	Dielectric Constant, ε	Velocity of Propagation, %
Polyethylene	2.25	67
TFE	2.00	71
Foam Polyethylene	1.65 - 1.60	78 -81
Foam FEP	1.60	80
Silicone	3.0	58
Air	1.0	100

$$Z_o = \frac{276}{\sqrt{\epsilon}} \log_{10} \left[\frac{2x}{d}\left(\frac{1-h^2}{1+h^2}\right)\right], \text{ohm} \quad (5\text{–}9)$$

Capacitance

$$C = \frac{3.68\epsilon}{\log_{10}\left[\frac{2x}{d}\left(\frac{1-h^2}{1+h^2}\right)\right]}, pF/\text{ft} \quad (5\text{–}10)$$

Inductance

$$L = 28.07 \log_{10} \left[\frac{2x}{d}\left(\frac{1-h^2}{1+h^2}\right)\right], \mu H \quad (5\text{–}11)$$

where D = diameter of cable core

d = diameter of conductor

x = distance, center to center, between the two conductors, in.

h = ratio, x/D

ϵ = dielectric constant of insulation

Eqs. 5–8 through 5–11 are used as approximations at frequencies of 10 MHz and higher.

Fig. 5–12 illustrates one type of a dual coaxial cable. As each component is an individual coaxial cable, Eqs. 5–3 through 5–6 are used to determine Z_o C, and L.

5–4.1.7 Propagation Constant

If a line is terminated into its characteristic impedance, and a signal 'is transmitted down the line, there will be a change in both magnitude and phase of the voltage and current continuously along the line. The real part of the propagation constant (attenuation constant) represents the change in magnitude due to line loss, and the imaginary part represents the phase shift from the end of the line.

The propagation constant γ may be determined by the following equations which are valid at any frequency when R, L, C, and G are known and accurate.

$$\gamma = \sqrt{(R + j\,\omega\,L)\,(G + j\,\omega\,C)} = a + j\,\beta \qquad (5\text{–}12)$$

where

γ = propagation constant

R = resistance, ohm/unit length

ω = $2\pi f$, rad/sec

π = 3.14

f = frequency, Hz

L = inductance, H/unit length

G = conductance, ohm/unit length

C = capacitance, F/unit length

a = attenuation constant, neper/unit length

β = phase constant, rad/unit length

Nepers may be converted to decibels by multiplying by 8.686, and radians to degrees by multiplying by 57.3.

The propagation constant may also be determined by input impedance measurements. This method is commonly used when long lengths of coaxial cables are available. The propagation constant is calculated from the following equation

$$\tan\,(\gamma \ell) = \sqrt{\frac{Z_{sc}}{Z_{oc}}} = a + j\beta \qquad (5\text{–}13)$$

where

γ = propagation constant

ℓ = length of cable, ft

Z_{sc} = input impedance, with far end short circuited

Z_{oc} = input impedance, with far end open circuited

Eq. 5–13 is valid at all frequencies and any line length. The same length must be used for both open and short circuit measurement.

5–4.1.8 Attenuation and Phase Shift

All transmission lines, or coaxial cables, experience losses. These losses, termed attenuation, will decrease the efficiency of the line, which in turn limits the power capabilities. The loss of electrical power in coaxial cables can be attributed to two causes – the first cause being the conductor resistance that results in power loss due to conductor heating by radio frequency currents passing through the conductors. The second cause is the dielectric loss caused by poor dielectric materials. It is, therefore, desirable to use dielectric compounds having a low power factor and a low dielectric constant in order to minimize the losses. On the assumption that the best conductor material is used, the resistance loss in the conductor then may be minimized only at the expense of size and weight. The larger the conductors, the lower the resistance, which results in lower losses. Again, considering a cable as having many small sections – with each section consisting of the lumped parameters R, L, C, and G, which give a propagation constant $\gamma = a + j\,\beta$ (Eqs. 5–12 and 5–13) – then the total attenuation is equal to the number of sections times a. Likewise, the total phase shift is equal to the number of sections times β.

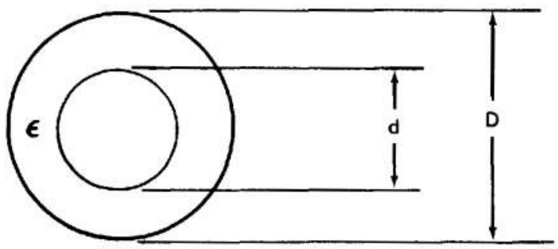

Figure 5–9. Relationship of Diameters to Dielectric Constant

By use of unit quantities *R*, L, C, and *G* the attenuation and phase constants may be obtained at any frequency by Eq. **5–12** as follows:

$$a + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$$

By expanding and equating the real and imaginary components, the attenuation becomes:

$$a = \left\{\frac{1}{2}\left[\sqrt{(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2)} + RG - \omega^2 LC\right]\right\}^{\frac{1}{2}} \quad (5\text{–}14)$$

and the phase constant becomes:

$$\beta = \left\{\frac{1}{2}\left[\sqrt{(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2)} - RG + \omega^2 LC\right]\right\}^{\frac{1}{2}} \quad (5\text{–}15)$$

If ω is sufficiently large, and *RG* is very small compared to $\omega^2 LC$, the following are good approximations at **high** frequency (approximately **1** MHz):

$$a = \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}} = \frac{R}{2Z_o} + \frac{GZ_o}{2} \text{ ,neper/unit length} \quad (5\text{–}16)$$

or since one decibel = **8.686** nepers

$$a = 4.343\left(\frac{R}{Z_o} + GZ_o\right) \text{ ,db/unit length.}$$

$$\beta = \omega\sqrt{LC} \quad (5\text{–}17)$$

The attenuation due to conductor **loss *a*,** is (for conductor loss refer to **Eq. 5–24)**

$$a, = 4.343\frac{R_o}{Z_o} \text{ ,db/unit length} \quad (5\text{–}18)$$

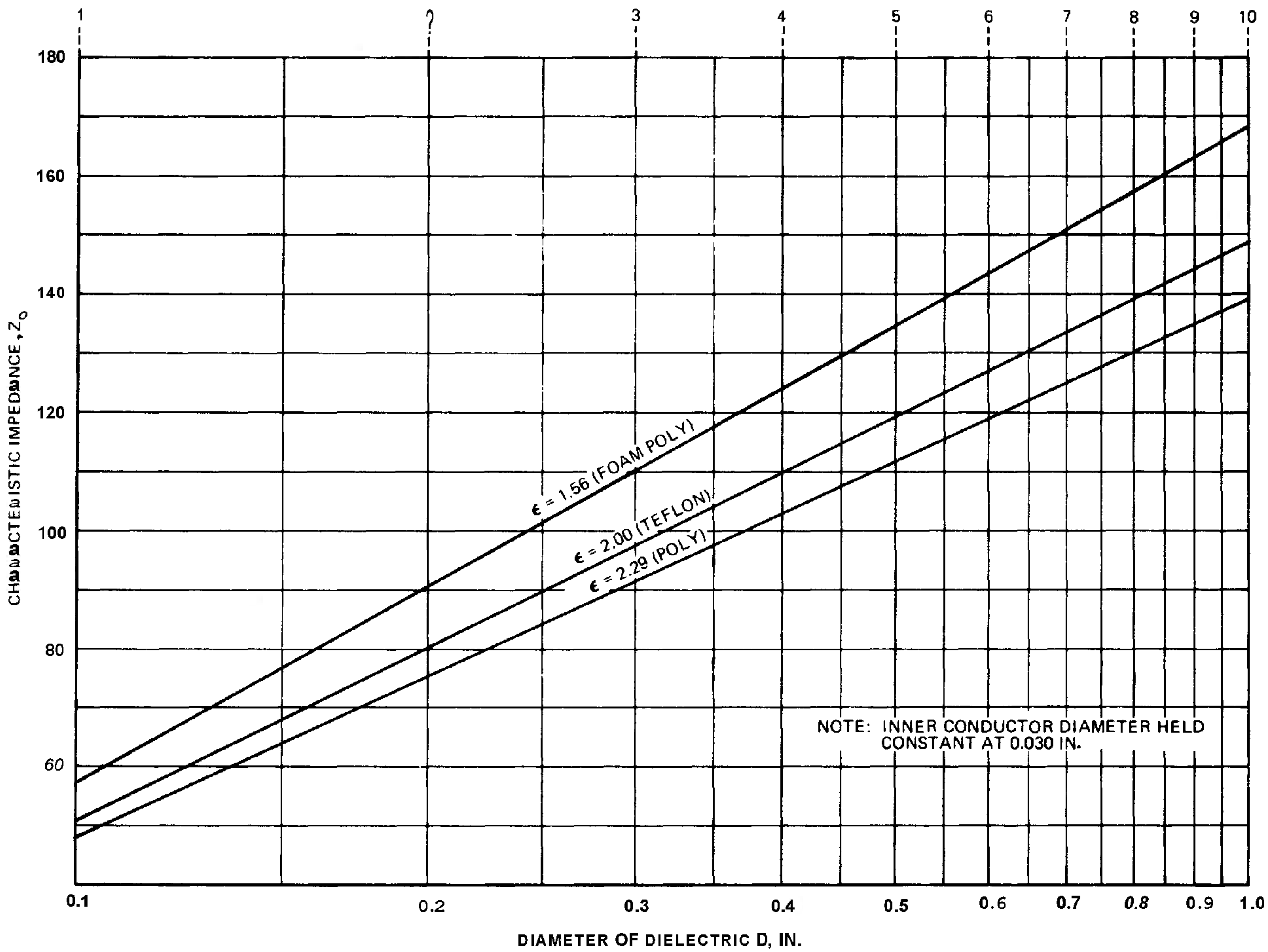

*Figure **5–10.** Changes in Z_0 Due to D/d Ratio Change*

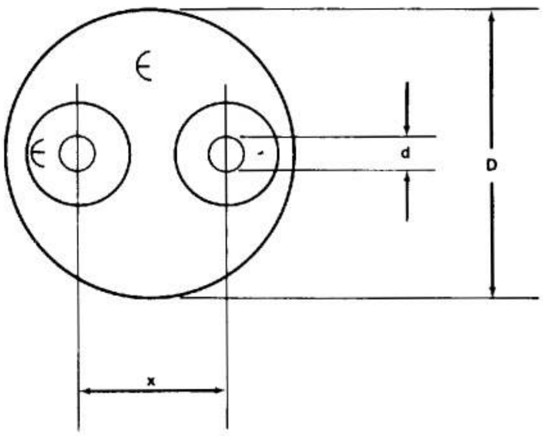

Figure 5–11. Twin Coaxial Cross Section

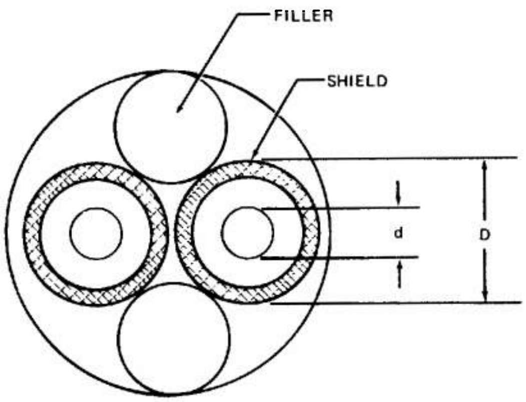

Figure 5–12. Dual Coaxial Cross Section

High frequency resistance for solid and tubular conductors is:

$$R_o = \frac{\rho}{2\pi\delta(d/2)} + \frac{\rho}{2\pi\delta(D/2)} = \frac{\rho}{2\pi\delta}\left[\frac{1}{(d/2)} + \frac{1}{(D/2)}\right] \text{, ohm/unit length} \quad (5\text{–}19)$$

For any nonmagnetic material, the skin depth δ is:

$$\delta = k\sqrt{\frac{\rho}{f_o}} \text{, unit length} \quad (5\text{–}20)$$

where

$$k = \frac{1}{\sqrt{\pi\mu}}$$

Therefore, **Eq.** 5–19 becomes:

$$R_o = \frac{\sqrt{\rho f_o}}{2\pi k}\left[\frac{1}{(d/2)} + \frac{1}{(D/2)}\right] = K\sqrt{f_o}\left[\frac{1}{(d/2)} + \frac{1}{(D/2)}\right], \text{ohm/unit length} \qquad (5\text{–}21)$$

where

$$K = \frac{\sqrt{\rho}}{2\pi k}$$

Values of K for various nonmagnetic materials are:

K = 41.6 x 10^{-9} for copper

= 40.2 x 10^{-9} for silver

= **83** x 10^{-9} for brass (approximately)

For other nonmagnetic materials, K is proportional to the square root of the resistivity.

For a copper cable, the resistance R per 100 ft can be expressed as:

$$R = 0.1\sqrt{f}\left(\frac{1}{d} + \frac{1}{D}\right), \text{ohm/100 ft} \qquad (5\text{–}22)$$

The notation for **Eqs.** *5–18* through *5–22* follows:

d = diameter of center conductor, in.

D = diameter of outer conductor, in.

f_o = frequency, Hz

f = frequency, MHz

R_o = resistance of coaxial cable, ohm/unit length

R = resistance of coxial cable, ohm/100 ft

δ = skin depth, unit length

μ = absolute permeability, 1.257 x 10^{-6} **H/m** (if nonmagnetic)

ρ = conductor resistivity, ohm-unit length

When the conductors are stranded or braided, the resistance becomes:

$$R = 0.1\sqrt{f}\left(\frac{K_s}{d} + \frac{K_b K_\rho}{D}\right) \quad (5-23)$$

where

K_s = stranding factor (approximately 1.3 for 7 strands)

K_b = braiding factor 2.0 for 0.25 in. diameter core
2.5 for 0.50 in. diameter core
3.0 for 0.75 in. diameter core
4.0 for 1.00 in. diameter core
5.0 for 1.50 in. diameter core

K_ρ = resistivity factor when outer conductor material differs from center conductor.

$$\left(K_\rho = \sqrt{\frac{\rho_{oc}}{\rho_{cc}}}\right)$$

By use of **Eqs.** 5–7 and 5–23 the conductor loss of Eq. 5–18 becomes

$$\alpha_c = \frac{0.4343\sqrt{f}}{\frac{138}{\sqrt{\epsilon}}\log_{10}\frac{D}{d}}\left(\frac{K_s}{d} + \frac{K_b K_\rho}{D}\right), \text{db/100 ft}$$

$$\alpha_c = \frac{3.14 \times 10^{-3}\sqrt{\epsilon f}}{\log_{10} D/d}\left(\frac{K_s}{d} + \frac{K_b K_\rho}{D}\right), \text{db/100 ft} \quad (5-24)$$

The attenuation due to dielectric loss α_d is

$$\alpha_d = 4.343\, G Z_o, \text{ db/unit length} \quad (5-25)$$

The conductance of the dielectric G is

$$G = \omega C\,(PF), \text{ mhos/unit length} \quad (5-26)$$

$$\alpha_d = 4.343\omega C(PF)\sqrt{\frac{L}{C}} = 4.3430\sqrt{LC}(PF) = 4.343\beta(PF), \text{db/unit length} \quad (5-27)$$

$$\beta = \frac{2\pi}{\lambda} = \frac{2\pi}{\lambda_o}\sqrt{\epsilon} = \frac{2\pi f\sqrt{\epsilon}}{V_o} \quad (5-28)$$

$$\alpha_d = 2.78 f\sqrt{\epsilon}\,(PF), \text{db/100 ft} \quad (5-29)$$

where f = frequency, MHz

V_o = velocity in free space, ft/sec

λ = wavelength

λ_o = wavelength in free space, ft

ϵ = dielectric constant

PF = power factor of dielectric

Total attenuation in db/100 ft then becomes

$$a = a_c + a_d = \frac{3.14 \times 10^{-3} \sqrt{\epsilon f}}{\log_{10} D/d}\left(\frac{K_s}{d} + \frac{K_b K_p}{D}\right) + 2.78 f \sqrt{\epsilon}(PF) \qquad (5\text{–}30)$$

Fig. 5–13 is a graphical representation of attenuation versus frequency for some of the more common radio frequency coaxial cables having nominal impedances of 50, 75, 95, and 125 ohms.

5–4.1.9 Corona and Voltage Rating

Corona is the ionization of air that may exist within a coaxial cable. This corona effect is produced by self sustained electrical discharges in these limited air spaces. These electrical discharges are caused by the influence of the electrical field in this region; therefore, small voids resulting from improper manufacturing techniques will initiate corona at a much lower voltage than that for a cable of proper manufacture. Corona has three effects on the performance of coaxial cable in that it will:

1. Cause premature electrical failure of the dielectric.

2. Cause interference with electrical communication, measurements, and control.

3. Cause a reduction in efficiency, due to the energy loss.

A slightly higher voltage is required to initiate corona than to sustain it. The corona voltage specified for coaxial cable is the voltage at which corona, once initiated, will stop; and is termed "corona extinction voltage"

The maximum voltage at which a coaxial cable may be operated is determined by the corona extinction point.

The voltage that can safely be applied to a coaxial transmission line is limited by the onset of corona, i.e., the ionization of air spaces in the immediate vicinity of a highly localized stress. The intrinsic surge strength of the dielectric materials used for support is extremely high in comparison with gases. For perfect cylindrical conductors in air the maximum voltage stress e_{max} occurs directly at the face of the inner conductor and is given by the following equation:

$$e_{max} = \frac{0.868}{d \log_{10} D/d} kV/\text{in. or volt/mil} \qquad (5\text{–}31)$$

where
d = diameter of center conductor, in.

D = diameter of dielectric, in.

The maximum peak voltage V_p which exists at any point along the line will generally differ from the input voltage when the line is not terminated properly. The exact value will depend upon the degree of mismatch, the electrical length, and the attenuation of the line. However, the ratio of the maximum voltage to the input voltage cannot exceed the actual value of the voltage standing wave ratio (VSWR) which should be used as a conservative derating factor. Table 5–2 shows the voltage rating and other characteristics of some of the more commonly used 50- and 75-ohm (polyethylene and Teflon dielectrics) coaxial cables.

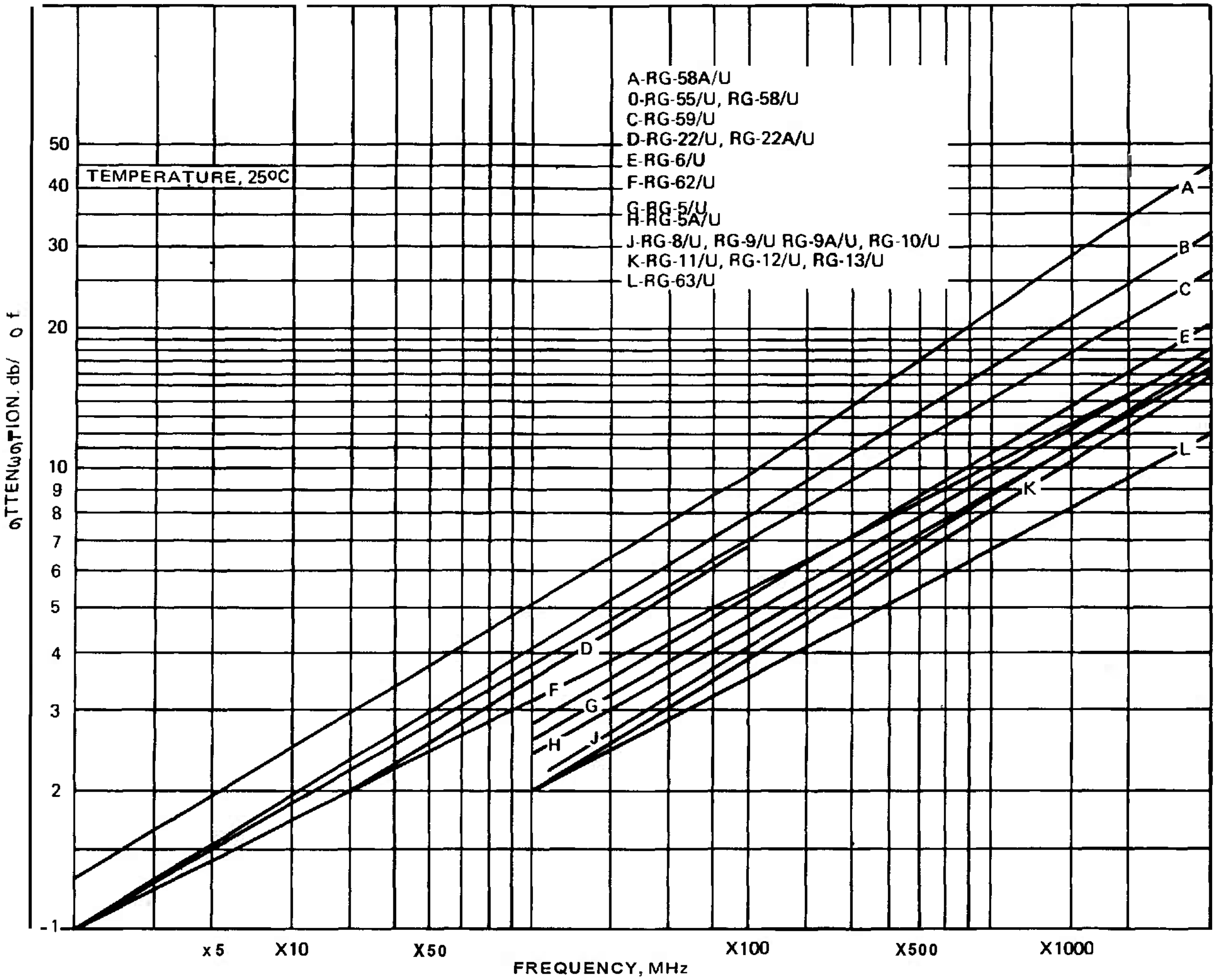

Figure 5– 13. Attenuation vs Frequency – Polyethylene Cable

TABLE 5–2

CHARACTERISTICS OF STANDARD RF CABLES

Type RG-	Inner Conductor	OD of Dielectric, Nominal in.	Shielding Braid(s)	Overall Diameter, Nominal in.	Weight, lb/100 ft	Maximum Operating Voltage, rms
			50-ohm Polyethylene Dielectric			
174/U	710.0063 Copperweld*	0.060	Tinned Copper	0.100	0.80	1,500
122/U	27/0.005 Tinned Copper	0.096	Tinned Copper	0.160	1.6	1,900
58C/U	19/0.0071 Tinned Copper	0.116	Tinned Copper	0.195	2.5	1,900
55B/U	0.032 Solid Silver Copper	0.116	Two Tinned Copper	0.206 (max)	3.1	1,900
5B/U	0.051 Solid Silver Copper	0.181	Two Silver Copper	0.328	8.3	3,000
8A/U	7/0.0285 Copper	0.285	Copper	0.405	9.9	5,000
9/BU	710.0285 Silver Copper	0.280	Two Silver Copper	0.420	12.6	5,000
14A/U	0.102 Solid Copper	0.370	Two Copper	0.545	20.1	7,000
17A/U	0.188 Solid Copper	0.680	Copper	0.870	44.6	11,000

* Copperweld is a trade name for copper covered steel described in par. 3.2.1.2, MIL€-17.

TABLE 5–2 (CONT.)

Type RG-	Inner Conductor	OD of Dielectric, Nominal in.	Shielding Braid(s)	Overall Diameter, Nominal in.	Weight, lb/100 ft	Maximum Operating Voltage, rms
			50-ohm Polyethylene Dielectric			
19A/U	0.250 Solid Copper	0.910	Copper	1.120	72.0	14,000
			75-ohm Polyethylene Dielectric			
59B/U	0.0230 Solid Copperweld"	0.146	Copper	0.242	3.6	2,300
6A/U	0.0285 Solid Copperweld"	0.185	Inner: Silver-coated Copper Outer: Copper	0.332	7.4	2,700
11A/U	710.0159 Tinned Copper	0.285	Copper	0.405	8.9	5,000
13A/U	710.0159 Tinned Copper	0.280	Two Copper	0.420	11.4	5,000
34B/U	710.0249 Copper	0.460	Copper	0.630	21.6	6,500
164/U	0.1045 Solid Copper	0.680	Copper	0.870	-----	10,000
			50-ohm Teflon Dielectric Cables			
196A/U	710.004 Silver Copperweld"	0.034	Silver Copper	0.080 (max)	0.58	1,000

* **Copperweld is a trade name for copper covered steel described in par. 3.2.1.2, MIL-C-17.**

TABLE 5–2 (CONT.)

Type RG-	Inner Conductor	OD of Dielectric Nominal in.	Shielding Braid(s)	Overall Diameter, Nominal in.	Weight, lb/100 ft	Maximum Operating' Voltage, rms
			50-ohm Teflon Dielectric Cables			
188A/U	7/0.0067 Silver Copperweld*	0.060	Silver Copper	0.1 10 (max)	1.09	1,200
141A/U	0.039 Solid Silver Copperweld*	0.1 16	Silver Copper	0.190	3.0	1,900
142B/U	0.039 Solid Silver Copperweld*	0.1 16	Two Silver Copper	0.195	4.5	1,900
143A/U	0.059 Solid Silver Copperweld*	0.185	Two Silver Copper	0.325	10.8	3,000
115/U	7/0.028 Silver Copper	0.250	Two Silver Copper	0.375	13.8	5,000
115A/U	710.028 Silver Copper	0.255	Two Silver Copper	0.415	14.9	5,000
87A/U	7/0.032 Silver Copper	0.280	Two Silver Copper	0.425	15.3	5,000
119/U	0.102 Solid Copper	0.332	Two Copper	0.465	22.5	6,000

* Copperweld is a trade name for copper covered steel described in par. 3.2.1.2, MIL-C-17.

TABLE 5–2 (CONT.)

Type RG-	Inner Conductor	OD of Dielectric, Nominal in.	Shielding Braid(s)	Overall Diameter, Nominal in.	Weight, lb/100 ft	Maximum Operating Voltage, rms
			50-ohm Teflon Dielectric Cables			
94/U	19/0.0225 Silver Copper	0.292	Two Copper	0.445	19.2	7,000
117A/U	0.188 Solid Copper	0.620	Copper	0.730	52.5	7,000
			75-ohm Teflon Dielectric Cables			
187A/U	7/0.004 Silver Copperweld*	0.060	Silver Copper	0.110 (max)	1.06	1,200
140/U	0.025 Solid Silver Copperweld*	0.146	Silver Copper	0.233	4.5	2,300
144/U	7/0.0179 Silver Copperweld*	0.285	Silver Copper	0.410	12.0	5,000

* Copperweld is a trade name for copper covered steel described in par. 3.2.1.2, MILC-17.

5–5 AIR-SPACED CABLES

5–5.1 GENERAL CONSTRUCTIONAL DETAILS

Table 5–3 lists the characteristics of some typical semi-solid, air-spaced coaxial cables which incorporate a variety of dielectric designs and outer conductor materials. The dielectric core may be in the form of thread wraps, braided threads, taped or solid helixes, multiple tubes, splines, or foams. The outer conductor most frequently is a copper braid, either single or double, but is often a solid aluminum tube. The exact construction for a particular cable is specified on its appropriate drawing, Standard, or Specification, and is selected for use on the basis of the desired electrical performance consistent with the required physical and mechanical properties of its application.

5–5.2 USES

The air-spaced cable is utilized where one of three following characteristics is desired:

1. Low capacitance and/or attenuation.

2. Smaller in physical size over cables using other dielectric materials, and of equal impedance.

3. Weight savings, but with some sacrifice in dielectric strength.

5–6 VOLTAGE STANDING WAVE RATIO (VSWR)

Whenever an electrically uniform – R, L, C, and G constant throughout the line – transmission line is terminated in its characteristic impedance, any energy sent down the line will be completely absorbed by the termination. If the line is terminated in any other impedance, there will be reflections retransmitted from the termination – the sending end of the line. The reflected voltage V_r is related to the incident voltage V_i arriving at the load by the relationship of Eq. 5–32.

$$\text{reflection coefficient} = \mathcal{R} = \frac{V_r}{V_i} \tag{5–32}$$

In both magnitude and phase, $\mathcal{R}$ is a complex quantity.

$$\mathcal{R} = \frac{Z_r - Z_o}{Z_r + Z_o} \tag{5–33}$$

where Z_o is the characteristic impedance of the uniform line and Z, is the load impedance. Also, the current reflected may be related to the incident current by the equation:

$$\mathcal{R} = \frac{-I_r}{I_i} \tag{5–34}$$

where I_i is the incident current and I_r is the reflected current.

The voltage at the load is the vector sum of V_i and V_r, and the load current is the vector sum of I_i and I_r. The reflected voltage and current are subject to the same propagation constant (attenuation and phase shift) in traveling back along the line toward the sending end as is the incident wave in traveling from sending end to receiving end. At any point on the line the actual voltage is made up of the vector sum of the incident voltage wave traveling down the line and the reflected voltage traveling back along the line. Since both these voltages are shifting in phase along the line, there will be points where the incident and reflection voltages will add in phase to give a voltage maximum. There will also be points along the line, half way between voltage maximum, where the voltage will add out of phase to give a voltage minimum. If an AC volt meter is moved along the line, it will rise and fall between these maxima and minima, therefore, the ratio of $\frac{V_{max}}{V_{min}}$ is called the voltage standing wave ratio (VSWK). Obviously there will be current maxima and minima, and the minimum will be displaced 90° along the line from a voltage maximum (the current maxima will be at voltage minimum; current minima, at a voltage maximum).

5–6.1 REFLECTION–COAX1AL CABLE SYSTEM

It is desirable to minimize reflection in a coaxial cable system for several reasons, some of which are:

1. The reflection can cause echos that will transmit false information. In a digital transmission system a reflected pulse may not be distinguishable from a transmitted pulse, and cause improper registration. In TV or visual data transmission the echo can cause double pictures.

2. Reflected energy represents energy that does not reach the intended load (attenuation is increased).

TABLE 5–3
CHARACTERISTICS OF SEMI-SOLID RF CABLES

RG Type	Capacitance, $\mu\mu F/ft$	Impedance, ohm nominal	Conductor Dia, in.	Material (Dielectric)	Dielectric Dia, in.	Overall Dia, in.
62A/U	14.5	93	00253	a2 *	0.146	0.242
63B/U	11.0	125	00253	a2 *	0.285	0.405
114A/U	6.8	185	0007	A-2*	0.285	0.405
125/U	7.8	150	00 [illegible]9	A-2 *	0.406	0.600
189/U	22.0	50	0.2[illegible]1	Mylar tape	0.634	0.875
210/U	14.5	93	0025	F[illegible] **	0.146	0.242
236/U	24.0	50	0 [illegible]2	Mylar tape	0.421	0.600
244/U	15.5	75	0 102	Mylar tape	0.421	0.500
252/U	24.0	50	0 165	Polyethylene tubes	0.456	0.630
268/U	23.0	50	0 161	Polyethylene helix	0.353	0.498
279/U	20.0	75	0025	F-3 **	0.110	0.145
280/U	27.5	50	0 1144	F-3 **	0.327	0.480
326/U	24.5	50	0.210	Polyethylene spline	0.550	0.697

* A-2: Air-spaced polyethylene

** F-3: Air-spaced polytet

3. The high voltage standing wave ratio can exceed the voltage rating of the line if the line is being used close to its maximum rated voltage.

4. The current maxima can overheat the conductor and insulation. The loss due to reflection may be calculated from Eq. **5–35.**

$$\text{Reflection loss} = 10 \log_{10} \left(\frac{1}{1 - \rho^2} \right), \text{db} \qquad (5\text{–}35)$$

The magnitude of reflection coefficient can be calculated if measurements of **VSWR** have been made from Eq. 5–36.

$$\rho = \frac{VSWR - 1}{VSWR + 1} \qquad \textbf{(5–36)}$$

The phase angle is equal to 2ϕ, where ϕ is the electrical angle to the nearest voltage maximum on the generator side of the point where ρ is measured. Measuring $VSWR$ and ϕ gives a powerful tool for determining impedances at high frequency when a known line Z_o is used.

5–6.2 REFLECTION CAUSES — COAXIAL CABLE SYSTEMS

Even though a coaxial cable is terminated in its characteristic impedance, there may be multiple reflections set up along the entire line. This is due to nonuniformity of the cable itself. One principal cause would be the variation in the diameter of the cable core dielectric, which results in impedance changes. Other reasons could be poor concentricity of the conductor within the dielectric, variations in braid, and rising sharp bends during installation. If impedance variations or discontinuities exist and if they occur at evenly spaced intervals: each causing only a very small reflection, a very high $VSWR$ could be obtained at a particular frequency where these discontinuities are one half wave length apart on the line, so that each adds in phase to all the rest.

If a transmission line is to be used over a band of frequencies where these reflections could cause trouble, it is important that the line be measured for $VSWR$ over the entire frequency range to be used. This is most conveniently done by sweep measurement techniques. where the frequency is automatically shifted over the range and the reflections shown on a cathode ray tube display.

5–7 POWER RATING

The maximum RF power a coaxial line may safely transmit can be limited either by the voltage introduced to the peak power or the thermal heating due to the average power. Which of these is the predominating factor will vary according to operating conditions and the design of the transmission line. The peak power P_P rating is determined directly by the voltage rating, and is expressed by **Eq. 5–37**

$$P_P = \frac{V_p^2}{2Z_o} \qquad \textbf{(5–37)}$$

where V_p is the maximum peak voltage.

The peak is affected by any of the design features, mechanical imperfections, or external factors which tend to degrade the corona level. For continuous wave (CW), dielectric losses may limit the power to a level below that of Eq. 5–36.

5–7.1 POWER HANDLING CAPACITY

The average power handling capacity will be determined by the attenuation of the line, and the minimum "hot spot" temperature that the dielectric or conductor can withstand continuously. Excessive temperature can result in conductor migration due to softening of the dielectric material, mechanical damage due to differential expansion, or shortened life due to chemical deterioration. The amount of heat generated W in a matched system is the difference between the input power P_1 and the output power P_2, watts/unit length (generally in ft), and can be expressed in terms of attenuation a as follows:

$$a = 10 \log_{10} \frac{P_1}{P_2}, \text{db} \qquad \textbf{(5–38)}$$

$$W = P_1 - P_2 = P_1 - \frac{P_1}{\text{anti} \log_{10}(a/10)} \qquad (5\text{–}39)$$

The rate of heat dissipation from the line depends on the diameter, materials, color of the outer covering, and the ambient temperature and altitude. The amount of heat which flows radially from the line will depend on the composite thermal resistivity R_{TH} of the dielectric, any jacketing materials used, and the temperature gradients present therein. Heat is generated internally, at the center conductor, in direct proportion to its individual attenuation. By equating the heat generated, from Eq. 5–39, to the heat dissipated for a given temperature rise AT between the center conductor and the ambient temperature, the maximum average power rating P_T can be established from Eq. 5–40.

$$W = \frac{\Delta T}{R_{TH}} = P_T \left[1 - \frac{1}{anti\ log_{10}(a/10)}\right] \quad (5-40)$$

$$P_T = \frac{\Delta T}{R_{TH}\left[1 - \frac{1}{anti\ log_{10}(a/10)}\right]}$$

The temperature rise will depend on many factors such as the dielectric material used, dimensions, convection and radiation conditions, etc. Polyethylene (low density) coaxial cables are rated for use at a maximum temperature of 80°C on the center conductor. When a higher temperature or an increase in power ratings is desired, a Teflon insulated coaxial cable' is used. Teflon is recommended for temperatures up to 250°C (482°F) for cables classified as miniature cables. Figs. 5–14 and 5–15 show average power curves for some of the more commonly used 50-ohm polyethylene and Teflon cables, respectively.

5–7.2 POWER RATING DUE TO VSWR

Longitudinal variations in voltage and current as a result of a mismatched load will reduce the average permissible power. When attenuation is small, so the VSWR is nearly constant over the entire length, then:

$$\frac{\text{Average power lost in the line with } VSWR}{\text{Average power lost in the line (matched)}} \approx \frac{1}{2}\left[VSWR + \frac{1}{VSWR}\right] \quad (5-41)$$

Axial heat flow, particularly in the center conductor, tends to reduce its temperature for short wavelengths. When the wavelength is very long, the power rating for the matched line should be divided directly by the *VSWR*. The maximum temperature rise occurs at the point of the *VSWR* minimum.

The amounts by which the power handling ability of Teflon and polyethylene cables decrease with *VSWR*, altitude, and temperature are shown in Figs. 5--16 and 5–17.

5–8 SHIELDS

There are many types of shields used in the construction of coaxial cables. The more popular types are the braided shield, sleeved or metallic tubing, and a conductive spiral or longitudinal wrap. The shield acts to confine the dielectric field inside the cable insulation; provide a barrier to any external energy or radiation; and in the case of high voltage operation, provide increased safety to human life.

The most commonly used wire gage sizes for individual shield wires in a braid are from #34 AWG through #38 AWG inclusive. The braid is constructed with machines having 16 or 24 carriers, with the number of wires per carrier ranging from 2 to 8, and the number of picks per inch ranging between 10 and 30. The nominal braid angle is approximately 30 to 35 degrees.

5–8.1 PICKS

The point at which two carriers cross is called the pick. The number of these picks per inch in a line parallel to the axis of the conductor is referred to as picks per inch.

5–8.2 CARRIERS

The carrier is the spool which carries a group of parallel wires that are woven to form the shield. In the weaving process half the carriers spiral in one direction around the cable and half spiral in the opposite direction.

5–8.3 ENDS

The ends are the number of parallel wires on each carrier. Four ends per carrier are shown in Fig. 5–18.

The factors d, N, C, and P can be varied to give the desired percent of coverage for the cable being shielded. See Eq. 1–4, par. 1–9.3.

Although solid type sheaths, such as copper or aluminum tubes, provide low attenuation and good shielding effectiveness, there is a distinct disadvantage due to the loss of flexibility.

Copper, steel, and aluminum tapes and foils are also used for shielding purposes, but they *too* are much stiffer than a braid. Tapes are usually considered when the cables are expected to encounter severe mechanical abuse, or in some cases, to prevent rodent damage.

Foils – such as aluminum, copper, or laminates – are mostly used in shields for low frequency applications. This type of shielding is not recommended for use when the cable will be subjected to great amounts of flexing. Under extreme flexing this type of shield may break and the continuity of the shield will be lost.

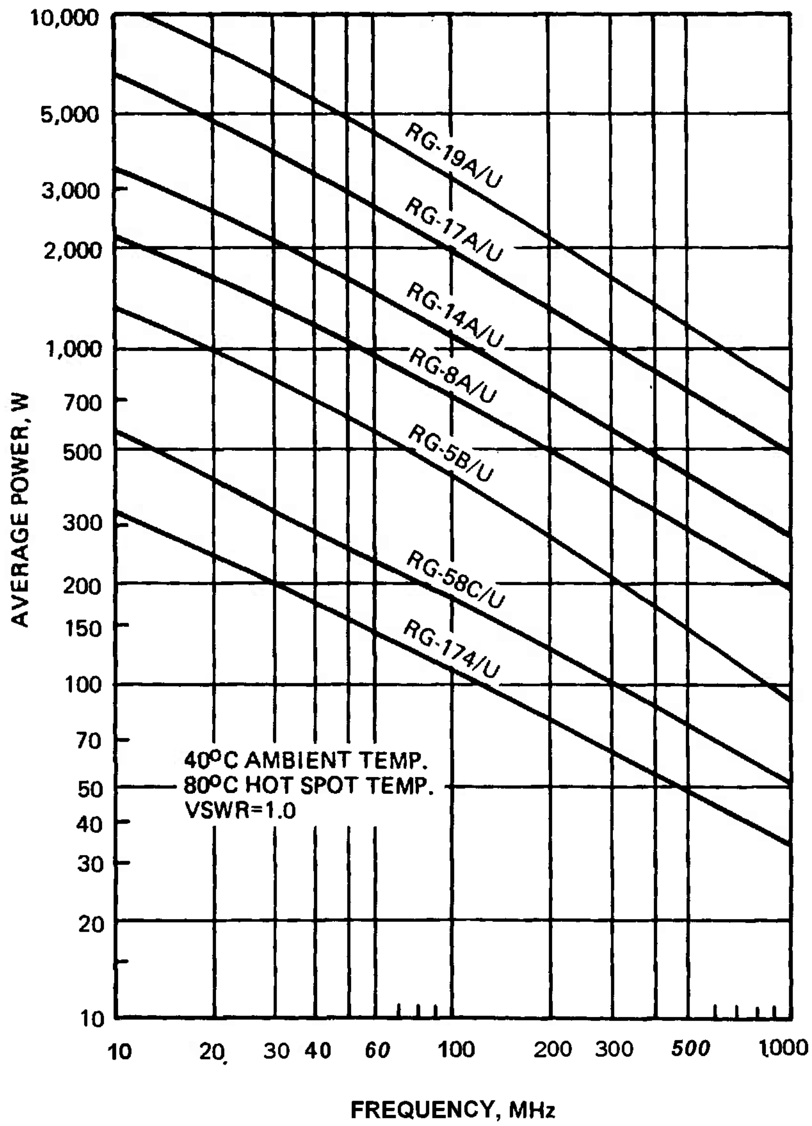

Figure 5–14. Average Power Ratings of 50-ohm Polyethylene Cables

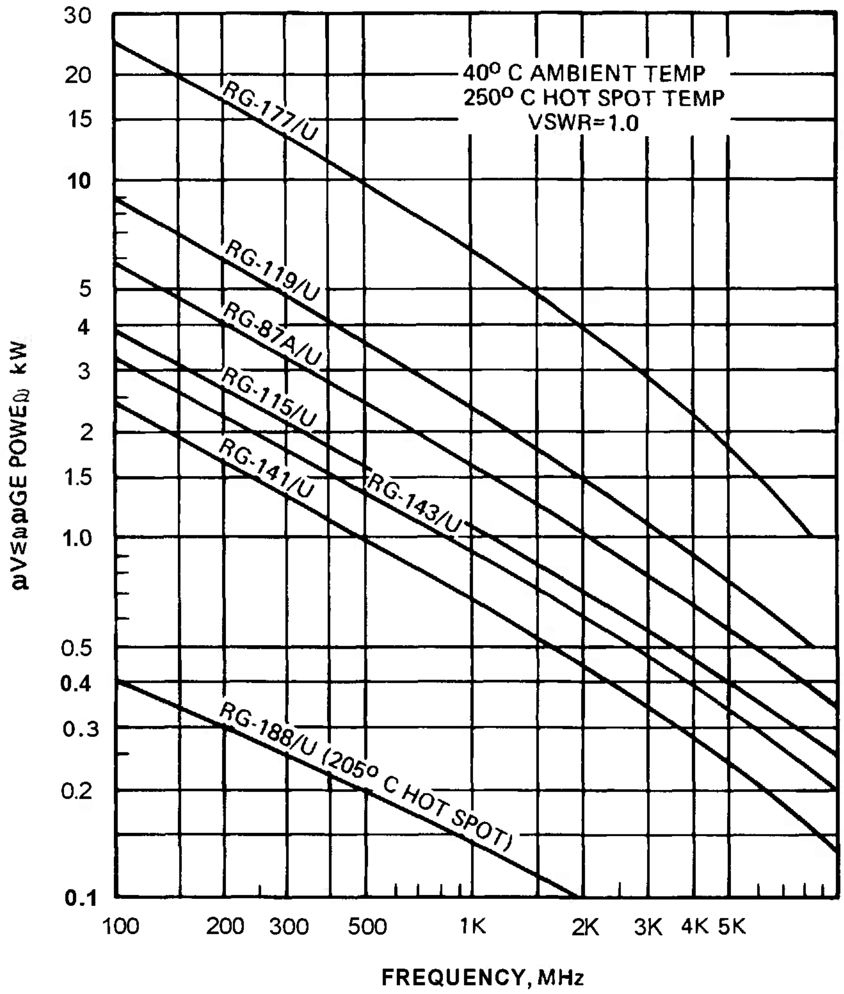

Figure 5–15. Average Power Ratings of 50-ohm Teflon Cables

5–9 SHIELDING EFFECTIVENESS

5–9.1 SURFACE TRANSFER IMPEDANCE

The surface transfer impedance is the most practical unit of measuring the relative effectiveness of shielding. It is defined as the ratio of voltage on the surface of the outer conductor, to the total current carried by the inner conductor. It is a function only of frequency and the design parameters of the line. Therefore, at higher frequencies (above 1000 MHz), the shielding effectiveness becomes an important factor. A braided double shield improves the quality of shielding to some extent, however, some radiation of electrical energy may occur at microwave frequencies through the interstices of the shielding braids. The use of a triaxial construction (two shields insulated from one another) improves the effectiveness of the shielding considerably. The effect of this type construction is two individual shields operating separately. To obtain the best shielding performance using this type construction, both shields must be brought to the termination point with the insulating material separating them. Table 5–4 provides data on shielding effectiveness for various types of shields which have been used in the construction of shelded wires or coaxial cable.

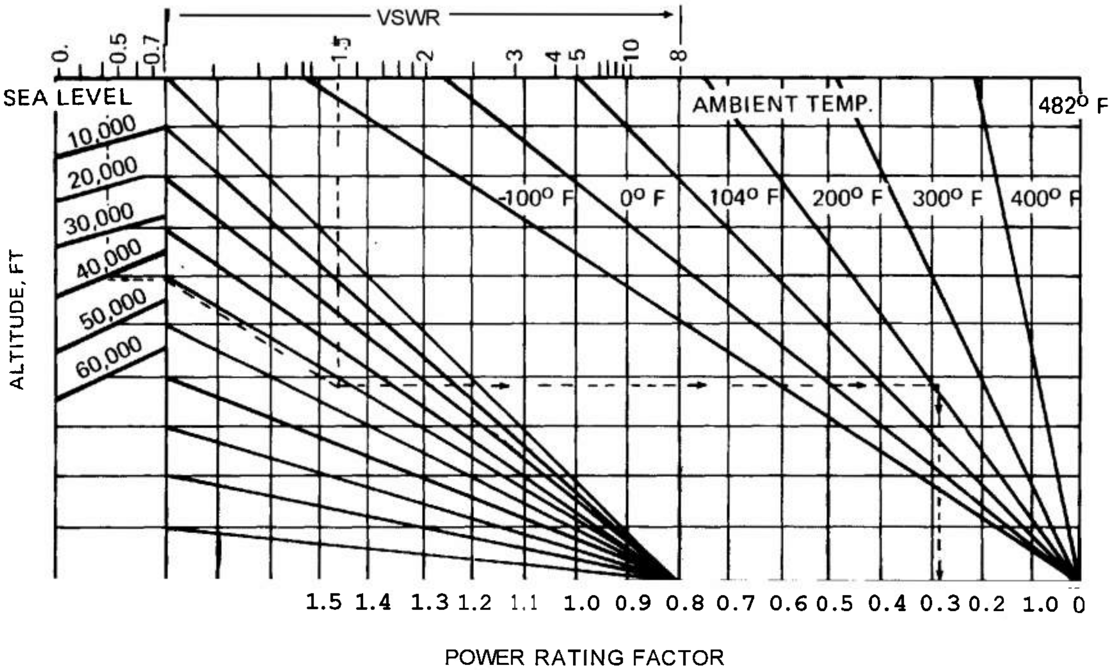

Figure 5–16. Power Rating Due to VSWR–Teflon Cable

5–9.2 REFERENCE

For additional information on shielding, shielding effectiveness, and power rating refer to Refs. 15 and 16.

5–10 TRANSMISSION UNBALANCE

5–10.1 GENERAL

In most cases, with the use of dud or twin coaxial cable, it is required that the line be as perfectly

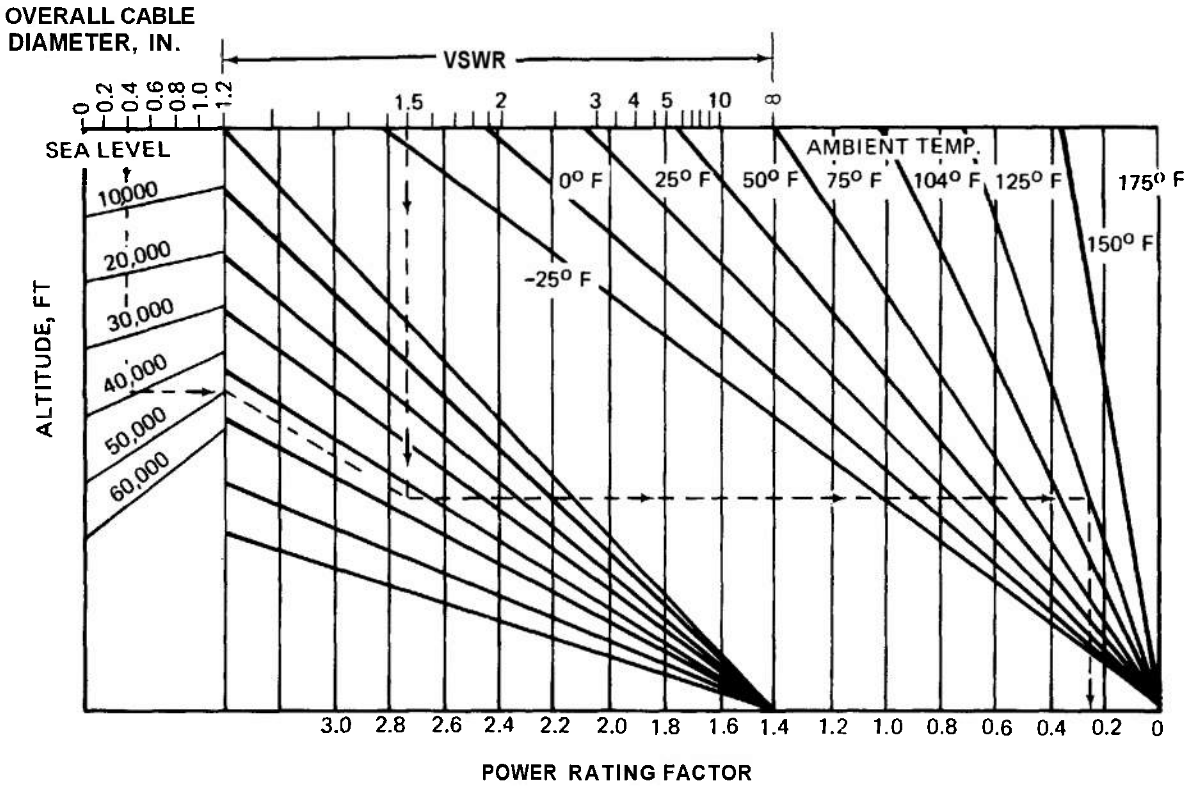

Figure 5–17. Power Rating Due to VSWR—Polyethylene Cable

balanced as possible. This means that a cable of a certain physical length must have both lines equal in electrical length. If one line differs in characteristic impedance from the other, then the electrical length also differs, which will cause both a voltage drop and phase angle variation between the lines.

5–10.2 REFERENCES FOR TEST AND MEASUREMENT

Ref. **14** describes the test set-up and method of measurement. A more comprehensive discussion of the test and test procedures may be found in Ref. 11.

5–11 COVERINGS AND SHEATHS

5–11.1 USES

It is common practice to provide a nonmetallic covering or sheath over the cable shield. This prevents the shield from coming' in contact with other live electrical circuits. acts as a barrier to moisture, provides mechanical protection, and reduces self-generated noise.

5–11.2 FIBROUS OR TEXTILE

Fibrous or textile braids – such as acetate, rayon, nylon, Dacron and Fiberglas – provide good flexibility.

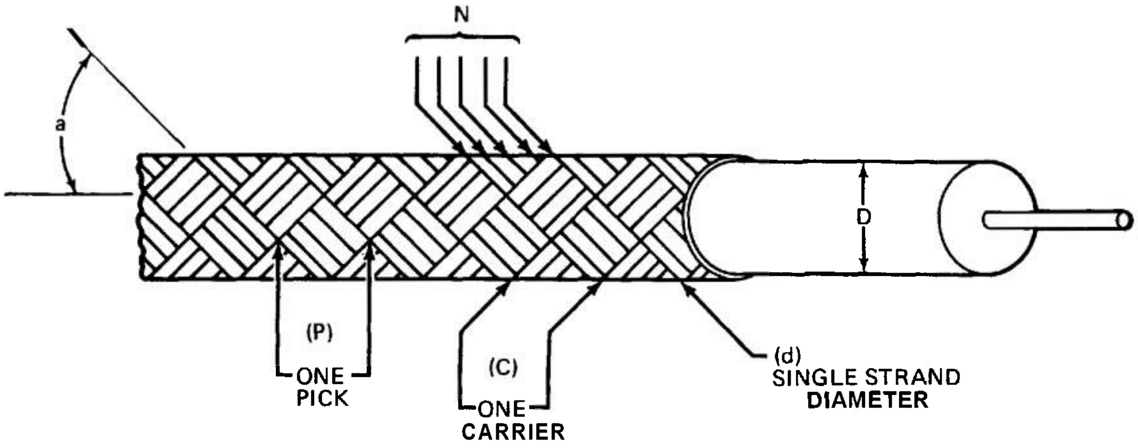

Figure 5–18. Shield–Constructional Details

where

a = braid angle, deg (relative to cable axis)

N = number of ends per carrier

P = pick

C = carrier

d = diameter of single shield end

D = diameter of cable core under braid

When driven shields are used, extruded nylon, polyethylene, polyvinylchloride, Teflon, or other insulation should be used to electrically isolate the shield from the surroundings.

5–12 SPECIAL PURPOSE COAXIAL CABLES

5–12.1 PULSE CABLES

Because pulse cables must be capable of transmitting high voltage, direct current pulses, with peak powers in the order of megawatts, the requirements are much more stringent than that of conventional coaxial cables. The more important requirements are in respect to corona levels, shielding effectiveness, and low frequency attenuation.

To provide a cable with a high corona level. a good physical bond between center conductor and the dielectric, and between the dielectric and outer conductor or sheath, is necessary to eliminate air pockets. Polyethylene is used as a dielectric for cables with moderate powers; for higher operating temperatures and power levels, rubber-type insulations are used. The flexibility of the cable is increased, and because the rubber-type insulation adheres better to the inner and outer conductor, voltage stresses during flexing will be minimized.

Most pulse cables are constructed in triaxial form. Because of the very high powers involved, a reduction of spurious electromagnetic radiation is mandatory. The attenuation and average power handling capacity under pulse conditions is dependent directly on the duty cycle, and is established by the system requirements and limitations.

For a more complete discussion and additional information refer to Refs. 9, 10, and 12.

5–12.2 DELAY LINES

Delay lines are primarily used in pulse forming circuits and systems, and for matching high impedance circuits. The high impedance of these cables is achieved by increasing the series inductance of the center conductor and the cable capacitance, which results in phase and attenuation characteristics similar to a low pass filter. These characteristics remain fairly constant until frequency cut-off is reached.

The center conductor consists of a fine enameled wire which is closely wound around a hollow insulating core. A thin tape, or extruded dielectric, is placed over

TABLE 5–4

SHIELDING EFFECTIVENESS K_e @ 1 MHz * FOR VARIOUS SHIELD MATERIALS AND CONSTRUCTIONS

	Where K_e = 0 for perfect shielding K_e = 1 for no shielding
Type of Shield	Relative Shielding Effectiveness at 1 MHz
Tinned Copper #36 AWG 50% Coverage	3.4×10^{-3}
Tinned Copper #36 AWG 75%coverage	1.42×10^{-3}
Flat Braid Tinned Copper 0.002 in. thick, 50% coverage	8.26×10^{-3}
Semi-conductor material only	No apparent shielding
Double faced aluminum on Mylar backing 100%coverage	22.7×10^{-3}
1/4 in. aluminum foil, 0.005 in. thick 100%coverage	16.3×10^{-3}
Triax (shields separated with polyvinyl extrusion)	0.200×10^{-3}

* *See* par. 1-9.5

this spiraled conductor. The thickness of the wrap or extrusion will determine the capacitance of the cable. This is followed by a served or braided outer conductor. Protection is usually provided by the use of a vinyl covering or sheath. Construction of such cables can provide delays of 0.040 to 1.1 μsec/ft, with surge impedance values of 900 to 3000 ohms. Applications for this type cable are in radar, timing circuits in conjunction with computors, and television systems.

For a more complete discussion and additional information refer to Ref. 12.

5–12.3 LOW NOISE CABLE

Low noise cables have constructions very similar to conventional coaxial cables except that a semi-conductive material? such as carbon, is dispersed with another compatible material – such as vinyl or polyethylene – and placed over the dielectric core. This semi-conductive barrier, between the dielectric and shield, tends to suppress mechanical noises which develop from unusual mechanical abuses – such as the cable dropping onto a hard surface or receiving a sharp blow.

For a more complete discussion and additional information refer to Ref. 12.

5–13 PRACTICAL CONSTRUCTIONAL CONSIDERATIONS

5--13.1 SIZE

In selecting the size of a coaxial cable the three prime factors which must be kept in mind are attenuation, characteristic impedance, and the capacitance. Determination of attenuation is a function of the power losses in the conductor and dielectric, and with low loss dielectrics, is primarily the I^2R

losses. Therefore, the smaller the center conductor, the larger the attenuation. The ratio D/d – where D is the diameter of insulation or core, and d is the diameter of the conductor – is the prime determining factor of Z_0 and capacitance. The capacitance for a given length will decrease as the ratio *D/d* increases and, at the same time, the Z_o will increase. This is readily understandable by Eqs. 5–2 through 5–4. The most often used values of characteristic impedance in the application of coaxial cables are 50, 75, and 95 ohms. Values exceeding 125 ohms are very impractical since they will necessitate the use of a very small and fragile center conductor, or a very large core and overall diameter.

5–13.2 CONCENTRICITY AND ECCENTRICITY

To insure against variable electrical characteristics, a coaxial cable should be constructed as concentrically as possible. A mechanically perfect cable would be 100% concentric and 0% eccentric. Since capacitance is a function of *D/d*, the capacitance would vary along a line length if the concentricity were varying, and consequently, the characteristic impedance would also have irregularities. These impedance variations stemming from eccentricity are lower, or much less, than those from diameter variation. A 50% concentricity change produces less than a 10% impedance change.

5–13.3 ABRASION

The selection of the cable sheath, in respect to its abrasion resistance qualities, would largely depend on the environmental conditions to which the cable would be subjected. Reference should be made to Chapter 2, "Insulation", in selecting the proper insulation material for specified abrasion-resistant requirements.

5–13.4 CONTAMINATION

In some cases there is an additional requirement for a coaxial cable sheath; it must be noncontaminating. Over a period of time, within the operating temperature range of the cable, any sheath materials used must not leech or exude any material which will pass through the braid or shield and contaminate the primary dielectric material to the extent that it will affect the power factor of the dielectric material. This limits some of the sheath material selection possibilities when using plasticized materials such as vinyl sheaths. The choice of a vinyl sheath material must be such that the ingredients will not damage the electrical properties of the coaxial cable over the specified operating temperature range. It is extremely important that the sheaths be truly a moisture barrier because water, having a very high dielectric constant, will seriously affect the performance of coaxial cable should moisture enter into the cable. See Chapter 2, "Insulation"

5–14 ENVIRONMENTAL CONDITIONS

5–14.1 GENERAL CONSIDERATIONS

The environmental conditions to which a coaxial cable will be subjected is a prime consideration before the actual design of such a cable can be considered. The more important factors are the temperature limits, reaction from contact with foreign agents and fluids, humidity, and altitude or vacuum. Each gage size used in the construction of a center conductor is limited by the amount of current it will pass (see Chapter 1 "Conductors"). The heat that the passing current will generate is also a consideration since it must be kept within the temperature range of the cable core insulation material. Chapter 2 "Insulation" lists the thermal limits of many insulation types available which are presently being used.

5–14.2 INSULATION GUIDE

A guide to the selection of the proper insulation materials with respect to immersion, humidity, and altitude will also be found in Chapter 2 "Insulation".

Coaxial cables will withstand lower dielectric breakdown values, and will exhibit lower corona extinction points, in a partial vacuum. The lowest corona values occur in a vacuum corresponding to approximately 100,000-foot altitude. If environmental factors other than atmospheric are to be encountered, the dielectric properties of the cable should be investigated.

5–15 DISCUSSION OF APPLICATION – MAJOR USAGE

The application of coaxial cables is found in all phases of electronics today. Some of the major uses of coaxial cable are as follows:

a. Construction of electronic equipment

b. Innerconnection for electronic systems of all types

c. Lead in for antennas and interconnection of antenna arrays. Specially constructed coaxial cables with foam dielectrics (low dielectric constant) are adaptable to feed antenna systems for broadcast communications and closed circuit television.

d. Audio frequency applications, because of low cross-talk qualities

e. High voltage pulse applications

f. Low noise cable. Noise may be caused from capacitance changes, and electrical shield noise caused by the resistance of the shield. Some remedies for this self-generated noise are the use of a good conductor material, and the use of semi-conductive materials between the cable core (dielectric) and ground or shield or a mechanically tight shield made with a noncorrosive material such as silver-coated copper.

g. Radar and sonar applications

h. Computer and data processing

i. Multiconductor cables having coaxial cable components for control systems

j. High impedance cable, commonly called delay cable

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CHAPTER 6

CONTROL AND SIGNAL CABLES

6–1 INTRODUCTION

Military control and signal cables are defined as multiconductor cables, shielded and unshielded, for use in circuits 300 and 600 volts root mean square (rms). This chapter considers all component parts, regardless of the number, as being identical in construction (#11 AWG and smaller). Cables utilizing component parts that are not identical are discussed in Chapter 8, "Special Purpose Cables".

6–2 APPLICATIONS OF CONTROL AND SIGNAL CABLES

Control and signal cables are sometimes termed "supervisory cable" and are used for monitoring data recordings and for conveyance of information e.g., communications, telemetering temperature, pressure, flow, indicating lights, and operation of inner connections of protective devices, such as relays, circuit breakers, motor controllers, transformers, panel board control switches, and other current sensing devices.

Control and signal cables are used extensively in the aircraft, missile and space programs, radar, ground support, data processing, etc.

6–3 CONSTRUCTIONAL DESIGN FACTORS

Control and signal cables are, in a great many cases (except when made to a particular MIL-Spec), designed to be incorporated into a particular electrical and electronic circuit and system. Therefore, prior to the actual cable design, the engineer must know, or be able to select, information from the items listed below. Each will be discussed only briefly in this chapter since each has been fully detailed in previous chapters.

a. Number of circuits needed

b. Selection of conductors and insulation (Chaps. 1 and 2)

c. All electrical requirements (such as voltage and current ratings, DC resistance, attenuation, impedance, insulation resistance, capacitance, cross-talk, etc. (Chaps. 3 to 5)

d. Cable use – portable or nonportable

e. All mechanical and environmental conditions to which the cable will be subjected.

The required cable may be a simple twisted pair—designed in a similar manner to cables listed in MIL-C-27072, MIL-C-55021, MIL-C-13777, and MIL-C-3432 – or it might be a large multiconductor cable applicable to the same specifications. Some engineers deem it good practice to provide for 2 or 3 extra circuits, to be used as spares, when designing a cable. The main functions to be considered in the design of a multiconductor cable are discussed in detail later in this chapter.

6–3.1 PHYSICAL CONSIDERATIONS

If it is known a cable will be subjected to great amounts of flexing, then a stranded type conductor should be considered rather than a solid type. Selected conductors must also be capable of carrying the required current. Conductor insulations are mainly selected considering temperature limits, voltage ratings, current ratings, size, and cost. Voltage rating for control and signal cable is nominally 300 and 600 volts (rms). By taking advantage of the high volt-per-mil rating of insulating materials available today, minimum diameters can be obtained. A great amount of basic insulated wire, constructed for cable use, is made in accordance with MIL-W-16878D. Control and signal cables are nominally operated using low values of current, however, it should be kept in mind that the current capacity of an insulated wire is limited by temperature. The operating temperature of the wire, which is the ambient temperature plus the temperature increase due to current flow, should not exceed the temperature rating of the insulation. For example, using an insulation rated at 105°C, and operating the wire or cable in a 90°C ambient temperature, the maximum allowable increase in temperature due to current flow will be 15°C. For more detailed information on conductors refer to Chapter 1. For insulation, refer to Chapter 2.

6–3.2 ELECTRICAL CONSIDERATIONS

Electrical parameters – such as DC resistance, attenuation, and impedance – may or may not be a specific consideration. If these were definite requirements, then other parameters – such as capacitance, dielectric constant, and velocity of propagation – would also enter into the proper cable design. This would hold true particularly if the required cable were to be a multiconductor cable consisting of a group, or groups, of coaxial cable whose primary function is to match some type of input cable, and output is to be matched to a particular characteristic impedance. Minimum attenuation may also be a requirement in this case, and because attenuation is primarily affected by the I^2R losses of the line, the resistance of the line should also be kept to a minimum. At the same time, the low attenuated signals may require fast travel time, and since the velocity of a propagation is mainly affected by the dielectric constant of the insulating materials, the proper compound must be selected. Chapter 5, "Coaxial Cables", discusses all these electrical parameters in detail and is a helpful guide in the design of the cable type discussed here. Cable "cross-talk" may be minimized by cabling technique of multiconductor cables and is discussed par. 6–7.

6–4 CABLE TYPES

Control and signal cables are classified in two distinct types: "portable" and " nonportable", each of which is discussed.

6–4.1 PORTABLE

Portable types are those cables specified in MIL-C-13777E. Portable cable is a configuration that may be moved many times or used in temporary installations which might impart abusive handling. The portable cable construction must employ a much more flexible and tougher sheathing, such as polychloroprene, and may possibly require special constructional engineering to enable the configuration to withstand the impacting, bending, and/or twisting encountered in its use. (Impact, bend, and twist testing and test fixtures are discussed in par. 6–7.

Cables constructed to MIL-C-3432 are actually closely related to commercial type cable. This specification covers the design data for low-, medium-, and heavy-duty cables. These cables are also of an all rubber construction which is rapidly becoming obsolete and being replaced by polychloroprene sheathed cables which are superior to rubber for environmental and mechanical reasons. Polychloroprene is more resistant to oil-based fluids, less affected by ozone, and is less susceptible to damage due to temperature and humidity changes. Cables constructed to MIL-C-3432 for use as portable-type cables are not recommended. Environmental and mechanical guarantees, such as given with cables constructed to MIL-C-13777E, cannot be expected.

6–4.2 NONPORTABLE

Nonportable types are those cables specified in MIL-C-27072. Nonportable types of cable are used in a permanent installation where the cable is not intended to be moved or abused to any great extent; therefore, the physical requirement would not be as stringent as for the portable types.

Regardless of the type, portable or nonportable, there are environmental and mechanical factors which should be given consideration. Pars. 6–5 and 6–7, "Multiconductor Cable Design" and "Multiconductor Cable Testing", cover these requirements in detail.

6–5 MULTICONDUCTOR CABLE DESIGN

6–5.1 GENERAL CONSIDERATIONS

A multiconductor cable may be interpreted as two or more conductors in any one complex. Normally speaking, a two-conductor cable is called a pair; three-conductor, a triplicate; four-conductor, a quadruplicate; and five-conductor, a quintuplicate. In this chapter we will be concerned mostly with the larger configurations of ten and more conductors. Multiconductor control cables have a large number of identical components cabled together to form a complex. The overall cable must be as physically round as possible, light weight as possible, small as possible in overall diameter, and not contain a great number of large air spaces or voids. All these considerations – plus the flexing quality, physical abuse, and electrical parameters – must be taken into consideration in the design of the completed complex.

6–5.2 SPECIFIC CONSTRUCTION CONSIDERATIONS

The following is a breakdown of the main functions to be considered in the design and manufacture of a multiconductor cable complex:

a. Insulated conductor components

b. Cabling or twisting of conductor components

c. Shielding or braiding

d. Fillers

e. Binders

f. Sheathing

g. Armor

Fig. 6–1 is a typical multiconductor cable design showing the relative location and use of each of the above-mentioned categories.

Table 6–1 considers all conductors, or components, as being equal in size, and will be helpful in determining the overall size of various configurations. A multiplying factor is used, multiplied by the diameter of one conductor or component, to give D the calculated diameter of the twisted components

$$D = fd \text{, in.} \tag{6–1}$$

where

f = multiplying factor from Table 6–1

d = diameter of single component, in.

6–6 MULTICONDUCTOR CONSTRUCTION

We shall now consider each of these categories individually, explaining the functions and design criteria of each separately.

6–6.1 CONDUCTORS AND COMPONENTS

First, it is necessary to understand that a cable component is not necessarily one insulated conductor; the component could be a group of insulated

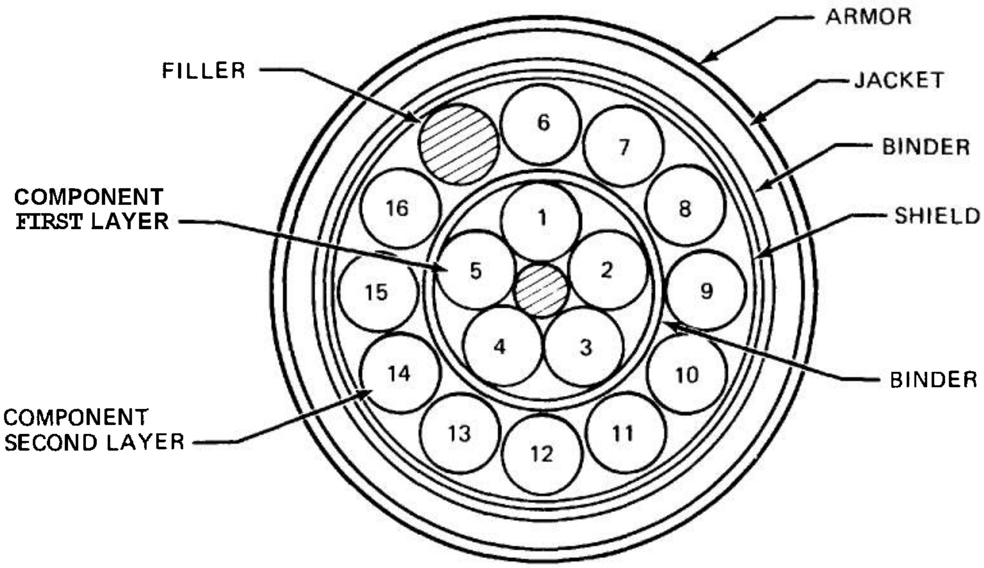


Figure 6–1. Typical Multiconductor Cable Design

TABLE 6–1

COMPONENT TWIST–DIAMETER MULTIPLYING FACTOR

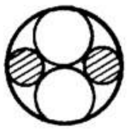
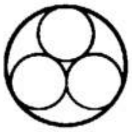
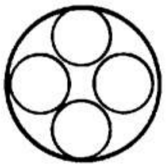
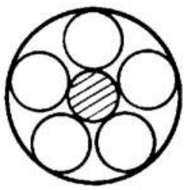
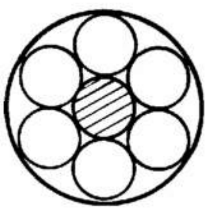
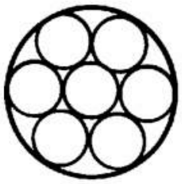
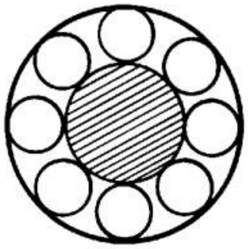
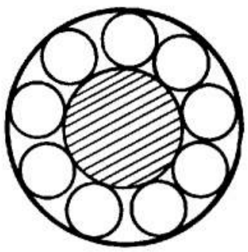
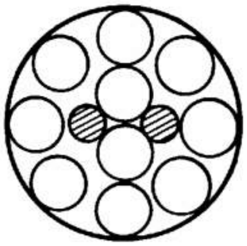
Cable Design Configuration	No. Conductors	Multiplying Factor f
	2	2.0
	3	2.15
	4	2.41
	5	2.70
	6	3.0

TABLE 6–1 (CONT.)

Cable Design	No. Conductors	Multiplying Factor f
	7	3.0
	8	3.35
	9	4.0
	10	4.0

conductors. To define the term "cable component", we could say a component is any completed member that is to be placed within the complete unit. For example, a cable may contain sixty (60) conductors divided into twelve (12) components of five (5) conductors each, every component having the same construction; or it could contain five (5) components, consisting of two components of eight (8) conductors each, two components of fourteen (14) conductors each, and one component of sixteen (16) conductors, each component containing a different construction. Component conductors are chosen with regard to (1) the environmental and performance requirements such as flexibility, thermal environment, cold bend qualities, voltage, current and (2) installation needs such as solderability, pottability, etc.

6–6.2 COMPONENT STRANDINGS

Generally, there are three basic strandings used in the construction of cable components (see Chapter 1).

1. Concentric. The concentric stranding is recommended for sizes equal to and smaller than #10 AWG where flexibility and conductor concentricity are essential. This is almost mandatory if thin-wall insulations are to be used.

2. *Bunch.* The bunch stranding may be used for conductor sizes of #10 AWG and smaller where heavy wall insulations are needed and economy is a prime factor. Bunch stranding, however, should only be employed where medium or heavy insulations are specified because it is not a truly round construction and may have high strands which would result in a dangerously thin wall at the high strand point.

3. Rope. Rope stranding is recommended for the larger AWG sizes in order to maintain good flexibility.

6–6.3 BASIC INSULATED WIRE.

The conductor insulation can be one or a combination of materials, dependent on basic overall cable construction, environment, and function. All environmental and electrical factors must be considered in the proper selection of the basic insulation. Refer to Chapter 2, "Insulating Materials," for selection of the best insulation. Where the wall thickness of the primary insulation if 0.015 in. or less, the use of extruded nylon as an insulation covering is recommended, and particularly for conductors used in temperatures up to 105°C where excellent cut-through resistance and abrasion resistance is required. In shielded components, where insulation walls are less than 0.015 in. thick, the use of nylon or a high temperature equivalent protective insulation covering is necessary to prevent short circuits from developing due to the braid ends puncturing the thin insulation. This type of protective covering has been highly successful for use in cables where physical abuse is high, and is particularly effective in the protection it affords shielded components. Even though the nylon insulation covering used in multiconductor cables adds to the stiffness of the component, it does not decrease the overall flexibility; on the contrary, increased flexibility is usually obtained due to the extremely smooth surface of the nylon, which tends to reduce the binding effect between adjacent layers when the cable is flexed. Extruded nylon would normally be found on #12 AWG conductor size and smaller. For the larger AWG sizes a saturated nylon braid may be used, but generally, a heavier wall of insulation is supplied with no additional covering. Refer to Table 7-16.

6–6.4 COMPONENT SHIELDING

In many components, and in many overall configurations, the use of a shield may be required. In the majority of components the generally accepted AWG size wire used for shielding is #38, #36, or #34. For larger overall shields the use of AWG #32 or #30 wire may be required to obtain the correct coverage. The **#38** AWG wire for shields, in general practice, is only used for very small components or cables where a minimum size is a definite requirement. Table 6–2 lists the recommended shield braid wire sizes for specified core diameters, or the overall shielding over the assembled components. Also listed is the approximate increase in size due to the shield application.

The overall shield coverage usually specified on cable components, and overall shields, is between 85 and 90 percent, and is dependent on the cable core size, number of carriers, number of picks per inch, and number of ends per carrier. It has been found, however, that a shield coverage of 75 percent is usually adequate and results in lower cost and lighter weight. The equations for calculating shield coverage and braid angle can be found in Chapter 1, "Conductors."

TABLE 6–2

DIAMETER INCREASE DUE TO SHIELD APPLICATION

Core Diameter, in.	Shield Braid Size, AWG	Added Increase in Diameter, in.
0 - 0.05	#38	0.017
0.051 - 0.300	#36	0.022
0.301 - 0.900	#34	0.027
0.901 - 1.700	#32	0.034
1.700 and up	#30	0.044

In order to facilitate terminating a shielded conductor or component, it should have good shield "push back" qualities; i.e., the shield must easily push back, or slide away, from the cut end of the conductor or component. This quality is obtained by the use of a correct braid angle which is calculated relative to the axis of the conductor. It has been found that a 20" to 40° angle will assure adequate push back of the shield for termination purposes. Fig. 6–2 pictorially shows this angle.

It is noted in Fig. 6–2 that points A and B denote the braid angle relative to the axis of the conductor; it can readily be seen that the wider the angle, or closer to 90" this angle becomes, the more difficult it becomes to push or slide back the shield. On larger cable core diameters it is not always possible to maintain a braid angle in the 20" to 40" range, therefore, in cables with a core diameter in excess of approximately 0.400 in. the shield angle shall be the lowest possible.

6–6.5 COMPONENT SHIELD COVERING AND COMPONENT JACKET DIMENSIONS

In a multiconductor construction, it is advisable that a shield covering be used for various reasons. This is felt to be necessary even though the shields may be electrically common at point of termination. One of the reasons for a shield covering is to protect unshielded, insulated conductors from mechanical damage by adjacent shields. This is necessary because of the abrasion produced between shielded components and unshielded components, which in time may actually wear through the insulation causing a short circuit. Another reason is the prevention of random noise generation and electrical interference that may occur when the cable is flexed. This covering will also help prevent electrical distortion and cross-talk in a conductor, caused by ground loops within the cable complex. It also prevents abrasion between the shields of adjacent conductors. The two most common shield coverings for low temperature applications are extruded nylon and a lacquered nylon braid. A shield covering must not be confused with a shield insulation for driven shields. Neither of the above materials is considered good for dielectric insulation protection. For dielectric protection, or shield insulation, a heavier wall of an insulating material–such as polyethylene, vinyl, or polyester/polyethylene–would be recommended.

Dimensions of component jackets for light- and medium-duty cables should be in accordance with Table 6–3. The minimum wall thickness at any cross section should not be less than 70% of the average wall thickness at the cross section.

6–6.6 CABLING

The cabling, or twisting, operation is a very important function. Its primary effects are felt in the mechanical performance of the cable. In the design of a multiconductor complex the conductors should be so arranged in the overall design that a flexible, circular, cross section, with the smallest possible overall

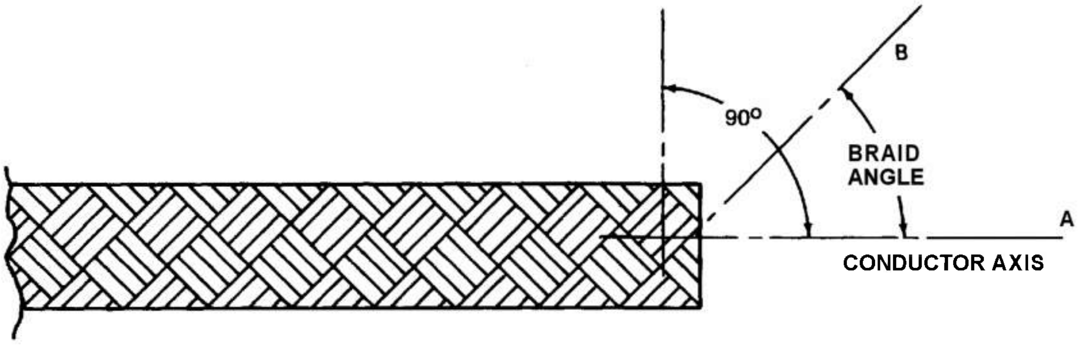


Figure 6–2. Braided Shield Angle

diameter will be obtained. The planetary-type cabling or twisting machine keeps all components in the same plane and eliminates any twisting action of the individual components of a complex.

6–6.6.1 Lay

In the design of a cable complex, cabling lay length is important. "Cable lay length" is the distance of advance, measured axially, of one turn of any one component within the cabled group. For good cable design, lay length should be eight to sixteen times the "pitch diameter" of the layer in which the component is a member. A longer lay causes excessive stiffness; a shorter lay is expensive and may contribute to conductor or component damage during cabling. In the selection of the lay length, use as long a lay as possible consistent with flexibility and electrical parameters required. Use a short lay when hard core cable is desirable for flexibility, or to allow adjacent layers to be cabled without the components falling into the component interstices of the underlying layer.

TABLE 6–3

AVERAGE WALL THICKNESS–SHIELD COVERING (LIGHT- AND MEDIUM-DUTY)

Component OD, in.	Shield Covering, in.		Shield Insulation, in.			
	Nylon Ext. Wall	Nylon Braid Wall	Polyester/ Polyethylene Tape	PVC	PE	TFE or FEP
0.000 - 0.100	0.004	—	0.006	0.010	0.010	0.008
0.101 - 0.200	0.006	—	0.006	0.013	0.013	0.010
0.201 - 0.250	0.008	—	0.006	0.0 13	0.013	0.012
0.251 - 0.500	—	0.007	0.006	0.018	0.018	0.015
0.501 - 0.750	—	0.007	0.006	0.027	0.027	0.020
0.751 - 1.000	—	0.007	0.006	0.035	0.035	0.025

6–6.6.2 Pitch Diameter

"Pitch diameter" refers to that diameter which is twice the distance measured to the center of any conductor or component from the center of the cabled core. Fig. 6–3 depicts lay length and Fig. 6–4 shows pitch diameter.

6–6.6.3 Lay Construction

Cable lay may be either of two constructions:

1. Unidirectional Lay–meaning all component layers twisted in one direction, with either a right or left hand lay.

2. Contrahelical Lay–(Fig. 6–5) indicating all component layers twisted so that each component layer has a lay that is opposite in direction from each preceding component layer.

Unidirectional lay, or all layers twisted in the same direction, is recommended for cables that are required to withstand physical abuse, or where maximum flexibility is required. Where physical abuse or flexibility is not a problem, cables utilizing contrahelical lays may be used. In a contrahelical type construction the use of fillers is held to a minimum because of the opposite direction lapping of the components in adjacent layers. When using the unidirectional lay, each layer must be full and round with no large voids. This must be done to prevent components of the above layers from falling into the cable interstices, or voids, in the under layers caused by poor component spacing. Each succeeding layer should have a different lay length to keep the layers concentric.

6–6.7 CABLE FILLERS

Fillers in a cable are used for various reasons. The two most common are as a center core and as a replacement for missing or unnecessary components in order to maintain the firm and full outer perimeter of a layer. Filler materials are available in many forms, and are composed of nearly every known material. Some of the more common forms and materials used are jute, cotton-polyethylene tubes, rods, or twisted film, polyvinylchloride rods or tubes, Fiberglas, nylon, and asbestos yarns. The filler material must, of course, be compatible with the rest of the cable materials used and must perform the requirements of the pertinent specification. As an example a PVC filler material would not ordinarily be used in a cable employing Teflon components because a Teflon-type construction would be expected to have a high temperature requirement.

A fibrous type filler–i.e., cotton, nylon, etc.–is most frequently used as a core filler or to fill the larger cable interstices, because of their softness, ability to crush into place, and low cost. This is particularly true when cables must withstand severe flexing and/or abuse. Fibrous fillers, however, have the disadvantage that they will wick moisture into the cable; twisted

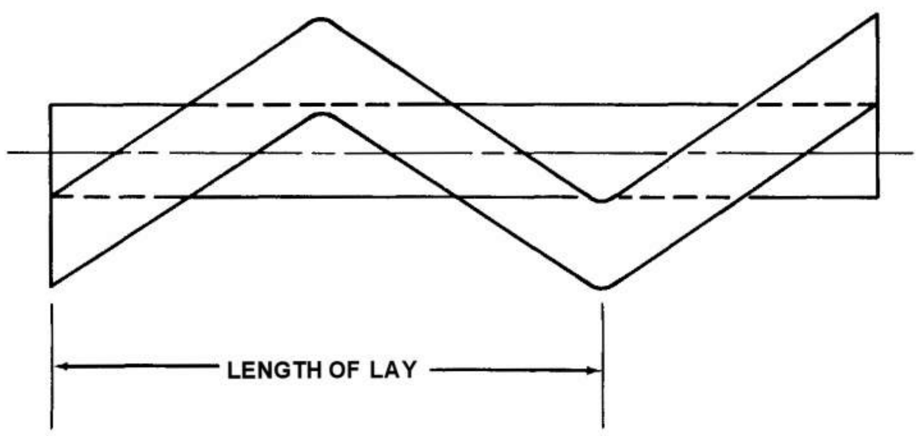


Figure 6–3. Length of Lay

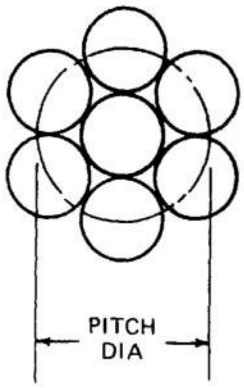


Figure 6–4. Pitch Diameter

polyethylene film type fillers, if exposed, will also wick moisture into the cable.

6–6.8 COLOR CODING CONTROL AND SIGNAL CABLES

The use of color coding in a cable is frequently required for circuit identification where it is impractical to electrically check both ends of the cable after installation. There are many methods of color coding a multiconductor cable, and in many cases the cable construction will determine the method of color coding.

6–6.8.1 Color Coding Methods

A few of the more common methods of color coding are:

a. Color coding the primary dielectric or jacket using colored compounds.

b. Single, solid color extrusion, usually white, and then ink striping–using vari-colored, spiral, longitudinal, or hash mark stripes.

c. Where textile braids are used, the use of vari-colored textile strands or carriers in order to weave in a colored stripe.

d. The use of printed words or numbers to denote the color desired.

e. The use of a worded or numbered tape, applied spirally or longitudinally to the primary dielectric, or under the shield or sheath.

6–6.8.2 Color Code Application

When using the striping method of color coding, the stripe sequence is designated as follows: a "base stripe",

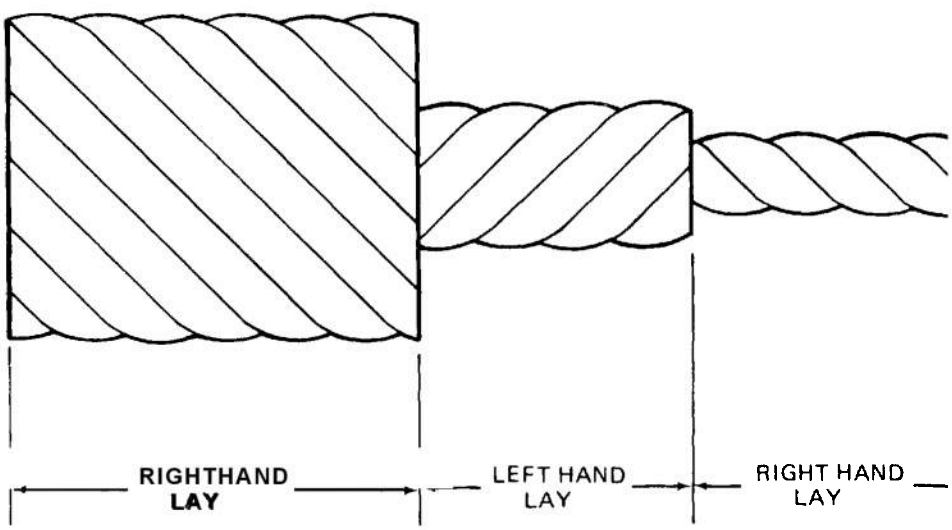


Figure 6–5. Contrahelical Lay

or wide stripe, will be applied as a continuous helical stripe. The base stripe may also be the main body color of the primary insulation. The base stripe is distinguishably wider than any of the succeeding stripes in the color group. The succeeding stripes in the group are called tracer stripes. All stripes will be separated from each other, and from each group, by not less than the width of the succeeding stripe.

The application of the colored stripe will be accomplished by the use of inks or materials containing pigments or dyes which are least affected by sunlight or the various plasticizers used in the manufacture of the plastic material being striped. They must remain fast under the effects of operating temperature and humidity, and be free from fading under normal operating conditions and handling. They must be impervious to abrasion during handling, be unmistakably readable under incandescent lighting, and be nonconductive. The length of "lay" of the colored stripe should be as indicated in Table 6–4.

The stripe width is measured perpendicularly to the axis of the stripe. The width of the base stripe, or widest stripe, will be 0.031 in. minimum when the striping surface is 0.047 in. or larger. When the striping surface is 0.046 in. or smaller, the base stripe must be not less than 2/3 the nominal diameter of the striping surface. The narrow, or tracer stripe, will in all cases be not less than 1/2 the width of the base stripe when single stripe coloring is used. The spacing between stripes should be not less than twice the width of the base stripe.

6–6.8.3 Color Code and Related Numbers

Standard colors and their related numerical values should be as shown in Table 6–5.

The color coding sequence – using numbers to designate colored stripes – is: if three stripes are required, the second narrow, or tracer, stripe is of a higher numerical value than the first narrow, or tracer, stripe. As an example, the numbers shown in Table 6–5 would be used as follows: A solid black wire would be number 0, a solid red wire, number 2, etc. Numerical number 92 would indicate a white insulation with a red base stripe. Numerical number 936 would indicate a white insulation, an orange base stripe, and a blue tracer stripe. A three stripe color coding would follow the same pattern, i.e., numerical number 9147 would indicate a white insulation, a brown base stripe, and tracer stripes of yellow and violet, in that order.

6–6.8.4 Specifications

Standards have been set on the depth and shade of the coloring used in the striping of wire. The standards used on wire for military use are usually MIL-STD-104, MIL-STD-686, and MIL-STD-681, in which the limits for electrical insulation colors are established. The light and dark colors, as established by these Specifications, are the extremes within which the color of the insulation must fall, when so required. The Military Specifications regarding color coding or marking are:

a. MIL-STD-104

b. MIL-C-13777E*

c. MIL-STD-686

*This specification spells out color coding methods and values for cables pertinent to this specification.

TABLE 6–4

STRIPING–LAY LENGTH

Diameter of Striped Surface	Up to 0.088 in.	0.089 in. - 0.110 in.	0.111 in. and up
Length of Lay Maximum	1.0 in.	1.5 in.	2.0 in.

TABLE 6–5

COLOR CODE AND RELATED NUMBERS*

Color Number	Color Indicated
0	Black
1	Brown
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet
8	Gray
9	White

* From Ref. 6

6–6.9 CABLE BINDERS

When twisting components, or groups of components, together into a completed cable over which an outer shield or sheath is to be placed, it is important for this core to be held together so (1) the original cabled shape will be preserved, (2) the electrical properties of the component groups will not be disturbed, and (3) the outer extruded sheath material will not adhere to the inner components, making the cable nearly inflexible and very difficult to strip for termination. This material, or layer, is called a binder or separator, and may be applied in various methods. The most common method utilizes a tape which must be of a material which is compatible with both the cabled components and outer sheathing material. The more common tapes used for this purpose are polyethylene terephthalate (Mylar), polyvinylchloride (PVC), polyethylene, Teflon, polypropylene, silicone-impregnated glass, PVC-impregnated cotton, laminated Mylar and aluminum, and Teflon-impregnated glass. Depending upon the cabled construction, and/or cable requirements, this tape is usually helically wound with the overlap from 75 percent to open. The most common tape wrap utilizes a 50 percent overlap. The percent overlap is determined as the amount the leading edge of one wrap overlaps the trailing edge of the preceding wrap, expressed as a percent of tape width. A butt wrap is where the trailing edge of one wrap just meets the leading edge of the preceding wrap, giving 100 percent coverage., but no overlap. An open wrap is where a space is left between the trailing and leading edges of the tape, giving less than 100% coverage. Another application method of a binder or separator is using a fibrous, woven or braided material, such as cotton, nylon, or glass. In some instances this method is required because of the rough surface formed by the woven or braided binder. The rough surface offers excellent bonding qualities to the outer sheath extrusion. Normally, the braided fiber-type binder or separator is used in cables which are required to absorb heavier abusive treatment. In many instances a Mylar tape binder is used to hold the cabled components in place during manufacture since it can be applied immediately at the cabling machine; this application is followed by a braided fiber separator.

6–6.10 CABLE SHEATHS

The overall covering of a cable is a very important feature of the overall cable design, both from a service and appearance standpoint. There are many extrudable sheathing materials in use today. Some of the more common materials are polyethylene, polyvinylchloride, polychloroprene, tetrafluoroethylene (TFE), fluorinatedethylene propylene (FEP), silicone rubber, natural rubber, butyl rubber, and nylon. There are varied reasons why certain materials are required, or would be chosen, for an overall cable sheath. A few of the more common reasons for a certain sheathing material selection are flexibility, abusive treatment protection, moisture resistance, underground or under water installation, exposure to unusual climates or environments, weight of overall cable constructions, relative costs, etc. For further detailed information on physical and electrical aspects of sheathing compounds refer to Chapter 2.

Shown in Table 6–6 are some of the more common sheathing materials and their properties.

6–6.11 SHEATH APPLICATION

There are several methods for application of sheaths or outer jackets on control and signal cables. It is found, however, that the conventional extrusion method, using thermoplastics and rubber compounds is the most satisfactory and most often used. With this method the tooling is adjusted to produce a tight extrusion. The tubing method is also used. Unlike the conventional extrusion process, the tubing method does not impregnate the construction beneath the sheath, but does follow the general contour or shape of the underlying core. This method produces a slightly looser sheath construction than the extrusion method. Polyester tape wraps are sometimes used as cable sheaths or jackets. Heat sealing of the wrap to produce a continuous sheath may or may not be required. This of course will depend upon the environmental and mechanical conditions encountered. In most cases this tape wrap is followed by an additional extruded sheath. The method of applying "blown-on tubing" has become obsolete, except for cable harnessing. This method requires the forcing of air into a length of tubing which expands it to a point where the underlying core may be passed through. The air pressure is then removed and the tubing (smaller ID than the OD of the core) allowed to return to its normal size. This method is frequently used with harnesses which require many breakout points. Because the sheath will be broken at these breakout points, molding processes around these breakout areas are normally employed. A primary objection to this method is that the sheath is continuously under stress and, therefore, any nicks or splits will propagate down the cable length.

Construction of elastomeric cable sheaths falls basically into one of two categories, i.e., reinforced or nonreinforced. See Table 6–7.

A reinforced construction has a reinforcing layer composed of an open braid between two layers, or walls, of sheathing compound. The two layers of sheathing compound join and vulcanize together in the open spaces between threads and adhere to the thread yarns. The most common reinforced sheath employs cotton or seine twine braid, or a left and right serving of reinforcing agent. The construction can be seen pictured in Fig. 6–6.

As noted in Fig. 6–6 the reinforcement would be the seine twine braid.

6–6.12 ARMOR

Because of the extreme abuse a cable is required to absorb during or after installation, more protection is often required than any sheath alone can give. In this case an overall armor is applied. Since the armor will be continuously exposed to the elements, it must not rust or corrode under any condition or climate; it must absorb unusual punishment without rupture or fraying and still afford protection to the outer sheath; and it must be flexible enough to be usable in any normal installation. The armor on a cable is usually constructed utilizing one or more of the following: aluminum, stainless steel, galvanized steel, or beryllium-copper. The armor may be in a braided form, serving in either single or double layer, or in a solid tube (smooth or corrugated). When aluminum braid is used, it should be painted with an aluminum paint to prevent oxidation and deterioration of the aluminum strands. It is not considered practical to apply armor to cables of less than 0.3 in. in diameter. It is recommended that a #28 AWG wire strand be used to construct the armor braid. When employing aluminum armor and paint, it is very important that the aluminum paint chosen be chemically compatible with the underlying sheath material used. The characteristics of an armor, such as percent coverage and braid angle, are calculated using the same formula–i.e., Eq. 1-4–as any inner shield.

TABLE 6–6

SHEATHING MATERIALS AND THEIR PROPERTIES

Usage	PVC 90°C	Polyethylene	Arctic Polychloroprene	FEP	Polyurethane
	Continuous Operating Temperature				
Stationary Installation	-85° to 90°C	–85" to 85°C	–55" to 75°C	–200" to 200°C	-55° to 90°C
Flexed Installation	-10° to 90°C	-85" to 75°C	-55° to 75°C	-55" to 200°C	–55" to 75°C
Abrasion Resistance	Good	Excellent	Good	Fair	Excellent
Ability To Take Impact Loading	Fair	Fair	Excellent	Poor	Excellent
Flexibility 30°C	Good	Good	Excellent	Good	Excellent
Crack Resistance 0°C	Fair	Good	Excellent	Good	Good
-40°C	Poor	Good	Good	Good	Good
Fluid Resistance (continual soak)	Swells or dissolves in hydrocarbons present in fuels and lubricants. Resists alcohol and paraffin based oils. Dissolves in ketones and esters.	Swelled by some fuel hydrocarbons above 60°C. Resists alcohol, minerals, acids, and alkalis.	Resistant to oils, greases, and most solvents. Attacked by chlorinated hydrocarbons and benzene based solvents. Resistant to alcohols.	Not measurably attacked by any known fluid within useful temperature range.	Resistant to oils, greases, alcohols. Swells in ketones and chlorinated solvents. Water immersion qualities poor (ester types). See Chapter 2

Note

Fluid resistances noted in Table 6–6 apply to continuous soaking. Occasional spillage of reactive solvents will generally have little or no effect upon cable capabilities or service.

TABLE 6–7

COMMON OVERALL POLYCHLOROPRENE SHEATH—WALL THICKNESS

Diameter of Cable Under Sheath, in.	Minimum Sheath Thickness, in.	
	Nonreinforced	Reinforced
0.425 or less	0.040	0.090
0.426 to 0.700	0.050	0.090
0.701 to 1.000	0.070	0.1 10
1.001 to 1.500	0.090	0.125
1.501 to 2.000	0.1 10	0.140
2.001 & larger	0.125	0.155

It has been found that an armor coverage of approximately 80% will give adequate physical protection to a cable under moderately heavy abusive conditions and an armor braid angle of approximately 50" to 55°, especially on the larger cables, allows sufficient flexibility during normal installation.

For very severe abuse, as experienced in submarine telephone cable or oil well down-hole cable, a double serve of very heavy steel strands, laid contrahelically with 95%-100% coverage on each layer, is used over the sheath. These strands may be up to 0.25 in. in diameter.

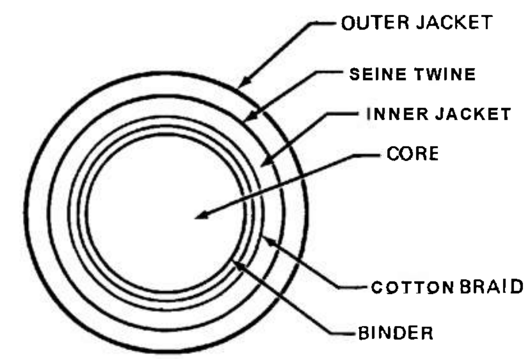


Figure 6–6. Reinforced Sheath Configuration

6–6.13 CABLE IDENTIFICATION MARKING

In most cases a cable is required to have a manufacturer's identification and cable nomenclature information as an integral part of the cable construction. This may be done by one of two basic methods: (1) the outer sheath of the cable may be printed, using an indented marking, an ink .marking or print applied longitudinally, or (2) if this is impractical because of an overall armor or unprintable sheathing material or contour, a printed tape is inserted in the cabled core or under the outer sheath. This printed tape is generally made of a material that will conform to the cable test requirements. Printed tapes of Mylar, cotton, glass, and Teflon-impregnated glass are some of the more common types used. In addition to using these tapes as identification markers, it sometimes becomes necessary for a user to have a serially numbered footage marker tape inserted into the cable for installation convenience. These tapes usually have a width of 1/8 in. They are also manufactured in 3/16 in. and 1/4 in. widths although any width down to 1/16 in. can be obtained with the desired printed information.

With some materials, such as **PVC,** the indent method is sometimes injurious to the sheath because the depth of the letter indentions onto the sheathing compound cuts the wall of the sheath down to the depth of the embossing and thus may affect cold bend properties.

6–7 MULTICONDUCTOR CABLE TESTING

6–7.1 CABLE CROSSTALK

Cross-talk in a multiconductor cable is the phenomenon of any conductor, or group of conductors, having sufficient electrical or magnetic coupling to induce the signal into another conductor, or group of conductors, adjacent to it. The solution to this type of problem is to either contain the signal or to insure that the induced voltages will cancel as much as possible within the given conductor, or group of conductors. With single conductors this is accomplished by the application of a shield over the individual conductor. Shielding is considered in Chapter 5. The cross-talk, or leakage, in a cable component becomes increasingly worse with the increase in frequency and/or level of the inducing signal.

Adequate cross-talk reduction may frequently be achieved in paired constructions without the expense of shielding by carefully controlling capacitance unbalance, and by varying the lay of adjacent twisted components within any layer and from layer to layer. Changing the direction of lay from right hand lay to left hand lay in adjacent components within any one layer also is helpful.

A typical example of a twisted pair, multiconductor complex is shown in Table 6–8. The cable construction shown in this table employs the lay variance method, with unidirectional lay, which may be accomplished on conventional twisting machines and is as effective as the opposite direction lay method in cables employing two or more layers.

Control cables usually do not have cross-talk requirements.

6–7.2 TESTS AND TEST METHODS

The requirements of a multiconductor cable dictate the tests needed. Listed are the more common tests called for in multiconductor cable construction. A discussion of the tests, methods, and the effects they have on constructional design engineering follows.

6–7.3 MULTICONDUCTOR CABLE TESTS

Tests to be considered are:

a. Cold Bend

b. Impact

c. Torque

d. Twist

e. Bend

TABLE 6–8

Pair Location	Pair No.	Right Hand Lay, in.
Core	1	2.00
	2	2.50
	3	3.00
First Layer	4 - 6 - 8 - 10	2.75
	5 - 7 - 9 - 11	2.25
	12	3.25
Second Layer	13 - 15 - 17 - 19 - 21 - 23 - 25	2.50
	14 - 16 - 18 - 20 - 22 - 24	2.00
	26	3.50

f. Dielectric (AC and DC)

g. Insulation Resistance

h. Capacitance (Mutual and Unbalance)

i. Abrasion Resistance

j. Tensile or Breaking Strengths

k. Cross-talk

6–7.3.1 Cold Bend Test

A cold bend test is performed on a cable to determine if all materials used are compatible with the lowest operating temperature required, and whether processing has been correct, i.e., is the cable structurally engineered to withstand a bend at the required lowest operating temperature, and what effect will the sub-zero temperatures and severe bending have on the cable electrically? The majority of cold bend tests require a mandrel diameter that is ten times the overall cable diameter. The cable is usually arranged so that one end is attached to a mandrel and a carefully specified weight attached to the free end of the cable. This weight is enough to keep the free end of the cable straight at the required temperature while the cable is undergoing the bend test. The attached end of the cable should be wound at least one turn on the mandrel prior to reducing the temperature to be sure of a smooth start.

It is important to remember, when evaluating cold bend test results, that data received on cable cold bends are from a controlled bending rate. Sudden sharp bends, or rapid unreeling of cable at lowered temperatures, may shatter a cable that has passed the cold bend test at identical temperatures under controlled speeds.

It is essential, for test reproductibility, that the bending rates be maintained by power driven apparatus. Hand bending is useless because of the variability of rate. It is necessary, then, to specify the greatest anticipated bend rate and incorporate this in the cold bend test required. Bending must also be conducted within the cold chamber without opening the doors. A very slight exposure to a room temperature draft invalidates the test; this exposure causes the surface of the wire to warm and greatly improves the cable's chance of passing.

6–7.3.2 Impact Test

The impact test–whether performed at room temperature, elevated temperatures, or lowered temperatures–is designed to show the result of a continuous, measured impact on the cable materials, and how this controlled impact affects a cable electrically. In some cases an impact on a cable would show no injurious effects to the cable sheath but, with improper internal construction, could break or damage one or more of the internal components, causing electrical short circuits or conductor opens due to internal component damage. A typical impact test jig is pictured in Fig. 6–7.

This test simulates vehicular traffic over a cable, backfilling with stones over directly buried cable, and other physical abuse.

As noted in Fig. 6–7, a cable design is engineered to withstand a certain specified weight in pounds, dropping a specified distance, and impacting a specified area at a specified rate of impacts per minute. During impact all cable conductors, including any inner or outer metallic shields, are electrically tied in series and a specified electrical load imposed throughout the cable configuration. The testing apparatus is equipped with a counter, and any conductor or shield short or open circuit automatically stops the impact testing apparatus, showing exactly how many impacts were absorbed in the given area before breakdown.

6–7.3.3 Torque Test

Torque tests and twist tests are very similar in technique, the only difference being the information sought. A torque test is designed to find the force required to twist or bend a cable at a specified temperature, usually the lowest temperature at which the cable will be handled. The test data sought are how flexible a cable construction is at a given temperature. This is generally accomplished by use of a torque wrench attached to a mandrel end outside the environmental test chamber, with the cable arranged as for a cold bend test. This test must be run through once at a specified temperature, without the cable, to determine the amount of friction of the apparatus.

6–7.3.4 Twist Test

A twist test is concerned with how many twists of a given nature can be absorbed by a specimen before

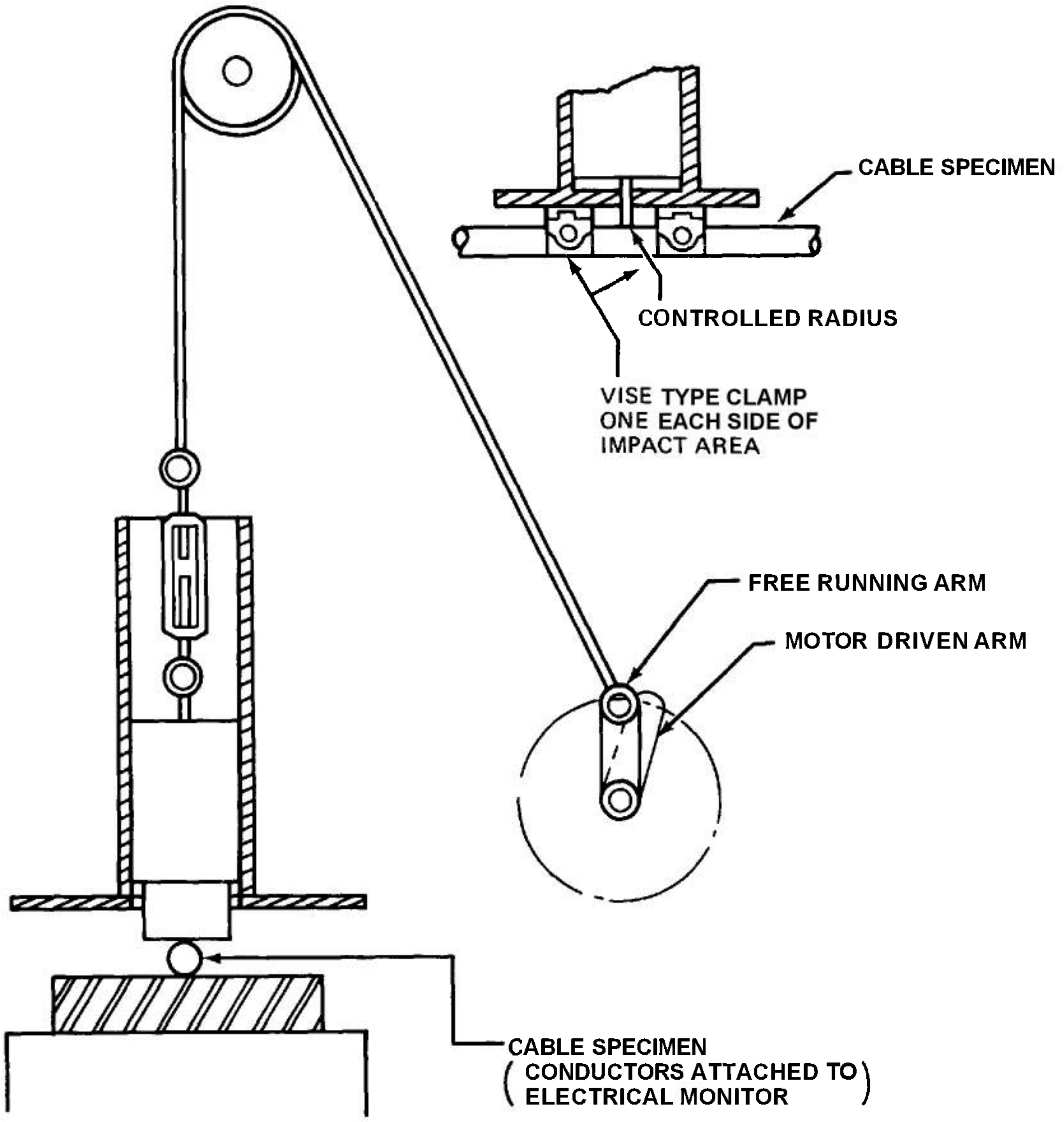


Figure 6–7. Impact Test Fixture

destruction. This test is accomplished by attaching a given weight to the free end of the specimen, and twisting the weight, which in turn rotates one end of the specimen a given amount with respect to the other end. Fig. 6–8 shows a common twist apparatus which is especially severe because bending occurs over the top sheave, while twisting occurs between the sheave and the weight.

As can be seen by Fig. 6–8, the weight slides a predetermined distance at a given rate, inflicting both a 180" twist (±90° from center) and a 180" bend' simultaneously. During this test voltage is imposed between all conductors and shields, with alternate wires tied electrically in series, to determine when conductor failure or short between conductors occurs. This test may also be conducted at any required temperature.

6–7.3.5 Bend Test

The majority of multiconductor flex tests are run on the basis of a 90" bend in one direction and a 90"

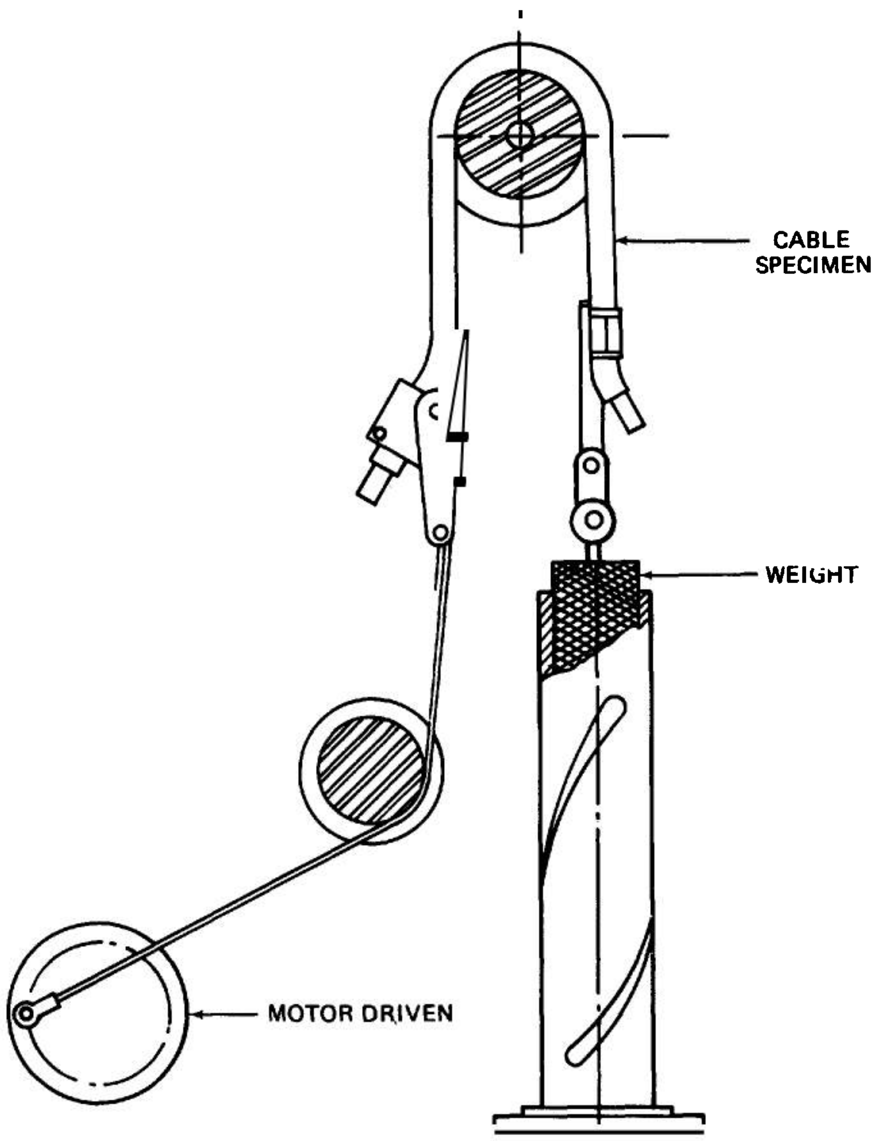


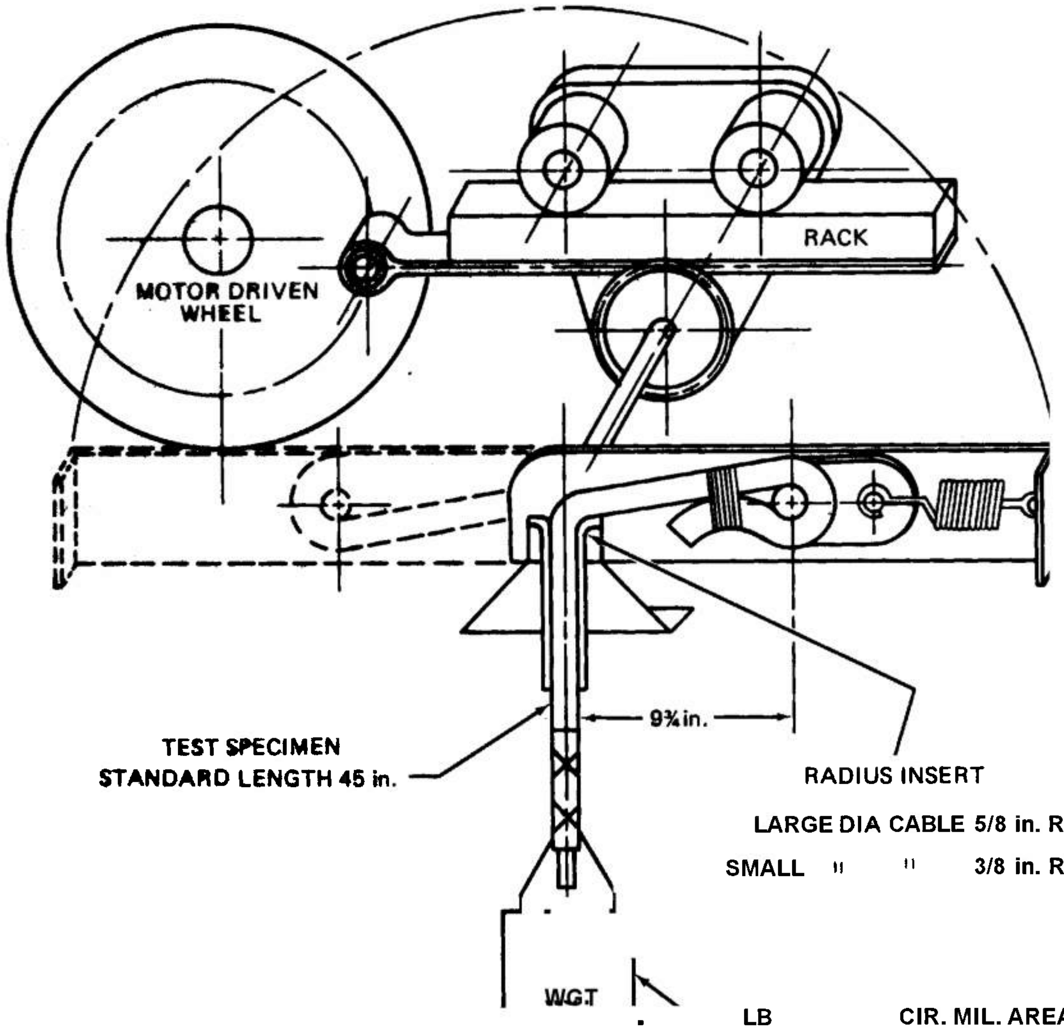
Figure 6–8. Twist Test Fixture

bend in the opposite direction. This series of bends, or flexes, constitutes one cycle. This test is used to ascertain how many extreme bends a cable construction will absorb before destruction. The first deteriorations likely to appear are conductor breakage or sheath cracking. Shown in Fig. 6–9 is a typical 90° bend test fixture.

A combination of twist test and bend test very well simulates actual handling of portable cable in the field where frequent reeling and unreeling with the inherent kinking and pulling occur.

6–7.3.6 Dielectric and Pulse Dielectric Tests

Dielectric tests should be given to all completed cables and components in the course of quality assurance procedures. There are numerous methods of applying either alternating (AC) or direct (DC) voltage to a specimen, depending on the configuration.



LB	CIR. MIL. AREA
20	14,000
25	17,500
30	21,000
35	24,500
40	28,000
45	31,000
50	35,000

Figure 6–9. Ninety-degree Bend Test Fixture

If a cable has no shield, or outer conductor, the specimen may be immersed in water and voltage applied between the conductor and water, using the water as a ground potential. With a shielded wire the voltage is applied between conductor and shield, generally using the shield as a ground potential. In a two-conductor pair, voltage is applied from conductor to conductor. If a shield is required, voltage is then applied from conductor to conductor and each conductor to shield, again using the shield as ground potential. The voltage and length of test vary with different specifications. A general rule of thumb for most dielectric applications is a 60 Hz, alternating test voltage of twice rated voltage plus 1000 volts. Direct current test voltages are generally from 2 to 5 times the rms alternating voltages, depending on the material used.

A recently devised test method, which is a 100 percent substitute for tank testing, is the pulse dielectric test method. This new dielectric test method is used on all unshielded wires up to approximately 0.375 in. in diameter. This dielectric test may also be useful in testing for flaws in the outer jacket of the coaxial type component where the coaxial component diameter is no larger than 0.375 in. This test procedure has been incorporated in MIL-C-13777E, and is expected to be included in other pertinent specifications very shortly. The pulse dielectric test fixture is shown in Fig. 6–10.

The wave form of the voltage consists of a sharp rise pulse followed by a damped wave train. The pulse repetition rate is such that at least three pulses shall occur while any portion of the wire specimen is within the electrode; this factor governs the speed of the wire reeling through the electrode. The equipment includes a fault finding apparatus which, in case of failure, automatically shuts off the high voltage, stops reeling mechanism, and gives a visible indication of failure.

It has been ascertained that this method of test has many advantages over the tank test method. Among these advantages are:

a. The testing is done as a final operation, at either cabling or spooling, prior to shipment, and not as an extra operation. This reduces costs, facilitates ease and speed of manufacture, and, due to the elimination of

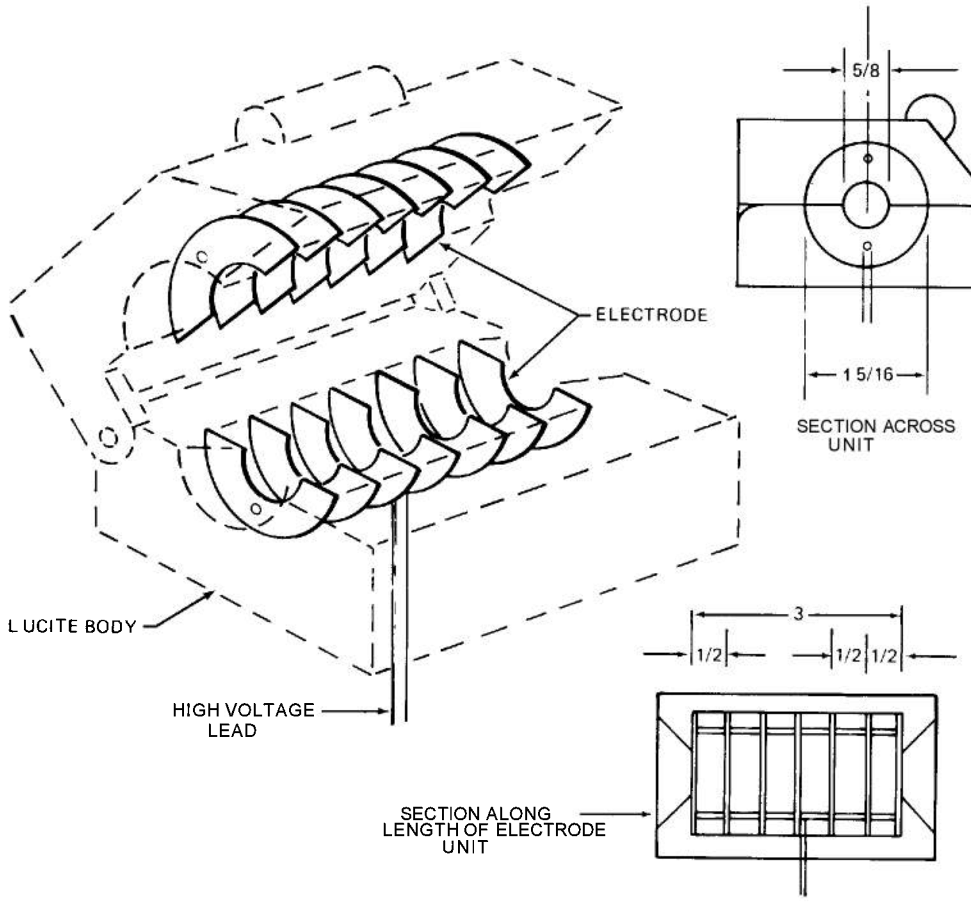


Figure 6–10. Pulse Dielectric Test Fixture

reeling and unreeling, assures the high quality of the wire just prior to use or shipment.

b. When testing a reel of wire in tank test, and when a dielectric failure occurs, the resulting sudden power surge emanating from the failure through the insulation has a tendency to damage adjacent layers of wire. This proves costly in time and material. This disadvantage is overcome using the pulse dielectric test method.

c. The pulse dielectric method does not destroy the conductor or insulation in the flaw, or failure, area, therefore, this area can be examined and the cause of the flaw determined and consequently eliminated or repaired. This is especially valuable if certain predetermined lengths of wire are required.

d. Water is not used, eliminating the wicking of water up into the conductor and possible conductor corrosion.

6–7.3.7 Insulation Resistance Test

An insulation resistance test is a method of determining the loss of a given electrical charge through an insulation, whether it be a primary insulation or an outer sheath. Insulation resistance is measured by enclosing the insulated conductor, or conductors, within a conducting material (shield, water, etc.) in intimate contact with the conductor insulation, and measuring the leakage current between the center conductor and the conducting material.

Since the insulation resistance consists of many parallel paths, increasing the length decreases the insulation resistance; and increasing the outer diameter of the insulation increases the resistance since the leakage path is increased. To establish a value for insulation resistance R Eq. 6–2 may be used.

$$R = K \log_{10} \frac{D}{d}, \text{ megohm-1000 ft} \qquad (6\text{–}2)$$

where

D = outer diameter of insulation

d = inner diameter of insulation

*K = resistivity constant for each insulation

Insulation resistance is normally determined by a direct measurement, using a high quality megohmeter, with voltage from 200 to 500 volts DC. Results are given in megohm-1000 ft from the following formula.

$$R = \frac{r \times L}{1000} \qquad (6\text{–}3)$$

where

R = insulation resistance, megohm-1000 ft

r = megohmeter reading, megohm

L = length of specimen, ft

*It is general practice to use the constant K listed in Table 6-9 to determine insulation resistance.

TABLE 6–9

ELECTRICAL CONSTANTS–INSULATION MATERIALS

Insulating Material	Resistivity Constant K for Insulation Material	Dielectric Constant ε
Rubber, Code Grade	950	4 – 6
Rubber, ASTM-D-755	2000	3.5 – 5.5
Rubber, Butyl	10,000	2.4
Polyvinylchloride	500	3.5 – 6.0
Polyethylene	20,000	2.3
Tetrafluoroethylene (Teflon)	10^6	2.0
Monochlorotrifluoroethylene (Kel-F)	30,000	2.3 – 3.0

This test is a good quality control check on material used, the value set for the requirement being a function of the insulating compound. With the exception of rubber insulations, the test value is usually far in excess of circuit requirements. In materials having polar ingredients, such as rubber and PVC, a factor of 2 or 3 difference on different material batches is common, and changes under one order of magnitude are barely significant. The compounds are also very temperature sensitive and measurements must be made at the specified temperature.

6–7.3.8 Measuring Capacitance in a Multiconductor Cable

In the measurement of capacitance, in a multiconductor cable, there are many methods of taking the measurements, depending on the information desired and the cable configuration. Capacitance of a single, shielded conductor is explained in Chapter 5, "Coaxial Cable." In the measurement of multiconductor cables; direct capacitance, mutual capacitance, capacitance uniformity, and capacitance unbalance may be important depending on the application. Fig. 6–11 illustrates the capacitances in a pair within a multiconductor configuration.

Referring to Fig. 6–11:

a. C_3 represents the direct capacitance of the pair.

b. Mutual capacitance = C_3 in parallel with C_1 + C_2 in series, and is the actual capacitance seen by the circuit, unless $C_1 + C_2$ are grounded out.

Direct capacitance can be measured using C_A, C_B, and C_C by Eq. 6–4.

$$C_3 = \frac{(C_A + C_B) - C_C}{2} \qquad (6\text{–}4)$$

where (in Fig. 6–1 1)

$$C_A = C_1 + C_3$$

$$C_B = C_2 + C_3$$

$$C_C = C_1 + C_2$$

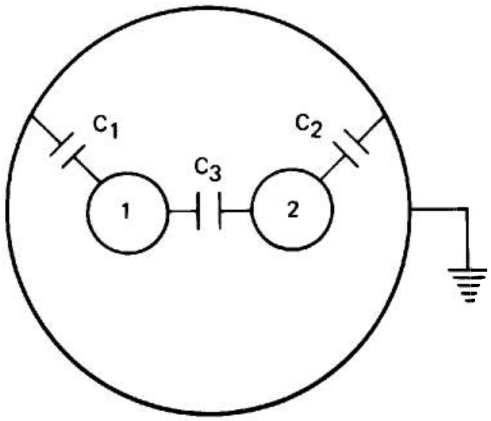


Figure 6–11. Capacitance of a Pair (Schematic)

Direct measurement using guarded bridge circuit may also be utilized. The mutual capacitance C_m on this type cable would be measured on each pair individually. The measurements would be taken as follows, using Eq. 6–5.

$$C_m = \frac{2(C_a + C_b) - C_c}{4} \qquad (6\text{–}5)$$

where

C_a = capacitance between the No. 1 conductor of a pair, and the No. 2 conductor of a pair tied to all other conductors in the cable.

C_b = capacitance between No. 2 conductor of a pair, and the No. 1 conductor of a pair tied to all other conductors in cable.

C_c = capacitance between No. 1 and No. 2 conductors tied together, and all other conductors in cable.

Capacitance unbalance should be low to prevent interference or cross-talk between circuits of multipair cable.

The capacitance unbalance of a paired conductor cable shall be measured as the unbalance of any selected pair against any adjacent pair; this includes between pairs, adjacent to each other, and layer-to-layer.

The capacitance involved and definition of pair-to-pair unbalance are shown in Fig. **6–12.**

For insulated conductors, letters *A* and *B* in Fig. **6–12** represent the two conductors of a pair, *C* and *D* the two conductors of any other adjacent pair. The capacitances *CAC, CAD, CBC, CBD,* and *CCD* are direct capacitances.

Capacitances *CAg, CBg, CCg, and CDg,* are direct capacitances between wires A, *B, C,* and *D,* respectively, and the other three conductors grounded.

The pair-to-pair capacitance unbalance C_u for these measurements is determined using **Eq. 6–6.**

$$C_u = (CAD + CBC) - (CAC + CBD) \qquad (6\text{–}6)$$

CAD represents the capacitance from wire *A* in one pair, to wire *D* in the adjacent pair only, all other conductors in this case are **left out of *the* circuit, or** hanging open. The same method would be used regarding *CBC, CBD,* and *CAC.* When the cable configuration has an overall metallic shield placed over the cabled conductors and under the outer sheath, the capacitance unbalance, pair-to-shield, is measured as in Fig. **6–13.**

Note:

> Direct capacitance is defined in ***American Standard Definition of Electrical Terms*** **(1941** – Def. **05.15.080)**

The two conductors of a pair are represented by ***a*** and *b* in Fig. **6–13.**

Cag = direct capacitance between *a* and shield

Cbg = direct capacitance between *b* and shield

Cap = direct capacitance between *a* and all other pairs

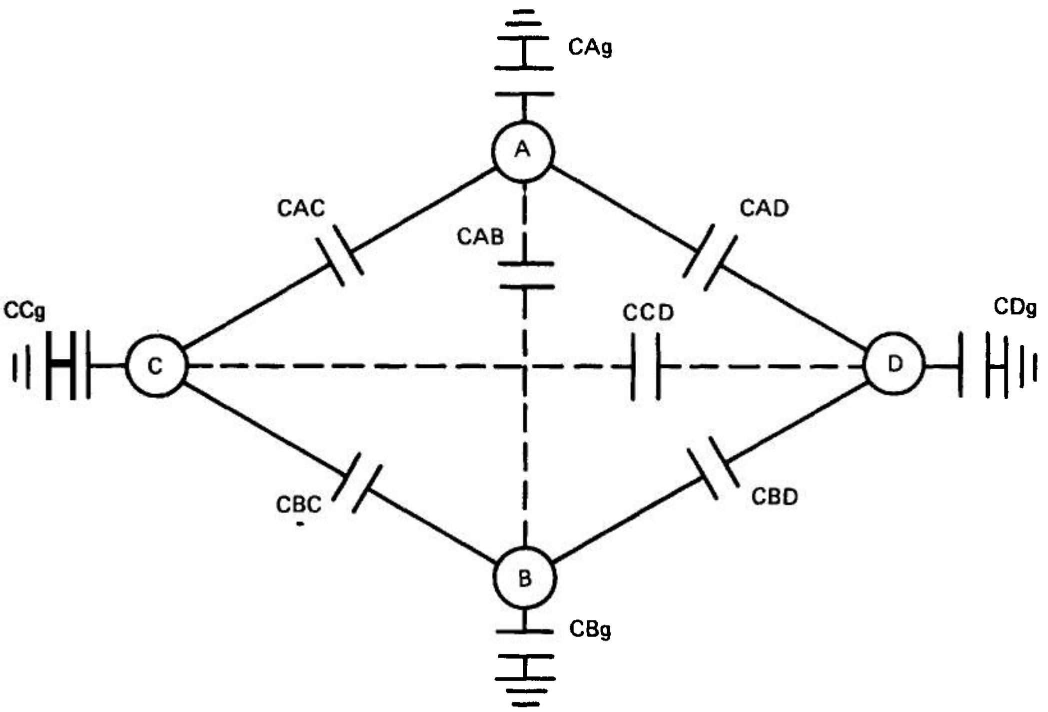


Figure 6–12. Pair-to-pair Capacitance Unbalance (Schematic)

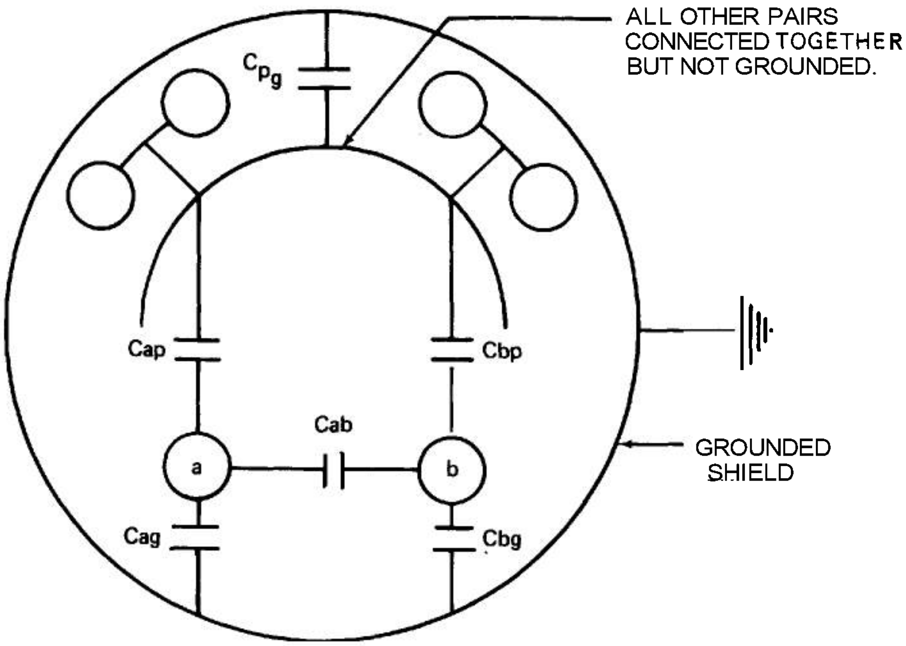


Figure 6–13. Pair-to-shield Capacitance Unbalance (Schematic)

Cbp = direct capacitance between b and all other pairs

C_{p_g} = direct capacitance between all other pairs and shields

Then, pair-to-shield capacitance unbalance is determined as $Cag - Cbg$. For pair-to-pair unbalance, the measurement is made exactly as for unshielded pair to pair, except the shield is connected to the grounded conductors in all cases. If the cable is constructed of twisted, shielded, sheathed pairs, the same holds true in measuring mutual capacitance C_m, except the shield is substituted for all other pairs in the cable as follows:

$$C_m = \frac{2(C_a + C_b) - C_c}{4} \qquad (6\text{–}7)$$

where

C_a = capacitance between No. 1 conductor, and No. 2 conductor tied to shield.

C_b = capacitance between No. 2 conductor, and No. 1 conductor tied to shield.

C_c = capacitance between No. 1 and No. 2 conductors tied together, and shield.

6–7.3.9 Abrasion Resistance

The abrasion resistance of a wire or cable is another way of determining how much abrasive abuse the insulation or sheath will absorb before destruction or failure under the specified conditions. There are three common methods for determining cable abrasion resistance:

1. A machine utilizing a moving sandpaper strip applying the abrasive action. This method is described in MIL-T-5438 and shown in Fig. 6–14.

2. The second method is a wheel employing tungsten carbide rods as the abrasive, the rods being mounted in a rotating wheel, or squirrel cage configuration, as shown in Fig. 6–15.

3. The third method is the scrape test. This method utilizes a metal rod of specified diameter, the diameter being dependent on the cable diameter under test. The rod is laid flat and in the same plane as the specimen,

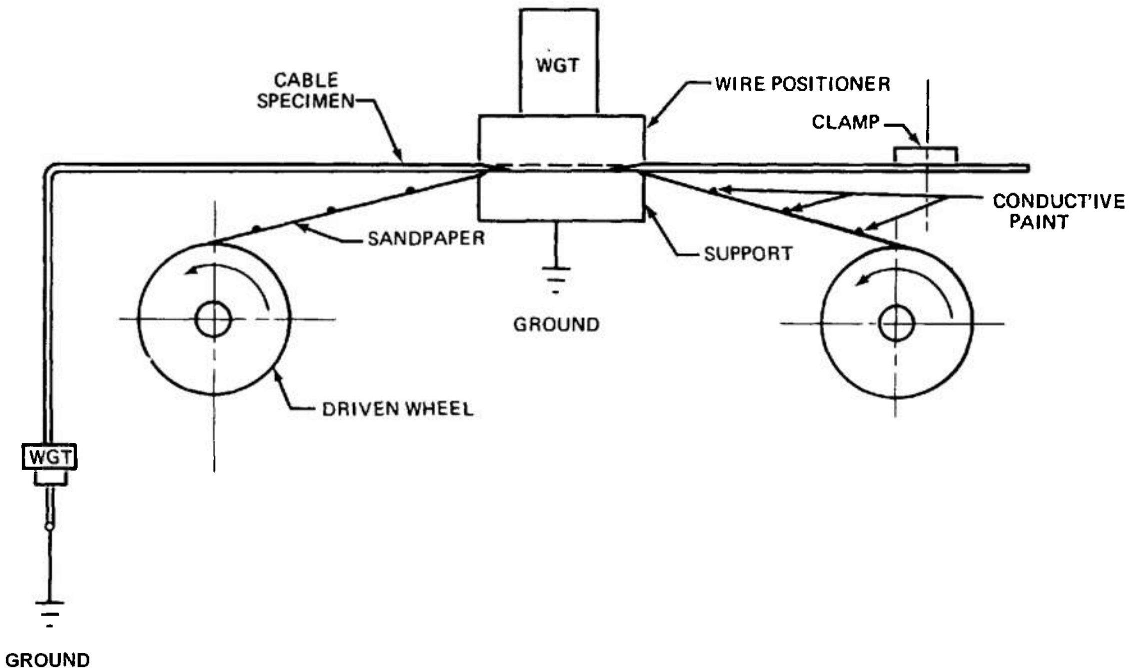


Figure 6–14. Sandpaper Abrasion Test Apparatus

but at right angles to the specimen. This rod is then moved forward and backward over the specimen surface a specified distance at a given rate under a specified load; or, in other words, "scraped" along the surface of the insulation. This test is usually performed to test the durability of striping or ink printing.

Most of these abrasion tests do not simulate exactly the service conditions, but do provide a basis for comparative measurements. The sandpaper abrasion test of MIL-T-5438, utilizing the #0000 grit paper, does not simulate use conditions to any degree; but with #400 grit aluminum oxide paper–as used in MIL-W-27300, MIL-W-22759, and others–the test is similar to wire being abraded on anodized aluminum or oxidized aluminum surfaces, as in an airplane wiring bundle, and is therefore much closer to use conditions than is the #0000 grit paper. The scrape abrasion tester is the closest to use conditions because it simulates dragging wire past a chassis edge or over aircraft structural members. Most abrasion of wire occurs in this fashion during installation, rather than in operation, and later if the installation techniques are improper.

As can be seen from Fig. 6–14, the sandpaper drags under the cable specimen, at a given speed, while the specimen is pressed down over a given area by a given force on the moving sandpaper belt. The sandpaper has conductive painted strips spaced evenly over the surface. When the sandpaper wears through the insulation, and the conductive strip comes in contact with the conductor, it breaks an electrical circuit, thus stopping the machine and indicating the number of inches of sandpaper needed to abrade through the insulation.

As can be seen in Fig. 6–15, the squirrel cage method is quite similar to the sandpaper method, except the rods act as the abrasive. Here again the wheel is driven at a given speed and the cable specimen is held with given force onto the abrasive rod surfaces. When break-through occurs, a circuit is broken causing the fixture to stop. A counter counts the wheel revolutions. Usually, the sandpaper test fixture and scrape abrader are used for smaller single conductors or shielded and jacketed components, whereas the squirrel cage type is used on larger configurations where sheath abrasion resistance is the only information sought.

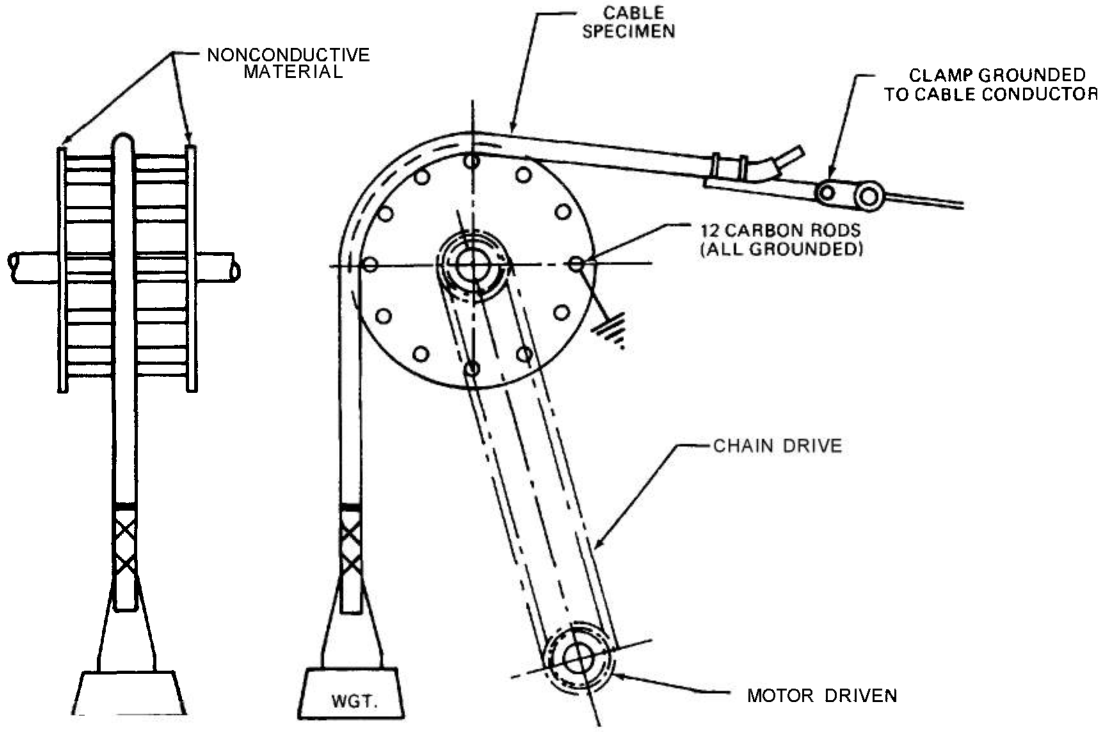


Figure 6–15. Tungsten Carbide Rod Abrasion Test Apparatus

6–7.3.10 Tensile Strength of Multiconductor Cable

In considering the tensile, or breaking, strength of a multiconductor cable, many problems are faced by the design engineer. It can be said of this type test that, as in a chain, the weakest link will break first. In other words it is entirely possible that, with improper engineering design, the innermost conductor of a multiconductor cable could break first under a tensile load even though the load be applied to the outer sheath. Usually, in a cable that is required to withstand severe tensile load, it is best to insert a strength member such as a stainless steel stranded rope as the center core or, in a woven or served configuration, incorporated into the outer sheath. This is much the same as a telephone aerial cable which uses a carrier for strength in installation. Steel strands incorporated within the stranded copper conductor component, such as is required in MIL-C-13777, is another good cable reinforcing method. An alternate method utilizes a braided, strong, metal shield over the entire cable core, incorporated as a sheath reinforcement, or applied as an overall armor. It must be noted, when applying a shield for tensile strength purposes, that the braid angle should be kept extremely low so as not to crush or stretch the cable excessively under tensile load. In testing cables for tensile strength or breaking strength, the test method used is a very important factor in order to gain correct data. Shown in Fig. 6–16 are the correct and incorrect methods of test.

As noted by Fig. 6–16, the incorrect method uses a clamp on each cable end; this allows sheath slippage and great force on the clamps which pull unevenly on the cable core. The correct method, as shown, has the cable ends clamped to the cable itself and around a mandrel, allowing most of the force, or pull, to be exacted in the center of the cable specimen and away from the ends thus allowing equal force to be exerted around the entire cable perimeter.

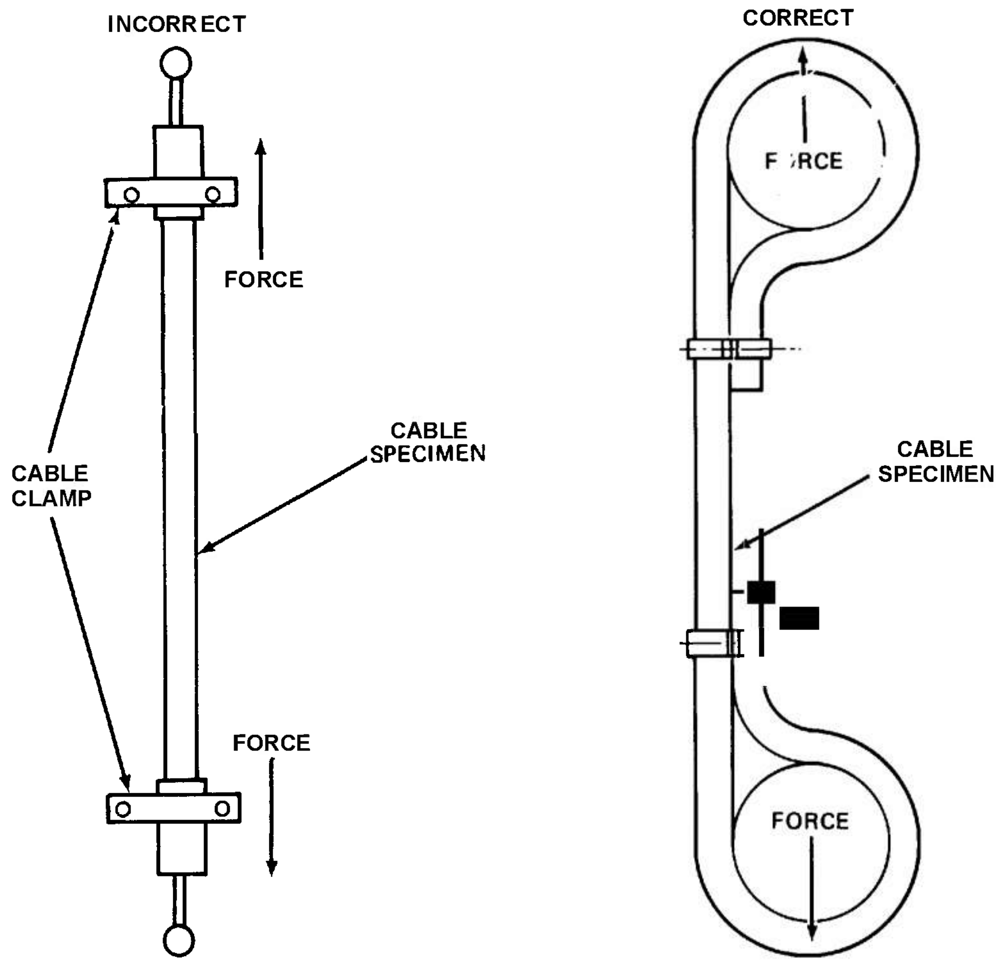


Figure 6–16. Tensile or Breaking Strength Test Methods

REFERENCES

1. *American Standard Definition of Electrical Terms,* **Definition 05.15.080, "Direct Capacitance".**

2. **MIL-C-3432,** *Cable and Wire, Electrical (Power and Control, Flexible and Extra Flexible, 300 and 600 volts).*

3. **MIL-C-13777E,** *Cable, Special Purpose, Electrical.*

4. **MIL-C-27072,** *Cable, Special Purpose, Electrical, Multi-Conductor.*

5. **MIL-STD-104,** *Limits for Electrical Insulation Color.*

6. **MIL-STD-681,** *Identification Coding and Application of Hook-Up and Lead Wire.*

7. **MIL-STD-686,** *Cable and Cord, Electrical; Identification Marking and Color Coding Of:*

8. **MIL-T-5438,** *Tester, Abrasion, Electrical Cable.*

9. **MIL-W-16878D,** *Wire, Electrical, Insulated, High Temperature (Navy).*

10. **MIL-W-22759,** *Wire, Electrical, Fluorocarbon Insulated, Copper.*

11. **MIL-W-27300,** *Wire, Electrical, Polytetrafluoroethylene Insulated, Copper, 600 Volt.*

12. **MIL-C-55021,** *Cables, Electrical, Twisted Pair and Triples, Internal Hook-Up, General Specification For.*

CHAPTER 7

POWER CABLES

7–1 INTRODUCTION

7–1.1 USAGE

Power cables are named for their function – the transmission of large quantities of electrical power. Further classifications often include the voltage rating; the number of conductors; the specific application, i.e., switchboard, lighting, etc.; and environmental conditions of use, i.e., portable, light-duty, heavy-duty, etc.

7–1.2 GENERAL DESIGN FACTORS

Most military power cables are designed for use at low voltages (up to 600 volts). The current may be DC or low frequency AC (usually not over 60 Hz).* In general, conductor sizes for military, primary power cables fall within the range of #10 AWG to #40 AWG.

7–2 MAJOR CONSTRUCTIONAL DESIGN FACTORS

Power cables have three basic components; namely a conductor, insulation, and a protective covering or sheath. The factors to be considered in arriving at a correct choice of each of these basic components, in order to design a useful power cable for a given application, are discussed in this chapter. For the sake of simplicity, each component will be considered separately, although it must be realized that there may be instances of interdependence or incompatibility which must be compromised in the final design.

* For aircraft and shipboard cable, some power circuits are operated from 400 to 1600 Hz. The basic design considerations remain the same as with 60 Hz, except that in larger conductors the current-carrying capacities may need to be derated. At this writing there is no agreement as to the degree of derating required at higher frequencies.

7–2.1 CONDUCTOR

There are three major decisions affecting the selection of the conductor for a power cable: (1) the conductor material, (2) the conductor size, and (3) the conductor form, i.e., whether solid or stranded, and if stranded, the number of strands.

7–2.1.1 Conductor Material

Copper is the most commonly used conductor material for power cables, although aluminum has found some use in application where flex requirements are minimal.

7–2.1.2 Conductor Size

There are three factors to be considered in determining conductor size: physical strength, required current-carrying capacity, and allowable voltage drop or resistance. Voltage drop is discussed in some detail in par. 7–4. Physical strength, as a criterion of conductor size, requires that the conductor be large enough to withstand the forces to be encountered in installation and service. Current-carrying capacity is determined by the electrical resistance of the conductor, the maximum allowable temperature for the insulation, and the ability of the installed system to dissipate heat. Chapter 4 lists methods for calculating current-carrying capacity vs temperature rise, and may be utilized to determine the current-carrying capacities of power cable. The temperature limits on insulated materials are defined in Chapter 2. Normally, the conductor is sized to facilitate efficient transmission with acceptable energy loss due to resistance heating. The referenced tables will indicate the temperatures at which various cables can be expected to operate under the given current loading and environment. Type of installation is a factor because of its influence on the ability of the cable to dissipate heat. Tables 7–1 through 7–11 show the current-carrying capacities of the principal sizes and types of power cables under various conditions of environment.

7–2.1.3 Conductor Form

In the size range normally used in power cables, conductors must be stranded to be flexible enough for installation. Flexibility is of particular importance for portable cables and field cables which must be repeatedly reeled out and re-reeled during their use.

Generally speaking, the finer the strand that is used to make up the conductor, the more flexible the finished conductor will be. However, the finer the strand, the more costly the conductor is to manufacture. Also, in an insulated cable, the conductor contributes only a portion of the flexibility (or stiffness) to the total cable. There is a point beyond which the insulation stiffness becomes a contributing factor and a more flexible conductor stranding will make very little practical difference in the flexibility of the complete cable. Tables 7–12 through 7–14 list the commonly accepted strandings for "flexible" and "extra flexible" copper conductors, and the accepted strandings for aluminum conductors.

7–2.2 INSULATION

The most important properties of insulation material used in 600-volt rms military power cables are the mechanical properties which contribute to the toughness and flexibility of the cable. For the ultimate in flexibility, elastomers such as SBR, butyl rubber, and EPK are the usual selections. However, cross-linked polyethylene or polyethylene with a protective jacket of nylon are being utilized as insulations. Polyvinylchloride compounds are useful in some applications. For elevated temperature environments, silicone rubber, TFE, and FEP have been utilized as primary insulation in special power cables. Generally speaking, in order to assure adequate mechanical protection, a minimum wall thickness is specified as well as minimum physical properties of the insulation. Tables 7–15 and 7–16 list typical physical properties specified for the most commonly used insulation materials and the wall thicknesses recommended for military power cables.

Although some consideration must be given to the electrical properties of the insulation, it should be recognized that at the low voltage levels and low frequencies under discussion here, such parameters as corona resistance, dielectric constant, and voltage breakdown are of relatively minor importance to the overall performance of the cable.

7–2.3 SHEATH

Polychloroprene compounds are by far the most commonly used sheath or jacket materials. Some use is also made of chlorosufonated polyethylene, PVC, polyurethane polymers, ethylenepropylene rubber, and SBR for this purpose. Butyl rubber has been used where resistance to certain missile fuels is a requirement. Table 7–17 lists the requirements normally specified for sheath compounds. Table 7–18 gives a guide to the wall thickness considered satisfactory for polychloroprene sheaths of power cables.

Reference is made to Chapter 2 for further information on the properties of insulating, jacketing, and sheathing materials.

7–3 ~~MISCELLANEOUS~~ CONSTRUCTIONAL DESIGN FACTORS

7–3.1 SHIELDS

Shielding is not generally required for voltage stress distribution or current leakage drain in 600-volt rms power cables. Occasionally, shielding may be specified as a barrier to radio frequency interference outside the cable, or in the case where switching transients may result in surge voltages in excess of 2000 volts rms and require external grounding for safety.

7–3.2 CABLING

Reference is made to Chapters 6 and 8 for a discussion of good cabling practices.

7–3.3 GROUND WIRES

It is common practice to incorporate ground wires where required, directly into the power cable, very much as though they were added conductors to multiconductor cable. In some instances, ground wires are the same size as the power conductors. However, in order to reduce cost, weight, and size, it is general practice to use somewhat smaller gage conductors as ground wires than those used as the power lines. Table 7–19 shows the minimum recommended size of ground wires to be utilized with given power conductors.

In all cases, it is mandatory that the ground wires be insulated, or at least physically separated, from the other conductors in the cable. Ground wires should also be stranded as in Table 7–20 to maintain the flexibility of the finished cable.

7–4 VOLTAGE DROP

While a cable may be designed to carry the necessary amperes, and have sufficient insulation for mechanical protection, larger conductors may be required because of voltage drop due to the conductor resistance. After determining the proper cable size, it is necessary to check the length of run required and determine that the voltage drop will not be excessive. If it is, larger cable must be used. Table 7–21 shows maximum cable length for single phase systems on power cable gage which result in a voltage drop of one volt.

TABLE 7–1

CURRENT-CARRYING CAPACITY IN UNDERGROUND DUCTS

ONE SINGLE-CONDUCTOR CABLE PER DUCT, 0–600 VOLTS, 0–60 Hz

Conductor Size, AWG#	Copper Temperature											
	60°C				75°C				90°C			
	Number of Equally Loaded Ducts in Duct Bank											
	Three	Six	Nine	Twelve	Three	Six	Nine	Twelve	Three	Six	Nine	Twelve
	Amperes per Conductor											
10	49	45	43	41	55	52	49	47	60	55	50	50
8	63	60	56	53	72	68	64	61	80	75	70	65
6	84	78	73	70	96	89	84	79	105	100	95	85
4	109	102	95	90	125	116	108	103	135	125	115	115
2	144	132	123	116	1[illegible]3	150	139	[illegible]	180	165	155	145
1	163	150	140	132	18[illegible]	172	159	[illegible]	205	190	175	165
0	18[illegible]	171	159	150	21[illegible]	196	183	[illegible]	235	215	200	190
[illegible]	[illegible]	198	182	169	247	226	209	195	270	250	230	215
000	245	223	205	192	283	258	241	222	310	280	265	[illegible]
0000	280	255	234	219	322	293	269	251	355	325	295	275

Correction Factors for Various Ambient Earth Temperatures

60°C		75°C		90°C	
15°C	1.06	15°C	[illegible]	15°C	1.04
[illegible]	[illegible]	20°C	1.00	20°C	1.00
25°C	0.94	25°C	0.95	25°C	0.96
30°C	0.87	30°C	0.90	[illegible]	[illegible]
35°C	0.79	35°C	0.85	35°C	0.89
40°C	0.71	[illegible]	0.80	40°C	0.85

Assumptions: All cables are in outside ducts

Ducts are nonmetallic

Ungrounded sheaths.

Note: Correction factor for aluminum conductors: 0.78.

TABLE 7—2

CURRENT-CARRYING CAPACITY IN UNDERGROUND DUCTS

THREE SINGLE CONDUCTORS PER DUCT, *0–600* VOLTS, *0–60* Hz

Conductor Size, AWG#	60°C					75°C					90°C				
	Number of Equally Loaded Ducts in Duct Bank														
	One	Three	Six	Nine	Twelve	One	Three	Six	Nine	Twelve	One	Three	Six	Nine	Twelve
	Amperes per Conductor														
10	41	38	32	30	27	47	42	36	34	31	50	45	40	35	35
8	54	48	43	39	38	62	55	49	45	42	65	60	55	50	45
6	70	61	55	50	46	80	70	63	57	53	90	75	70	65	55
4	91	80	71	64	59	104	91	81	73	68	115	100	90	80	75
2	120	103	92	83	76	137	118	105	95	87	150	130	115	105	95
1	138	118	104	94	86	158	135	119	108	98	175	150	130	120	110
0	156	134	118	106	97	179	153	135	121	111	195	170	150	135	120
00	180	150	135	120	110	205	175	150	135	125	225	190	165	150	140
000	205	175	150	135	125	235	200	175	155	140	260	220	190	170	155
0000	235	200	170	155	140	265	225	195	175	160	295	250	215	195	175

Correction Factors for Various Ambient Earth Temperatures

60°C		75°C		90°C	
15°C	1.06	15°C	1.04	15°C	1.04
20°C	1.00	20°C	1.00	20°C	1.00
25°C	G.94	25°C	0.95	25°C	0.96
30°C	0.87	30°C	0.90	30°C	0.93
35°C	0.79	35°C	0.85	35°C	0.89
40°C	0.71	40°C	0.80	40°C	0.85

Assumptions: All cables in given duct are same size and equally loaded.
All cables are in outside ducts.
Load Factor: 100%.
Ducts are nonmetallic.
Ungrounded sheaths.

Note: Correction factor for aluminum conductors: 0.78.

TABLE 7–3

CURRENT-CARRYING CAPACITY IN UNDERGROUND DUCTS

ONE THREE-CONDUCTOR CABLE PER DUCT, 0–600 VOLTS, 0–60 Hz

Conductor Size, AWG#	60°C					75°C					90"C				
	Amperes per Conductor														
10	38	35	31	29	28	44	40	35	33	32	50	45	40	35	35
8	50	44	40	37	35	57	50	46	42	40	65	55	50	45	45
6	64	57	52	48	44	73	65	60	55	50	80	70	65	60	55
4	84	74	67	61	57	96	85	77	70	65	105	95	85	75	70
2	108	96	86	78	72	124	110	99	89	83	135	120	110	100	90
1	126	109	97	88	82	144	125	111	101	94	160	140	120	110	105
0	141	123	110	100	93	161	141	126	114	106	176	156	141	126	116
00	160	140	124	113	105	183	160	142	129	120	202	177	156	141	131
000	183	160	143	130	120	210	183	164	150	137	229	204	178	163	153
0000	210	181	161	146	134	240	208	185	167	154	265	229	204	183	168

Correction Factors for Various Ambient Earth Temperatures

60°C		75°C		90"C	
15°C	1.06	15°C	1.04	15°C	1.04
20°C	1.00	20°C	1.00	20°C	1.00
25°C	0.94	25°C	0.95	25°C	0.96
30°C	0.87	30°C'	0.90	30°C	0.93
35°C	0.79	35°C	0.85	35°C	0.89
40°C	0.71	40°C	0.80	40°C	0.85

Assumptions: All conductors in cable of same size and load.
All cables are in outside ducts.
Load Factor: 100%.
Ducts are nonmetallic.
Ungrounded sheaths.

Note: Correction factor for aluminum conductors: 0.78.

TABLE 7-4

CURRENT-CARRYING CAPACITY IN ENCLOSED OR EXPOSED CONDUIT

SINGLE CONDUCTOR CABLES, 0–600 VOLTS, 0–60 Hz

Conductor Size, AWG#	Copper Temperature 60°C			75°C			90°C		
	Number of Cables in One Conduit								
	One	Two	Three	One	TWO	Three	One	Two	Three
	Amperes per Conductor								
10	30	28	25	40	35	35	45	40	40
8	42	37	33	55	45	45	65	55	50
6	55	49	44	70	65	55	85	75	65
4	73	65	59	95	85	75	110	100	90
2	98	86	78	125	110	100	150	130	120
1	114	98	90	145	130	115	170	150	135
0	130	115	105	165	146	136	195	171	156
00	150	132	119	195	171	151	225	202	181
000	172	153	138	220	199	178	260	229	209
0000	198	175	161	255	224	209	300	265	245

Correction Factors for Various Ambient Air Temperatures

60°C		75°C		90°C	
10°C	1.58	10°C	1.36	10°C	1.26
20°C	1.41	20°C	1.25	20°C	1.18
30°C	1.22	30°C	1.13	30°C	1.10
40°C	1.00	40°C	1.00	40°C	1.00
50°C	0.71	50°C	0.85	50°C	0.89

Assumptions: All ratings based on nonmetallic conduits.
All ratings based upon one isolated conduit **only**. Correction factors for groups of conduits are given in Table 7–6.
Load Factor: 100%.
All conductors in given conduit are the same size.

Note: Correction factor for aluminum conductors: 0.78.

TABLE 7–5

CURRENT-CARRYING CAPACITY IN ENCLOSED OR EXPOSED CONDUIT

THREE-CONDUCTOR CABLE, 0–600 VOLTS, 0–60 Hz			
Conductor Size, AWG#	Copper Temperature		
	60°C	75°C	90°C
	Amperes per Conductor		
10	27	35	40
8	33	44	50
6	44	57	65
4	57	73	85
2	74	95	110
1	84	109	130
0	97	125	146
00	110	143	166
000	128	165	193
3000	145	188	219
	Correction Factors for Various Ambient Air Temperatures		
10° C	1.58	1.36	1.27
20° C	1.41	1.25	1.18
30° C	1.22	1.13	1.10
40° C	1.00	1.00	1.00
50° C	0.71	0.85	0.90

Assumptions: All ratings based on nonmetallic conduits.
All ratings based on one isolated conduit only. Correction factors for groups of conduits are given in Table 7–6.
Load Factor: 100%.
All conductors of a given 3-conductor cable are the same size.

Note: Correction factor for aluminum conductors: 0.78.

TABLE 7–6

CURRENT RATING CORRECTION FACTORS FOR CABLES IN (VARIOUS GROUPINGS OF CONDUITS)

Number of Conduits	Horizontally					
Vertically	1	2	3	4	5	6
1	1.00	0.94	0.9 1	0.88	0.87	0.86
2	0.92	0.87	0.84	0.8 1	0.80	0.79
3	0.85	0.8 1	0.78	0.76	0.75	0.74
4	0.82	0.78	0.74	0.73	0.72	0.72
5	0.80	0.76	0.72	0.7 1	0.70	0.70
6	0.79	0.75	0.7 1	0.70	0.69	0.69

Note: These correction factors apply only when the spacing between conduit surfaces is not greater than conduit diameter, or less than one-fourth of conduit diameter.

TABLE 7–7

CURRENT-CARRYING CAPACITY IN AIR

SINGLE-CONDUCTOR AND THREE-CONDUCTOR CABLES. 0–600 VOLTS, 0–60 Hz						
Conductor Size, AWG#	60°C	75°C	90°C	60°C	75°C	90°C
	Amperes per Conductor					
10	35	44	50	29	38	45
8	47	61	70	39	50	60
6	64	83	95	50	65	75
4	86	110	130	67	86	100
2	117	150	175	88	113	130
1	135	172	200	100	129	150
0	158	202	235	114	147	170
00	183	235	275	132	171	200
000	212	273	320	150	194	225
0000	245	315	370	171	221	260
	Correction Factors for Various Ambient Air Temperatures					
10° C	1.58	1.36	1.27	1.58	1.36	1.27
20° C	1.41	1.25	1.18	1.41	1.25	1.18
30° C	1.22	1.13	1.10	1.22	1.13	1.10
40° C	1.00	1.00	1.00	1.00	1.00	1.00
50° C	0.71	0.85	0.90	0.71	0.85	0.90

Assumptions: Only single, isolated cables are considered. For groups of cables see correction factors listed in Table 7–8.
All conductors of 3-conductor cables are same size.
Load Factor: 100%.

Note: Correction factor for aluminum conductors: 0.78.

TABLE 7–8

CURRENT RATING CORRECTION FACTORS FOR (VARIOUS GROUPINGS OF CABLES IN AIR)

Number of Cables Vertically	Number of Cables Horizontally					
	1	2	3	4	5	6
1	1.00	0.93	0.87	0.84	0.83	0.82
2	0.89	0.83	0.79	0.76	0.75	0.74
3	0.80	0.76	0.72	0.70	0.69	0.68
4	0.77	0.72	0.68	0.67	0.66	0.65
5	0.75	0.70	0.66	0.65	0.64	0.63
6	0.74	0.69	0.64	0.63	0.62	0.61

Note: These correction factors apply only when the spacing between cables surfaces is not greater than the cable diameter, nor less than one-fourth of the cable diameter.

TABLE 7–9

CURRENT-CARRYING CAPACITY OF CABLES BURIED DIRECTLY IN EARTH

THREE SINGLE-CONDUCTOR CABLES SPACED 6 INCHES APART, BURIED 3 FEET UNDERGROUND, 0–600 VOLTS, 0–60 Hz			
Conductor Size, AWG#	60°C	75°C	90°C
8	70	80	90
6	90	105	115
4	115	130	145
2	145	170	185
1	165	190	210
0	190	220	240
00	220	250	275
000	245	280	310
0000	280	315	350
	Correction Factors for Various Ambient Earth Temperatures		
15°C	1.06	1.04	1.03
20°C	1.00	1.00	1.00
25°C	0.94	0.95	0.96
30°C	0.87	0.90	0.93
35°C	0.79	0.85	0.89
40°C	0.71	0.80	0.85

Assumption: Load Factor: 100%
Note: Correction factor for aluminum conductors: 0.78.

TABLE 7–10

CURRENT-CARRYING CAPACITY OF CABLES BURIED DIRECTLY IN EARTH

THREE-CONDUCTOR CABLES, SPACED 18 INCHES APART, BURIED 3 FEET UNDERGROUND															
0–600 VOLTS, 0–60 Hz															
Conductor Size, AWG#	Copper Temperature														
	60°C					75°C					90°C				
	Number of Equally Loaded Cables														
	One	Three	Six	Nine	Twelve	One	Three	Six	Nine	Twelve	One	Three	Six	Nine	Twelve
	nductor														
10	46	42	38	35	34	53	48	42	40	39	61	55	48	42	42
8	61	53	48	45	42	69	61	56	51	48	79	67	61	55	55
6	77	69	63	58	53	88	79	73	67	61	97	85	79	73	67
4	102	90	81	74	69	116	103	93	85	79	127	115	103	91	85
2	131	116	104	94	87	150	133	120	108	100	165	145	135	120	110
1	152	132	117	106	99	174	151	134	122	114	195	170	145	135	125
0	169	148	132	120	111	194	169	151	137	127	210	190	170	150	140
00	190	170	150	135	125	220	192	171	155	144	240	210	190	170	155
000	220	190	170	155	145	250	220	195	180	165	270	240	210	195	165
0000	250	215	190	175	160	285	245	220	200	185	315	270	240	220	200
	Correction Factors for Various Ambient Air Temperatures														
15°C	1.06					1.04					1.04				
20°C	1.00					1.00					1.00				
25°C	0.94					0.95					0.96				
30°C	0.87					0.90					0.93				
35°C	0.79					0.85					0.89				
40°C	0.71					0.80					0.83				

Assumption: Load Factor: 100%.

Note: Correction factor for aluminum conductors: 0.78.

TABLE 7–11

CURRENT-CARRYING CAPACITY, PORTABLE POWER CABLE

RUBBER-INSULATED, RUBBER-SHEATHED						
Conductor Size, AWG#						
8	45	40	35	30	25	20
6	60	50	50	40	35	30
4	85	70	65	55	45	35
2	110	95	90	75	65	55
1	130	110	100	85	75	65
0	150	130	120	100	85	70
00	175	150	135	115	95	75
000	205	175	155	130	110	85
0000	235	200	180	150	125	100

Assumptions: Maximum conductor temperature, 60°C
All conductors in given cable are the same size.
Ambient temperature: 40°C. For other ambient temperatures, use the following correction factors:

10°C	1.58
20°C	1.41
30°C	1.22
40°C	1.00
50°C	0.71

Note:

Layers on Reel	Correction Factor
1	0.85
2	0.65
3	0.45
4 and more	0.35

TABLE 7–12

"FLEXIBLE" CONDUCTOR STRANDINGS OF ANNEALED COPPER WIRE

Conductor Size, AWG#	Type of Stranding	Number of Strands	Nominal Dia of Each Strand, in.	Nominal Conductor Cross-sectional Area, circular mils	Nominal Conductor Dia, in.	Max Conductor Resistivity, ohm/1000 ft @ 25°C	Approximate Conductor Weight, lb/1000 ft
10	Bunch	104	0.0100	10,380	0.126	1.14	32.5
8	Rope	7x7	0.0184	16,510	0.166	0.715	51
6	Rope	19x7	0.0140	26,240	0.210	0.450	82
4	Rope	19x7	0.0177	41,740	0.266	0.283	132
3	Concentric	19x7	0.0199	52,620	0.299	0.213	167
2	Concentric	37x7	0.0160	66,360	0.336	0.180	210
1	Concentric	37x7	0.0180	83,690	0.378	0.142	266
0	Concentric	37x7	0.0202	105,600	0.424	0.113	334
00	Concentric	37x7	0.0227	133,100	0.477	0.086	422
000	Concentric	37x7	0.0255	167,800	0.536	0.069	533
0000	Concentric	37x7	0.0286	211,600	0.601	0.054	670

TABLE 7–13

"EXTRA FLEXIBLE" CONDUCTOR STRANDINGS OF ANNEALED COPPER WIRE

Conductor Size, AWG#	Type of Stranding	Number of Strands	Nominal Dia of Each Strand, in.	Nominal Conductor Cross-sectional Area, circular mils	Nominal Conductor Dia, in.	Max Conductor Resistivity, ohm/1000 ft @ 25°C	Approximate Conductor Weight, lb/1000 ft
10	Rope	7x37	0.0063	10,380	0.126	1.14	32.5
8	Rope	7x24	0.0063	16,510	0.157	0.715	53
6	Rope	7x38	0.0063	26,240	0.202	0.450	84
4	Rope	7x60	0.0063	41,740	0.272	0.283	132
3	Bunch	19x28	0.0100	52,620	0.304	0.213	169
2	Bunch	19x35	0.0100	66,360	0.338	0.180	211
1	Bunch	19x44	0.0100	83,690	0.397	0.142	266
0	Bunch	19x56	0.0100	105,600	0.451	0.113	338
00	Bunch	7x7x27	0.0100	133,100	0.470	0.086	425
000	Bunch	7x7x34	0.0100	167,800	0.533	0.069	535
0000	Bunch	7x7x43	0.0100	211,600	0.627	0.054	676

TABLE 7–14

CONDUCTOR STRANDINGS, ALUMINUM WIRE (EC, HARD-DRAWN)

Wire Designation	Type of Strandings	Number of Strands	Nominal Dia of Each Strand, in.	Nominal Conductor Cross-sectional Area, circular mils	Nominal Conductor Dia, in.	Max Conductor Resistivity, ohm/1000 ft @ 20°C	Approximate Conductor Weight, lb/1000 ft
AL-8	Bunch	41	0.0201	16,564	0.155	1.093	16
AL-6	Bunch	7x10	0.0201	28,280	0.205	0.641	27
AL-4	Bunch	7x15	0.0201	42,420	0.255	0.427	41
AL-2	Rope	7x24	0.0201	67,872	0.320	0.268	65
AL-1	Bunch	7x30	0.0201	84,840	0.358	0.214	84
AL-0	Bunch	19x14	0.0201	107,464	0.408	0.169	102
AL-00	Bunch	19x18	0.0201	138,168	0.465	0.133	140
AL-000	Bunch	19x22	0.0201	168,872	0.522	0.109	173
AL-0000	Bunch	19x28	0.0201	214,928	0.575	0.085	218

TABLE 7-45

PHYSICAL PROPERTIES OF INSULATION

Physical Property	SBR Type IS*	SBR Type IS-L*		SBR Type IJ-S*	Butyl**	PVC Type IP*	Polyethylene Type F***
Original Properties							
Tensile Strength, min psi	600	600		1000	600	1800	1400
Elongation, min %	250	250		300	450	125	250
Set, max in.	1/2	3/8		1/2	30/64	—	—
Brittleness Temp, max °C	—	-55		—	—	—	—
Properties After Aging							
Aging Conditions:	Bomb Oxygen	Bomb Oxygen	Air	Bomb Oxygen	Bomb Air	Oven Air	Oven Air
Medium Temp, °C	70	80	127	70	127	100	100
Pressure, psi	300	300	80	300	80	—	—
Time, hr	96	168	20	96	20	96	48
Tensile Strength, min % Retention	75	50	50	75	70	—	75
Elongation, min % Retention	65	50	50	75	75	80	75

* Per MIL-I-3930C Designation.
** Per MIL-C-915B Designation.
*** Per MIL-C-13777E Designation.

TABLE 7–16

RECOMMENDED INSULATION WALL THICKNESSES

Duty *	Conductor Sizes	Insulation Material			
		SBR	Butyl	PVC	Polyethylene
		Wall Thickness, Nominal, in.			
L	10	0.021	0.021	0.021	0.015
M	10-8	0.038	0.038	0.038	0.020
H	10	0.047	0.047	0.047	0.025
	8-6	0.055	0.055	0.055	0.030
	4-2	0.063	0.063	0.063	0.035
	1	0.070	0.070	0.070	0.040
	0-0000	0.078	0.078	0.078	0.045

* Per MIL-C-3432C as follows:

L - Light-duty Cables: Light-duty cables are intended for use in test equipment in short lengths, or for interconnection of major components. They are intended to withstand any severe flexing and frequent manipulation. Light-duty cables should not be used where they will be stepped on, run over by vehicles, beaten, or subjected to severe impacts. Lightduty cables are suitable for lightweight portable tools or small motor and generator leads where flexibility, rather than long life, is essential.

M - Medium-duty Cables: Medium-duty cables are intended to withstand the same usage as heavy-duty cables with the exception that they should not be used where they will be run over by vehicles or be subjected to severe impacts. They are intended to be a substitute for all uses of heavy-duty cables when the reduction in weight would be advantageous to the equipment in which they are used. Medium duty-cables are suitable for small portable tools, sound equipment, radio receivers, and motor leads which do not require the heavier, sturdier, heavy-duty cables.

H - Heavy-duty Cables: Heavy-duty cables are intended for use where they will be subjected to extreme service impacts or will be run over by heavy vehicles, such as trucks, tanks, or the like. They are designed to withstand severe flexing and mechanical abuse, over long periods of time, without deterioration. Heavyduty cables are suitable for portable tools, extension lamps, charging cables, and control cables.

TABLE 7–17

CABLE SHEATHS—PHYSICAL PROPERTIES

Physical Properties	Sheathing Compound				
	PVC	SBR	Polychloroprene		
	Type JP *	Type JS-L	Type JN	Type JN-L	Arctic **
Original					
Tensile Strength, min psi	1500	1500	1800	1500	1800
Elongation, min %	100	300	300	300	300
Set, max in.	—	3/8	1/4	3/8	3/8
Tear Resistance, min lb/in.	—	25	—	20	20
Brittleness Temp, max °C	—	-55	—	-55	-55

Aged	PVC Type JP *			SBR Type JS-L			Type JN			Type JN-L			Arctic **		
Aging Conditions	Air Oven	Oil Bath	Oxygen Bomb	Air Oven	Oil Bath	Oxygen Bomb	Air Oven	Oil Bath	Oxygen Bomb	Air Oven	Oil Bath	Oxygen Bomb	Air Oven	Oil Bath	Oxygen Bomb
Temperature, °C	100	70	—	70	—	70	—	121	70	70	121	70	—	121	70
Pressure, psi	—	—	—	—	—	300	—	—	300	—	—	300	—	—	300
Time, hr	95	18	—	168	—	95	—	18	95	168	18	95	—	18	96
Tensile Strength, min psi	—	—	—	—	—	—	—	—	1600	—	—	—	—		1600
Elongation, min %	—	—	—	—	—	—	—	—	250	—	—	—	—	—	250
Tensile Strength, min % of orig	80	80	—	75	—	75	—	60	75†	80	60	75	—	60	—
Elongation, min % of orig	60	60	—	65	—	65	—	60	75††	80	60	75	—	60	—

Ozone Chamber: Type JN and JN-L -50 pphm ǂ conc. @ 38°C for 168 hours – No visible cracking.
Arctic Type -50 pphm conc. @ 50°C for 168 hours – No visible cracking.

* Per MIL-I-3930C

** Per MIL-C-13777E

† Not less than 1600 psi

†† Not less than 250%

ǂ Ozone concentration - parts per hundred million.

TABLE 7–18

RECOMMENDED SHEATH THICKNESSES — POLYCHLOROPRENE

Core Diameter, in.	Sheath Wall Thickness, Nominal in.		
	Light-duty*	Medium-duty*	Heavy-duty*
0.125 and Under	0.020	0.027	0.035
0.126 to 0.155	0.022	0.031	0.040
0.156 to 0.219	0.024	0.039	0.045
0.220 to 0.234	0.026	0.039	0.078
0.235 to 0.290	0.031	0.047	0.078
0.291 to 0.300	0.031	0.047	0.094
0.301 to 0.430	0.050	0.063	0.094
0.431 to 0.540	—	0.070	0.094
0.541 to 0.640	—	0.078	0.109
0.641 to 0.740	—	0.094	0.125
0.741 to 0.850	—	0.109	0.141
0.851 to 1.100	—	0.125	0.156
1.101 to 1.320	—	0.156	0.172
1.321 to 1.550	—	0.172	0.188
1.551 to 1.820	—	—	0.203

Note: Double-layer sheaths shall be used on cables whose sheath wall thickness, as specified, is 0.109 in. or over. Such double-layer sheaths should be applied in two concentric layers so cured or vulcanized that they are strongly bonded together; the outer layer to be at least 50%of the total thickness. A reinforcement, consisting of an open braid, or two layers applied in reverse directions, of seine twine, or the equivalent, shall be provided between the layers of the sheath.

* See note in Table 7-16.

TABLE 7–19

SIZE OF GROUND WIRES, ANNEALED COPPER

Conductor Size, AWG#	Number of Conductors		
	Two	Three	Four
	Min Ground Wire Size, AWG		
8	10	12	12
6	10	10	12
4	8	8	10
2	6	8	9
1	5	7	8
0	4	6	7
00	3	5	6
000	2	4	5
0000	1	3	4

TABLE 7–20

CONSTRUCTIONAL DETAILS OF ANNEALED COPPER GROUND WIRES FOR "FLEXIBLE" AND "EXTRA FLEXIBLE" CABLE CONSTRUCTION

Ground Wire Size, AWG#	Flexible				Extra Flexible			
	Type Stranding	Number of Strands	Nominal Dia of Each Strand, in.	Nominal Conductor OD, in.	Type Stranding	Number of Strands	Nominal Dia of Each Strand, in.	Nominal Conductor OD, in.
2	Concentric	19	0.0185	0.092	Bunch	65	0.010	0.101
0	Concentric	19	0.0234	0.117	Bunch	104	0.010	0.126
9	Concentric	7x7	0.0164	0.148	Bunch	7x19	0.010	0.146
8	Concentric	7x7	0.0184	0.166	Rope	7x24	0.010	0.157
7	Rope	7x7	0.0206	0.185	Bunch	7x30	0.010	0.179
6	Concentric	19x7	0.0140	0.210	Bunch	7x38	0.010	0.202
5	Concentric	19x7	0.0158	0.237	Bunch	7x48	0.010	0.235
4	Concentric	19x7	0.0177	0.266	Bunch	7x60	0.010	0.272
3	Concentric	19x7	0.0199	0.299	—	—	—	—
2	Concentric	19x7	0.0233	0.335	—	—	—	—
1	Concentric	37x7	0.0180	0.378	—	—	—	—

TABLE 7—21

ESTIMATED MAXIMUM LINE LENGTH FOR I—VOLT DROP COPPER CONDUCTORS AT 60°C

Conductor Size, AWG #	Current, Amperes																	
	5	10	15	20	25	30	40	50	60	80	100	120	150	200	250	300	400	500
	Maximum Line Length (one-way)																	
10	90	45	30	23	18	15												
8	138	69	46	34	27	23	17											
6	220	110	73	55	43	36	27	22	18									
4	347	174	116	87	70	58	43	34	28	22	17							
2	553	277	184	138	110	93	69	55	46	34	27	23	17					
1	698	349	233	174	140	116	88	70	58	43	34	28	23	17				
0	879	439	295	219	176	146	110	88	73	55	44	36	29	21	17			
00	108	554	371	277	221	185	138	111	92	69	55	46	37	27	21	18		
000	.398	699	465	349	279	233	174	140	116	88	70	58	46	34	27	23	17	
0000	760	880	586	440	352	293	220	176	146	110	88	74	59	44	35	29	22	17

Notes:

1. For voltage drops other than 1 volt, multiply above footages by permissible voltage drop.

2. Check tables on current-carrying capacities to make certain current is not in excess of that allowed for specific construction and insulation.

3. Above table is based on DC circuits, or AC circuits having 100%power factor and disregarding the effect of line reactance. For lines in circuits having reactances of appreciable magnitude, it is suggested that reference be made to the *Standard Handbook for Electrical Engineers,* McGraw-Hill Book Co.

4. For conductor temperatures other than 60°C, multiply the footages in the above table by the appropriate correction factor which follows: (Cont. next page)

TABLE 7-21 (CONT.)

(Note 4 continued)

Conductor Temperature, °C	Correction Factor
25	1.14
40	1.07
50	1.04
60	1.00
75	0.95
90	0.91

REFERENCES

1. MIL-C-1958, *Cable, Cord, and Wire, Electrical (Shipboard Use).*
2. MIL-C-3432C, *Cable and Wire, Electrical (Power and Control, Flexible and Extra Flexible, 300 and 600 volts).*
3. MIL-C-13777E, *Cable, Special Purpose, Electrical.*
4. MIL-I-3930C, *Insulating and Jacketing Compounds, Electrical (For Cables, Cords and Wires).*
5. *Standard Handbook For Electrical Engineers,* McGraw-Hill Book Co., N.Y.

CHAPTER 8

SPECIAL PURPOSE CABLES

8–1 INTRODUCTION

8–1.1 GENERAL TYPES

This chapter discusses special purpose cables, including multiconductor design and application, ignition wire, and thermocouple cables. Special purpose cables are defined as cables designed with a specific use or application in mind. This chapter includes hybrid cables embodying principles utilized in Chapter 6, "Control and Signal Cables", and Chapter 7, "Power Cables".

8–1.2 DESIGN FACTORS

This chapter discusses the following two aspects of design criteria:

1. Design of cable

2. Choice of cable for equipment design

8–2 HYBRID CABLE DESIGN FACTORS

The design factors of a multiconductor hybrid cable configuration are essentially the same as those used for control and signal cable (Chapter 6), except that the emphasis is placed on those points dependent on the cable end usage. The following is a general check list used in the design of a multiconductor hybrid complex.

8–3 CONSTRUCTION CHECK LIST

8–3.1 BASIC INSULATED WIRES

a. Determine type and number of basic insulated wires (there may be several types within a given component or complex). As an example, a single hybrid complex may contain any given number of hook-up wires, coaxial cables, power cables, twisted pairs, triplicates, quads, etc., shielded or unshielded, jacketed or unjacketed, all cabled to form a round, uniform, overall cable.

b. Strand selection for each a, par. 8–3.1 (See Chapter 1).

(1) Strand material determination (copper, plated copper, steel, aluminum, etc.). More than one type of strand may be desired in any one stranding; for example, steel may be used with copper within a given stranding, the steel strands giving the desired strength, the copper strands giving the desired conductivity. A bare copper stranding may incorporate a silver-plated copper strand for circuit identification.

(2) Strand AWG size selection (dependent on stranded AWG size). More than one strand AWG size may be incorporated in any one completed stranding, i.e, the steel strands used as strength members may need to be a larger AWG size for the desired strength.

c. Stranding choice (See Chapter 1).

(1) Stranded AWG size selection (dependent on desired resistance, current, physical strength, etc.).

(2) Type of stranding selected (concentric, bunch, rope, etc.).

(3) Determine physical size of completed stranding.

(4) Stranding lay (dependent on flexibility, flex life, etc.).

d. Insulation selection for each of a, par. 8–3.1 (See Chapter 2).

(1) Insulation material (PE, PVC, SE, TE, etc.). Note that the strand material selection may be dependent on insulation selected, or vice versa (See Chapter 1).

(2) Determine insulation thickness and physical size of each basic insulated wire (See Chapter 2).

(3) Determine thickness of nylon, or other covering, over basic insulated wire (nylon covering, or

equal, is recommended in multiconductor cable for all insulations other than Teflon and polyester tapes). Determine overall diameter of each basic wire (See Chapter 2).

8—3.2 COMPONENT LAY-UP

Cabling (See Chapter 6).

a, Determine location of each component within overall configuration. Ideally, the larger components will be located in the center, and each successive layer will employ progressively smaller components. This method of conductor lay-up is desirable for the two following major reasons:

(1) To gain as much flexibility as possible without sharp bend damage to any component.

(2) It is usually easier to obtain a well rounded, outer perimeter, thus enhancing the completed cable appearance as well as making the sheath application process easier and, in many cases, less expensive.

b. Calculate the diameter of each layer and the overall construction.

c. Determine the lay length and lay direction of each cabled layer.

8—3.3 CORE BINDER

Binder (See Chapter 6).

a. Determine binder material to be used.

b. Determine binder application (tape, braid, etc.).

c. Calculate overall diameter over binder.

8—3.4 OUTER COVERING

Sheath (See Chapter 2).

a. Determine sheath material to be used.

b. Determine method of application — extrude, tube, etc.

c. Determine if sheath should be reinforced.

d. Calculate wall thickness.

e. Calculate overall cable diameter.

8—3.5 CABLE IDENTIFICATION

Manufacturer's identification (See Chapter 6).

a. Determine what type of manufacturer's identification is required — print, embossing, tape, etc.

b. Determine where manufacturer's identification is to be located within cable complex.

8—3.6 PROTECTIVE BRAID

Armor (See Chapter 6).

a. Determine type of armor material to be used — aluminum, galvanized steel, etc.

b. Calculate percent coverage and braid angle if armor is of a braided construction.

c. Calculate overall diameter of cable.

8—4 SAMPLE HYBRID CABLE CONFIGURATION

Par. 8—3 presents the basic design criteria to be considered in the design and lay-up of a typical hybrid multiconductor cable configuration. We shall now take as an example the following requirements and follow them through to cable lay-up and design.

8—4.1 SAMPLE CABLE REQUIREMENTS

a. Number of conductors total = 71

The 71 total conductors are to be broken up as follows:

(1) 13 shielded, jacketed pairs	#16 AWG
(2) 4 singles, unshielded	#16 AWG
(3) 14 shielded, jacketed singles	#16 AWG
(4) 2 singles, unshielded	#8 AWG
(5) 3 shielded, jacketed groups of five	#16 AWG
(6) 2 shielded, jacketed triples	#16 AWG

(7) 1 shielded, jacketed group of four # 16 AWG

Wire sizes were determined by current to be carried and allowable voltage drop for required lengths of cable. Shielding is determined by signals to be carried and isolation needed.

b. Temperature Range: –55° to 70°C, ambient.

c. Cable Flexibility: flexibility must be maintained at –55°C.

d. Component identification required.

e. Manufacturer's identification required.

f. Voltage Requirements:

(1) Up to 1000 volts rms between conductors (3000 volts rms test voltage).

(2) Up to 300 volts rms between shields (1000 volts rms test voltage).

g. Medium Mechanical Handling (Portable) (See Chapter 7).

(1) Impact test (See Chapter 6).

100 complete cycles on each specimen, without failure, using a 27.5 lb weight at each of the following temperatures:

(a) 6 specimens at –55°C

(b) 6 specimens at +70°C

(2) Bend test (See Chapter 6).

1000 complete cycles on each specimen, without failure, using an 85 lb weight at each of the following temperatures:

(a) 3 specimens at –55°C

(b) 3 specimens at +70°C

(3) Twist test (See Chapter 6).

1000 complete cycles on each specimen, without failure, using an 85 lb weight at each of the following temperatures:

(a) 3 specimens at –55°C

(b) 3 specimens at +70°C

h. Minimum overall diameter to meet other requirements.

8–4.2 SAMPLE CABLE CONSTRUCTIONAL FACTORS

The cable would be laid up as follows, with some of the more important reasons for the selection of materials.

a. Selection of Strandings (Ref. Tables 1–4 and 1–6).

(1) #16 AWG: 19 strands of #29 AWG, tin-plated, diameter of each strand = 0.0113 in.

(a) Diameter of 19/29 stranding = 0.0113 in. x 5 = 0.057 in. (rounded to nearest mil). From Table 1–6, diameter is 0.057 in.

(b) Tinned copper is adequate for temperatures encountered and improves solderability over bare copper.

(2) #8 AWG: 133 strands of #29 AWG, tinned copper, diameter of each strand = 0.0113 in.

(a) Diameter of 133/29 stranding = rope stranded in 19 groups of 7 strands each = 0.0113 in. x 3 = 0.0339 in. x 5 = 0.170 in. diameter. From Table 1–6, diameter is 0.169 in.

(b) Conductors are stranded for flexibility.

(c) Conductors are plated for corrosion resistance.

b. Selection of Primary Insulation.

Polyethylene (low-density normally) was selected for both primary insulations because of environmental temperatures and dielectric properties.

c. Selection of Insulation Coverings.

(1) #16 AWG: All conductor insulations covered with extruded nylon.

(2) #8 AWG: Conductor insulation covered with impregnated nylon braid.

Conductor insulations are covered for physical protection from internal cable injury such as shield end puncture, abrasion of component to component or conductor insulation to shield, and for performance under mechanical environment.

Extruded nylon was used, except where physical size of the conductor diameter was prohibitive.

d. Braided Shield Selections.

(1) Shield material in all cases will be tinned copper.

(2) Shields will have a minimum coverage of 75%.

(3) Shields will have minimum practical braid angle (less than 35") for good flexibility and termination qualities.

e. Selection of Component Jackets.

All jackets shall be polyethylene (high- or low-density dependent upon applications).

Polyethylene was selected for jacketing because of environmental temperature range and physical qualities (twist, bend, impact, etc.) desired in overall cable.

8—4.3 SAMPLE CABLE LAY-UP

With the preceding information available, it is now possible to lay up the individual cable components.

8—4.3.1 Component Construction (Refer to par. 8—4.1)

(1) Component 1:

(a) Number of conductors: 13 shielded, jacketed pairs

(b) AWG size: #16(19/29) tinned copper, diameter 0.057 in.

(c) Primary dielectric: polyethylene, diameter 0.077 in.

(d) Dielectric covering: extruded nylon 0.009 in. wall, diameter 0.095 in.

(e) Twist: two above cabled together with a 2 in. right hand lay, diameter 0.190 in.

(f) Shield: 6 ends #36 AWG tinned copper, 24 carrier, 8.2 picks/in.

(g) Braid coverage: 91%, braid angle 20.2°, diameter 0.212 in.

(h) Jacket: polyethylene (clear), 0.017 in. wall, diameter 0.246 in.

Note

Cable components will be exposed for five feet at either end, when terminated. This requirement necessitated the heavy wall of protective nylon (0.009 in.) over individual components. Normally, a 0.004 in. wall is sufficient and gives adequate internal protection.

(2) Component 2

(a) Number of conductors: 4 singles

(b) AWG size: #16 (19/29) tinned copper, diameter 0.057 in.

(c) Primary dielectric: polyethylene, diameter 0.077 in.

(d) Dielectric covering: extruded nylon 0.009 in. wall, diameter 0.095 in.

(3) Component 3:

(a) Number of conductors: 14 shielded, jacketed singles

(b) AWG size: #16 (19/29) tinned copper, diameter 0.057 in.

(c) Primary dielectric: polyethylene, diameter 0.077 in.

(d) Dielectric covering: extruded nylon 0.009 in. wall, diameter 0.095 in.

(e) Shield: 5 ends #36 AWG tinned copper, 16 carrier, 9 picks/in.

(f) Braid coverage: 87%, braid angle 20.4°, diameter 0.117 in.

(g) Jacket: polyethylene (clear), 0.015 wall, diameter 0.147 in.

(4) Component 4:

(a) Number of conductors: 2 singles

(b) AWG size: #8 (133/29) tinned copper, diameter 0.170 in.

(c) Primary dielectric: polyethylene, diameter 0.230 in.

(d) Dielectric covering: saturated, braided nylon fiber, diameter 0.247 in.

(5) Component 5:

(a) Number of conductors: 3 shielded, jacketed groups of 5

(b) AWG size: #16 (19/29) tinned copper, diameter 0.057 in.

(c) Primary dielectric: polyethylene,' diameter 0.077 in.

(d) Dielectric covering: extruded nylon 0.009 in. wall, diameter 0.095 in.

(e) Twist: five above cabled together with a 2.5 in. right hand lay, diameter 0.256 in.

(f) Filler: Place one 0.075 in. fungus-resistant cotton filler in core.

(g) Binder: 0.0005 in. thick x 3/4 in. wide Mylar tape wrap 50% overlap, diameter 0.258 in.

(h) Shield: 8 ends #36 AWG tinned copper, 24 carrier, 8 picks/in.

(i) Braid coverage: 88%, braid angle 29.1°, diameter 0.280 in.

(j) Jacket: polyethylene (clear), 0.025 in. wall, diameter 0.330 in.

(6) Component 6:

(a) Number of conductors: 2 shielded, jacketed groups of 3

(b) AWG size: #16 (19/29) tinned copper, diameter 0.057 in.

(c) Primary dielectric: polyethylene, diameter 0.077 in.

(d) Dielectric covering: extruded nylon 0.009 in. wall, diameter 0.095 in.

(e) Twist: three above cabled together with a 2 in. right hand lay, diameter 0.204 in.

(f) Shield: 6 ends #36 AWG tinned copper, 24 carrier, 12 picks/in.

(g) Braid coverage: 87.5%, braid angle 30.7°, diameter 0.251 in.

(h) Jacket: polyethylene (clear), 0.022 in. wall, diameter 0.295 in.

8–4.3.2 Component Color Coding (Refer to par. 84.1)

With a cable of this complex nature it is mandatory to have a clearly understandable color coding for circuit identification. The following is one suggestion, although others may serve as well.

(1) Component 1:

(a) 13 shelded, jacketed pairs.

(b) Each shielded, jacketed pair shall contain 1 black and 1 white conductor.

(c) Each shielded, jacketed pair will contain a 1/8 in. wide x 0.001 in. thick, printed Mylar marker tape placed longitudinally between the outer jacket and shield. This tape shall be legible through the clear outer jacket. The tape shall be printed every two inches as follows:

1. Pair #1 – 1
2. Pair #2 – 2 – etc. to cover the 13 pair

(2) Component 2:

(a) 4 singles

(b) All primary dielectrics, or dielectric coverings, shall be colored white.

(c) Each conductor shall be printed with black ink every 2 in. as follows:

1. #1 – 14

2. #2 – 15, etc. to cover the 4 singles.

(3) Component 3:

(a) 14 shielded, jacketed singles.

(b) All primary dielectrics, or dielectric coverings, shall be colored white.

(c) Each jacket shall be printed with black ink every 2 in. as follows:

1. #1 – 18

2. #2 – 19, etc. to cover the 14 singles.

(4) Component 4:

(a) 2 singles

(b) Primary dielectric is clear.

(c) Nylon braid shall be white.

(d) Extruded nylon jacket shall be clear.

(e) Each jacket shall be printed with black ink every 2 in. as follows:

1. #1 – 32

2. #2 – 33

(5) Component 5:

(a) 3 shielded, jacketed groups of 5 conductors.

(b) All primary dielectrics, or nylon coverings, white with helical ink striping as follows:

1. white primary

2. white primary – black stripe

3. white primary – yellow stripe

4. white primary – blue stripe

5. white primary – gray stripe

(c) Each shielded, jacketed group shall contain a 1/8 in. wide x 0.001 in. thick printed Mylar marker tape placed longitudinally between the outer jacket and shield. The tape shall be legible through the clear outer jacket. The tape shall be printed every 2 in. as follows:

1. #1 – 34

2. #2 – 35

3. #3 – 36

(6) Component 6:

(a) 2 shielded, jacketed groups of 3.

(b) Each shielded, jacketed group of 3 shall contain conductors with white primary dielectrics, or nylon coverings, and helical ink striping as follows:

1. white primary

2. white primary – orange stripe

3. white primary – brown stripe

(c) Each shielded, jacketed group shall contain a 1/8 in. wide x 0.001 in. thick printed Mylar marker tape placed longitudinally between the outer jacket and shield. The tape shall be legible through the clear outer jacket. The tape shall be printed every 2 in. as follows:

1. #1 – 37

2. #2 – 38

(7) Component 7:

(a) 1 shielded, jacketed group of 4

(b) The shielded, jacketed group of 4 shall contain conductors with white primary dielectrics, or nylon coverings, and helical ink striping as follows:

1. white primary

2. white primary – green stripe

3. white primary – black stripe

4. white primary – yellow stripe

(c) The shielded jacketed group shall contain a 1/8 in. wide x 0.001 in. thick printed Mylar marker tape placed longitudinally between the outer jacket and shield. The tape shall be legible through the clear outer jacket. The tape shall be printed every 2 in. with the marking "#1 – 39."

8–4.3.3 Component Precabling Tests

The components for the cable are now complete. It is suggested that after completion, the components be given a precabling test to preclude any faulty components from being cabled into the complete complex. This test normally consists of a few very simple control checks such as conductor continuity, voltage checks, diameter checks, color coding conformance, etc.

8–4.3.4 Cable Core Lay-up

With the component parts completed, the next step is the calculation of cable core lay-up. The cable core, in this instance, means the cabling of all the components out to the binder tape. The major points to keep in mind for this phase are:

a. Keep larger conductors or components in as close to the center of the complex as possible, for the reasons mentioned previously in this chapter under Construction Check List, par. 8–3.

b. Keep overall core diameter to a minimum.

c. Distribute components throughout the complex to evenly distribute the weight, and obtain a well balanced and rounded cable.

d. Cable should employ the least amount of fillers feasible.

A list of component diameters and how many of each, will help in the calculation.

The list could be drawn up as follows:

Component 1: 13, of diameter 0.246 in.

Component 2: 4, of diameter 0.095 in.

Component 3: 14, of diameter 0.147 in.

Component 4: 2, of diameter 0.247 in.

Component 5: 3, of diameter 0.330 in.

Component 6: 2, of diameter 0.260 in.

Component 7: 1, of diameter 0.295 in.

With this information displayed in this fashion, select the group, or groups, of largest diameter components and form them in a circle as close to the center as possible. In this case these groups consist of component numbers 4, 5, 6, and 7. This configuration is shown in Fig. 8–1.

As seen in Fig. 8–1, the components are laid out in a basic circle and balanced, component 5 opposite component 5, component 6 opposite component 6, etc. With this basic part of the cable laid out in this manner, the next step is mostly arrived at by trial and error, i. e., fitting in the remainder of the components as well as possible while maintaining cable balance and minimum diameter. This is made easier only by experience and common sense. The best possible solution to this particular cable is shown in Fig. 8–2.

The next step is to fill all the larger cable voids with fillers. This is especially necessary around the outside perimeter in order that a true, round perimeter will be obtained. If this is not done, the cable – when sheathed – will have large irregularities in the sheath, making the application of the sheath difficult and presenting a very poor appearance. The placement and size of fillers in this cable will be as shown in Fig. 8–3.

8–4.3.5 Core Binder

As noted in Fig. 8–3 a binder has been applied to the overall core, in this case the. binder is to be a 0.001 in. thick x 1.5 in. wide Mylar tape, helically wrapped with a 50% overlap. The choice of tape width is dependent on these three basic factors:

1. Core diameter

2. The speed at which the cabling is performed

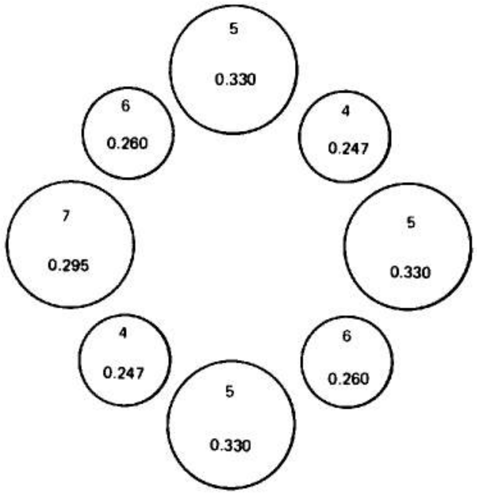


Figure 8–1. Hybrid Configuration–Component Placement

3. The amount of overlap desired

Table 8–1 is a general guide to help in the selection of tape widths for specified diameters.

The thickness of tape used is entirely dependent on the cable design engineer's judgment, but is kept to a minimum thickness where possible, to save weight and lower cost. The main function of this binder is to maintain the cable form until an outer covering, either shield or sheath, can be applied. If a shield is to be applied over the cabled core, the binder is of some value in protecting the components from stray shield ends puncturing the outer perimeter insulations.

8–4.3.6 Core Diameter Calculation

With the cable laid up to this point, the diameter of the cabled core can be calculated in one of two basic methods:

1. A scale drawing can be made, and the diameter measured.

2. By taking a cross section of the cable, and adding up all component plus void diameters in a straight line through the cross section.

Method 1 is by far the most reliable and accurate. The cable core diameter, in this case, comes to 1.614 in. over the binder tape.

8–4.3.7 Core Shielding

The next item to consider is the application of a shield. In most cases a core of this diameter will employ a #30 AWG size (see Chapter 1) shield wire, and the shield will utilize a braid angle as low as feasible while still maintaining a good percent of coverage. The braid used in this cable construction is:

1. 9 ends of #30 AWG tinned copper wire

2. 64 carrier braider

3. 4 picks/in.

When calculated, using **Eq.** 1–4, the braid angle is 32.7° and the coverage 88.5%.

8–4.3.8 Cable Separator

The next step is application of a separator. This separator is used primarily under a neoprene or rubber sheathing material so that the sheath, when applied, will strip easily from the shield and not imbed itself into the shield strands. The separator also affords extra strength and flexibility to the overall cable structure. The separator is usually composed of a braided or served fibrous material – such as cotton, glass, nylon, etc. – or a tape wrap such as Mylar, polyethylene, etc. In this sample cable a 26/2 cotton braid will be applied. The 26/2 denotes a 2-ply, 26-count cotton, and is normally purchased wound on bobbins suitable for use with a braiding machine or wrapping head. When using a braided-type separator, a coverage of 90% is desirable. Using the braid formula, **Eq.** 1–4, a 90% minimum coverage braid is calculated, and the following braid is applied as a separator:

1. 8 ends of 26/2 cotton

2. 48 carriers

3. 10 picks/in.

This braid gives:

1. 91.2% coverage

2. 65.4" angle

3. 1.688 in. diameter over braid separator

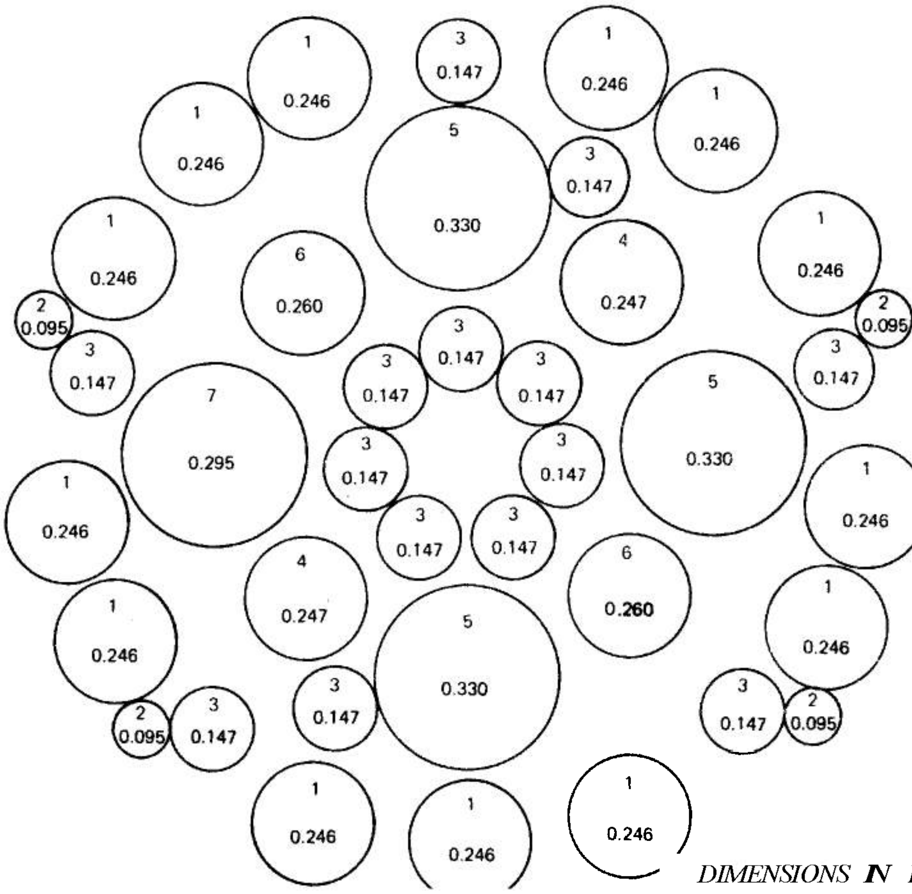


Figure 8–2. Hybrid Configuration—Component Placement

8–4.3.9 Cable Sheath

The application of a sheath is the next operation. The method for calculating overall cable diameter follows:

In Table **8–2** the polychloroprene sheath wall thickness recommended for a **1.688** in. core diameter is **0.135** in. Therefore, **1.688** in. core diameter + 2(**0.135** in.) = **1.958** in. overall diameter.

When determining a sheath or jacket wall thickness from a known overall diameter, calculate as follows:

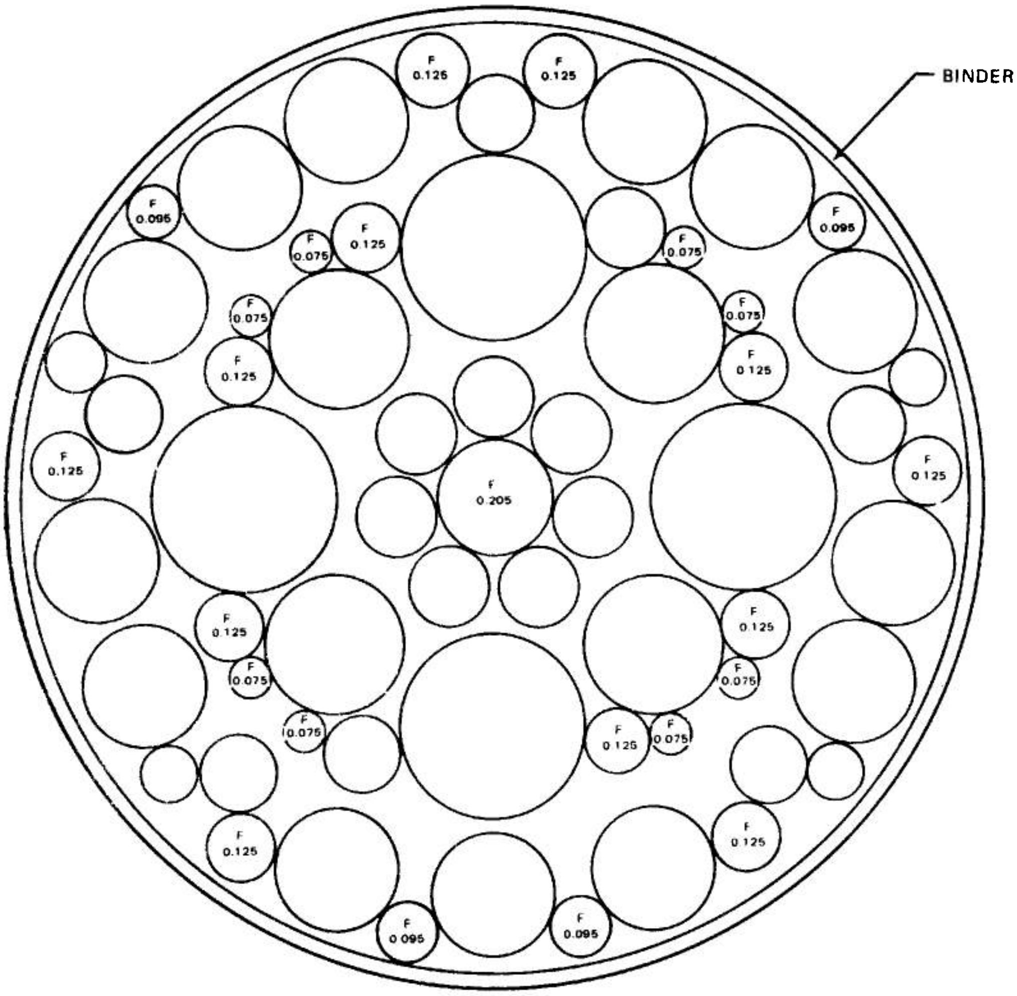
1.958 in. overall sheath or jacket diameter

−1.688 in. core diameter under sheath

0.270 in. total of two jacket or sheath wall thicknesses

Then: $\frac{0.270 \text{ in.}}{2}$ = 0.135 in. jacket or sheath wall thickness

When the cable sheath is of the reinforced type, the walls are calculated similar to a nonreinforced type sheath. A good rule of thumb when applying a reinforced sheath is 40% and 60%, i.e., the sheath wall is divided by the reinforcement, leaving **40%** of the total wall thickness next to the core, and **60%** of the total over the reinforcement layer. The heavier portion of sheath wall is almost always on the outside to afford greater protection and abrasive resistant qualities to the cable structure. Generally, the reinforcement is of a wide open braid or serve, and can be ignored in the calculation of the sheath wall thickness.



NOTE: THE BLANK CIRCLES REPRESENT THE CONDUCTORS

DIMENSIONS IN INCHES

Figure 8–3. Hybrid Configuration–Filler Placement

8–4.3.10 Cable Identification

The manufacturer's identification on a cable of this type is usually an ink print applied to the outside of the sheath during the sheathing operation. If the contour is such that printing is not feasible, or if an overall armor is applied, or the customer does not wish printing; a suitable printed manufacturer's marker tape is longitudinally laid in, usually under the metallic shield. These tapes are discussed in Chapter 6.

The cable construction discussed herein will, when completed, be as shown in Fig. **8–4.**

8–5 CHOICE OF CABLE FOR EQUIPMENT DESIGN

With the correct choice of cable construction to perform a certain function over a usable length of time, the user may be assured of relatively trouble-free operation. There are countless applications or environments that will be encountered and, therefore, countless cable configurations. For this chapter the cable choices will be broken into two broad categories: (1) light- or medium-duty cables and (2) heavy-duty cables.

TABLE 8–1

HELICAL WRAP TAPE WIDTH

SELECTION GUIDE

Minimum Tape Width, in.*	Core Diameter, in.
3/8	0.000 - 0.100
1/2	0.101 - 0.250
3/4	0.251 - 0.400
1	0.401 - 0.750
1-1/4	0.751 - 1.000
1-1/2	1.001 - 1.300
1-3/4	1.301 - 1.750
2	1.751 - 2.250
2-1/2	2.251 and larger

*Widths are for a 50% overlap of tape over specified core.

8–5.1 LIGHT- OR MEDIUM-DUTY CABLES

The intended usage of this type cable is for electrical and electronic applications in protected areas. These cables are flexible multiconductor cables for use within tunnels, trailers, or buildings, and in protected runways between buildings. The cables will be used for data transmission, audio and video signals, control power, and radio frequency signals for electronic equipment. The general construction of these cables is to omit any reinforcing agents and limit the insulations and sheath wall thicknesses to meet in use, operational demands. These cables will be small, light in weight, and less expensive than heavy-duty cables.

8–5.2 HEAVY-DUTY CABLES

The intended usage is for portable cables not permanently installed. These cables will be laid in the open where they may be subjected to vehicular traffic, direct burial, abuse in back filling, or shifting soil conditions caused by frost, heavy pedestrian traffic, etc. For the most part these cables are strengthened for extreme abuse by installing steel strands within the conductors, reinforcing the outer sheath, applying heavier walls of insulation and sheathing, and, occasionally, the application of an overall armor. The majority of the cables designed for heavy duty, or

TABLE 8–2

LIGHT- AND MEDIUM-DUTY CABLES—

AVERAGE OVERALL SHEATH WALL THICKNESSES, in.

Core Diameter, in.	PVC	Polyethylene	Polychloroprene	FEP
0.000 - 0.250	0.025	0.025	0.072	0.010
0.251 - 0.500	0.040	0.040	0.087	0.015
0.501 - 1.000	0.065	0.065	0.100	0.021
1.001 - 1.500	0.085	0.085	0.115	0.025
1.501 - 2.000	0.110	0.110	0.135	--------
2.001 - 2.500	0.125	0.125	0.152	--------
2.501 - 3.000	0.125	0.125	0.195	--------

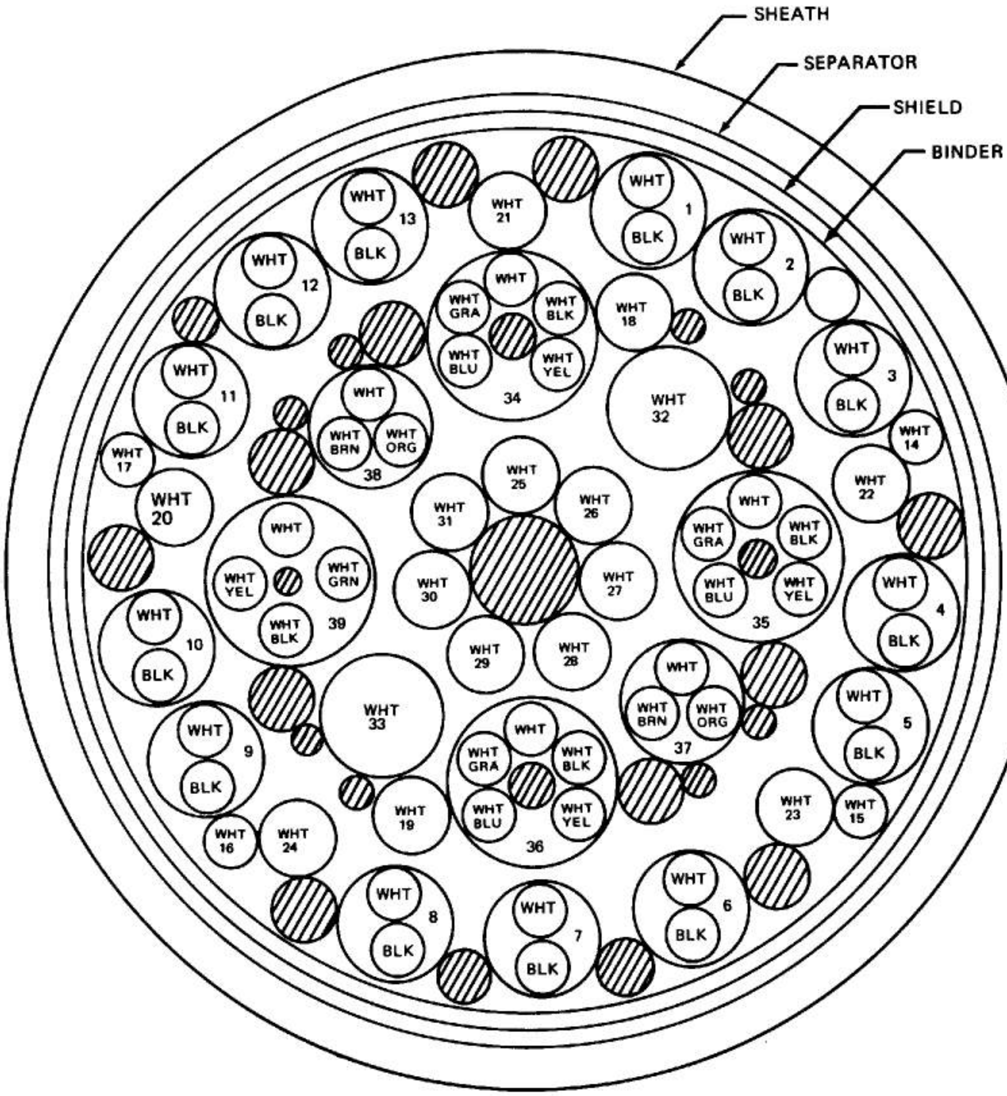


Figure 8–4. Hybrid Configuration–Completed Cable

extreme abuse, will employ a reinforced polychloroprene sheath.

Tables 8–3 through 8–5 will aid in the selection of insulation and sheath wall thicknesses for light-, medium-, and heavy-duty cables.

8–6 NONHOSING OR WATERBLOCKCABLE

8–6.1 GENERAL DESCRIPTION

A special purpose cable briefly discussed in the next few paragraphs is the submarine, or "nonhosing", cable types found in MIL-C-915B, MIL-C-2194, MIL€-23020, MIL-C-24145, etc. The general construction of these cables is very similar to any conventional multiconductor or coaxial type cable, except for one unique difference; the nonhosing cable type is capable of withstanding water pressures from 25 psi to 3,000 psi, the pressure being dependent on the construction and materials. The appropriate water pressure, when applied to one open end of a cable specimen, shall allow no longitudinal passage of water through the complex to the opposite end of the cable. The normal test specimen length for this type cable – when testing for longitudinal hydrostatic leakage – is five feet, and

TABLE 8–3

LIGHT- AND MEDIUM-DUTY CABLES—

AVERAGE JACKET WALL THICKNESSES FOR SHIELDED COMPONENTS, in.

Core Diameter, in	Nylon (Extruded)	Nylon (Braid)	PVC	Polyethylene	FEP	Polyester/ Polyethylene Tape
0.000 - 0.100	0.004	--------	0.012	0.012	0.008	0.006
0.101 - 0.200	0.006	--------	0.015	0.015	0.010	0.006
0.201 - 0.250	0.008	--------	0.015	0.015	0.012	0.006
0.251 - 0.500	--------	0.007	0.020	0.020	0.015	0.006
0.501 - 0.750	--------	0.007	0.030	0.030	0.020	0.006
0.751 - 1.000	--------	0.007	0.040	0.040	0.025	0.006

the time of pressure application varies from two to six hours. The nonhosing properties of this cable type are accomplished by inserting a "blocking compound" in all air voids of the cable during manufacture. This includes: (1) blocking the conductor stranding and then extruding the primary insulation very tightly over the blocked stranding, (2) blocking all interstices between components of a multiconductor configuration, and (3) blocking all braids, both metallic and fibrous. There must also be an integral adherence of all insulating layers; i.e., binder to core, sheath to binder, etc. A very important part of a waterblock cable is the selection of the blocking compound. This compound must be physically compatible with all the materials found in the cable structure; it must be capable of passing all the electrical and environmental tests required of the cable; and, very important, it must last the required cable shelf, or service, life without losing any of the inherent blocking qualities for which it was applied.

8–6.2 NONHOSING CABLE APPLICATIONS

The applications of the cable are for any area where the cable may pass through a liquid — not necessarily water, or wet installation — such as underground duct work. The blocked construction of the cable prevents the internal passage of liquid through the cable causing damage to the "black box" unit being controlled by the cable, or flooding of adjacent areas if the cable is cut or damaged during use.

8–7 THERMOCOUPLE CABLES

8–7.1 INTRODUCTION

When two wires of dissimilar metal are joined together to form an electrical circuit, and when one junction is maintained at a higher temperature than the other, an electromotive force (EMF) will be generated. This EMF is due to the temperature differential between the junctures. If the circuit is closed, and as long as there remains a temperature gradient from the "hot" to the "cold" junctions, current produced by this thermal EMF will continue to flow within the circuit. The principles which evolve from this phenomenon provide the basis for thermoelectric thermometry. The basic factors producing the thermoelectric output of these thermoelectric materials can be reproducedly controlled by alloying and heat treatment of the metals involved. As a result of the degree of this control, thermocouple wires and cables have become one of the most reliable and widely used means of accurate temperature measurement.

TABLE 8–4

HEAVY-DUTY CABLES–

AVERAGE JACKET WALL THICKNESSES FOR SHIELDED COMPONENTS, in.

Core Diameter, in.	Nylon	PVC	Polyethylene	FEP & TFE	PE Tape
0.000 - 0.100	0.007	0.015	0.015	0.010	0.008
0.101 - 0.200	0.009	0.018	0.018	0.015	0.010
0.201 - 0.250	0.010	0.018	0.018	0.015	0.012
0.251 - 0.500	--------	0.024	0.024	0.021	0.015
0.501 - 0.750	--------	0.034	0.034	0.025	0.020
0.751 - 1.000	--------	0.045	0.045	0.030	0.025

Core Diameter, in.	Polychloroprene
0.000 - 0.250	0.092
0.251 - 0.500	0.102
0.501 - 1.000	0.120
1.001 - 1.500	0.140
1.501 - 2.000	0.165
2.001 - 2.500	0.187
2.501 - 3.000	0.235

8–7.2 GENERAL OPERATIONAL FACTORS

A thermoelectric thermometer, or thermocouple, consists essentially of a pair of dissimilar metallic conductors usually joined by welding. The introduction of other materials or metals, such as in soldering, usually results in erroneous and misleading temperature data.

In order for the circuit to function as a thermocouple there must be a temperature difference between the "hot" and "cold" junctions, and one of the temperatures must be accurately known in order to act as a reference point. In extending from one temperature to the other, the conductor materials selected must span the needed temperature range or "temperature gradient".

In most applications the drop or rise in temperature is very abrupt, often taking place through a few inches of insulation. A typical thermocouple application is shown in Fig. 8–5.

If the thermocouple wires are initially homogeneous, and remain homogeneous during service, a sharp

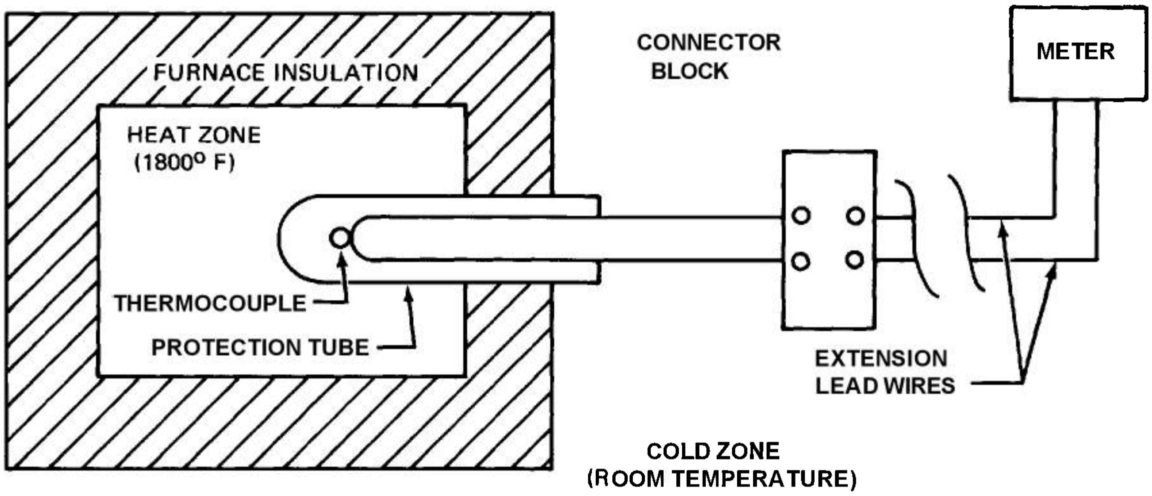


Figure 8–5. Typical Thermocouple Application

temperature gradient has no harmful effect upon the accuracy of the thermocouple unit. Under certain conditions, however, inhomogeneities may gradually develop in a pair of thermocouple wires due to oxidation, corrosion, evaporation, contamination, or metallurgical change, and thus create an EMF difference which may result in erroneous readings.

8–7.3 THERMOCOUPLE MATERIALS

The five most commonly used metals for use in thermocouple work are copper, iron, constantan, Chromel* and Alumel*. When united into thermocouples, the pairing would be as follows:

Pairs	Temperature Limits
a. Copper – Constantan	– 190" to 400°C
b. Iron – Constantan	– 190" to 750°C
c. Chromel* – Alumel* or T1** – T2**	– 190" to 1360°C

Many other alloy combinations are available for special purpose applications.

Chromel and Alumel are not normally preferred for temperatures below 0°C because of the small EMF gradient change per degree at the lowered temperatures. Frequently there are long runs from the thermocouple device to the instrumentation. These runs are normally made using copper conductors, but a much higher accuracy is obtained if the thermocouple metals are carried all the way. These long runs, or extensions, are called thermocouple lead cables and are discussed in ensuing paragraphs.

8–7.4 THERMOCOUPLE PROCUREMENT

In the procurement of random lengths of single-conductor, insulated, extension wire, it must be recognized that such wire is commercially combined in matching pairs to conform to established calibration curves. For this reason it is imperative that all single-conductor, insulated extension, or lead, wires be procured in the pairs to be installed, at the same time, and from the same source. For this reason thermocouple wires are usually furnished in cable form with a number of matched pairs of thermocouple lead wires.

8–7.5 CALIBRATION

All thermocouple cables and lead wires must be carefully calibrated against known temperature standards and certificates of calibration furnished.

8–8 THERMOCOUPLES VS LEAD WIRES

To differentiate between thermocouple cables and thermocouple lead wires in procurement, it must be

* Chromel and Alumel are trade names of Hoskins Mfg. Co.

** T1 and T2 are trade names of Driver Harris Co.

remembered that the thermocouple lead wires do not meet, and are not required to meet, as rigid an EMF tolerance as thermocouples, and should not be used as high accuracy measuring devices. Usually on lead wires and cables the insulation is the temperature limiting factor, whereas, on thermocouples the conductor is the temperature limiting factor. Thermocouple lead wires are used to run from the thermocouple to the instrument, and should have the same metals as the thermocouple in order to eliminate stray thermal EMF caused by junctions of dissimilar metals.

8–8.1 CONSTRUCTION

8–8.1.1 Conductors

Thermocouple cables and lead wires may be constructed with either solid or stranded conductors in any of the thermocouple metals. The AWG size normally ranges from #16 AWG to #36 AWG, but any gage size is available from approximately #8 AWG solid to #42 AWG solid.

8–8.1.2 Insulation

There are any number of insulations, or combinations of insulations, available for thermocouple wires and cables. Because of the low voltage handled in thermocouple work, low grade, electrically adequate insulation systems exist. This is generally true because the major concern in thermocouple work is environmental conditions. Shown in Table 8–6 is a typical cross section of some thermocouple insulations and their recommended, accompanying, overall insulations. The two general categories looked for when choosing insulations or jacketing are wicking or nonwicking properties of the materials. Table 8–6 shows the constructions that fall into these general areas.

8–8.2 CONSTRUCTIONAL EXAMPLES

Two constructional examples showing typical cables and color coding methods are:

1. Conductor size – #18 AWG stranded (7 strands #26 AWG).

   a. Wire type: Iron – Constantan

   b. Cabling: Parallel conductors

   c. Insulation:

      (1) Iron conductor: PVC – white

      (2) Constantan conductor: PVC – red

   d. Insulation over pair: extruded nylon – black

2. Conductor size: #18 AWG solid

   a. Wire type: Chromel – Alumel

   b. Cabling: Twisted pair

   c. Insulation:

      (1) Chromel conductor: extruded TFE – white – yellow spiral stripe

      (2) Alumel conductor: extruded TFE – white – red spiral stripe

   d. Insulation over pair: extruded FEP – clear – yellow spiral stripe

8–8.3 INSTALLATION

Thermocouples and thermocouple lead wires are normally installed with only the consideration due conventional electrical wiring. There is one very important, and often overlooked, difference in the installation of a thermocouple circuit, i.e., thermocouple cables and lead wires should always be twisted together when any outside electrical interference exists which could generate EMF variations, the result of which would be erroneous temperature readings.

Selection of conductor size in thermocouples and lead wires is made for mechanical considerations only. The one exception to this rule would be where a small amount of heat is to be measured in a relatively short period of time. In this case, using a large size conductor would act as a heat sink and give erroneous readings; accordingly, a smaller conductor would be much preferable in this instance. In other cases there is no connection between the selected AWG conductor size and temperature values or accuracy. A #40 AWG size conductor will record the same temperature value, and with equal accuracy, as a #8 AWG conductor size under the same exact conditions, but may not physically give the service life required simply because

TABLE 8–6

THERMOCOUPLE INSULATION AND JACKET SELECTION GUIDE

Single-conductor Insulation	Overall Insulation
Wicking Properties	
Lacquered glass	Lacquered glass
Nylon lacquered glass	Lacquered glass
Teflon tape - hi temperature varnished glass	Hi-temperature varnished glass
Lacquered glass	Lacquered cotton
Lacquered glass - nylon	Lacquered glass
Lacquered glass - polyvinylchloride	Lacquered glass
Lacquered glass	Lacquered glass - polyvinylchloride
Moisture-proofed asbestos	Moisture proofed asbestos
Moisture-proofed asbestos	Lacquered glass
Nylon hi temperature varnished asbestos/glass	Hi temperature varnished glass
Nylon hi temperature varnished asbestos/glass	Stainless steel braid
Teflon tape - hi temperature varnished asbestos	Hi temperature varnished glass
Moisture proofed asbestos	Lacquered cotton
Nylon	Lacquered cotton
Polyvinylchloride - nylon	Lacquered cotton
Glass polyvinylchloride - nylon	Nylon
Polyvinylchloride	Lacquered glass - nylon
Nonwicking Properties	
Teflon tape	Teflon tape
Nylon	Nylon
Polyvinylchloride	Nylon
Polyvinylchloride - nylon	Nylon
Nylon	Polyvinylchloride
Extruded tetrafluoroethylene	Extruded tetrafluoroethylene
Extruded fluorinatedethylenepropylene	Extruded fluorinatedethylenepropylene

the smaller size will not stand the abuse likely to occur.

8–8.4 ELECTROMOTIVE FORCE

Table 8–7 shows the temperature EMF correlation for the three most widely used thermocouple cables.

8–9 IGNITION WIRE — HIGH VOLTAGE

8–9.1 INTRODUCTION

The function of an ignition wire is the transmission of high-impulse voltage, electrical energy from a coil or transformer to a spark plug. The electrical energy can be considered to flow in the form of a high voltage pulse of low amperage, followed by a low frequency, damped wavetrain. The major applications are, of course, in aircraft and automotive ignition systems.

8–9.2 DESIGN CONSIDERATIONS

8–9.2.1 Conductor

The electrical properties of the conductor are usually not of prime importance. The lengths of wire are relatively short and the circuit has an initial inherent resistance of several hundred thousand ohms

TABLE 8–7

THERMOCOUPLE-TEMPERATURE-EMF CORRELATION CHART*

EMF, Absolute Millivolts / Temperature, "C — Reference Junctions 0°C			
	Thermocouples		
Temperature, "C	Copper-Constantan	Iron-Constantan	Chromel-Alumel
	-5.411 @ -193°C	-7.78 @ -195°C	-5.75 @ -200°C
-150	4.603	-6.50	4.81
-100	-3.349	4.63	-3.49
-50	-1.804	-2.43	-1.86
0	0	0	0
50	2.035	2.58	2.02
100	4.277	5.27	4.10
150	6.703	8.00	6.13
200	9.288	10.78	8.13
250	12.015	13.56	10.16
300	14.864	16.33	12.21
350	17.821	19.09	14.29
400	20.874	21.85	16.40
450	——	24.61	18.51
500	——	27.39	20.65
550	——	30.22	22.78
600	——	33.11	24.91
650	——	36.08	27.03
700	——	39.15	29.14
750	——	42.32	31.23
800	——	45.53	33.30
850	——	——	35.34
900	——	——	37.36
950	——	——	39.35
1000	——	——	41.31
1050	——	——	43.25
1100	——	——	45.16
1150	——	——	47.04
1200	——	——	48.89
1250	——	——	50.69
1300	——	——	52.46
1350	——	——	54.20
1400	——	——	54.88 @ 1370°C

* **Taken from NES Circular 561, Ref.** *6*

at the spark gap, hence even a few thousand ohms, more or less, in the conductor does not significantly affect ignition performance. In fact, a high-resistance conductor is often very desirable in helping to suppress radio noise by damping out oscillations sooner. The physical properties of the conductor are an important feature of ignition wire. Because this is considered a permanent type installation, the physical strength properties required would only be dependent on the anticipated forces or abuse inflicted during installation and maintenance. Resistance to flex fatigue should be considered since there is generally appreciable vibration around an engine. Generally, the same conductor material and construction is used for ignition wire as for conventional cables, however, there is one construction that is unique to ignition-type cable; this is the carbon-impregnated fiber type of conductor. This type construction has excellent thermal properties and flex life. If copper is used as a conductor material, plating should be used because of the corrosion caused by the thermal conditions around the installation (see Chapter 1, "Conductors").

8—9.2.2 Insulation

The primary insulation material must have good electrical properties, be resistant to deterioration due to corona, and have as low a capacitance value as is feasible with construction and usage. Butyl and neoprene rubber, polyethylene, and silicone rubber, for high temperature, are possible materials. The governing factors in the choice of these insulating materials are usually the thermal environment, flexibility, and cost. In the case of butyl rubber, this material is not considered as good in a high temperature, oil-saturated environment as some of the other choices, and would therefore function more efficiently with a protective sheathing.

8—9.2.3 Reinforcing Braid

A reinforcing braid in most constructions is optional; the braid would be dependent upon the end-use requirement with regard to installation abuse in pulling the cable through conduits, ducts, etc. The choice of fiber is largely dependent upon the anticipated thermal environment and costs. Here again, a protective covering is recommended over the butyl sheath. A recent development utilizes a single extrusion of ethylene-propylene rubber serving as both primary insulation and sheathing. This material combines good electrical properties, good corona resistance, and adequate oil resistance. Cost savings are realized here by the single extrusion and the physical amount of material used.

8—9.2.4 Outer Protective Fiber Braid

An outer fiber braid is permissible in some specifications. However, this application should be avoided whenever possible. Wicking and fraying problems are inherent in this type of outer covering, and with the advent of the newer sheathing materials, the outer fiber braid is becoming increasingly unnecessary as well as being very undesirable.

8—9.2.5 Shield

A metallic shield, whether braided or otherwise, should be used only when absolutely necessary, and is required to screen out radio interference. It is generally used on aircraft ignition wiring, but the shield is not usually desirable because it contributes to the system capacitance and increases the required output needed from the high voltage source. The shielding material is usually copper with a tin, silver, or nickel plating. In some instances solid nickel or stainless steel may be used when extreme thermal or acid environments are to be encountered.

8—9.3 SPECIFICATIONS

MIL-C-3702 is an active Military Specification for ignition wire covering three temperature ranges; -54" to 121°C, -54" to 232°C, -54° to 316°C. Only the latter two are considered for aircraft application.

REFERENCES

1. MIL-C-915B, *Cable, Cord and Wire, Electrical (Shipboard Use).*
2. MIL-C-2194, *Cables, Power, Electrical, Reduced Diameter Type, Naval Shipboard*
3. MIL€-3702, *Cable, Power, Electrical; Ignition, High Tension.*
4. MIL€-23020, *Cable, Coaxial (For Submarine Use).*
5. MIL€-24 145, *Cable, Electrical, Special Purpose For Shipboard Use.*
6. National Bureau of Standards Circular 561, *Reference Tables for Thermocouples*

CHAPTER 9

TELEPHONE CABLES

9–1 INTRODUCTION

The term "telephone cables" covers a myriad of constructions and uses in the wire and cable field; therefore, for purposes of this handbook, telephone cables will be broken down into four major categories.

9–2 MAJOR CATEGORIES

1. *Audio Cord*

The relatively small wires and retractile cords used in telephone handsets and headsets.

2. *Field Wire*

Wire used to provide tactical units in the field with relatively portable communications systems. The equipments are rugged, can be installed and removed rapidly, and are comparatively easy to maintain.

3. *Multipair Telephone*

Covering from two- to twenty-six pair cable and used in relatively short distance telecommunications systems.

4. *Multichannel Communications*

Covering special purpose telephone cables for long distance telecommunications systems.

These four categories cover the major applications in military communication systems.

9–3 AUDIO CORD

An audio cord is defined as a wire or cable assembly designed for use on communication equipment at audio frequencies. The basic considerations required in an audio cord or cable are ruggedness, conductor resistance, compatibility with equipment, and mechanical and environmental performance.

There are many and varied audio cord designs for various special uses. The basic design for all audio cords and cables, however, is very similar, and incorporates the previously cited basic qualities to the required degree needed for performance conformance.

9–3.1 BASIC DESIGN

The categories of components to be discussed are:

1. *Conductor*

Stranded wire, or tinsel ribbon, for flexibility. Strand material dependent on electrical and/or physical; properties required.

2. *Separator*

Applied over conductor and under insulation, when needed, to insure free stripping quality of primary insulation. Separator material is usually an organic, synthetic fiber or yarn.

3. *Shields*

Shields are used in audio cords for shielding out electrical interference. A shield *does* add to the overall diameter and weight, but is sometimes deemed necessary for the reasons stated.

4. *Primary Insulation*

A specially compounded, vulcanized, elastomer; synthetic, natural, a blend. or a thermoplastic such as vinyl or polyethylene material.

9–3.2 TINSEL CORD (MIL-C-3849A)

Normally, in the manufacture of tinsel cord there are four basic steps to be followed. These four steps can be considered standard in the manufacture of tinsel cords, although there are many variations of each.

9–3.2.1 Basic Design

The four basic procedures and the terminology used are given in the paragraphs which follow.

1. *Tinsel Ribbon*

The single, flat, metalic, conducting material used as the basic conductor.

2. *Tinsel Strand*

Made up of one or more tinsel ribbons spirally wound on a flexible fabric thread strength member.

3. *Tinsel Conductor*

Consisting of 2 or more tinsel strands around a fabric thread strength member.

4. *Tinsel Cord*

The completed product consisting of insulated tinsel conductors, usually wrapped around a flexible yarn staycord, with 'an overall protective covering.

9–3.2.2 Construction and Tests

The paragraphs which follow describe the four basic manufacturing and testing procedures of the above components.

1. *Tinsel Ribbon*

Tinsel ribbon is usually fabricated by rolling a piece of round wire to a desired thickness and width consistent with physical and electrical properties desired. The metals employed to fabricate the tinsel ribbon are usually pure copper, pure silver, tinned or silver-plated copper, or a copper alloy (usually tinned) designed to meet the required properties. The three main properties of tinsel ribbon are:

a. DC resistance

b. Breaking strength

c. Flexure characteristics

2. *Tinsel Strand*

The tinsel strand is constructed using a selected fibrous yarn core and helically wrapping one or more tinsel ribbons around this core with a specified lay length. The fibrous core must be of a strength to meet the tensile and elongation requirements, and must not contaminate or corrode the tinsel ribbon under the specified environmental conditions. High tenacity rayon is frequently used because of its high strength and low stretch qualities.

3. *Tinsel Conductor*

The tinsel conductor is composed of a specified number of individually insulated tinsel strands cabled around a fibrous core. The tinsel strands are covered with a protective, close-knit, fibrous braid or serve, and insulated with an extruded plastic or elastomer covering. This insulation is color coded by using colored compounds or ink striping.

4. *Tinsel Cord*

The completed tinsel cord is constructed by twisting the selected number of insulated tinsel conductors into a smooth uniform core (usually around a staycord) and covering it with an extruded plastic or rubber sheath overall. The tinsel cord is now complete except for the jacket, and if required, is now ready for electrical extensile/retractile cord construction.

9–3.3 RETRACTILE (HELICAL) CORDS

9–3.3.1 Basic Design and Construction

Retractile cords are accomplished by forming a precut length of the cord into a helical, spiral form (except for each end) with adjacent turns contiguous, and heat-setting the plastic jacket or curing the rubber jacket in this form to attain a permanent set in the configuration. The cables, particularly those with a vulcanized jacket, are then reverse twisted for improved' retractile properties. The sheath selection in this type of cable is very important for the following reasons:

1. Sheathing compound cannot become sticky or tacky under operating conditions because extensile and/or retractile properties will be affected.

2. Sheath must remain very flexible over entire operating temperature.

3. Sheath must maintain its elastic properties after repeated flexing over operating temperature range.

9–3.3.2 Tests

After the helical retractile cord has been designed and constructed, the tests are basic for normal usage. The basic tests are given in the paragraphs which follow. (Other tests may be employed for special cables or special usage.)

1. *Extension Qualities*

A specified cable length must extend to a specified distance, at a specific temperature, under a specified load, and remain for a specified time period. After this time period has expired and the load is removed, the cable coil must retract to its original length or a specified percentage thereof.

2. *Retractile Qualities (Low Temperature)*

The completed electrial cord is placed in a cold chamber at a specified temperature, in a horizontal position, for a specified length of time. At the conclusion of the time period the cord is extended a specified distance and rate while at this temperature. No fracture of the jacket, conductor insulation, or conductors shall occur. While still at this reduced temperature, the cord is released, and within a specified time must retract to within a certain percentage of the original retracted position.

3. *Low Temperature Impact Resistance*

After a specified time at a specified temperature ("cold soak"), and while in the cold chamber, a specified weight is dropped a given distance on the retractile cord helix. The jacket and insulation are then examined for cracks or other defects.

4. *Static Loading*

The cord is suspended vertically at room temperature, with a specified weight attached to the free end, for a specified time period. The weight shall be sufficient to extend the cord a specified percentage of its original retracted state. After the time period, and with the weight removed, the cord is laid at rest in a horizontal plane; within a specified time the cord should return to a specified percentage of its original retracted form.

5. *Continuity*

Each conductor of the cord shall be continuous upon final completion. When conducting the continuity test, many times the cord conductor will indicate continuity when the conductor is actually broken. One test procedure to overcome this situation is to run a noise level test on the cord length. If the conductor is actually broken, even though the two broken ends of the conductor are touching and indicating continuity, the noise level will increase above the specified limit.

6. *DC Resistance*

Upon cord completion, the DC resistance of each conductor shall be as specified.

7. *Extension-retraction Flex-life*

At a specific temperature the cord is extended a certain multiple of its relaxed length and allowed to retract. This action, in this sequence, constitutes one flex cycle. Rate of extension and retraction per cycle is specified. After a given number of cycles, the cord may be given one turn about its longitudinal axis and the test continued. Upon completion of the specified number of cycles, continuity and/or conductor resistance is measured.

8. *Flex-life*

Retractile cords are usually of a specified length in inches, and contain a specified number of turns, with straight sections at each end for ease of terminating the individual insulated conductors. The straight section is placed under tensile load and bent 180° back and forth around a mandrel of specified diameter at a specific temperature, for a specified number of bend cycles. The most sensitive indicator for flex-life failure is the noise level test.

9. *Dielectric Strength*

A specified voltage is applied between each conductor, one at a time, with the remaining conductors at ground potential, for a specified time. No dielectric failure or breakdown of any conductor shall occur.

10. *Insulation Resistance*

A specified insulation resistance shall be realized when a potential is applied between each conductor of the cable, one at a time, when other conductors are at ground potential.

9–3.4 MINIATURE CABLES (SPECIAL PURPOSE) (MIL-C-10392B)

These types of straight cables are used at potentials up to 300 volts rms; utilize a reduced diameter; are very flexible and light weight; and have excellent tensile properties for their size. These cables are designed for an operating temperature range of –40"to 60°C.

9–3.4.1 Basic Design

Some of these miniature special purpose cables and their constructions are outlined in the paragraphs which follow.

1. *Conductors*

The conductors for the various cables in MIL-C-10392B are as shown in Table 9–1.

2. *Conductor Construction*

a. The 404 circular mil area conductors will consist of 41 strands of #40 AWG (0.0031 in.) tinned, annealed, cadmium copper, bunch-stranded (see Chapter 1).

b. The 1620 circular mil area conductors will consist of 168 strands of #40 AWG (0.0031 in.) tinned, annealed, cadmium copper, rope-stranded (See Chapter 1).

3. *Separator*

A fibrous yarn (rayon or nylon) should be closely served over the conductor if the insulating compound is not free stripping.

4. *Insulation*

The insulation should be a specially compounded elastomeric material meeting the requirement of Type IS*, MIL-I-3930* (Buna *S* or Buna *S* and natural rubber) extruded over the conductor or separator. The insulation should have a minimum 0.010 in. wall thickness and a maximum 0.097 in. diameter over the 1620 circular mil conductor.

5. *Color Coding*

The conductors should be color-coded using differently colored insulating compounds. For color coding sequence on cables refer to MIL-C-10392B.

* This may eventually be changed to Type IS-L for -55° to +75°C.

6. *Stay Cords (MIL-C-5 72).*

Stay cords shall consist of a fiber core tightly overlaid with a closely woven fiber braid. These should act as flexible strength members and should be incorporated within the multiconductor configuration. Stay cords should be as follows for the specified cables:

a. Cables: WD 27 A/U, WM 69 B/U, two stay cords – 25 lb minimum breaking strength each.

b. Cables: WT 15 A/U, WF 11 A/U, WM 59 A/U, WM 60 A/U, WM 61 A/U, WM 62 A/U, WM 64 A/U, WM 70 B/U, WM 111 A/U, one stay cord -60 lb minimum breaking strength.

7. *Cabling*

a. The insulated conductors of cables WT 15 A/U, WF 11 A/U, WM 59 A/U, WM 60 A/U, WM 61 A/U, WM 62 A/U, WM 63 A/U, and WM 64 A/U should be twisted concentrically around a central staycord in the color-coded sequence of MIL-C-10392B, with the lay length as shown in Table 9–2.

b. Cable WD 27 A/U should be twisted with two stay cords and a maximum lay length of 0.500 in.

c. Cable WM 69 B/U should be twisted with two stay cords and a maximum lay length of 0.875 in.

d. Cable WM 70 B/U should be twisted, around a central stay cord, with a maximum lay length of 0.875 in.

e. Cable WM 111 A/U should be twisted around a central stay cord and shall employ three fibrous fillers. The cable shall have a maximum lay length of 0.875 in.

Figs. 9–1 through 9–4 show cable configurations of cable types B,C,D and E, and indicate color coding sequences for cable types A,B,C,D, and E.

8. *Separator*

An outer, braided, fibrous separator should be loosely applied over the cabled conductors. Even though this braid shall be loosely applied, it should afford excellent coverage.

TABLE 9–1

CONDUCTOR CHART—AUDIO CORDS

Cable Type	No. of Conductors	No. of Conductors of Each Size	AWG Size (Nominal)	Circular Mils (Nominal)	Cable Diameter, in. (Nominal)
WD 27 A/U	2	2	24	404	0.146
WT 15 A/U	3	3	24	404	0.212
WF 11 A/U	4	4	24	404	0.2 12
WM 59 A/U	5	5	24	404	0.212
WM 60 A/U	6	6	24	404	0.252
WM 69 B/U	6	2	18	1620	0.262
		4	24	404	
WM 111 A/U	7	2	18	1620	0.280
		5	24	404	
WM 61 A/U	7	7	24	404	0.252
WM 62 A/U	8	8	24	404	0.262
WM 70 B/U	8	2	18	1620	0.285
		6	24	404	
WM 63 A/U	9	9	24	404	0.280
WM 64 A/U	10	10	24	404	0.297

TABLE 9–2

CABLING CHART–AUDIO CORDS

Cable	Max Lay Length, in.
WT 15 A/U	0.500
WF 11 A/U	0.875
WM 59 A/U	1.125
WM 60 A/U	1.250
WM 61 A/U	1.250
WM 62 A/U	1.625
WM 63 A/U	1.750
WM 64 A/U	2.250

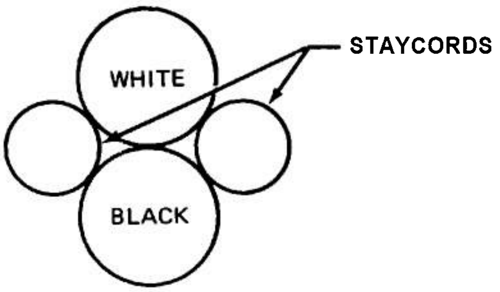


Figure 9–1. Special Purpose Cable–WD 27 A/U

9. *Sheath*

The sheath, in all cases, should be composed of a specially compounded SBR, meeting the requirements of Type JS* per MIL-1-3930. The sheath wall should be 0.015 in. minimum for Cable WD 27 A/U, and 0.020 in. for all other cables.

10. *Identification Marking*

Cables should be ink printed on the outer sheath for identification.

* This may eventually be changed to Type JS-L for -55°C (rather than -40°C) operation.

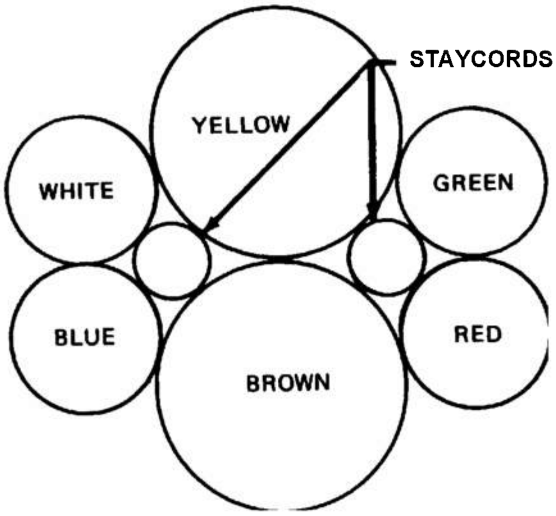


Figure 9–2. Special Purpose Cable–WM 69 B/U

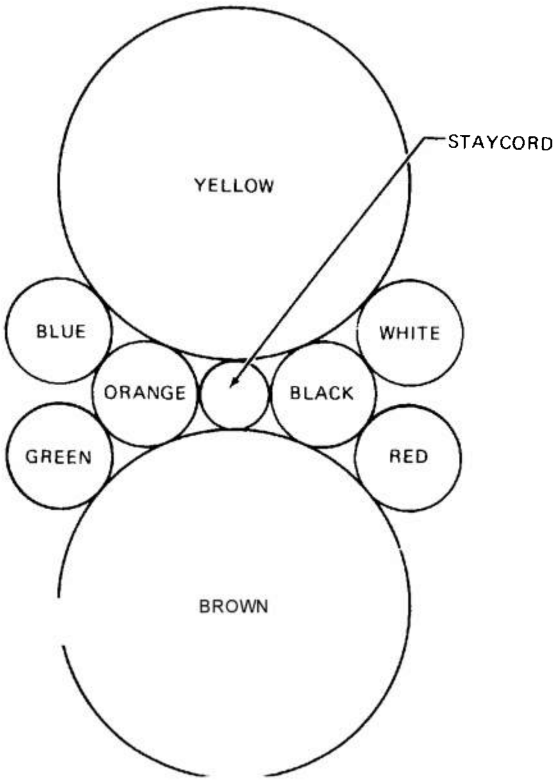


Figure 9–3. Special Purpose Cable–WM 70 B/U

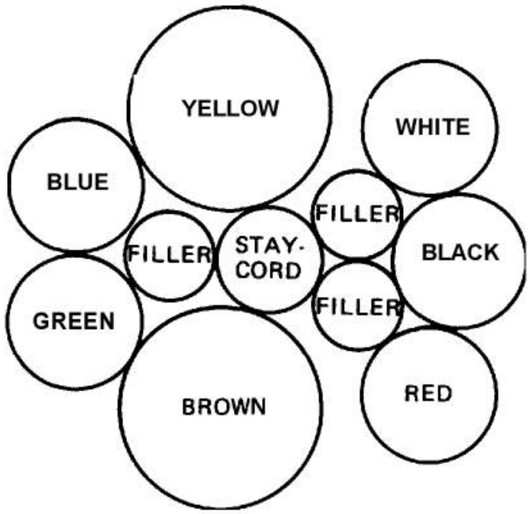


Figure 9–4. Special Purpose Cable–WM 777 A/U

9–3.4.2 Tests

1. DC Resistance * (at 20°C)

   a. #24 AWG: 39.0 ohm/1000 ft maximum.

   b. #18 AWG: 9.7 ohm/1000 ft maximum.

2. Dielectric Strength*

   a. Dry: 1000 volts rms for 1 sec.

   b. Wet: 500 volts rms for 1 sec.

3. Insulation Resistance * (at 15.6°C): Conductor Insulation 600 megohms/1000 ft minimum.

4. Flex-life**: Conductor continuity should remain unaffected after 30,000 cycles.

5. Cold Bend**: No cracking of conductor insulation or sheath when tested at -40°C.

9–3.5 MULTICONDUCTOR CORD (RETRACTILE) (MIL-C-13273)

The paragraphs which follow discuss the configurations and requirements for three typical multiconductor, retractile, electrical cords.

* Tests conducted per J-C-98.

** Tests conducted per MIL-C-10392B.

NOTE:

Due to the development of new and different conductor and insulating materials a contract has been issued by the U.S.Army Electronics Command for the development of subminiature retractile cords to reduce size and weight over existing cords. For further information on the progress of these subminiature cords reference should be made to the following U.S. Army Electronics Command Contracts:

DA-28-043-AMC-00471 (E), Subminiature Cords.

DA-28-043-AMC-00045 (E), Extra Flexible, Lightweight, Tactical Cable.

9–3.5.1 Usage

These cables are designed for basically the same applications as the existing cords, but are lighter in weight and smaller in size. The cords to be discussed are:

1. Cord WD 9/U (2-conductor)
2. Cord WT 2/U (3-conductor)
3. Cord WF 4/U (4-conductor)

The cord types indicated are for use on communications equipment at audio frequencies in a temperature range from –55° to + 85°C for continuous operation. The cables are designed for extension, in normal service, to five times their normal retracted lengths.

9–3.5.2 Basic Design

1. *Conductors*

The three cables–WD 9/U, WT 2/U, and WF 4/U –all utilize the same cadmium copper alloy conductor

2. *Insulation*

The insulating material should be a specially compounded elastomer. The extruded minimum wall should be 0.010 in., and the maximum diameter over the insulated conductor should be 0.080 in.

3. *Color Coding*

Color coding shall be attained by use of colored insulating material as follows:

a. WD 9/U (2 conductor):

(1) Conductor #1-White

(2) Conductor #2-Black

b. WT 2/U (3 conductor)

(1) Conductor #1-White

(2) Conductor #2-Black

(3) Conductor #3-Red

c. WF 4/U (4 conductor)

(1) Conductor #1-White

(2) Conductor #2-Black

(3) Conductor #3-Red

(4) Conductor #4-Green

The conductors must be capable of free stripping.

4. *Cabling*

All conductors should be cabled together, in the specified color code sequence, with a right hand lay of 1.5 in. maximum.

5. *Sheath*

The sheath shall consist of a specially compounded elastomer (SBR or SBR–natural rubber blend). When extruded, the average sheath wall on any cross section should be 0.010 in. and the minimum thickness on the straight sheath thickness shall be 0.020 in. The average overall diameters should be as follows:

a. WD 9/U (2-conductor) 0.220 in.

b. WF 2/U (3-conductor) 0.250 in.

c. WF 4/U (4-conductor) 0.250 in.

9–3.5.3 Retractile Construction

The completed electrical cord should be helical in form. The helix shall be left hand in its lay with a maximum diameter of 7/8 in. for WD 9/U (2-conductor), and 1-1/8 in. for WT 2/U (3-conductor) and WF 4/U (4-conductor).

9–3.5.4 Retractile Testing

1. *Extensile and Retractile Properties*

At room temperature the finished cords shall be extended to five times their retracted length and allowed to retract freely. After a total of six extensile and retractile cycles, the adjacent coils shall remain contiguous when the cord is placed on a horizontal surface.

2. *Stretch*

The helical cord shall be capable of 60,000 cycles of stretching to 4 times its retracted length at 40 cycles/minute. After this cycling the DC resistance of any conductor shall not have changed by more than 10% of its original value, and the cord shall return to within 20% of its original retracted length.

3. *Extension*

The helix, when suspended, shall be capable of extension to a minimum of 2-1/2 times its retracted length at room temperature under an 8-oz load for two-conductor cables, and a 10-oz load for three- and four-conductor cables.

4. *Other Tests*

a. Low Temperature Extension

b. Retraction After Static Load

c. DC Resistance

d. Dielectric Strength

e. Insulation Resistance

f. Continuity

All tests shall be performed per MIL€-13273 (Signal Corps). Tinsel cords may also be used in multiconductor configurations where great flexibility is required. A cable containing a number of tinsel cords has great flex-life, but is not considered appropriate where undue physical abuse is a factor. Very good tensile, or breaking, strength qualities can be incorporated in a multiconductor tinsel cable but abuse, such as impacting, will very rapidly cause damage and deterioration of cable operation.

9–3.6 SPECIFICATIONS

Specifications for telephone retractile cables, cords, and cord assemblies include:

a. MIL-C-3885A, *Cable Assemblies and Cord Assemblies, Electrical (For use in electronic, communication, and associated electrical equipment).*

b. MIL€-3884, *Cord, Electrical (Short Lay).*

c. MIL€-1 1997A (Signal Corps), *Cord Assembly, Electrical, CX-215 ( )/U (Retractile).*

d. MIL-W-3795A, *Wire, Electrical (Tinsel).*

e. MIL€-1 3273 (Signal Corps), *Cord, Electrical (Retractile 2, 3 and 4 Conductor, WD 9/U, WT 2/U, WF 4/U).*

f. MIL-C-10392B, *Cables, Special Purpose, Electrical (Miniature).*

g. MIL€-3883 , *Cord, Electrical (Audio Frequency).*

h. MIL-C-3849A, *Cord, Electrical (Tinsel).*

9–3.7 ALTERNATE CONSTRUCTIONS

Other types of insulation, such as polyethylene or polyvinylchloride, may be used with success in the manufacture of retractile cords. They may not require as heavy a wall of insulating compound, therefore, creating a cost and weight savings. It must be noted that the polyvinylchloride used in this operation must be for either the cold temperature range, to −55°C, or the high temperature range, to +85°C. A single polyvinylchloride compound to cover this temperature range has not been developed to date.

9–4 FIELD WIRE

9–4.1 USAGE

Field wire is manufactured in relatively long lengths (usually 0.5 - or 1 - mile package) and is designed for use in communication systems in the field. This means it must necessarily be rugged, very portable and light weight, of minimum cost, and be compact in package. A typical field wire communication system consists of field telephones, teletypewriters, switchboards, and radio wire integration stations all interconnected by field wire lines. The paragraphs which follow describe some typical field wire constructions, installations, and usages, along with some typical physical and electrical characteristics.

9–4.2 INSTALLATION FACTORS

There are three basic methods for the installation of a field telephone communication system:

1. *Surface*

This constitutes simply laying the cable, or cables, over the ground between equipments in as straight a line as feasible.

2. *Buried*

This method employs a ditch where a cable, or cables, are laid, with or without ducts, and covered over.

3. *Aerial*

This method of installation strings the cable from trees or preinstalled poles.

There are advantages and disadvantages to each installation method. Listed in Table 9–3 are the comparable features of each.

9–4.3 FIELD WIRE TYPES

The cables discussed cover the typical range of construction and usage; they are:

1. Electrical Telephone Cable (Infantry Field Wire) Twisted Pair, No.'s WD-1/TT (Std A) and WD-14/TT (Std B)

TABLE 9–3

INSTALLATION FACTORS–FIELD WIRE

Line Type	Advantages	Disadvantages
Surface	Easy to install. Fastest to install. Easy to maintain and repair. Easily recovered.	Subject to damage by vehicles, fire, weapons, personnel, and rodents. Affected by weather and climate. Requires more rugged cable construction, affecting weight and cost.
Buried	Less subject to damage than surface or aerial. Least affected by weather and climate.	Most difficult to repair. More time and equipment for installation. Difficult to recover, cannot be installed in some terrain.
Aerial	Less subject to damage than surface lines. Easy to maintain and repair.	More construction time than surface lines. Affected by weather and climate. Requires greater cable tensile and/or breaking strength quality.

2. Telephone Cable No. WF-16/U

3. Telephone Cable No. WD-36/TT

Shown in Table 9–4 are some comparative data on field cable characteristics. Notes with respect to this table are:

1. WD-1/TT is standard field wire for U.S. Army. WD-14/TT could be used as a substitute for WD-1/TT when WD-1/TT is in short supply.

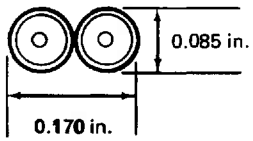
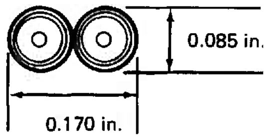
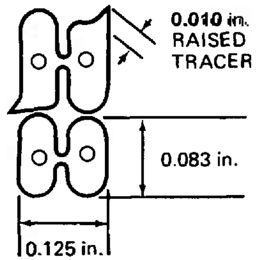
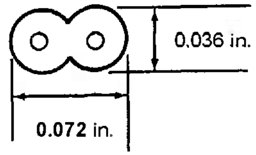
2. WD-36/TT, because of its small size and aluminum conductor construction, has application limitations. This cable, because of its light weight, is excellent for a quick, temporary, nonrecoverable installation only–such as demolition or assault operations. WD-36/TT should not be considered as a replacement for WD-1/TT or WD-14/TT cables which are more rugged. WD-36/TT is used only in dispenser form, and is not buried or installed on poles.

9–4.4 CONSTRUCTION

With the advent of new materials, such as high-density or cross-linked polyethylene, new communication cables can be developed to replace the standards now in operation. The use of highdensity polyethylene improves the electrical and physical capabilities while lowering the cost and weight in a comparable cable. Lowering the cost and weight are, in a great part, due to the possiblity of omitting the protective nylon or fiber braid covering over the primary insulation when using high density polyethylene.

TABLE 9–4

COMPARISON CHART—FIELD WIRE

Characteristics	Cable WD–1/TT	Cable WD–14/TT	Cable WF–16/U	Cable WD–36/TT*
				
Construction	Twisted pair	Twisted pair	2 Parallel pair, twisted	Parallel pair
Conductor	7 Strands/0.011 in.	7 Strands/0.011 in.	7 Strands/0.011 in.	Solid #23 AWG (0.0226 in.)
	3 Galvanized steel	3 Galvanized steel	Cadmium copper alloy	Aluminum
	4 Tinned copper	4 Tinned copper		
Insulation	Polyethylene	Polyethylene	Hi-density polyethylene	Polyethylene
Jacket and Diameter	Nylon, 0.088 in. max	Hi-strength nylon braid, 0.088 in. max	None-0.125 in. x 0.083 in. Nominal each pair.	None-0.072 in. x 0.036 in.
Twist	†R.H.L., 6 in. max	†R.H.L., 6 in. max	†R.H.L., 6 in. max	None

* Furnished in canvas dispensers only.

† Right hand lay.

TABLE 9–4 (CONT.)

Characteristics	Cable WD-1/TT	Cable WD-14/TT	Cable WF-16/U	Cable WD-36/TT*
Tensile Strength, lb	200	200	200 (1 00/pr)	25
Dielectric Breakdown, volts rms	10.000	10,000	10,000	1,000
DC Resistance max, ohm/1000 loop ft @ 20°C	46	46	53.5	125
Capacitance μF/mile				
Wet	0.124	0.124	0.095	0.185
Dry	0.052	0.052	0.060	0.080
Impedance-ohm, 1 kHz				
Wet	520	520	675	875
Dry	810	810	900	1030
Attenuation, db/mile, 1 kHz				
Wet	2.5	2.5	2.6	5.9
Dry	1.6	1.6	2.0	3.6
Insulation Resistance, megohms-1000 ft @ 15.6°C	1 x 10^6 min/cond	1 x 10^6 min/cond	1 x 10^6 min/cond	5 x 10^2 min
Temperature Range, "C	–40 to +80	–40 to +80	–55 to +100	–40 to +80
Weight, lb/mile	50	50	62	8.5

* Furnished in canvas dispensers only

A comparison was made using standard cables and cables utilizing highdensity polyethylene. The cable constructions and some comparative electrical and physical characteristics are shown in Table 9–5.

9–4.5 TEST DATA

In Figs 9–5 through 9–9 some comparative test data are plotted on the cable constructions shown in Table 9–5.

9–4.6 PACKAGING

Field cables of the types described are normally ordered in lengths ranging from 0.25 mile to 2.5 miles when supplied on reels. There is often a special packaging requirement other than coiling the wire on a spool or reel. These packages are called dispensers and are normally equally concerned with wire pay-off as well as wire packaging, and contain 0.25 or 0.5 mile lengths.

Dispensers such as those pictured in Figs 9–10 and 9–11 have many useful features, among them are:

1. Very portable, lightweight, and relatively inexpensive.

2. Capable of high speed pay out (40 mph or greater).

3. The wire will lay flat, without kinks or coils, after pay-out.

4. No special mounting devices are necessary for use.

5. Two or more dispensers may be mounted in tandem for extended wire lengths if required.

TABLE 9–5

CABLE CONSTRUCTION COMPARISON CHART

	Cable A*	Cable B**	Cable C †	Cable D ‡
Conductor	7 Strands/0.011 in. 4 copper 3 steel	7 Strands/0.011 in. 4 copper 3 steel	7 Strands/0.011 in. 4 copper 3 steel	#23 AWG solid Aluminum
Insulation Material	Polyethylene	Hi-density poly.	Hi-density poly.	Polyethylene
Insulation diameter	0.070 in. ea. cond.	0.070 in. ea. cond.	0.070 in. x 0.140 in.	0.036 in x 0.072 in
Jacket Material	Ext. nylon	None	None	None
Jacket diameter	0.085 in. ea. cond.			
Cabling	Twisted pair	Twisted pair	Parallel pair	Parallel pair
Weight, lb/mile	50	40	40	8.5
Avg. Tensile strength, lb	200	202	203	27.5
I.R. (minimum), ohms				
Dry	4×10^{12}	5×10^{12}	5×10^{12}	2×10^{12}
Wet	2×10^{12}	5×10^{12}	5×10^{12}	5×10^{12}
After Humidity	1 x 105	2 x 105	1×10^5	3 x 104
DC Resistance, ohm/mile	220	220	220	620
Dielectric Strength, rms/1 minute	1000	1000	1000	1000

* **Standard WD-1**

** **Twisted pair WD-1 (no nylon jacket)**

† **Parallel pair WD-1 (no nylon jacket)**

Standard WD-36

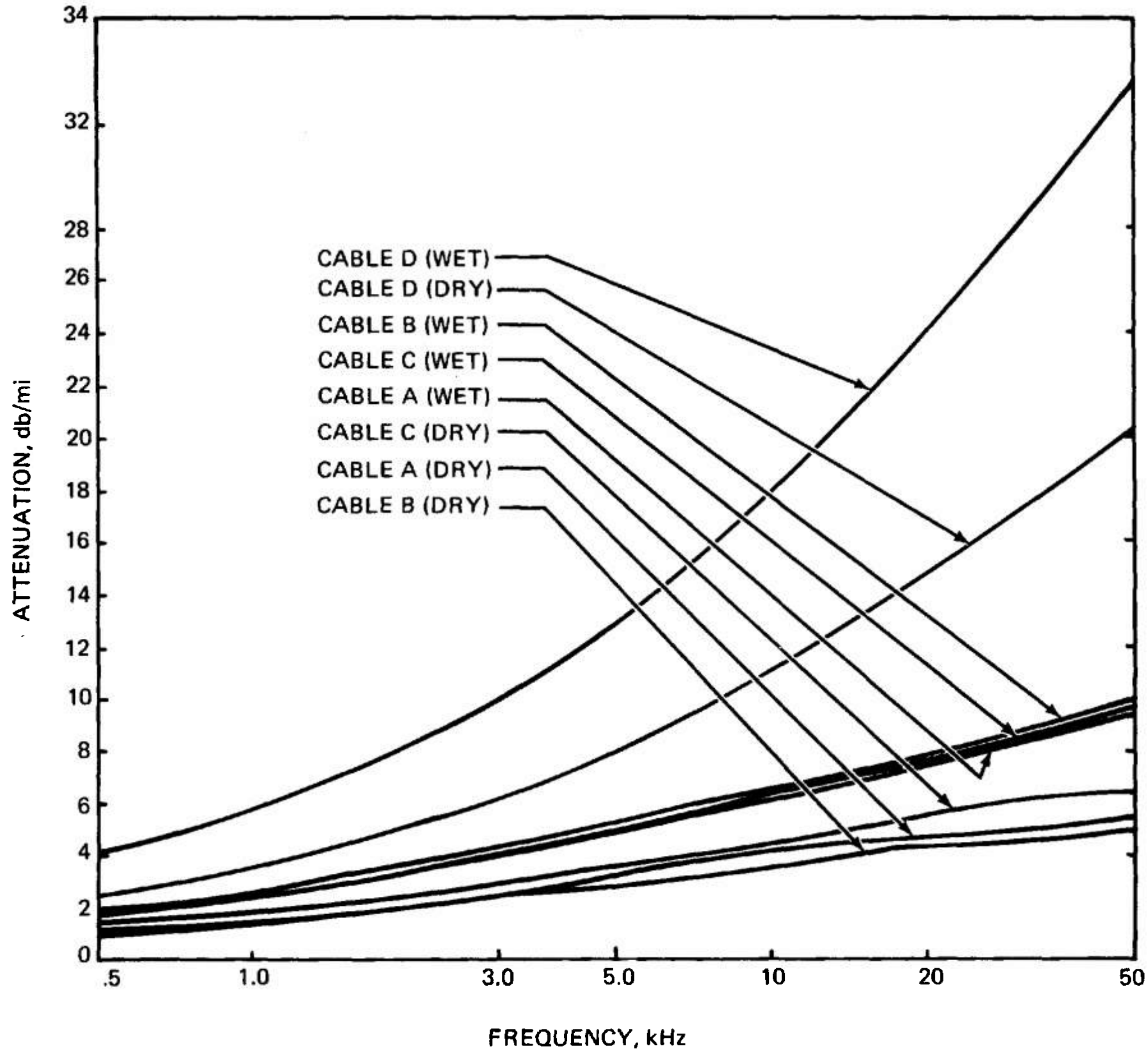


Figure 9–5. Field Wire Comparison–Attenuation vs Frequency

9–4.6.1 Canvas Dispenser Construction

Fig. 9–10 indicates these features:

1. "D" rings – steel, used for dispenser mounting.

2. Side panels – duck, moisture and mildew repellant.

3. Grommet – hi strength, flexible, elastomer compound.

4. Tape, double-backed (white) and single-backed (olive drab).

9–4.6.2 Plastic Dispenser Construction

Fig. 9–11 shows another type of dispenser similar to the one illustrated in Fig. 9–10 but lighter in weight, more compact, and affording the wire more physical protection. In this type of dispenser the wire is wound on a plastic mandrel attached to one side of the case. After the wire has been formed over the mandrel, the entire coil is then encased in a heat shrunk, vacuum preformed, plastic cover. When the package is complete, it forms a semi-rigid, sealed casing which can withstand much physical abuse.

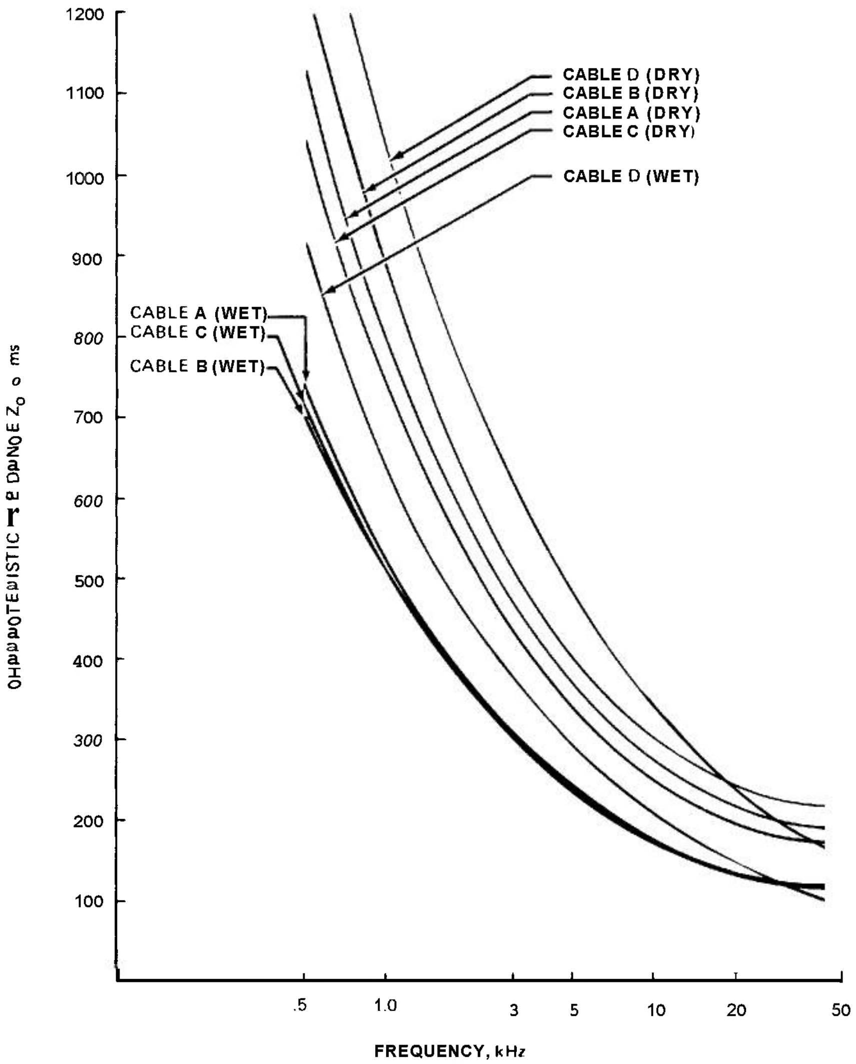
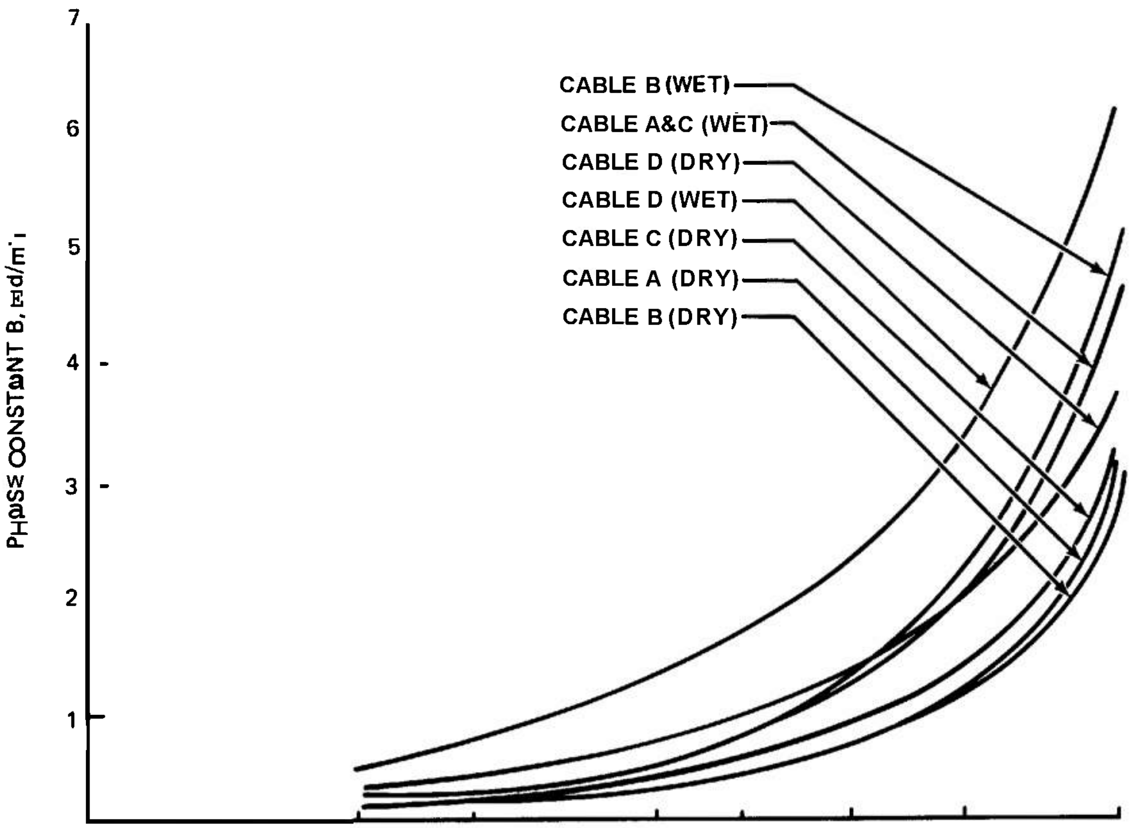


Figure 9–6. Field Wire Comparison–Characteristic Impedance vs Frequency



9–4.7 SPECIFICATIONS

Some pertinent specifications that refer to field wire and cable, and field wire and cable packaging are:

1. MIL-C-55462(EL),

   a. *Cable, Telephone, WD-36/TT Dispenser.*

   b. *Cable MX-6894( )/TT and Dispenser.*

   c. *Cable MX-6895( )/TT.*

2. MIL-C-55425(EL), *Cable, Telephone, WF-16/U.*

3. MIL-C-10369, *Cable, Telephone, Field, for Rapid Payout (MX 306-A/G).*

4. ECOM Technical Report 2657, *Laboratory Evaluation of Field and Assault Cable.*

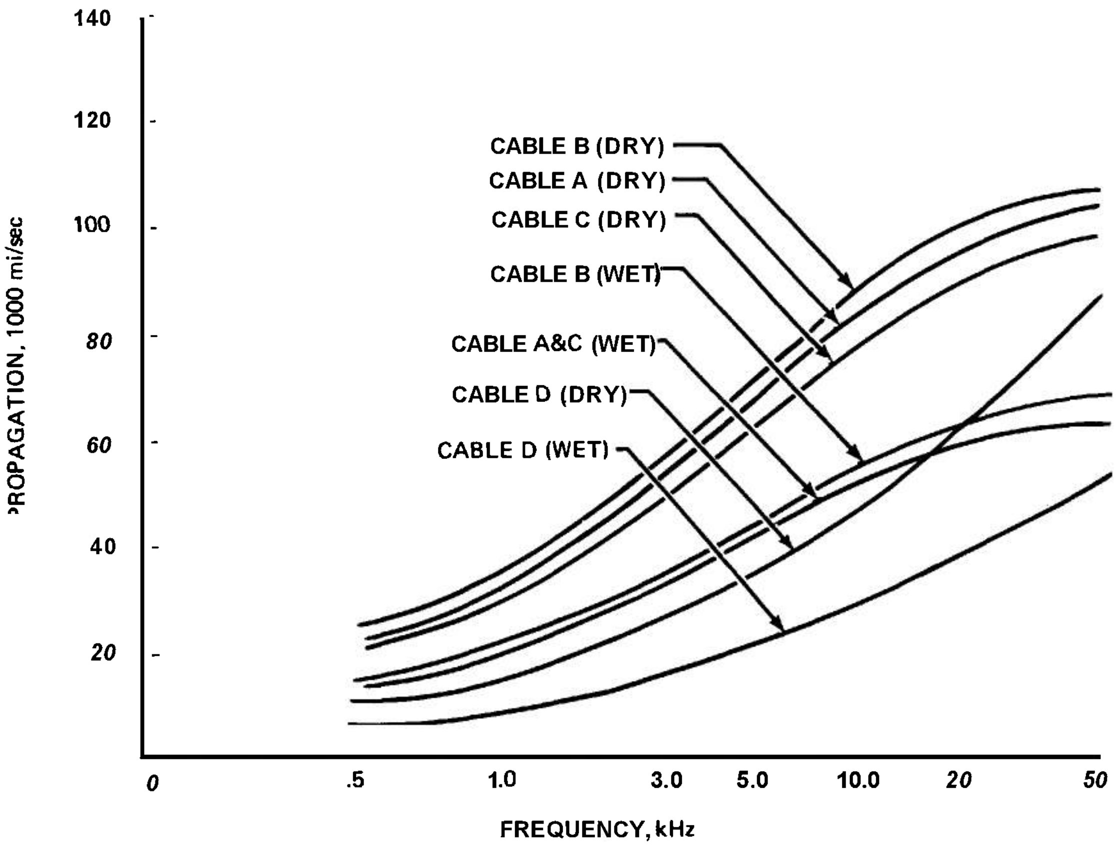


Figure 9–8. Field Wire Comparison– Velocity of Propagation vs Frequency

5. FM 24-20, *Field Wire and Field Cable Techniques.*

6. MIL-C-13294B and Amendment 3 (EL), *Cable, Telephone, Electrical (Infantry Field Wire, Twisted Pair, Wire WD-1/TT and WD-14/TT).*

9–5 MULTIPAIR TELEPHONE CABLES

9–5.1 USAGE

Multipair telephone cables are normally used inside a building or in a protected area. They find great use in work such as switchboard connection cables, where a great many wires are utilized in a relatively small space. The construction for multipair telephone cables is much the same as is required in any other multiconductor cable, except for the fact that all components are twisted pairs and are normally all the same physical size.

9–5.2 CABLE REQUIREMENTS

The requirements of multiconductor telephone cables are much the same as any other multiconductor cable, except for the following:

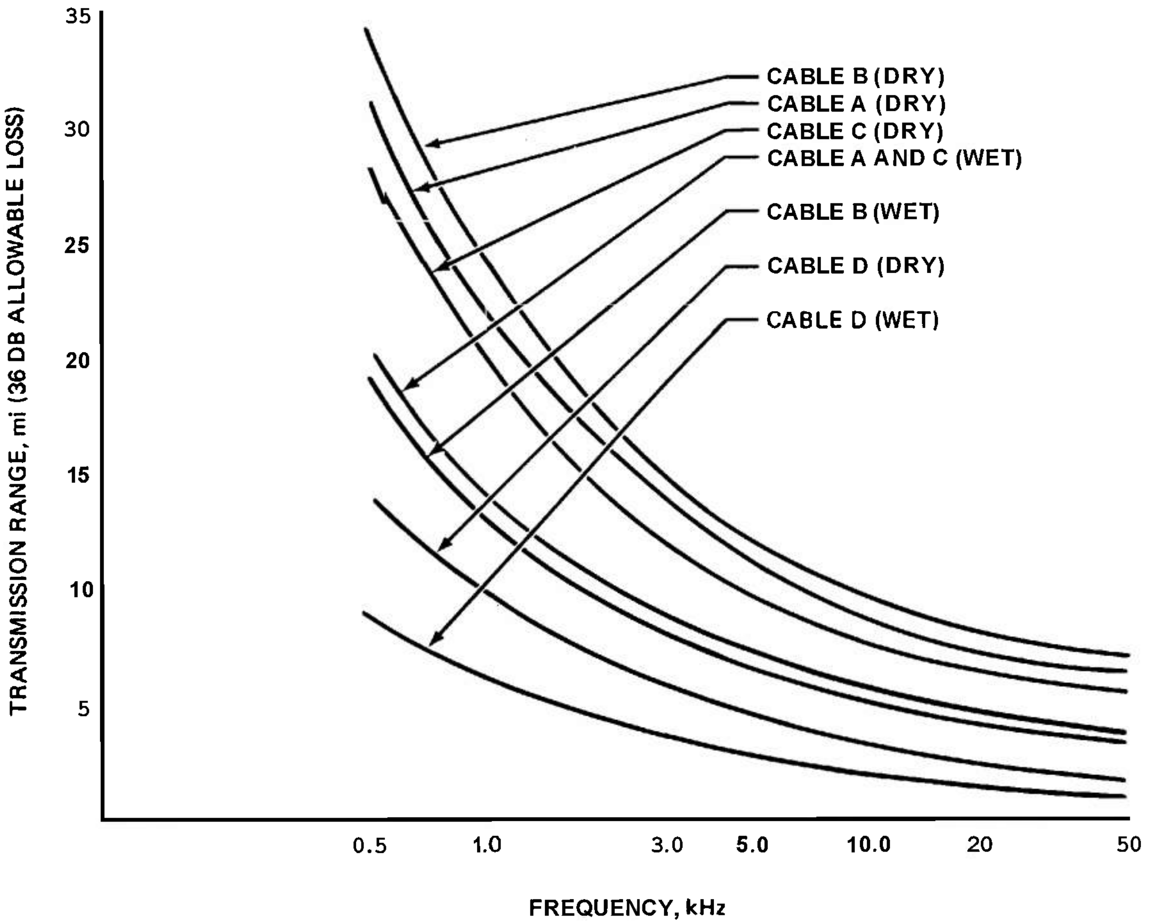


Figure 9–9. Field Wire Comparison—Transmission Range vs Frequency

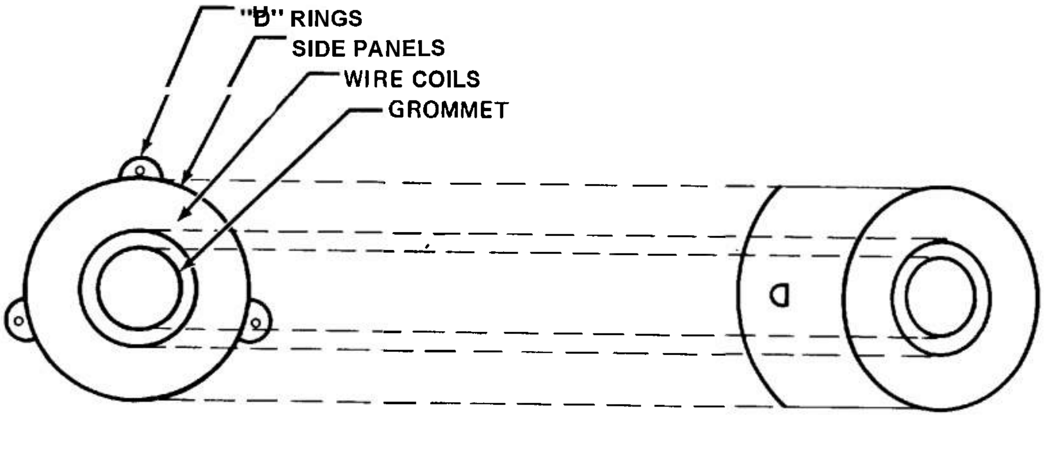


Figure 9–10. Canvas Dispenser—Field Wire

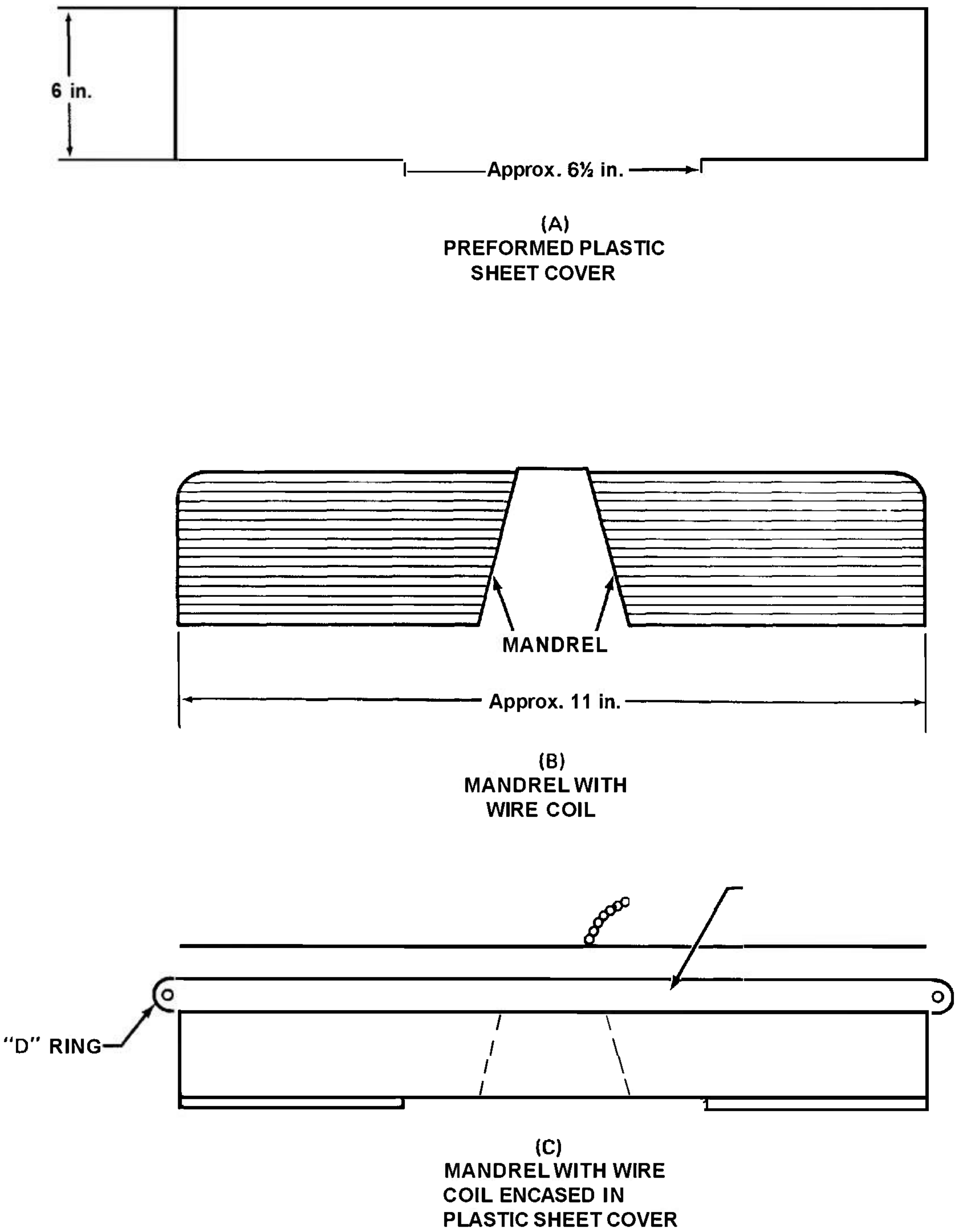


Figure 9–77. Semi-rigid Dispenser–Field Wire

a. Voltages carried are normally very small, and the same emphasis is not placed on the voltage breakdown quality of the insulations as on those insulations used for power circuits.

b. In the paired component construction, the capacitance – unbalance, mutual capacitance – and cross-talk qualities are very important for efficient operation of the system.

The more important electrical characteristics in a multipair telephone cable are:

a. DC Resistance

b. Insulation Resistance

c. Dielectric Strength

d. Attenuation

e. Mutual Capacitance

f. Capacitance Unbalance

9–5.3 REASONS FOR TESTING

An explanation of why the cited electrical characteristics are important to cable operation and.the reason for testing follows:

a. *DC Resistance*

The DC resistance of each conductor is measured to determine conductor size, material uniformity, and as a control on attenuation.

b. *Insulation Resistance*

The insulation resistance is important to assure dielectric material uniformity and quality, and for a check on moisture penetration.

c. *Dielectric Strength*

Cables should be checked 100% for dielectric strength integrity to assure that the installed cable will transmit the desired signal in a trouble-free manner. This is the reason that the required dielectric test voltage is many times greater than the operating voltage.

d. *Attenuation*

The attenuation requirement is limited to insure against high electrical losses. With correct attenuation, the desired operating signal will reach the termination in sufficient strength to be detected.

e. *Mutual Capacitance*

The mutual capacitance of each pair in the multiconductor configuration is checked, one against the other, to assure capacitance uniformity throughout the paired cable.

f. *Capacitance Unbalance*

The capacitance unbalance of conductor to conductor in a pair, and pair to pair in the cable, is checked to minimize cross-talk between circuits within the cable.

9–5.4 BASIC DESIGN

The majority of telephone cables employ 4 basic AWG-sized conductors: #26 AWG, #24 AWG, #22 AWG, and #19 AWG, and usually utilize solid wires. These conductors are normally bare copper, but are sometimes tinned copper. When a stranded conductor is desired, steel strands should be integrated with the copper strands to give added strength.

9–5.5 ELECTRICAL CHARACTERISTICS

Table 9–6 gives some typical characteristics of a pair within a multipair cable for the various conductor AWG sizes. All the data are based on a nominal 0.010 in. wall of polyethylene primary insulation.

9–5.5.1 Mutual Capacitance (Pair)

The mutual capacitance of a pair is defined as that capacitance measured between the two wires of a pair with the remainder of the conductors within a cable connected to shield or sheath and grounded. Mutual capacitance C_m is computed using Eq. 9–1.

$$C_m = \frac{2(C_a + C_b) - C_c}{4} \qquad (9\text{–}1)$$

where

C_a = Capacitance between No. 1 conductor and No. 2 conductor. No. 2 conductor connected to all remaining conductors (and shield if any) and ground.

C_b = Capacitance between No. 2 conductor and No. 1 conductor. No. 1 conductor connected to all remaining conductors (and shield if any) and ground.

C_c = Capacitance of No. 1 and No. 2 conductors connected together, against all remaining conductors (and shield if any) and ground.

9–5.5.2 Capacitance Unbalance (Pair)

The capacitance unbalance of a pair may be determined using Eq. 6–6. This measurement is often referred to as the Coefficient of Asymmetry.

$$C_u = \frac{400(C_a - C_b)}{2(C_a + C_b) - C_c}, \% \qquad (9\text{–}2)$$

where C_a, C_b, and C_c are defined as in Eq: 9–1 for mutual capacitance.

9–5.6 CONSTRUCTION

The description of a multipair telephone cable which follows typifies the construction and material used in this type of cable as specified in MIL-C-55036. The cable shall be composed of 26 pair. As an example of a typical construction, we shall use #24 AWG stranded, tin-coated copper conductors, insulated with polyethylene, color-coded, cabled, binder-wrapped, sheathed with either a polyvinylchloride or polychloroprene compound, and armored with a galvanized steel braid.

1. *Conductors*

Each conductor shall consist of 6 strands of tin-coated copper wire, concentrically stranded around a single galvanized steel strand. Each strand has a nominal diameter of 0.008 in., and the stranded diameter is 0.024 in.

2. *Primary Insulation*

The conductor shall be insulated with a nominal 0.010 in. wall thickness of extruded highdensity polyethylene. The diameter over each insulated conductor shall be 0.044 in.

3. *Color Code*

The 26-pair cable shall be fully color coded, as in MIL€-55036 (Signal Corps), using the insulation material for the base color, with a circumferential ink stripe for the band.

4. *Pair Twist*

The insulated conductors shall be twisted into pairs, utilizing the varied pair lay for reduction of cross-talk as shown in Table 6–8.

5. *Cabling*

The varied lay pairs shall then be cabled together to form a three-layer construction with a left hand lay of not more than 5 in.

6. *Marker*

A manufacturer's marker of nonhygroscopic material, denoting the manufacturer's name, shall be laid parallel with the cabled core axis under the core binder, or under the core wrap if no binder is used.

7. *Binder*

At manufacturer's option an open serve of nylon yarn may be applied over the core with a right hand lay.

8. *Core Wrap*

The core shall be covered with a 0.001 in. thick Mylar tape wrap with a minimum of 15% overlap.

9. *Inner Sheath*

An extruded process, tightly applied, polyvinylchloride or polyethylene sheath, of a nominal 0.016 in. wall, shall be placed over the core wrap.

10. *Braid*

A galvanized steel braid consisting of 2 ends #28 AWG wire, 16 carriers, 3 picks/in. shall be applied over the inner sheath.

TABLE 9–6

MULTIPAIR CABLE—ELECTRICAL CHARACTERISTICS (PAIR)

Electrical Characteristics	AWG Size			
	#26	#24	#22	#19
Nominal Conductor Resistance, ohm/mi @ 20°C	221	138	86	43
Nominal Conductor Resistance, ohm/loop mi @ 20°C	442	276	172	86
Minimum Insulation Resistance, megohm/mi	1000	1000	1000	1000
Dielectric Strength, DC Voltage conductor-to-conductor for 3 sec	2400	3000	3600	4500
Nominal Attenuation @ 1 kHz, db/loop mi	2.85	2.28	1.79	1.25
Average Mutual Capacitance, μF/mi @ 1 kHz	0.083 ±0.007	0.083 ±0.007	0.083 ±0.007	0.083 ±0.007
Nominal Capacitance Unbalance, pair-to-pair @ 1 kHz/1000 ft	40	40	40	40

11. *Outer Sheath*

An extruded process, tightly applied, polyvinylchloride or polychloroprene outer sheath, of an 0.047 in. wall, shall be applied over the galvanized braid.

12. *Identification Marking*

The outer sheath shall have ink printed cable identification markiags at specified intervals.

9–5.7 TESTS FOR CABLE

a. Low Temperature:

(1) Cold Bend @ –40°C, 1.5 in. mandrel

(2) Cold Bend @ –50°C, 3.75 in. mandrel

b. Breaking Strength: 800 lb minimum

c. DC Resistance: 62 ohm/1000 loop ft, maximum each conductor

d. Dielectric Strength: 3 *kV* DC (3 sec)

e. Insulation Resistance: 10,000 megohm/1000 ft minimum

f. Conductor Resistance Unbalance: 4% maximum each pair

g. Mutual Capacitance: 0.090 μF/mile maximum

h. Capacitance Unbalance: 160 $\mu\mu$F/1000 ft maximum

i. Attenuation: 2.7 db/mile maximum

9–5.8 SPECIFICATIONS

Some of the specifications now in effect for the manufacture and procurement of military multipair telephone cables are:

a. MIL-C-55425(EL), *Cable, Telephone, WF-16/U.*

b. MIL€-55036 (Signal Corps), 26 *pair Cable, Telephone, WM-130( )/G.*

c. MIL€-1 3268 (Signal Corps), *Cable, Telephone (#19 A WG and #20 A WG Switchboard Cable).*

9–6 TELEPHONE MULTICHANNEL COMMUNICATION CABLES

9–6.1 USAGE

In general telephone multichannel communication cables are used to form a transmission line to link stations of a military carrier to telephone communication systems over relatively long distances. The assemblies are to be used in any climate. The lines are laid on the ground, under water, buried, or strung aerially from trees or poles.

In a transmission system there are various phases used to form the completed system. In general these phases are as follows:

a. Phase 1

A multiconductor cable of specified length (the main, or longest length of the assembly) with a universal connector at each end for quick assembly or disassembly. One or more of these lengths are connected together to form the length desired.

b. Phase 2

A multiconductor cable of approximately 100 feet in length, the same construction as in Phase 1, with a universal connector at each end. This shorter assembly is used to span short distances between equipments, between equipment and the end of a line, or between two cabled assemblies.

c. Phase 3

A multiconductor cable of approximately 12 feet in length, a universal connector at one end and exposed conductors at the opposite end. This cable assembly is used for connections to equipments that are not provided with connectors; for example, when making local tests on equipments, for connectors to open-wire lines, or when making tests on cable line.

d. Phase 4

With some carrier telephone systems a telephone loading coil assembly is used to reduce system attenuation and thus permit greater spacing of repeaters. This loading coil is connected in the cable system at the junction of two Phase 1 cable lengths. A loading coil assembly is a metaliic cylinder approximately *6* in. in length with a universal connector at each end and containing one or more loading coils to suitably decrease the system attenuation over the system's usable frequency range.

9–6.2 CONSTRUCTION

The information which follows describes the constructional details of a typical cable used in a multi-channel communication system as specified in MIL€-10581. The cable to be described is a telephone field carrier cable of the "Spiral Four" type. "Spiral Four" means a star quad, long distance communication cable, and of portable type construction.

1. *Conductor*

The conductors shall be stranded, annealed, bare copper. The stranding shall be concentric and each strand diameter shall be 0.0136 in.

2. *Insulation*

Polyethylene, heat-stabilized, extruded, with a 0.014 in. minimum wall.

3. *Cable Core*

Solid polyethylene rod, heat-stabilized.

4. *Cabling*

Four conductors, two brown-colored (pair #1) and two natural-colored (pair #2), cabled around the core with a 2 in. right hand lay. When cabling, the two conductors constituting a pair shall not be adjacent, but diagonally opposite when viewed from cross section.

5. *Inner Jacket*

Extruded natural polyethylene. The jacket shall be extrusion applied. Extrusion application is mandatory in order to fill all cable core voids and consequently hold core in above cabled position. Jacket shall have a round, smooth, outer perimeter.

6. *Stabilizing Tape*

A capacity stabilizing tape shall be applied over the inner jacket, either longitudinally or in a helical wrap, at manufacturer's option. The tape shall have a surface resistivity of less than 10,000 ohms per square unit of material used.

7. *Identification Marker*

A standard manufacturer's identification marker tape shall be inserted over the stabilizing tape, as well as a separate additional marker tape denoting year of manufacture.

8. *Braid*

An open-weave stainless steel braid shall be applied over the stabilizing tape.

9. *Sheath*

The outer sheath shall be composed of a tough, tight fitting, nonfree stripping, low temperature, plastic compound.

9–6.3 TESTS FOR CABLE

a. Breaking Strength

b. Low Temperature Range to −55°C

c. DC Resistance

d. Dielectric Strength

e. Insulation Resistance

f. Capacitance Unbalance (pair-to-pair)

g. Capacitance Unbalance (pair-to-ground)

h. AC Resistance

i. Mutual Capacitance (conductor-to-conductor)

9–6.4 PULSE CODE MODULATION CABLES

9–6.4.1 FDM and PCM Systems

For many years Spiral Four cables, such as previously described, were used as standard equipment in field telephone communication systems. These systems were referred to as FDM (Frequency Division Multiplex) systems. These systems operated at a frequency of approximately 400 kHz. Recently a more refined system has come into use utilizing two coaxial cables instead of the usual four wire systems. This system is called a PCM (Pulse Code Modulation) system. Cables used in PCM systems are Signal Corp cables CX-4245 and CX-11230; these two cables are described and discussed later in this chapter.

9–6.4.2 Cable Requirements

A recent PCM system cable, Signal Corps No. CX-4245/G, was developed and tested. The cable exhibited two major deficiencies, although the electrical characteristics were satisfactory. Accordingly, this cable was considered only as a limited standard. The two major deficiencies noted were as follows:

1. Inadequate tensile strength to resist breakage during typical installation and payout.

2. Excessive weight and stiffness for easy field handling and payout.

This configuration and the corresponding test results did, however, point up the necessity and importance of the shielding qualities of the construction. In PCM systems this quality is considered a major portion of the effectiveness of the installed system. Highlighted also were weight and the tensile properties needed, especially in aerial installations where the cable is strung from pole to pole over appreciable spans.

With these points in mind, a second cable configuration was developed to try to overcome the deficiencies noted in the CX-4245/G cable. The second cable, CX-11230 ( )/G (Reference c – par. 9–6.8) was fabricated utilizing smaller coaxial cable constructions with an extruded, foamed, polypropylene dielectric. Thin extruded, polyethylene jackets were applied over each coaxial shield in order to isolate each coaxial cable, affording better shielding qualities and still using the same shield configuration. The two coaxial cables were then twisted and a Mylar binder tape, a shielding braid, and an overall sheath were applied to the twisted coaxial cables.

9–6.5 CONSTRUCTION AND PERFORMANCE DATA

Comparative construction and performance data of CX-4245/G and CX-11230 ( )/G are given in Table 9–7.

To improve the shielding effectiveness and strength of the cable, and at the same time reduce the weight of the cable, a shield consisting of a closely woven #32 AWG, 30% conductive, copperweld strand was used on the CX-11230 ( )/G. Furthermore, the shield of the cable was carried through the shell of the dual coaxial connector in the termination of the CX-11230 ( )/G; whereas, the shield of the CX-4245/G was terminated approximately two feet from the back of each single coaxial connector. This shield construction and carry-through accomplished three things:

1. It increased the shielding effectiveness by the increased shielding coverage of the cable core, the increased conductivity of the wires used in the shield configuration, and the direct shield termination to the shell of the connector.

2. It increased the flexibility and tensile properties of the cable.

3. It reduced the weight of the cable.

An extruded, black polyethylene sheath was applied overall with smaller major and minor diameters.

9–6.6 CABLE TESTING

The qualification tests performed on each cable are described in the paragraphs which follow.

9–6.6.1 Test Procedures and Requirements

For procedures and requirements for the following tests refer to Specification No. 2321606 ITT Federal Laboratories:

a. Dielectric Strength

b. Dimensional Stability

c. Flow Test

d. Tubing Test

e. –55°C Bend Test

f. Low Temperature After Aging

g. Breaking Strength – Static

h. Breaking Strength – Dynamic

i. Attenuation

j. Impedance

k. Shielding Effectiveness

l. Tensile Strength

m. Sag

9–6.6.1.1 *Test Procedures*

The following is a more detailed discussion of the attenuation, shielding effectiveness, tensile, and sag qualities of the aforementioned cables.

9–6.6.1.2 *Shielding Effectiveness*

The shielding effectiveness of the PCM system was tested in the following two major areas.

1. Framing tests, or susceptibility of system to pickup of electromagnetic radiation from outside transmitters.

2. Radiation, or interference, from system which could affect outside receivers.

The basic cable communication configuration for field testing the system consisted of two half-mile cable lengths with connector assemblies, mated at the half-mile point and installed on a pole line. The terminal ends were connected to PCM equipment which was housed in shelters one mile apart.

9–6.6.1.2.1 *Framing Test*

The framing, or susceptibility, criterion was the ability to operate a radio set, transmitting at full power, as close as 100 feet from the system without causing "loss of frame" of the PCM terminal equipment. The radiation from the cable criterion was to have no pickup of the PCM signal greater than 3 db above ambient noise level, by a suitable detector, at a distance as close as fifty feet to the system.

TABLE 9–7

CONSTRUCTION AND PERFORMANCE DATA—PCM CABLES

Coaxial Cable	CX-4245/G	CX-11230( )/G
Construction:		
Conductor	#22 AWG (710.010 in.), 0.030 in. annealed bare copper	#22 AWG (7/0.010 in.), 0.030 in. annealed bare copper
Primary Insulation	Solid polyethylene, 0.108 in.	Foamed propylene, 0.090 in.
Shield	#36 AWG, Copper Alloy 85, 0.138 in.	#36 AWG, Copper, 0.117 in.
Jacket	Hidensity polyethylene, 0.170 in.	Low-density polyethylene, 0.139 in.
Twist	6 in. right hand lay	6 in. right hand lay
Binder	None	Mylar tape, 0.001 in., 25% overlap
Shield	#30 AWG, Copper, 0.400 in. (major dia)	#32 AWG, 30% conductivity copperweld, 0.324 in. major dia
Overall Jacket	Hi-density polyethylene, 0.440 in. (major dia)	Medium-density polyethylene, 0.364 in. (major dia)
Performance Data:		
Weight, lb/mi	500	308
Strength, lb	450	750
Connector Retention, lb	140	400
Shielding RFI dist, ft	<100	<100
Vehicle Crossings	25,000	30,000
Handling	Stiff	Flexible

Provisions were made in the test set up to allow evaluation of the effects of various shielding and grounding configurations. Shown in Table 9–8 are test results obtained on cable CX-11230 ( )/G for seven different test conditions. The equipments used were:

a. AN/TCC – 46 PCM equipment housed in the shelters and connected to cable terminal ends.

b. TD-206 Pulse Restorer modified with two-foot "pigtail" cables terminated with connectors which mated with the CX-11230( )/G Cable.

c. AN/GRC – 26 Radio Set transmitting at full power.

Shown in Fig. 9–12 is a schematic of field test set up for transmission and shielding tests.

TABLE 9–8

FRAMING OR SUSCEPTIBILITY DATA—PCM CABLES

(RADIO SET OPERATING AT 2.304 MHz)

Test Point	Test Condition Number						
	1	2	3	4	5	6	7
A	130	110	200	55(G,U)	48(U)	65(U)	20(G,U)
B	100	100	300(G)	50(G,U)	45(G,U)	55(U)	10(G,U)
C	90	85	150(G,U)	40(G,U)	50(U)	50(G,U)	10(G,U)
D	85	74	300(U)	35(G,U)	50(G,U)	50(U)	10(G,U)
	← In Frame Distance (Feet from Cable) →						

Note: G=Shield braids grounded at both shelters.
U=Shield braids ungrounded at both shelters.

Test Conditions

Condition 1. Without restorer. Coaxial and shield braids not shorted at connectors. Shield braids not continuous from cable to cable.

Condition 2. With restorer. Restorer and restorer leads unshielded. Other conditions same as in Condition 1.

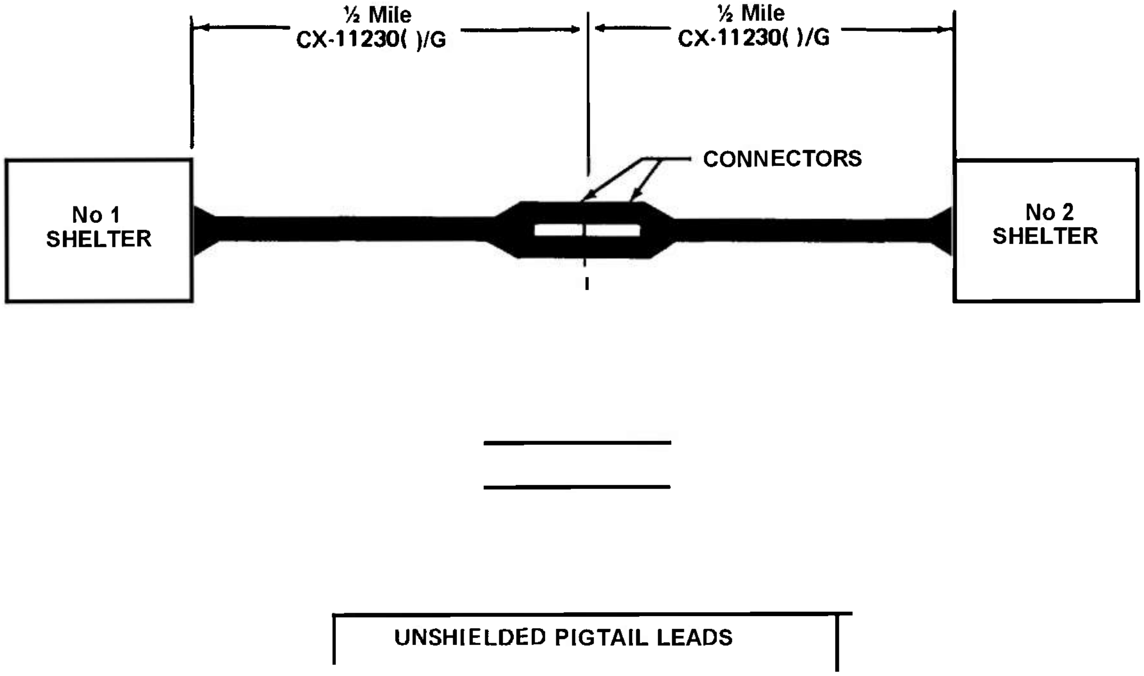
Condition 3. With restorer. Coaxial and shield braids shorted at connectors. Other conditions same as in Condition 2.

Condition 4. Without restorer. Other conditions same as in condition 3.

Condition 5. Without restorer. Coaxial and shield braids not shorted at connectors. Shield braids continuous from cable to cable.

Condition 6. With restorer. Restorer and restorer leads shielded. Other conditions same as in Condition 5.

Condition 7. With restorer. Coaxial and shield braids shorted at connectors. Shield braids continuous from cable to cable.



The conclusions, based on the Table 9–8 data, show that the one significant factor of Conditions 4 through 7 is that the shield braids are continuous from cable to cable. It is important then, that the connector utilized provide a means for preserving the continuity of the shield braid from assembly to assembly.

9–6.6.7.2.2 Radiation from Cable

Measurements were obtained using the same PCM cable and system set up as in framing tests. The measurements were made with an NM-20B, RI-FL meter at 2.304 MHz. The results of these tests are shown in Table 9–9 under four different test conditions, all without continuity of shield braids from cable to cable.

TABLE 9–9

RADIATION FROM CABLE DATA–PCM CABLES (RADIO SET OPERATING AT 2.304 MHz)

Test Point	Test Condition Number			
	1	2	3	4
A	10	20	0	2
B	12	23	0	0
C	7	20	0	1
D	7	21	0	1
	← Radiation (db above ambient) →			

Note: Radiation was measured at a distance of 50 feet from cable.

Test Conditions

Condition 1 ● Without restorer. Coaxial and shield braids not shorted at connectors. Shield braids not continuous from cable to cable.

Condition 2 ● With restorer. Restorer and restorer leads unshielded. Other conditions same as in Condition 1.

Condition 3 ● With restorer. Coaxial and shield braids shorted at connectors. Other conditions same as in Condition 2.

Condition 4 ● Without restorer. Other conditions same as in Condition 3.

9–6.6.1.2.3 Calculation of Shielding Effectiveness (References a and d of par. 9–6.8)

The equation, put in written form, for evaluating the relative shielding effectiveness of a cable configuration is presented as:

$$\text{Shielding Effectiveness}(SE) = \frac{\text{Energy transmitted into inner coaxial}}{\text{Energy leakage into outer coaxial}} \quad (9\text{–}3)$$

The resulting mathematical equation as expressed in logarithmic form is:

$$SE = 20 \log_{10}\left(\frac{V_I}{V_L}\right) + 10 \log_{10}\left(\frac{R}{Z_o}\right) + 20 \log_{10}\left(\frac{1}{\sin \beta_c L}\right)$$

$$-10 \log_{10}\left[2 + \frac{R}{Z_t} + \frac{Z_t}{R} \quad (1 + \omega^2 C_D{}^2 R^2)\right] + 3, \text{ db} \quad (9\text{–}3a)$$

where

V_I = voltage input

V_L = voltage output

R = resistance across output characteristic

Z_o = cable characteristic impedance

Z_t = impedance of triaxial tester

C_D = discontinuity capacitance

β_c = phase constant of cable

ω = radian

l_t = length of triaxial tester

The values of Z_o, Z_t, β_c, and C_D are all dependent on the physical and dimensional characteristics of the various test specimens and the tester. Therefore, from the standpoint of comparison evaluations of a particular cable type, the only portion of the equation that varies with external braid type is the $20 \log_{10} \frac{V_I}{V_L}$ relation. Shown in Fig. 9–13 is a schematic diagram of a typical test set up for low frequency (0.2 to 10 MHz) shielding effectiveness measurements.

9–6.6.1.3 Tensile and Sag (References b and e, par. 9–6.8)

Very important in the manufacture of a cable to be used in aerial installations are the tensile or breaking strength qualities which, in a great part, determine the sag factors which can be allowed over a span. Determining the cable tension over a specified sagging span (such as between two poles) is calculated according to the following procedure:

a. Determine Sag Factor by Eq. 9–4

$$\text{Sag Factor} = \frac{S_a}{S_p} \qquad (9\text{–}4)$$

b. With the Sag Factor calculated by Eq. 9–4, enter the Sag Table 1, Rome Cable Co. Manual, for the given parameter and determine a corresponding value x, the numerical equivalent of the Sag Factor.

c. Determine T by Eq. 9–5

$$T = \frac{S_p W}{x} \qquad (9\text{–}5)$$

where

S_p = span, ft

S_a = sag, ft

W = cable weight, lb/ft

T = tension in unsupported cable span, lb

x = numerical equivalent of sag factor (from Sag Table 1).

Sample calculation:

a. Given:

Span = 150 ft

Sag in 150 ft span = 2 ft

Cable weight = 0.0964 lb/ft

b. Solution:

$$\text{Sag Factor} = \frac{2}{150} = 0.0133$$

From Sag Table 1, Rome Cable Co. Manual, determine x

$$\frac{(150)(0.0964)}{T} \text{ for sag factor of } 0.0133 = 0.106 \text{ (from Sag Table 1).}$$

$$T = \frac{(150)(0.0964)}{0.106}$$

T = 136.4 lb tension

It is important to note that the tension T as determined in the calculations, is not the only determining factor in the amount of tension a cable span may have to withstand. Environment – or where the cable is installed – will have a great bearing on the tension, or tensile properties, of installed aerial systems. Some factors which must be taken into consideration are ice and/or snow loading, wind whip, rain, temperature, etc. Table 9–10 shows minimum sag for Spiral Four and PCM cable aerial spans based on tensions of 100 lb at 60°F. The table shows sag for various span lengths of self-supported cables carried on poles or frames in medium loading areas. Cables that are attached directly to trees should have a greater sag allowance. Normally, wires and cables increase in length (sag) with a temperature increase but, because of its construction, Spiral Four cable will decrease in length, or sag, as temperatures increase. For this reason greater sags are provided for Spiral Four cable type at *lower* temperatures.

Table 9–11 indicates minimum sag for self-supported Spiral Four cables calculated for different temperatures.

The sag for any span length other than those shown in Tables 9–10 and 9–11 may be found by substituting values from the tables and using Eq. 9–6.

$$\text{Unknown sag} = \frac{(B-A)}{(C-A)} \times (c-a) + a \qquad (9\text{–}6)$$

where

B = span length for which sag is required, ft

A = span length in table just before B, ft

C = span length in table just after B, ft

a = sag given in table for span length A, in.

c = sag given in table for span length C, in.

9–6.7 LIGHTNING PROTECTION OF CABLE SYSTEMS

See *Electrical Report of Tactical Communications Systems,* Contract DA-36-039-SC-73089, U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey.

9–6.8 REFERENCES FOR PCM AND MULTICHANNEL CABLES AND SYSTEMS

The following specifications and documents are recommended for further information on PCM cables and systems, and multichannel telephone communications cables.

a. ECOM Technical Report 2788, *Shielding Effectiveness of PCM Cable System.*

b. ECOM Technical Report 2711, *Aerial Installation of Cable Assembly, Special Purpose, Electrical CX-4245 ( )/G.*

c. ECOM Technical Report DA Task 1E640306D48706 *Evaluation of Preliminary Engineering Development Models of Cable Assembly, Special Purpose, Electrical CX-11230 ( )/G.*

d. J. A. Allen of USAECOM, Technical Paper, *A Proposed Standard for Testing the Shielding Effectiveness of Coaxial Cables and Shielding Materials.*

e. TM 11-381, *Cable Assembly CX-1065G, Telephone Cable Assemblies CX-1606/G and CX-1512/U, and Telephone Loading Coil Assembly CU-260/G.*

f. MIL-C-10581 (Signal Corps), *Cable, Telephone; Cable Assemblies, Telephone; Coil Assembly, Telephone Loading;* Dwg SC-A-4684643, *Cable Assembly, Special Purpose, Electrical CX-4245( )/G.*

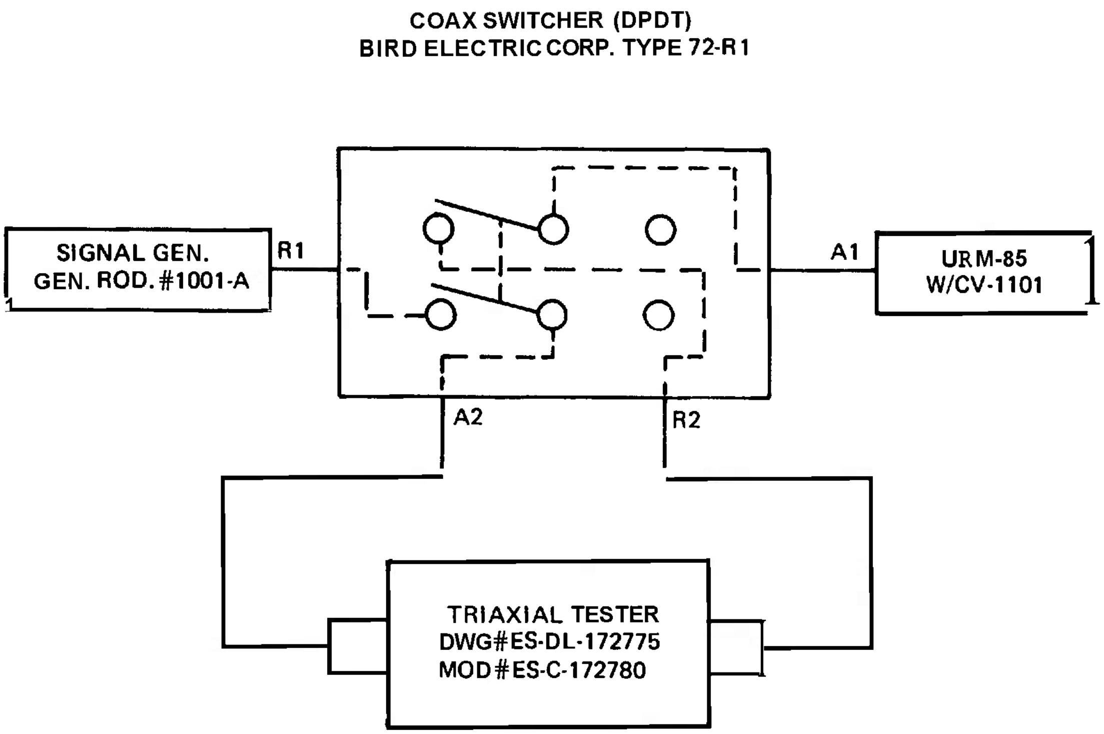


*Figure 9–13. **Low** Frequency Shielding Effectiveness Test Set-up*

TABLE 9–10

SAG DATA—SPIRAL FOUR AND PCM CABLES

	CX-4245/G CX-11230( )/G	Spiral - 4 WF-8/G
Span, ft	Sag, in. at 60°F	Sag, in. at 60°F
100	16	11
125	24	17
150	36	25
175	48	37
200	72	64

TABLE 9–11

SAG AT VARIOUS TEMPERATURES—SPIRAL FOUR CABLE

Span Length, ft	0°F	32°F	60"F	90"F	120°F
	Minimum Sag, in.				
100	13	12	11	11	10
125	19	18	17	16	15
150	28	26	25	24	23
175	40	38	37	35	34
200	68	66	64	62	61
250	139	137	136	134	132
300	224	222	221	219	217

REFERENCES

1. USAECOM Contract No. DA-28-043-AMC-00045 (E), *Extra Flexible, Lightweight, Tactical Cords.*

2. USAECOM Contract No. DA-28-043-AMC-00471 (E), *Subminiature Cords.*

3. FM 24-20, *Field Wire and Field Cable Techniques.*

4. J-C-98, *Wire and Cable, Insulated; Methods of Sampling and Testing.*

5. MIL-C-572, *Cords, Yarns and Monofilaments; Organic Synthetic Fiber.*

6. MIL-C-3849, *Cord, Electrical (Tinsel).*

7. MIL-(2-3883, *Cord, Electrical (Audio Frequency).*

8. MIL-(2-3884, *Cord, Electrical (Short Lay).*

9. MIL-C-3885, *Cable Assemblies and Cord Assemblies.*

10. MIL-C-10369, *Cables, Telephone, Field, For Rapid Payout, (MX-306 A/G).*

11. MIL-C-10392, *Cables, Special Purpose, Electrical (Miniature).*

12. MIL-C-10581, *Cable, Telephone; Cable Assemblies, Telephone; Coil Assemblies, Telephone Loading.*

13. MIL-C-11997, *Cord Assembly, Electrical, CX-2151 ( )/U (Retractile).*

14. MIL-C-13268, *Cable, Telephone* (No. *19 AWG and 20 A WG) Switchboard Cable.*

15. MIL-C-13273, *Cord, Electrical (Retractile 2, 3, and 4 Conductor, WD-9/U, WT-2/U, WF-4/U).*

16. MIL-C-13294, *Cable, Telephone, Electrical, (Infantry Field Wire) Twisted Pair, Wire WD-I/TT and WD-14/TT.*

17. MIL-C-55036, *Cable, Telephone, WM-130( )/G.*

18. MIL-C-55425, *Cable, Telephone, WF-16 ( )/U.*

19. MIL-C-55462, *Cable, Telephone WD-36 ( )/TT Dispersion, Cable MX-6894 ( )/TT and Dispersion, Cable MX-6895 ( )/TT.*

20. MIL-W-3795, *Wire, Electrical (Tinsel).*

21. USAECOM Technical Report 2657, *Laboratory Evaluation of Field and Assault Cable.*

APPENDIX

Document	Title
ASTM-B-33	*Tinned, Soft or Annealed Copper Wire for Electrical Purposes.*
ASTM-B-286	*Specification For Copper Conductors For Use In Hook-up Wire for Electronic Equipment.*
ASTM-B-298	*Specification for Silver-Coated, Soft or Annealed Copper Wire.*
ASTM-B-355	*Specification for Nickel-Coated, Soft or Annealed Copper Wire.*
ASTM-D-150-59T	*Tests for A-C Capacitance, Dielectric Constant, and Loss Characteristics of Electrical Insulating Materials.*
ASTM-Reference	**Special Technical Publication #319**
CX-4245/G	*Aerial Installation of Cable Assembly, Special Purpose.*
CX-11230 ( )/G	*Evaluation of Preliminary Engineering Development Models of Cable Assembly, Special Purpose, Electrical.*
J-C-98	*Wire and Cable, Insulated; Methods of Sampling and Testing.*
MIL-C-17	*Cables, Radio Frequency, Coaxial, Dual Coaxial, Twin Conductor and Twin Lead.*
MIL-C-572	*Cords, Yarns, and Monofilaments; Organic Synthetic Fiber.*
MIL-C-915B	*Cable, Cord, and Wire, Electrical (Shipboard Use).*
MIL-C-2194	*Cables, Power, Electrical Reduced Diameter Type, Naval Shipboard.*
MIL-C-3432C	*Cable and Wire, Electrical (Power and Control, Flexible and Extra Flexible, 300 and 600 Volts),*
MIL-C-3702	*Cable, Power, Electrical; Ignition, High Tension.*
MIL-C-3849A	*Cord, Electrical (Tinsel).*
MIL-C-3883	*Cord, Electrical (Audio Frequency).*
MIL-C-3884	*Cord, Electrical (Short Lay).*
MIL-C-3885	*Cable Assemblies and Cord Assemblies.*
MIL-C-7078	*Specification For Cable, Electric, Aerospace Vehicle.*

APPENDIX (CONT.)

Document	Title
MIL-C-10369	*Cables, Telephone, Field, For Rapid Payout (MX-306 A/G).*
MIL-C-10392B	*Cables, Special Purpose, Electrical (Miniature).*
MIL-C-10581	*Cable Telephone; Cable Assemblies, Telephone; Coil Assemblies, Telephone Loading.*
MIL-C-11311	*Cables, Telephone, WD-31/U and WT-24/U (Inside Telephone Station).*
MIL-C-11997A	*Cord Assembly, Electrical, CX-2151 ( )/U (Retractile).*
MIL-C-13268	*Cable, Telephone (No. 19A WG and 20A WG) Switchboard Gzble.*
MIL-C-13273	*Cord, Electrical (Retractile 2, 3, and 4 Conductor, WD-9/U, WT-2/U, WF-4/U).*
MIL-C-13294B	*Gzble, Telephone, Electrical (Infantry Field Wire) Twisted Pair, Wire WD-1/TT and WD-14/TT.*
MIL-C-13777E	*Cable, Special Purpose, Electrical.*
MIL-C-23020	*Gzble, Coaxial (For Submarine Use).*
MIL-C-23206	*Cable, Electric, Thermocouple.*
MIL-C-24145	*Cable, Electrical, Special Purpose, For Shipboard Use.*
MIL-C-25038	*Cable, Electric, Aircraft, High Temperature and Fire Resistant.*
MIL-C-27072	*Cable, Special Purpose, Electrical, Multi-Conductor.*
MIL-C-27500	*Gzble, Electrical, Shielded and Unshielded, Aircraft and Missile.*
MIL-C-55036	*Cable, Telephone, WM-13( )/G.*
MIL-C-55425	*Cable, Telephone, WF-16/U.*
MIL-C-55462	*Cable, Telephone, WD-36/TT Dispenser, Cable, MX-6894 ( )/TT and Dispenser, Cable, MX-6895 ( )/TT.*
MIL-E-572	*Environmental Testing, Aeronautical and Associated Equipment, General Specification For.*
MIL-I-3930C	*Insulating and Jacketing Compounds, Electrical (For Cables, Cords, and Wires).*
MIL-M-20693	*Molding, Plastic Material, Polyamide (Nylon) Rigid.*
MIL-STD-104	*Limits For Electrical Insulation Color.*
MIL-STD-202	*Selected Standards for RF and Acoustical Parts.*

APPENDIX (CONT.)

Document	Title
MIL-STD-454	*General Requirements For Electronic Equipment.*
MIL-STD-681	*Identification Coding and Application of Hook-up and Lead Wire.*
MIL-STD-686	*Cable and Cord, Electrical; Identification Marking and Color Coding Of*
MIL-STDS 10	*Environmental Test Methods For Aerospace and Ground Equipment.*
MIL-T-5438	*Tester, Abrasion, Electrical Cable.*
MIL-W-76	*Wire and Cable, Hook-up, Electrical, Insulated.*
MIL-W-3795A	*Wire, Electrical (Tinsel).*
MIL-W-5086	*Wire, Electrical, 600 Volt, Copper, Aircraft.*
MIL-W-5088	*Wiring, Aircraft, Installation Of.*
MIL-W-7139	*Wire, Electrical, Polytetrajluoroethylene Insulated, Copper, 600 Volt.*
MIL-W-8777	*Wire, Electrical, Silicone Insulated, Copper, 600 Volt.*
MIL-W-12349	*Wire, Hook-up Monochlorotrifluoroethylene Insulated.*
MIL-W-16878D	*Wire, Electrical, Insulated, High Temperature (Navy).*
MIL-W-22759	*Wire, Electrical, Fluorocarbon Insulated, Copper.*
MIL-W-27300	*Wire, Electrical, Polytetrafluoroethylene Insulated, Copper, 600 Volt.*
MIL-W-81044	*Wire, Electric, Crosslinked Polyalkene Insulated, Copper.*
MSFC-332	*Cables, Electrical, General Specification For.*
NAS-702	*Wire, Electrical, Insulated, Copper, Hook-up and General Purpose (For 105°C Service).*
QQ-W-343	*Wire, Electrical and Nonelectrical, Copper, Uninsulated.*

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13. *General Electric Contract DA-28-043-AMC-00296(E),* **25** June **1965.**

14. *General Electric Contract DA-36-039-SC-88974,* **12** March **1964.**

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20. *Laboratory Evaluation of Field and Assault Cable,* USAECOM Technical Report **2657.**

21. *Measurement of Transmission Unbalance – Dual Coaxial and Twin Conductor Cable,* Tech. Memo. **M-1344,** U. S. Signal Corps Engineering Laboratories, Ft. Monmouth, **26** December **1950.**

22. *Method for Calculation of Current Rating of Hook-up Wire,* EIA Standard *RS-2*1**4,** November **1958.**

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GLOSSARY

(In general, terms are defined with specific reference to their use in conjunction with electrical wire and cable)

– A –

abrasion resistance. Ability of material or cable to resist surface wear.

accelerated aging. A test performed on material or cable meant to duplicate long time environmental conditions in a relatively short space of time.

accelerator. A chemical additive which hastens a chemical reaction under specific conditions.

activator. A chemical additive used to initiate the chemical reaction in a specific chemical mixture.

adjacent conductor. Any conductor next to another conductor, either in the same multiconductor cable layer or in adjacent layers.

alternating current resistance. The resistance offered by any circuit to the flow of alternating current.

ambient temperature. Any all-encompassing temperature existing within the given area.

American wire gage. A standard used in the determination of the physical size of a conductor determined by its circular mil area. Usually expressed as AWG.

ampere. The unit used for measuring the quantity of an electric current flow. One ampere represents a flow of one coulomb per second.

antioxidant. A substance which prevents or slows down oxygen decomposition of a material.

antiozonant. A substance which prevents or slows down material degradation due to ozone reaction.

armor. Mechanical protection, usually accomplished by a metallic layer of tape, braid, or served wires. Normally found only over the outer sheath.

attenuation. Power loss in an electrical system. In cables the loss is expressed in decibels per unit length of cable.

audio frequency. Pertaining to that band of frequency which is audible to the human ear. Usually 20 to 20,000 Hz.

autocatalytic degradation. Pertaining to degradation of certain materials, whereby the breakdown products of the initial phase of their degradation accelerate the rate at which subsequent degradation proceeds.

– B –

binder. Usually a spirally served tape or thread wrap used for holding assembled cable components in place awaiting further manufacturing operations.

braid. A fibrous or metallic group of filaments interwoven in cylindrical form to form a protective covering over one or more wires.

braid angle. A term used in the determination of the braid configuration relating to the angle of the braided filaments or fibers in relationship to the axis of the cable core being braided.

braid carrier. A spool or bobbin on a braiding machine holding one group of strands or filaments consisting of a specified number of ends. The carrier revolves during the braiding operation.

braid ends. In a braid, the given number of strands used to make up one carrier. The strands are wound side by side on the carrier bobbin and lay parallel in the finished braid.

braider. A machine used to apply a woven fibrous or metallic braid over a cable diameter.

breakout. A term used to define a wire or group of wires in a multiconductor configuration which terminates somewhere other than at the end of the configuration.

building wire. Wire used for light and power in permanent installation utilizing 600 volts or less. Usually in an enclosure and which will not be exposed to outdoor environments.

bunch strand. Any number of conductor strands twisted together in one direction with the same lay length.

butt wrap. A spirally wrapped tape over a cable core, where the trailing edge of one wrap just meets the leading edge of the preceding wrap with neither overlap nor spacing.

– C –

cable. An insulated conductor or twisted group of conductors used for the transmission of electrical energy.

cabling. The act of twisting together two or more insulated components by machine to form a cable.

capacitance. The ratio of the electrostatic charge on a conductor to the potential difference between the conductors required to maintain that charge.

capacitive coupling. Electrical interaction between two conductors caused by the capacitance between them.

capillary action. The phenomenon of liquid rising in a small interstice due to surface tension.

cast tape, A material which is formed directly into a tape by means of flowing or "casting" a solution or dispersion of the film–forming material onto a suitable carrier, then removing the solvent–as opposed to skiving or slicing a block of material into a tape form.

ceramic. Pertaining to a product made from inorganic, nonmetallic materials fused or fired at high temperatures; used as an insulation in cables when extremely high temperatures are to be encountered.

circular mil. A measurement used in determining the area of wire. The area of a circle one one-thousandth inch in diameter.

cladding. A method of applying a layer of metal over another metal, whereby the junction of the two met'als is continuously welded.

coaxial. A cable configuration having two cylindrical conductors with coincidental axes; such as a conductor with a tubular shield surrounding the conductor and insulated from it.

cold flow. Permanent deformation of the insulation due to mechanical forces, without the aid of heat softening of the insulating material.

cold joint. A soldered joint made with insufficient heat.

cold work. The hardening and embrittlement of a metal by repeated flexing action.

color code. A colored identification mark applied to the outside of a wire or cable component, usually in the form of a stripe, to identify a given component within a complex.

compound. A term used to designate an insulating material made by mixing two or more ingredients. To compound: the mixing together of two or more different materials to make one material.

concentricity. In a wire or cable, that measurement which is the location of the center of the conductor with respect to the geometric center of the circular insulation.

concentric stranding. A group of uninsulated wires twisted so as to contain a center core with one or more distinct layers of spirally wrapped, uninsulated wires laid overall to form a single conductor. When more than one layer is present each layer must have a different lay length.

conductance. A measure of the ability of any material to conduct an electrical charge. Conductance is a ratio of the current flow to the potential difference causing the current flow at its ends.

conductivity (electrical). A term used in describing the capability of a material to carry an electrical charge, i.e., conductance of a unit cube of any material. Conductivity of metals is usually expressed as a percentage of copper conductivity–copper being one hundred percent (100%).

conductor. Any material capable of easily carrying an electrical charge.

contrahelical. A term meaning the application of two or more layers of spirally twisted, served, or wrapped materials, where each successive layer is wrapped in the opposite direction to the preceding layer.

control cable. A multiconductor cable made for operation in control or signal circuits, usually flexible, relatively small in size, and with relatively small current ratings.

convection. A conveying, or transference, of heat or electricity by moving particles of matter.

copolymer. A term used to designate that two or more monomers are polymerized together to form a different material.

core. In cables, a term used to denote a component, or assembly of components, over which other materials are applied—such as additional components, shield, sheath, or armor.

corona. A discharge due to ionization of a gas (usually air) due to a potential gradient exceeding a certain critical value.

corona initiation point. The critical value, in the application of an electrical potential, where corona is first noticed by the detection device.

crimp termination. A wire termination that is applied by physical pressuring of terminal to wire.

cross-linked. Inter-molecular bonds produced between long chain molecules in a material to increase molecular size by chemical or electron bombardment, resulting in a change in physical properties in the material – usually improved properties.

cross-sectional area. The area of the cut surface of an object cut at right angles to the long axis of the object.

cross-talk. Electrical interference between two adjacent insulated conductors, whereby a signal in one of the conductors will be picked up by the adjacent conductor.

current-carrying capacity. The current a conductor of given size and length is capable of carrying safely without exceeding its temperature limitations.

current penetration. The depth a current of a given frequency will penetrate into the surface of a conductor carrying the current.

cut-through resistance. The ability of a material to withstand mechanical pressure, usually a sharp edge of prescribed radius, without separation.

– D –

decibel. Unit to express differences of power level. Example: The decibel is 10 times the common logarithm of the power ratio. It is used to express power gain in amplifiers or power loss in passive circuits or cables.

delay line. A cable made to provide very low velocity of propagation with long electrical delay for transmitted signals.

denier. A term describing the weight of a yarn, which in turn determines its physical size.

derating factor. A factor used to reduce a current carrying capacity of a wire when the wire is used in other environments from that for which the value was established.

dielectric. An insulating material, usually having a very low loss factor.

dielectric constant. That property K of an insulating material which is the ratio of the parallel capacitance C of a given configuration of electrodes with the material as the dielectric, to the capacitance of the same electrode configuration with a vacuum as the dielectric.

dielectric phase angle. Angular difference in phase between the sinusoidal alternating potential difference applied to a dielectric, and the component of the resulting alternating current.

dielectric strength. A term used to describe the limit, without damage, of an insulating material to an applied voltage potential.

direct capacitance. The capacitance measured directly from conductor to conductor through a single insulating layer.

direct current resistance. The resistance offered by any circuit to the flow of direct current.

direction of lay. The direction of twist, either clockwise or counterclockwise, of a component, or group of components, when looking axially down the length.

dissipation factor. The ratio of the conductance of a capacitor, in which the material is the dielectric, to its susceptance; or, the ratio of its parallel reactance to its parallel resistance; or, the ratio of the power loss to the circulating KVA.

drain wire. In a cable, an uninsulated wire laid over the component, or components, and used as a ground connection. A drain wire is frequently placed under a shield.

drawing. In the manufacture of wire, pulling the metal through a die, or series of dies, for reduction of diameter to specified size.

dual coaxial cable. A configuration consisting of two individually insulated conductors, parallel or twisted, placed within an overall shield and sheath.

duct. An underground or overhead tube used for carrying electrical conductors.

durometer. A measurement used to denote the hardness of a substance.

— E —

eccentricity. Like concentricity, a measure of the center of a conductor's location with respect to the circular cross section of the insulation; expressed as a percentage of center displacement of one circle within the other.

elastomer. Any elastic, rubber-like substance, such as natural or synthetic rubber.

electric gradient. The space rate of change of potential at a point in the direction of the greatest change.

electrical length. That length of cable expressed as degrees of a cycle, or fraction of a wavelength, for the signal transmitted. The equivalent electrical length of a cable equals the physical length times the square root of the dielectric constant.

electrode. A conductor through which a current enters or leaves an electrolytic cell, arc furnace, vacuum tube, gas discharge tube, or other nonmetallic conductor.

electrolytic corrosion. Corrosion by means of electrochemical erosion.

electrolytic tough pitch. A term describing the method of raw copper preparation to ensure a good physical and electrical grade copper finished product.

electrolysis. The production of chemical changes by passage of current through an electrolyte.

electromagnetism. Magnetism caused by the flow of an electric current.

electromotive force. That force which determines the flow of electricity; a difference of electric potential.

electroplate. The term used to indicate the application of a metallic coating on a surface by means of electrolytic action.

embossing. A means of marker identification, the thermal molding of lettering in the sheath material of cable.

ends, In braiding, a term used to denote the number of wires or threads wound side by side on a braider carrier.

exothermic. Characterized by the liberation of heat.

— F —

farad. A unit of electric capacity.

fibrous filler. A material used to fill interstices in cables, made from fibers such as cotton, glass, etc.

field wire. A term defining a small, light, wire type, usually produced in long lengths for use in communications in the field.

filler. (a) A material used in the cable to fill large interstices where there are no electrical components. (b) A substance, often inert, added to a compound to improve properties and/or decrease cost.

film. Another term to describe thin plastic sheeting.

flat conductor. A wire manufactured in a flattened form, as opposed to round or square.

flex-life. Ability of a conductor wire or cable to withstand repeated bending.

flux. (a) A material that helps produce fusion, as solder flux.
(b) A continuous flowing or passing, as in the field created by a magnet.

fraying. In cabling, a term used to describe the unraveling of a fibrous braid.

frequency. Of an alternating electric current that number of hertz (cycles per second), or completed alternations, per second.

— G —

gage. A term used to denote the physical size of a wire.

giga-. A numerical prefix denoting one billion, as a gigahertz is one billion cycles per second.

ground. An electrical term meaning to connect to the earth, or other large conducting body to serve as an earth, thus making a complete electrical circuit.

ground support cable. A cable construction, usually rugged and heavy, for use in ground support control or power systems.

— H —

hard drawn **copper wire.** Copper wire that has been drawn to size and not annealed.

harness. A term used to describe a group of conductors laid parallel or twisted by hand, usually with many breakouts, laced together or pulled into a rubber or plastic sheath, used to interconnect electrical circuits.

hash mark stripe. A noncontinuous, helical stripe, applied to a conductor for circuit identification.

heat distortion. Distortion or flow of a material or configuration due to the application of heat.

heat seal. In cabling, a method of sealing a tape wrap jacket by means of thermal fusion.

heat shock. A test to determine stability of a material by sudden exposure to a high temperature for a short period of time.

helical stripe. A continuous, colored, spiral stripe applied over the outer perimeter of an insulated conductor for circuit identification purposes.

helix. A spiral winding.

henry. An electrical unit denoting the inductance of a circuit in which a current varying at the rate of one ampere per second produces an electromotive force of one volt.

hertz. A designation of electrical frequency meaning cycles per second.

hook-up wire. A wire used for low current, low-voltage (under 1000V) applications, internally within enclosed electronic equipment.

horizontal stripe. A colored stripe running horizontally with the axis of a conductor, sometimes called a longitudinal stripe, used as a means of circuit identification.

hot dip. A term denoting the covering of a surface by dipping the surface to be coated into a molten bath of the coating material.

hybrid cable. A multiconductor cable containing two or more types of conductors.

— I —

ignition cable. A cable designed primarily for automotive ignition systems.

impact strength. A test designed to ascertain the punishment a cable configuration can absorb, without physical or electrical breakdown, by impacting with a given weight, dropped a given distance, in a controlled environment.

impedance. The ratio of the effective value of the potential difference between two terminals to the effective value of the current flow produced by that potential difference.

inductance. That property of an electrical circuit by virtue of which a varying current induces an electromotive force in that circuit, or in an adjacent circuit.

insulation. A nonconductive material usually surrounding or separating two conductive materials. Often called the dielectric in a radio frequency cable.

insulation resistance. That property of an insulating material which resists electrical current flow through the insulating material when a potential difference is applied.

integral belt. In a cable, a layer of insulation or semi-conductive material applied usually by extrusion over two or more insulated, twisted or parallel conductors, to form a round smooth cylinder.

interconnecting wire. A type of wire for external use in electronic equipments where exposed to physical abuse. Interconnecting wire encompasses both control and power circuits.

interstice. In a cable construction, the space or void left between or around the cabled components.

ionization. The act of splitting into, or producing, ions.

irradiation. The exposure of a material to high energy emissions. In insulations for the purpose of favorably altering the molecular structure.

— J —

jacket. A material covering over a wire insulation or an assembly of components. An overall jacket on a complex cable grouping is also often referred to as a sheath.

— K —

kilocycle. A term denoting one thousand cycles.

kilohertz. A term denoting one thousand cycles per second.

kilovolt. A term denoting one thousand volts.

kilowatt. A term denoting one thousand watts.

— L —

lacquer. The term used in cable manufacture to designate the liquid resin, or compound, applied to a fibrous braid to prevent fraying, wicking, moisture absorption, etc., in the braid.

laminated tape. A term used to describe a tape consisting of two or more layers, usually each layer being a different material, sealed or laminated together to form one tape.

lay. A term used in cable manufacturing to denote the distance of advance of one member of a group of spirally twisted members in one turn, measured axially.

life cycle. A test performed on a material or configuration to determine the length of time before failure, in a controlled, usually accelerated, environment.

litz wire. A conductor made up of several insulated, twisted wires to reduce skin effect and lower radio frequency losses.

longitudinal wrap. A tape applied longitudinally with the axis of the core being covered, as opposed to a helical, or spiral, tape-wrapped core.

loop resistance. The total resistance of two conductors measured round trip from one end (twisted pair, shield and conductor, etc.).

loss factor. The loss factor of an insulating material is equal to the product of its dissipation and dielectric constant.

low loss dielectric. An insulating material, such as polyethylene, that has a relatively low dielectric loss, making it suitable for transmission of radio frequency energy.

low noise cable. A cable configuration specially constructed to eliminate spurious electrical disturbances, caused by capacitance changes or self generated noise, induced by either physical abuse or adjacent circuitry.

lug. A term commonly used to describe a termination, usually crimped or soldered to the conductor, with provision for screwing down to a terminal.

— M —

magnetic field. The region within which a body or current experiences magnetic force.

magnetic flux. The rate of flow of magnetic energy across or through a surface (real or imaginary).

megacycle. One million cycles.

megahertz. One million cycles per second.

megavolt. One million volts.

megawatt. One million watts.

megohm. One million ohms.

melt extrude. To heat a material above its crystalline melt point and extrude it through an orifice.

mho. An electrical unit of conductivity, being the conductivity of a body with the resistance of one ohm.

microfarad. One millionth of a farad.

microhenry. One millionth of a henry.

microinch. One millionth of an inch.

microwave. A short electrical wave, usually a wavelength of less than 30 cm.

microwave frequency. The frequency of a microwave, usually above 1000 hertz.

mil. One one-thousandth of one inch.

millivolt. One one-thousandth of one volt.

mining cable. A flame-retardant cable especially constructed to withstand long time immersion for underground use in the environment of a mine or tunnel.

mismatch. A termination having a different impedance than that for which a circuit or cable is designed.

modulus of elasticity. The ratio of stress to strain in an elastic material.

monofilament. A term denoting a single strand filament as opposed to a braided or twisted filament.

monomer. A term denoting a single property or ingredient. A molecule of low molecular weight used as a starting material for polymerization to produce molecules of larger molecular weight, called polymers.

multiconductor. More than one component within a single cable complex.

mutual capacitance. Capacitance between two conductors when all other conductors, including ground, are connected together and then regarded as an ignored ground.

– N –

neper. An electrical unit similar to decibel, used to express the ratio between two amounts of power existing at two distinct points. A neper is 8.686 decibels.

noncontaminating compound. A compounded material that will not leach ingredients, so as to contaminate or degrade adjacent materials, under given environmental conditions.

– O –

ohm. A unit of electrical resistance, the resistance of a circuit in which a potential difference of one volt produces a current of one ampere.

ohm-pound/mile. A unit of weight resistivity expressing the resistance of a wire one pound in weight and one mile in length.

organic fiber. A fiber derived or composed of matter originating in plant or animal life, or composed of chemicals of hydrocarbon origin, either natural or synthetic.

overlap. The amount the trailing edge laps over the leading edge of a spiral tape wrap.

ozone test. Exposure of material to a high concentration of ozone to give an accelerated indication of degradation expected in normal environments.

– P –

paste extrude. An extrusion method whereby the extrudable material is in a fine powder form, mixed with a lubricant, and forced through a die of given size, without heat, as opposed to melt extrude.

peak voltage. The maximum instantaneous voltage.

percent conductivity. The conductivity of a material expressed as a percentage of that of copper.

phase. A particular stage, or point of advancement, in an electrical cycle. The fractional part of the period through which the time has advanced, measured from some arbitrary point, usually expressed in electrical degrees, where 360" represents one cycle.

phase shift. A change in phase of a voltage or current after passing through a circuit or cable.

pick. In a braid, a pick is the open area left by the crossing of any two carriers in the weave, axially along the weave.

picofarad. One trillionth of a farad.

pin. Denoting an electrical terminal, usually in a connector. Normally a smaller termination than a lug.

pitch diameter. The diameter of a circle passing through the centers of the conductors in any layer of a multiconductor cable.

planetary twister. A twisting machine whose payoff spools are mounted in rotating cradles that hold the axis of the spool in a fixed direction as the spools are revolved about one another so the wire will not kink as it is twisted.

plasticizer. A chemical agent added in compounding plastics to make them softer and more flexible.

plating. The electrolytic application of one metal over another.

polar ingredient. Any ingredient in a material or complex capable of ionization.

polymer. A material having molecules of high molecular weight, formed by polymerization of lower molecular weight molecules.

potting. The sealing of a cable termination, or other component, with a liquid which thermosets into an elastomer or solid compound to exclude moisture.

power factor. The ratio of the power to the effective values of the electromotive force multiplied by the effective value of current, in volts and amperes, respectively. The cosine of the angle between voltage applied and the current resulting.

primary insulation. The layer of material which is designed to do the electrical insulating, usually the first layer of material applied over the conductor.

propagation constant. A complex quantity, characteristic of a radio frequency transmission line, which indicates the effect of the line on the transmitted wave. The real part indicates the attenuation, the imaginary part the phase shift.

pulse cable. A cable specifically constructed to withstand and transmit repeated high voltage pulses without undue physical or electrical degradation.

push back, That property of a braid or shield which allows the braid or shield to be pushed back along the cable core easily.

— R —

rated voltage. That voltage at which an electrical component can operate for extended periods without undue degradation or safety hazard.

reactance. That part of the impedance of an alternating current circuit which is due to capacitance or inductance.

reflection loss. That part of a signal which is lost due to reflection of power at a line discontinuity.

reinforced sheath. The outermost covering of a cable, or that cable sheath which is constructed in layers, with a reinforcing material, usually a braided fiber, molded in place between layers.

resistance. The property of an electric circuit which determines, for a given current, the rate at which electric energy is converted into heat, and has a value such that the current squared multiplied by the resistance gives the power converted.

ribbon cable. A cable consisting of two or more conductors laid parallel in one plane and held in place by some means.

root mean square. The effective value of an alternating periodic voltage or current.

rope strand. A conductor composed of a center group of twisted strands surrounded by one or more layers of similar groups of twisted strands.

round wire. A wire circular in cross section, as opposed to flat, square, etc.

rupture. In the breaking strength or tensile strength tests, the point at which a material physically comes apart, as opposed to yield strength, elongation, etc.

— S —

semi-rigid. A cable containing a flexible inner core and a relatively inflexible sheathing material, such as a metallic tube, but which can be bent for coiling, spooling, or placing in a duct or cable run.

series resistance. Any sum of resistances, installed in sequential order, within one circuit.

serve. Any filament, or group of filaments, such as wires or fibers, helically wound around a central core.

sheath. The material, usually an extruded plastic or elastomer, applied outermost to a wire or cable. Very often referred to as a jacket.

shield. In cables, that metallic layer applied over the dielectric, or group of dielectrics, composed of woven, braided, or served wires, foil wrap or tubular metallic construction, to prevent electrostatic or electromagnetic interference between the enclosed wires and external fields.

shunt. A device used to divert part of an electric current.

signal. An electric current used to convey information; digital, analog, audio, or video.

sinter. To thermally cure or treat a material.

skived tape. Tape shaved in a thin layer from a cylindrical block of material.

spark test. A test designed to locate pin-holes in an insulated wire by application of an electrical potential across the material for a very short period of time while the wire is reeled through an electrode.

specific gravity. The ratio of the weight of any volume of substance to a weight of an equal volume of some substance taken as a standard, usually water for liquids.

spiral wrap. A term given to describe the helical wrap of a tape or thread over a core.

square mil. The area of a square, one mil by one mil.

strand. A single uninsulated wire.

strand lay. The distance of advance, of one strand of a spirally stranded conductor, in one turn, measured axially.

surface resistivity. The surface resistivity of a material is the ratio of the potential gradient parallel to the current along its surface to the current per unit width of the surface, usually expressed in ohms.

Note: Surface resistivity of a material is numerically equal to the surface resistance between two electrodes forming opposite sides of a square, the square size being immaterial.

– T –

tank test. A term used to describe a voltage dielectric test, where the specimen to be tested is submerged in a liquid and a voltage potential placed between the conductor and the liquid as ground.

tape wrap. A term denoting a spirally or longitudinally applied tape material wrapped around the either insulated or uninsulated wire, and used as an insulation or mechanical barrier.

tarnish. A term used to describe a discolored or stained conductor or shield wire, caused by exposure to the atmosphere.

tear test. A test to determine the tear strength of an insulating material.

temperature coefficient of resistivity. The amount of resistance change of a material per degree of temperature rise.

temperature stress. The maximum stress which can be applied to a material at a given temperature without physical deformation.

tensile strength. A term denoting the greatest longitudinal tensile stress a substance can bear without tearing apart or rupturing.

tensile stress. Force, per unit cross-sectional area, applied to elongate a material.

tension set. The condition when a plastic material shows permanent deformation caused by a stress, after the stress is removed.

thermal aging. Exposure to a given thermal condition or a programmed series of conditions for prescribed periods of time.

thermal alloying. The act of uniting two different metals to make one common metal by the use of heat.

thermal expansion. The expansion of a material when subjected to heat.

thermal rating. The maximum or minimum temperature at which a material will perform its function without undue degradation.

thermal resistance. That change in the electrical resistance of a material when- subjected to heat. Resistance to heat flow from conductors to outer surface of insulation or sheath in a wire or cable.

thermal resistivity. Thermal resistance of a unit cube of material.

thermocouple. A thermocouple wire joined at one end and used in conjunction with a thermoelectric temperature measuring device. When a temperature difference exists between the junction and the device, a voltage is generated which can be calibrated to indicate temperature.

thermocouple wire. A two-conductor cable, each conductor employing a dissimilar metal, made up specifically for temperature measurements.

thermocouple lead wire. Similar to thermocouple wire, except the degree of accuracy in temperature measurements is not as high, and it is used to transmit thermocouple information to remote indicators.

thermosetting. The act of a material changing from a liquid, paste, or plastic form, to an elastomeric or rigid form, due to the application of heat.

tinsel wire. A very flexible conductor made by serving one or more very small, flat conductors over a fibrous core, such as a high tenacity rayon or glass fibers.

torque test. A test designed to ascertain the stiffness of a material under given environmental conditions.

tracer stripe. When more than one color coding stripe is required, the first (widest) stripe is the base stripe, the others, usually narrower stripes, being termed tracer stripes.

triaxial. A cable construction, having three coincident axes, such as conductor, first shield, and second shield, all insulated from one another.

true concentric. A true concentric stranding, or twisted cable, occurs when each successive layer has a reversed direction of lay from the preceding layer.

twin coaxial. A configuration containing two separate, complete coaxial cables, laid parallel or twisted around each other, in one complex.

– U –

ultraviolet degradation. The degradation caused by long time exposure of a material to sunlight or other ultraviolet rays containing radiation.

unidirectional concentric stranding. A unidirectional stranding is where each successive layer has a different lay length, thereby retaining a circular form without migration of strands from one layer to another.

unidirectional stranding. A term denoting, that in a stranded conductor, all layers have the same direction lay.

unilay stranding. A bunched construction having 19, 27, 37, or any number of strands, which might be found in a concentric stranding.

– V –

velocity of propagation. In cable measurements, a function of dielectric constant. The transmission speed of an electrical signal down a length of cable compared to speed in free space – expressed as a percentage of speed in free space.

volt. A unit of electromotive force.

voltage drop. A term expressing the amount of voltage loss from original input in a conductor of given size and length.

voltage standing wave ratio. The ratio of the maximum effective voltage to the minimum effective voltage measured along the length of a mismatched radio frequency transmission line.

voltage stress. That stress found within a material when subjected to an electrical charge.

volume resistivity. The volume resistance between two electrodes of unit area and unit distance apart, that are in contact with, or imbedded in, a specimen, is the ratio of the direct voltage applied to the electrodes to that portion of the current between them that is distributed through the volume of the specimen. Usually expressed in ohms/centimeter.

– W –

wall thickness. A term expressing the thickness of a layer of applied insulation.

water absorption test. A method to determine the water penetration through an insulating material after a given water immersion period.

waterblocked cable. A cable specially constructed with no internal voids, to allow no longitudinal water passage under a given pressure.

watt. A unit of electrical power; the power of one ampere of current pushed by one volt of electromotive force.

wavelength. The distance, measured in the direction of propagation, of a repetitive electrical pulse or waveform between two successive points that are characterized by the same phase of vibration.

wetting. The ability of a material to absorb moisture.

wicking. The logitudinal flow of a liquid in a wire or cable construction due to capillary action.

wire. (a) A single piece of slender, flexible metal, ranging in approximate size from a piece that is difficult to bend by hand, to a fine thread. (b) Several wires as in (a) twisted together (c) Wires as in (a) or (b) insulated.

– Y –

yield strength. The minimum stress at which a material will start to physically deform without further increase in load.

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