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Insulation

Directory/Encyclopedia Issue

No. 1

In this issue: A complete, comprehensive source of information on insulation . . . see pages 1 and 2

Section 24—Wire, Cable, And Assemblies (Except Magnet Wire)

Author Credit

This entire section was staff prepared.

INTRODUCTION

Wires and cables are an extremely complex subject. Thousands of pages could be written (and have been written). There is no simple and easy way to classify wires and cables—some are described by form (such as flat), some by general application (such as power) or by specific application (such as switchboard), some by type of conductor (such as copper), some by type of insulation (such as varnished cambric), some by property (such as high temperature), some by outer covering (such as steel armored), and some by voltage rating. Understandably, all this makes it very difficult to know where to begin and where to end in any fundamental discussion of wires and cables.

In order to simplify this situation, this section has been prepared with the intention of giving readers basic knowledge on wires and cables—terminology, selection considerations, common calculations and size data, construction materials (both metals and insulations), etc. This type of information is designed to permit readers to determine where their interests lie so that they may consult manufacturers for specific recommendations.

TERMINOLOGY AND DEFINITIONS

The following definitions are a portion of those approved by the American Standards Association (ASA C42.35 1957):

Cable—either a stranded conductor with or without insulation and other coverings (single-conductor cable), or a combination of conductors insulated from one another (multiple-conductor cable).

Cable Core—the portion of an insulated cable lying under the protec-

tive covering or coverings.

Cable Core Binder—a wrapping, tapes or cords around the several conductors of a multiple-conductor cable used to hold them together. (NOTE: Cable core binder is usually supplemented by an outer covering of braided jacket, or sheath.)

Armored Cable—a cable provided with a wrapping of metal, usually steel wires or tapes, primarily for the purpose of mechanical protection.

Cable Filler—the material used in multiple-conductor cables to occupy the interstices formed by the assembly of the insulated conductors, thus forming a cable core of the desired shape (usually circular).

Cable Sheath—the protective covering applied to cables. (NOTE: For power cables the sheath is usually lead.)

Jacket—a rubber or synthetic covering, sometimes fabric-reinforced, over the insulation, core or sheath of a cable.

Semi-Conducting Jacket—a jacket having a sufficiently low resistance that its outer surface can be kept at substantially ground potential by a grounded conductor in contact with it at frequent intervals.

Concentric-Lay Cable—either: (a) A concentric-lay conductor as defined later, or (b) A multiple-conductor cable composed of a central core surrounded by one or more layers of helically laid insulated conductors.

Duplex Cable—a cable composed of two insulated single conductor cables twisted together. (NOTE: The assembled conductors may or may not have a common covering of binding or protecting material.)

Lead Covered Cable (Lead Sheathed Cable)—a cable provided with a sheath of lead for the purpose of excluding moisture and affording mechanical protection.

Multiple-Conductor Cable—a combination of two or more conductors cabled together and insulated from one another and from sheath or armor-



Figure 1. variety of polyethylene protected wires and cables includes (left to right) control cable, thermocouple wire, high voltage anode lead wire, building wire, rural distribution wire, 600 v power cable, gas station wire, GTO wire, power cable, shielded twin lead wire, shielded control cable, and telephone cable (center). Courtesy E. I. du Pont de Nemours & Co. Inc.

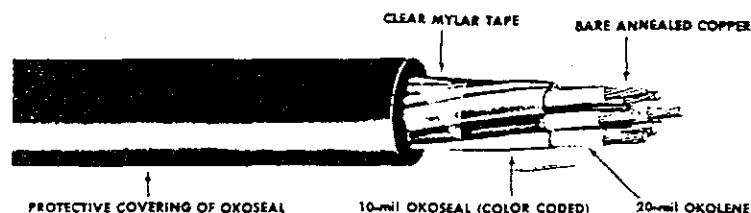


Figure 2. general purpose control cable for all types of installations with multiwall construction. Photo courtesy The Okonite Co.

where used. (NOTE: Special cables are referred to as 3-conductor cable, 7-conductor cable, 50-conductor cable, etc.)

Serving of a Cable—a wrapping applied over the core of a cable before the cable is leaded, or over the lead if the cable is armored. (NOTE: Materials commonly used for serving are jute or cotton. The serving is for mechanical protection and not for insulating purposes.)

Shielded-Type Cable—a cable in which each insulated conductor is enclosed in a conducting envelope so constructed that substantially every point on the surface of the insulation is at ground potential or at some predetermined potential with respect to ground under normal operating conditions.

Triplex Cable—a cable composed of three insulated single-conductor cables twisted together. (NOTE: The assembled conductors may or may not have a common covering of binding or protecting material.)

Conductor—a wire or combination of wires not insulated from one another, suitable for carrying electric current.

Bare Conductor—a conductor not covered with insulating material.

Concentric-Lay Conductor—a conductor composed of a central core surrounded by one or more layers of helically laid wires. (NOTE: In the most common type of concentric-lay conductor, all wires are of the same size and the central core is a single wire.)

Copper-Covered Steel Wire—a wire having a steel core to which is fused

an outer shell of copper.

Cross-Sectional Area of a Conductor (Cross-Section of a Conductor)—the sum of the cross-sectional area of its component wires, that of each wire being measured perpendicular to its individual axis.

Plain Conductor—a conductor consisting of one metal only.

Resistive Conductor—a conductor used primarily because it possesses the property of high electric resistance.

Rope-Lay Conductor or Cable—a cable composed of a central core surrounded by one or more layers of helically laid groups of wires. (NOTE: This kind of cable differs from a concentric-lay conductor in that the main strands are themselves stranded. In the most common type of rope-lay conductor or cable, all wires are of the same size and the central core is a concentric-lay conductor.)

Solid Conductor—a conductor consisting of a simple wire.

Stranded Conductor—a conductor composed of a group of wires, or of any combination of groups of wires. (NOTE: The wires in a stranded conductor are usually twisted or braided together.)

Cord—a small, very flexible insulated cable. (NOTE: There is no sharp dividing line in respect to size between a cord and a cable.)

Factor of Assurance of Wire or Cable Insulation—the ratio of the voltage at which completed lengths are tested to that at which they are used.

Taped Insulation—insulation of helically wound tapes applied over a

conductor or over an assembled group of insulated conductors. (a) When successive convolutions of a tape overlap each other for a fraction of the tape width, the taped insulation is lap wound. This is also called positive lap wound. (b) When a tape is applied so that there is an open space between successive convolutions, the construction is known as open butt or negative lap wound. (c) When a tape is applied so that the space between successive convolutions is too small to measure with the unaided eye, it is closed butt taping.

Intercalated Tapes—two or more tapes, generally of different composition, applied simultaneously in such a manner that a portion of each tape overlies a portion of the other tape.

Strip Process Insulation—insulation consisting of one or more strips of unvulcanized thermosetting material folded around a conductor and vulcanized after application.

Thermal Resistance of a Cable—the resistance offered by the insulation and other coverings to the flow of heat from the conductor or conductors to the outer surface. (NOTE: The thermal resistance of the cable is equal to the difference of temperature between the conductor or conductors and the outside surface of the cable divided by rate of flow of heat produced thereby. It is preferably expressed by the number of degrees Centigrade per watt per foot of cable.)

Lay—the lay of any helical element of a cable is the axial length of a turn of the helix of that element. (NOTE: Among the helical elements of a cable may be each strand in a concentric-lay cable, or each multiple conductor in a multiple-conductor cable.)

Direction of Lay—the lateral direction in which the elements of a cable run over the top of the cable as they recede from an observer looking along the axis of the cable.

Strand—one of the wires, groups of wires, or any stranded conductor.

Twisted Pair—a cable composed of two small insulated conductors twisted together without a common covering. (NOTE: The two conductors of a twisted pair are usually substantially insulated, so that the combination

is a special case of a cord.

Wire—a slender rod or filament of metal. (NOTE: The definition restricts the term to what would be ordinarily understood by the term *solid wire*. In the definition, the word *center* is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an *insulated wire*; while primarily the term *wire* refers to the metal, nevertheless when the context shows that the wire is insulated, the term *wire* will be understood to include the insulation.)

Composite Conductor—two or more strands of different metals, such as aluminum and steel or copper and steel, assembled and operated in parallel.

Duck Tape—tape of heavy cotton fabric, such as duck or drill, which may be impregnated with an asphalt, rubber or synthetic compound.

Filled Tape—fabric tape which has been thoroughly filled with a rubber or synthetic compound, but not necessarily finished on either side with this compound.

Single-Faced Tape—fabric tape finished on one side with a rubber or synthetic compound.

Double-Faced Tape—fabric tape finished on both sides with a rubber or synthetic compound.

Skim Tape—filled tape coated on one or both sides with a thin film of cured rubber or synthetic compound to produce a coating suitable for vulcanization.

Solid-Type, Paper-Insulated Cable—oil-impregnated, paper-insulated cable usually lead covered, in which no provision is made for control of internal pressure variations.

Pressure Cable—an oil-impregnated, paper-insulated cable in which a positive gauge pressure is maintained in the insulation under all operating conditions.

Self-Contained Pressure Cable—a pressure cable in which the container for the pressure medium is an impervious flexible metal sheath, reinforced if necessary, which is factory-assembled with the cable core.

Oil-Filled Cable—a self-contained pressure cable in which the pressure

medium is low viscosity oil having access to the insulation.

Gas-Filled Cable—a self-contained pressure cable in which the pressure medium is an inert gas having access to the insulation.

Pipe Cable—a pressure cable in which the container for the pressure medium is a loose fitting rigid metal pipe.

Oil-Filled Pipe Cable—a pipe cable in which the pressure medium is oil having access to the insulation.

Gas-Filled Pipe Cable—a pipe cable in which the pressure medium is an inert gas having access to the insulation.

SELECTION CONSIDERATIONS

As is true with any electrical insulating material or insulated component, the selection of wires and cables should be based on how satisfactorily the construction materials used meet the conditions or requirements of use. Since wires and cables are used to conduct electricity, selection of conducting metals in the proper size should be one of the first considerations.

Because of the great variety of uses, wires and cables are probably subjected to a wider range of operating conditions than any other electrical component. If one visualizes the myriad of uses outside, underground, submersed in water, and inside electrical/electronic equipment, missiles, steel mills, mines, chemical plants, etc., the availability of so many different types of wire and cable can readily be understood. Requirements of the application will determine the particular characteristics required. The discussion that follows offers suggestions as to factors that should be considered but it is recommended that readers analyze their own specific uses to make sure that all requirements are evaluated. Wires and cables can be custom-engineered to meet nearly any conditions.

From a physical standpoint, *tensile strength and elongation* should be considered for any wire subjected to tension or pulling during assembly and application or operation. *Abrasion resistance* is a factor during some assembly operations and for



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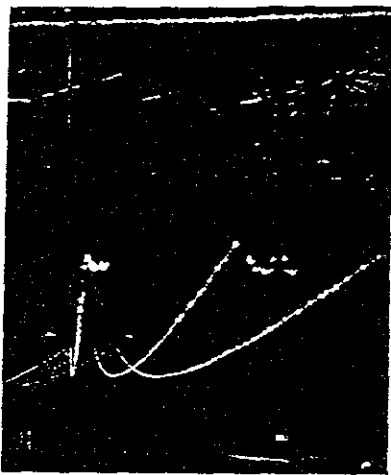


Figure 3, conductors aglow with corona. Corona, a discharge of electricity, is emitted in this case because the three single conductors are arranged for a transmission of 460,000 volts, but are being energized at a new world high of approximately 750,000 volts. Conductors coming into the transmission tower from the upper right are without corona because they are bundled in groups of four—the proper arrangement for transmissions of this size. Photo courtesy General Electric Co.



Figure 4, contour cable developed to replace bulkier round wiring in missiles. Flat metal strip conductors embedded in plastic ribbon save almost half the weight of conventional cable. Photo courtesy Hughes Aircraft Co.

cables that might be pulled over the ground or which might rub against tree limbs. *Cold flow* of insulation can be important where the wire will be exposed to continuous pressure at particular points. *Flexibility and brittleness* are considerations from the standpoint of facilitating handling and service life if the wire is to be bent during use. *Adhesion* of the different materials of construction, *hardness, resilience, and tear, impact, shear, fatigue, and compressive strengths* must also be evaluated for many uses. *Expansion and contraction* of the different materials of construction relative to each other and to the whole are factors. *Resistance to moisture and porosity* are vital for many jobs.

Some of the electrical characteristics that must be considered include *conductivity or insulation resistance, surface and volume resistivity, dielectric constant, dielectric strength, arc and track resistance, power factor, impulse strength, corona level, dielectric loss, capacitance, and inductance.*

Thermal properties of wire insulating and conducting materials include the *temperatures at which the materials soften, melt, vaporize, and freeze.* Others are *thermal resistance, coefficient of thermal expansion, resistance to heat shock, specific heat, thermal aging, low temperature flexibility, and thermal conductivity.* Thermal properties are very important in missile work, in equipment which is redesigned to fit smaller, more compact packages, and in areas where wires and cables are subjected to excessive temperatures during service.

Among the other characteristics which should be mentioned are *flammability, chemical stability, and resistance to acids, alkalis, fuels, oils, chemicals, solvents, radiation, weathering, sunlight, ozone, salt spray, and corrosion.*

ELECTRICAL CALCULATIONS

The following information from "The Rome Cable Manual of Technical Information," copyright, 1957, Rome Cable Corp., is published through the courtesy of the Rome Cable Division of the Aluminum Co. of America, Rome, N.Y.

Insulation Resistance of Cables

In general there are two possible leakage paths, one through the volume of the material and the other along the surface.

Volume insulation resistance of electricians is dependent upon the volume resistivity, usually expressed in ohm-cm. The d-c insulation resistance @ 60°F in ohms of a single conductor cable of length L is

$$R = \frac{k}{2\pi L} \log_e \frac{D}{d}$$

Where k = specific resistance, ohm-cm

d = diameter of conductor

D = outside diameter of insulated conductor

L = length of cable in cm

If the unit of cable is taken as 10 feet, the formula becomes

$$R = K \log_{10} \frac{D}{d}$$

where R = megohms—1000 ft.

K = constant for insulation

In this case K is known as the insulation resistance constant and, substituting this value in the above formula, the insulation resistance can be determined for any insulated conductor. Resistance measurements are greatly affected by temperature, for this reason are usually corrected to 60°F by use of temperature coefficients previously obtained for the particular insulation under test. The temperature coefficients are listed in most specifications for the insulation under consideration.

Surface resistivity is the resistance between two opposite edges of a surface which is usually 1 cm square. Surface resistivity is affected by the conduction power of a thin film of moisture, sometimes mingled with dust or foreign matter, on the surface of the insulating material. The surface resistivity is often a thousand times greater at low humidity than at high humidity.

Capacitance of Cable

The electrostatic capacitance of length of insulated wire to ground, expressed in microfarads per 1000 ft—is

$$C = \frac{0.00736\epsilon}{\log_{10} \frac{D}{d}}$$

where ϵ = dielectric constant (air = 1)

specific inductive capacity of the insulating material

D = outside diameter of the insulation

d = diameter of the conductor

The dielectric constant is a specific property of an insulating material and is both defined and measured by the ratio of the electrical capacity of a condenser having that material as the dielectric, to the capacity of the same condenser having air as the dielectric. The dielectric constant of air is unity. The dielectric constant is represented by the Greek symbol ϵ and is also referred to as *SIC* (specific inductive capacity).

The alternating-current phenomena associated with electrical capacitance are important in the wire and cable insulation field. At most commercial voltages and frequencies used in power distribution, the capacitance effects are negligible. At relatively high voltages the current due to capacitance may reach sufficient value to affect the circuit, and insulation for such applications is designed for moderately low dielectric constant. In communication work, the capacitance effect is pronounced and of great importance. Among other effects, the capacitance of the wire determines the maximum length of line over which the signal may be transmitted without excessive attenuation. It is important that insulations are designed with low dielectric constant in the communication field.

Electrical Stress In Cable Insulation

Dielectric Strength

The dielectric strength of a cable insulation is the electrical stress required to puncture an insulating wall of known thickness. This property is expressed in terms of volts per mil thickness. The dielectric strength of insulating materials is influenced by the rate of rise of the applied voltage and the total length of time the voltage is applied. A slow rate of rise usually will cause the material to puncture at a lower voltage than will a rapid rate of rise. Similarly a material may withstand a relatively high voltage for a short time, but will fail at a lower voltage of longer duration. For this reason, the standard method employed in the cable industry consists of two

tests. One is a short-time test whereby a voltage stress of 200 V/M is applied for a period of five minutes followed by a voltage time of 500 V/Sec. until breakdown occurs. The other is a long-time test whereby 200 V/M is applied for five minutes followed by 20% voltage increases at five minute intervals.

Maximum and Minimum Stress

The stress at any point in an homogeneous cable insulation may be calculated by the following formula:

$$S = \frac{E}{2.303 r \log_{10} \frac{D}{d}}$$

where S = Stress in volts per mil at a point in the insulation r mils from the axis

E = Voltage across the insulation in volts

d = Diameter of conductor

D = Diameter over insulation

r = Distance of point from the axis in mils

According to the formula the maximum stress occurs at the surface of the conductor and the minimum stress at the outer surface of the insulation. By differentiation, it can be shown that the maximum stress (at the conductor surface where $r = d/2$) has its lowest value when

$$\frac{D}{d} = 2.718$$

Electrical Losses In Cable Insulation

Dielectric loss is the time rate at which the electric energy is transformed into heat in a dielectric when it is subjected to a charging field (ASA).

The operating temperature of any cable depends upon the rate of heat generation in it and upon the rate at which the heat is dissipated. The heat is generated by the I^2R loss in the conductor and an energy loss in the insulation. This latter loss is called dielectric loss.

The dielectric loss in any cable equals the product of the specific inductive capacity of the insulation, the power factor of the insulation and a constant which takes care of the geometric dimensions of the cable, voltage stress, etc. It varies approximately with the square of the voltage.

The power factor of a dielectric ma-



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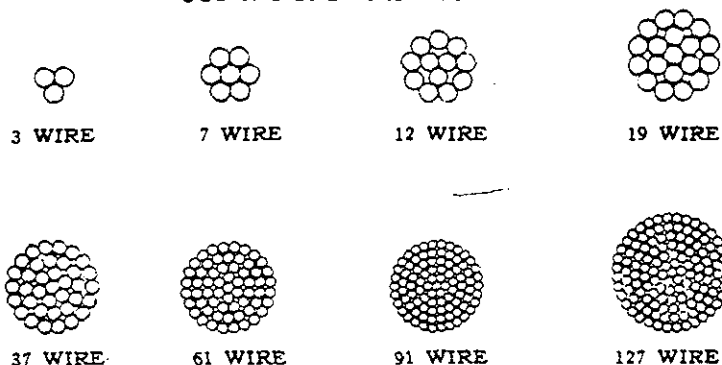
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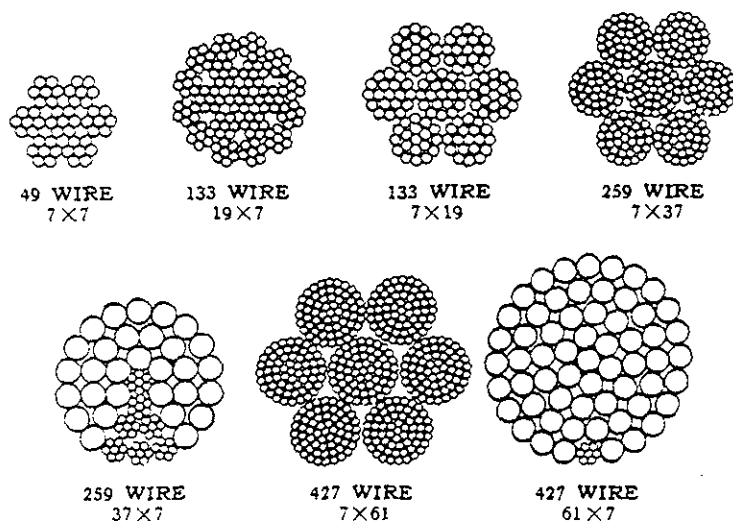
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CONCENTRIC LAY STRANDS



CONCENTRIC ROPE-LAY STRANDS



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material in an a-c field is the ratio of the power loss in the material to the product of the applied voltage and resultant current. Expressed vectorally, the voltage will lag the current by an angle Θ , less than the theoretical 90 degree. The power factor is the cosine of this angle and is often expressed in percent. Communication engineers frequently used the terms "imperfection angle" or "dissipation factor" Φ for the complement of the phase angle Θ . Hence, for an insulation with low power factor (less than .10) the power factor is equal to the tangent of the imperfection angle Φ .

Power factor is an important property in wire and cable insulations as it represents a power loss. In commercial power cables, this loss does not

become serious until it reaches a value of 5% or more—at which point the dielectric losses may cause excessive insulation heating for safe operation, particularly at potentials over 7500 volts. In communication cables, the power factor plays an important role as the actual power loss can represent an appreciable portion of the total energy in the circuit. Power factor is usually increased with increased water absorption, temperature, age and voltage. Most specifications for wire insulations state the maximum initial power factor or the maximum power factor after prolonged immersion in water.

The dielectric loss factor is the product of the power factor and the dielectric constant.

Inductance of Cable

The inductance of a circuit consisting of parallel conductors may be calculated by the approximate formula

$$L = (0.1404 \log_{10} \frac{b}{a} - 0.015) \times$$

where L = henries per 1000 feet of conductor

a = radius of conductor

b = spacing between center conductors

a and b must be expressed in same units.

The total inductance of a two-conductor transmission circuit per 1000 feet of circuit is twice the above value. The formula applies to both cable circuit and open wire lines.

The inductance of multiple-conductor cable depends principally upon the thickness of the conductor insulation. The belt or jacket affects it slightly.

The formula as it stands may be used for the approximate inductance of two-conductor concentric or coaxial cable if b is taken to be the inner radius of the outer conductor. The resulting value of inductance will be that for 1000 feet of cable.

WIRE AND CABLE CONSTRUCTION

Wire constructions are complex and varied. Cables may be jacketed, insulated, and shielded with many different layers of many different materials applied in many different sequences—and the same is true for the individual conductors within the cables. Thus, it can be seen that it would be impossible to list the constructions possible. Each material used is designed to control something to the finished product, and the properties of some materials lend themselves to specific applications with related requirements. Other materials are more universal in their applications.

Conductor materials may be solid or stranded. The metals may be alloys, plated, or clad. Primary insulation and jacketing materials may be served yarns, braids, tapes, roving, lap, felt, impregnants or coating extrusions. Some constructions include both inner and outer jacketing, braids, extrusions, etc. Shielding is generally braided or wrapped.

CONSTRUCTION MATERIALS

In addition to their use as conductors, metals are used for shielding, armor, and support in cables. In the case of lead, it is used as a waterproof jacket.

Conductor metals are selected not only on the basis of their conductivity but also on the basis of their mechanical properties, heat resistance, breaking strength, workability, coefficient of expansion, and other factors all enter into the consideration of what conductor metals should be selected for particular applications. Copper, of course, is the most common conductor. Other metals are being used in increasing amounts and the same is true for the various alloys and plated, plated, or clad metals.

Metals for shielding may serve a number of purposes. In coaxial cables, shielding in combination with the conductor and insulation determines electrical characteristics with the goal of matching of impedance to reduce power loss of signals or rf energy. In power cables shielding prevents surface discharges by providing even stress distribution. Shielding also restricts the electrical field of the conductor to the insulation and prevents external interference.

Metals which are used for armor provide many different types of physical protection. Properties of typical

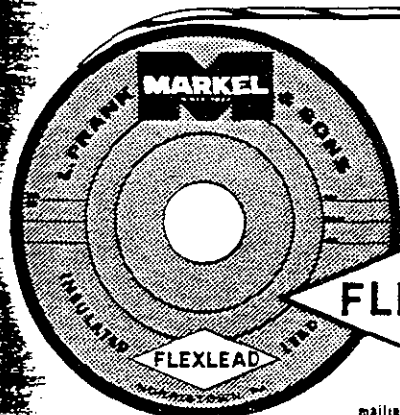
PROPERTIES OF RESISTANCE METALS AND ALLOYS

(Extracted from Tables Prepared by Driver-Harris Company)

MATERIAL	RESISTIVITY		COEF. OF LINEAR EXPANSION	APPROX. MELTING POINT Deg C	MINIMUM TENSILE STRENGTH Lbs./Sq. In. @ 20 C (68 F)	SPECIFIC GRAVITY
	Ohms (mil. foot)	Temperature Coefficient Per Deg C				
Kermex*	800	±.00002	.0000133	1400	130,000	8.105
Radiohm*	800	.00007	.0000155	1480	90,000	7.300
Nichrome*	675	.00015	.000017	1350	95,000	8.247
Nichrome V*	650	.00011	.000017	1400	100,000	8.412
Chromax*	600	.00036	.0000158	1380	70,000	7.950
Nirex*	590	.000125	.0000161	1395	80,000	8.55
Comet*	570	.00055	.000015	1480	75,000	8.15
Nilvar*	494	.00135	.000001	1425	70,000	8.08
Stainless Type 304	438	.00094	.000020	1399	100,000	7.93
142 Alloy	420	.0025	.0000053	1425	70,000	8.11
Advance*	294	±.00002	.0000149	1210	60,000	8.9
Therio*	294	.0038	.000006	1450	75,000	8.36
Manganin	290	±.000015	.0000187	1020	40,000	8.192
146 Alloy	275	.0032	.000008	1425	70,000	8.17
152 Alloy	260	.0036	.0000095	1425	70,000	8.247
Duranickel**	260	.001	.000014	1435	90,000	8.75
Midohm*	180	.00018	.0000175	1100	50,000	8.9
33 Alloy	162	.0024	.0000145	1420	75,000	8.60
R-63 Alloy	130	.003	.0000152	1425	70,000	8.72
Hytemco*	120	.0045	.000015	1425	70,000	8.46
Magne* (Gr. D**Nickel)	105	.0036	.0000143	1435	60,000	8.750
Permanickel**	100	.0036	.000014	1450	90,000	8.75
95 Alloy	90	.00049	.0000175	1100	35,000	8.9
Gr. E**Nickel	85	.0045	.0000146	1435	60,000	8.813
Gr. A**Nickel	60	.0050	.000015	1450	60,000	8.9
Lohm*	60	.0008	.000018	1100	50,000	8.9
High Brass	50	.0016	.0000202	930	55,000	8.53
99 Alloy	48	.0060	.000015	1450	50,000	8.9
Low Brass	40	.0017	.0000191	1000	47,000	8.6
30 Alloy	30	.0015	.0000175	1100	30,000	8.9
Commercial Bronze	25	.0020	.0000184	1040	37,000	8.7

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Insulation and Jacketing Materials

Quite naturally, the *primary insulation* on a wire or cable is used for insulation purposes. In those cases where the primary insulation is the only covering, it may also be considered to be fulfilling jacketing functions. *Jacketing* provides protection against moisture, solvents, acids, alkalis, fungus, chemicals, heat, radiation, and physical abuse such as abrasion and cutting. Jacketing also holds cable elements together and prevents contact between shielding and ground.

The method of applying the insulation or jacketing material will influence end properties. Application methods include braiding, extruding, taping, and dip coating. Different forms of the same material may be applied by different methods with dif-

ferent properties resulting.

Nearly all of the materials used for primary insulation and jacketing have been described in other sections and readers should refer to sections 6, 7, 8, 9, 12, 15, 16, 17, 18, 20, and 21 for additional details. In some cases, information on magnet wires in section 23 would also apply. It also should be remembered that fibrous materials are often coated or impregnated. Highlights of important insulating and jacketing materials will be briefly mentioned in the discussion that follows with references to the sections in which additional general data may be found—since many of these materials are specially compounded for wires and cables, readers should consult the manufacturers for specific data.

Acrylic—available in fibrous form for yarn servings and braids. Acrylic coating and impregnant also available (mostly for other uses). Other synthetic fibers find greater use for wire and cable insulation than the acrylics. In general, acrylics offer desirable physical and electrical properties and good resistance to most chemicals and

weathering. For special purpose insulation, acrylic elastomers can be used—they provide excellent resistance and good aging properties but chemical resistance is spotty—section 16.

Anodic Films—most of the publicity and possible potential for anodic film insulation (aluminum oxide coating on aluminum conductor) is concentrated in the magnet wire application area but some other wire applications have been suggested. The coating is thin, space-saving, inorganic and resistant to extreme temperatures (3600°F melting point). Although anodic film insulated conductors can be bent and processed without rupturing the film, flexibility is limited relative to other insulations.

Asbestos—fibrous asbestos wire and cable insulation is used in the form of yarn servings, felts, lap, roving and braid. Asbestos reinforced, combined with other materials also used. Where space is important, asbestos papers and purified asbestos papers may be used. Commonly, felted asbestos insulated wires and cables are available with all-asbestos insulation.

Properties of Metals at 20°C									
Metal	Specific Gravity	Specific Heat, Cal/Gram-°C	Melting Point °C	Resistivity, Microhm-Cm	Resistivity, Ohms (mil. foot)	Temperature Coef. of Resistivity, per °C	Thermal Cond., Cal-Cm/Sec-°C Cm²	Thermal Coef. of Linear Expansion /°C	Tensile Strength Lbs./Sq. In.
ALUMINUM.....	2.71	0.214	660	2.828	17.00	.00446	0.52	23 x 10 ⁻⁶	24,000
BRASS									
Commercial Bronze (90% Cu—10% Zn).....	8.80	0.092	1045	4.66	28.03	.00145	0.45	18 x 10 ⁻⁶	95,000
Low Brass (80% Cu—20% Zn).....	8.67	0.092	995	5.95	35.78	.00114	0.34	19 x 10 ⁻⁶	105,000
High Brass (70% Cu—30% Zn).....	8.53	0.092	930	6.90	41.50	.00098	0.26	20 x 10 ⁻⁶	120,000
COPPER									
Annealed Wire (100% Cond).....	8.89	0.0921	1083	1.7241	10.37	.00393	0.92	17 x 10 ⁻⁶	36,000-40,000
Hard Drawn Wire (97.5% Cond).....	8.89			1.7683	10.63	.00383			50,000-70,000
GOLD.....	19.30	0.031	1063	2.42	14.55	.0034	0.71	14.2 x 10 ⁻⁶	
IRON.....	7.86	0.107	1535	10	60.14	.0050	0.16	11.7 x 10 ⁻⁶	50,000
LEAD.....	11.3	0.031	327	22	132.31	.0039	0.083	28 x 10 ⁻⁶	1,800-4,000
MOLYBDENUM.....	10.2	0.061	2625	5.7	34.28	.0033	0.35	5 x 10 ⁻⁶	100,000
NICKEL.....	8.9	0.105	1452	7.8	46.91	.006	0.14	14 x 10 ⁻⁶	155,000
PLATINUM.....	21.45	0.032	1773	10.60	63.75	.00300	0.17	8.9 x 10 ⁻⁶	
SILVER.....	10.5	0.056	960	1.63	9.80	.0038	1.01	18 x 10 ⁻⁶	42,000
STEEL (Mild).....	7.8	0.107	1300-1475	12	72.17	.005	0.11	9 x 10 ⁻⁶	50,000-70,000
TIN.....	7.3	0.054	232	11.5	69.16	.0042	0.15	21 x 10 ⁻⁶	4,000-5,000
TUNGSTEN.....	19.3	0.032	3410	5.52	33.20	.0045	0.48	4 x 10 ⁻⁶	490,000
ZINC.....	7.14	0.092	419	6	36.08	.00347	0.27	28 x 10 ⁻⁶	7,000-30,000

BARE SOLID COPPER WIRE

Size*, Diameter*, Area*, Weight*, Breaking Strength and Resistance**

Size AWG	NOMINAL DIAMETER Inches	CROSS SECTIONAL AREA		NOMINAL WEIGHT Lbs./M ft.	HARD DRAWN		MEDIUM HARD DRAWN			ANNEALED	
		Circular Mils	Square Inches		Minimum Breaking Strength Lbs.	Max. d-c Resistance (a. 20 C Ohms M Ft.	Minimum Breaking Strength Lbs.	Maximum Breaking Strength Lbs.	Max. d-c Resistance (a. 20 C Ohms M Ft.	Maximum Breaking Strength Lbs.	Max. d-c Resistance (a. 20 C Ohms M Ft.
50	0.0010	1.00	.785X10 ⁻⁴	0.00303	.....	.....	.....	.....	.....	.....	.....
49	0.0011	1.21	.950X10 ⁻⁴	0.00366	.....	.....	.....	.....	.....	.....	.....
48	0.0012	1.44	1.13X10 ⁻⁴	0.00436	.....	.....	.....	.....	.....	.....	.....
47	0.0014	1.96	1.54X10 ⁻⁴	0.00593	.....	.....	.....	.....	.....	.....	.....
46	0.0016	2.56	2.01X10 ⁻⁴	0.00775	.....	.....	.....	.....	.....	.....	.....
45	0.0018	3.24	2.54X10 ⁻⁴	0.00981	.....	.....	.....	.....	.....	.....	.....
44	0.0020	4.00	3.14X10 ⁻⁴	0.0121	.....	27.6X10 ²	.....	.....	26.8X10 ²	.....	25.9X10 ²
43	0.0022	4.84	3.80X10 ⁻⁴	0.0147	.....	22.3X10 ²	.....	.....	22.2X10 ²	.....	21.4X10 ²
42	0.0025	6.25	4.91X10 ⁻⁴	0.0189	.....	17.2X10 ²	.....	.....	17.2X10 ²	.....	16.6X10 ²
41	0.0028	7.84	6.16X10 ⁻⁴	0.0237	.....	13.8X10 ²	.....	.....	13.7X10 ²	.....	13.2X10 ²
40	0.0031	9.61	7.55X10 ⁻⁴	0.0291	.....	11.2X10 ²	.....	.....	11.2X10 ²	.....	10.8X10 ²
39	0.0035	12.2	9.62X10 ⁻⁴	0.0371	.....	880	.....	.....	876	.....	847
38	0.0040	16.0	12.6X10 ⁻⁴	0.0484	.....	674	.....	.....	671	.....	648
37	0.0045	20.2	15.9X10 ⁻⁴	0.0613	.....	533	.....	.....	530	.....	512
36	0.0050	25.0	19.6X10 ⁻⁴	0.0757	.....	431	.....	.....	429	.....	415
35	0.0056	31.4	24.6X10 ⁻⁴	0.0949	.....	344	.....	.....	342	.....	331
34	0.0063	39.7	31.2X10 ⁻⁴	0.120	.....	272	.....	.....	270	.....	261
33	0.0071	50.4	39.6X10 ⁻⁴	0.153	.....	214	.....	.....	213	.....	206
32	0.0080	64.0	50.3X10 ⁻⁴	0.194	.....	168	.....	.....	168	.....	162
31	0.0089	79.2	62.2X10 ⁻⁴	0.246	.....	136	.....	.....	135	.....	131
30	0.0100	100	78.5X10 ⁻⁴	0.303	.....	108	.....	.....	107	.....	104
29	0.0113	128	100X10 ⁻⁴	0.387	.....	84.5	.....	.....	84.0	.....	81.2
28	0.0126	159	125X10 ⁻⁴	0.481	.....	67.9	.....	.....	67.6	.....	65.3
27	0.0142	202	158X10 ⁻⁴	0.610	.....	53.5	.....	.....	53.2	.....	51.4
26	0.0159	253	199X10 ⁻⁴	0.765	.....	42.7	.....	.....	42.4	.....	41.0
25	0.0179	320	252X10 ⁻⁴	0.970	.....	33.7	.....	.....	33.5	.....	32.4
24	0.0201	404	317X10 ⁻⁴	1.22	.....	26.7	.....	.....	26.6	.....	25.7
23	0.0226	511	401X10 ⁻⁴	1.55	.....	21.1	.....	.....	21.0	15.4	20.3
22	0.0253	640	503X10 ⁻⁴	1.94	.....	16.9	.....	.....	16.8	19.4	16.2
21	0.0285	812	638X10 ⁻⁴	2.46	.....	13.3	.....	.....	13.2	24.6	12.8
20	0.0320	1,020	804X10 ⁻⁴	3.10	.....	10.5	.....	.....	10.5	31.0	10.1
19	0.0359	1,290	1.01X10 ⁻³	3.90	.....	8.37	.....	.....	8.32	39.0	8.05
18	0.0403	1,620	1.28X10 ⁻³	4.92	85.5	6.64	67.6	76.5	6.61	49.1	6.39
17	0.0453	2,050	1.61X10 ⁻³	6.21	108	5.26	84.9	96.2	5.23	62.0	5.05
16	0.0508	2,580	2.03X10 ⁻³	7.81	135	4.18	106	120	4.16	73.0	4.02
15	0.0571	3,260	2.56X10 ⁻³	9.87	170	3.31	133	151	3.29	98.6	3.18
14	0.0641	4,110	3.23X10 ⁻³	12.4	214	2.63	167	189	2.61	124	2.52
13	0.0720	5,180	4.07X10 ⁻³	15.7	268	2.09	209	237	2.07	157	2.00
12	0.0808	6,530	5.13X10 ⁻³	19.8	337	1.65	262	297	1.64	197	1.59
11	0.0907	8,230	6.46X10 ⁻³	24.9	423	1.31	327	372	1.30	249	1.26
10	0.1019	10,380	8.15X10 ⁻³	31.43	529.3	1.039	410.4	467.5	1.033	314.0	.9988
9	0.1144	13,090	0.01028	39.62	660.9	.8241	513.9	585.9	.8199	380.3	.7925
8	0.1285	16,510	0.01297	49.98	826.1	.6532	644.0	734.8	.6498	479.8	.6281
7	0.1443	20,820	0.01635	63.03	1030	.5180	806.7	921.2	.5153	605.1	.4981
6	0.1620	26,240	0.02061	79.44	1280	.4110	1010	1154	.4088	762.6	.3952
5	0.1819	33,090	0.02599	100.2	1590	.3260	1265	1446	.3243	961.5	.3134
4	0.2043	41,740	0.03278	126.3	1970	.2584	1584	1814	.2571	1213	.2485
3	0.2294	52,620	0.04133	159.3	2439	.2050	1984	2273	.2039	1529	.1971
2	0.2576	66,360	0.05212	200.9	3002	.1625	2450	2814	.1617	1928	.1563
1	0.2893	83,690	0.06573	253.3	3688	.1289	3024	3484	.1282	2432	.1239
1/0	0.3245	105,600	0.08291	319.5	4518	.1022	3731	4311	.1016	2985	.09825
2/0	0.3648	133,100	0.1045	402.8	5519	.08021	4599	5330	.07980	3763	.07793
3/0	0.4096	167,800	0.1318	507.8	6720	.06362	5666	6588	.06330	4744	.06182
4/0	0.4600	211,600	0.1662	640.5	8143	.05045	6980	8143	.05019	5983	.04901

*From NBS Circular 31, 4th Ed.

**Calculated per ASTM B258-51T.

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non, in combination with varnished cambric (where moisture is a factor), or in combination with a thermoplastic (for switchboard work). The asbestos felt is impregnated with either a flame and heat resisting compound or a flame, heat, and moisture resisting compound. Suitable for low-voltage work, asbestos provides excellent heat resistance, non-flammability, flexibility, and resistance to most chemical conditions. It is used for power cable, rheostat wire, apparatus cable, lead wire, range wire, appliance wires and cords, mining cable, and other applications where heat is a problem. See section 8.

Buna N is also known as nitrile rubber. Specific properties depend on

the actual composition but generally, Buna N rubber offers excellent resistance to oils and solvents. Ozone resistance is good and is determined somewhat by the blend used. Buna N rubbers are the result of the copolymerization of acrylonitrile and butadiene. See section 16.

Buna S is a styrene-butadiene copolymer synthetic rubber characterized by good electrical properties and moisture resistance. Ozone resistance, physical properties, and chemical resistance are generally improved by blending with other materials. In this respect, it should be mentioned that both the synthetic and natural rubbers are not used "straight" but are blended with each other and other

products in order to improve properties. Thus, this discussion runs the risk of over-generalization—wire and cable producers should be consulted for specific information. See section 16.

Butyl Rubber—a polymer of isobutylene with small amounts of isoprene. this is an increasingly popular insulation and jacketing material. When properly compounded, butyl rubber is characterized by excellent resistance to oxidation and aging, exceptional ozone resistance, and very good electrical properties. Resistance to moisture, physical abuse, and chemicals is also good. Applications include low and high voltage power cables, apparatus and equipment

leads, control cables, and various other cables. See section 16.

Cellulose Acetate—available in yarn form for wire servings and braids as well as in film form for taped insulation. These materials are characterized by very good electrical properties per unit thickness. They are non-corrosive with moderate to good resistance to chemicals. The film has been used for lead wire insulation. Moisture resistance is good. See sections 8 and 18.

Ceramic—ceramic insulations are available in the form of fibrous alumina-silica yarns for servings and braids and also in the form of coatings. Heat and radiation resistances are excellent. Manufacturers should be consulted in regard to film flexibility and uses. Ceramic beads are another form used to provide physical separation. See sections 8 and 21. Also see *mineral insulation* below.

Cotton—cotton is used for servings and braids. Flexibility and strength are good. Treatments are required to provide chemical and fungus resistance. Heat resistance is limited. See section 8.

Fluoroelastomers—a number of these materials are available and some are suggested for use as wire insulations in critical applications where high costs are justified. Properties of the different types vary but generally, they all are characterized by excellent heat and chemical resistance. Five types are described in section 16.

Fluorinated ethylene propylene—FEP is similar to polytetrafluoroethylene (described later) but has a melting point about 50°C lower and slightly different physical properties. It is more easily processed than PTFE. Heat resistance and chemical inertness are outstanding. This material will likely be used in increasing amounts where requirements are severe. See section 15.

Gases—because of the complex construction and handling problems involved, gas filled cables are used only where necessary. See section 6.

Glass—glass fibers are used in yarn servings and braids. High tensile strength, non-flammability, flexibility, and resistance to moisture and high temperatures are characteristics of

glass fibers. Dielectric properties and protection against abrasion depend on other materials or treatments. See section 8.

Mica—mica is used as an insulation wrap in wires and cables to a very limited degree. See section 20.

Mineral Insulation—mineral insulated (MI) cable and thermocouple wire consists of one or more conductors surrounded by magnesium oxide insulation and enclosed in a liquid- and gas-tight metallic sheathing. Because the construction is completely inorganic, the cable is very heat resistant and inert to most conditions. See section 21.

Natural Rubber—rubber by itself is lacking in many properties required of wire and cable insulating and jacketing materials. However, by proper compounding and mixing with other products, it can be converted to a material with excellent physical properties, good electrical properties, and fair to moderate ozone resistance and chemical resistance. See section 16.

Neoprene—chemically, this synthetic rubber is known as polychloroprene. Its first use as a cable jacketing material was reported in 1933. Its application over lead sheathed and rubber insulated cables has grown rapidly since that time. Although the electrical properties of neoprene are inferior to many other insulations, they are adequate for low voltage work. The physical properties of neoprene are similar in some respects to natural rubber but it is considerably better from the standpoint of resistance to oil, ozone, heat, weather, sunlight, and aging. It does not support combustion and resists abrasion and cutting. It is used for a wide variety of wire and cable jacketing applications. See section 16.

Nylon—nylon is available in three forms for wires and cables: as a yarn for wire serving and braid; as an extrusion material (primarily for jackets); and a coating. For conductors of any but a small size, the electrical properties and hygroscopic properties of nylon limit its use to jacketing rather than primary insulation. Nylon extrusions are characterized by toughness and excellent oil resistance. See section 15.

Oils—cable oils and construction are discussed in section 7.

Paper—the National Electrical Code permits the use of paper insulated cable with a lead sheath for underground service conductors. Properties of unimpregnated paper are covered in section 9. Impregnated paper has improved electrical and moisture resistance properties. Paper is also used as a cable filler.

Polyester—this is supplied in the form of yarns for servings and braid and film for wire wraps. Generally, the polyesters are characterized by an excellent balance of strength, electrical, and thermal properties. They contribute to considerable space savings in communication and other wires and cables. See sections 8 and 18.

Polyethylene—a variety of types of polyethylene are used in wires and cables in very large amounts. Polyethylene has excellent electrical properties for wire and cable insulation, plus superior abrasion and solvent resistance. These properties in combination with moisture resistance, light weight, low brittle point, and durability have helped make polyethylene the large volume plastic that it is today. Polyethylene is used as an insulation or jacketing material for hook-up wire, coaxial cable, communication cable, line wire, lead wire, high voltage cable, etc. Conventional polyethylene has two limitations—supports combustion and it is not flexible as some products. In cases where stiffness is a problem, PVC is often used. Flame retardant types of polyethylene are available and are similar in most properties to conventional polyethylene although the service temperature is more conservative. Irradiated polyethylene can also be supplied—the radiation converts polyethylene from a thermoplastic to a infusible plastic which cannot be melted. Properties are quite similar to the conventional polyethylene except that some improvement in heat resistance and slight changes in other properties are reported. There has been quite a bit of investigation relative to the use of foamed polyethylene in coaxial cables—reports on actual

applications continue to grow in number. High density polyethylene reportedly offers properties similar to conventional polyethylene with some improvement in weathering, processing, and physical toughness. See section 15.

Polypropylene—a member of the same family as polyethylene, polypropylene is the newer of the two. It is the lightest of all plastics and is similar to polyethylene but offers even better heat resistance, tensile strength, abrasion resistance, and lower dielectric constant. For high frequency work, a specially purified grade is required. Investigations are under way for the use of foam. See section 15.

Polytetrafluoroethylene—this is the most thermally stable and chemically resistant of all carbonaceous insulating compounds. It is unaffected by sunlight, moisture, and practically all chemicals. Temperature range is -90 to $+250^{\circ}\text{C}$ and electrical properties are very constant over the temperature range and a wide range of frequencies. Insulation may be applied by extrusion or taping and in case where another material is used, by dispersion coating. See section 15.

Polytrifluorochloroethylene—this material approaches PTFE in many properties but is characterized by somewhat lower heat resistance. See section 15.

Polyvinyl chloride—PVC is widely used for primary wire insulation or jacketing on communication wires, control cables, bell wire, building wire, hook-up wire, fixture wire, appliance cords, power cables, lighting cables, motor leads, etc. Many different formulations are available including grades for high temperatures, low temperatures, flame resistance, deformation resistance, etc. Dielectric strength is excellent and flexibility is very good. Some formulations may have limitations when considering toughness, moisture resistance, and resistance to chemicals. However, by proper compounding, these properties can generally be tailored to meet the requirements of the application. PVC is probably the most versatile of the lower cost, conventional temperature wire insulations. See section 15.

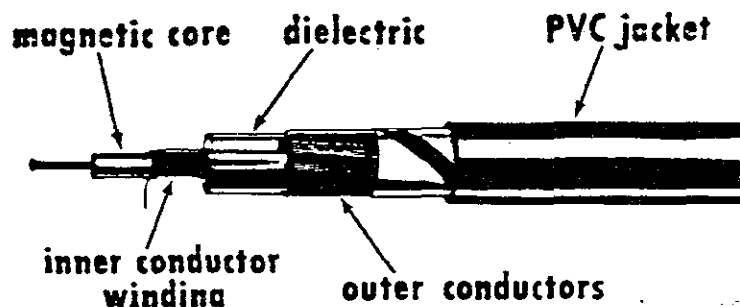


Figure 5. construction of a delay cable suggested for applications where extreme fidelity of signal transmission is important. Photo courtesy Columbia Technical Corp.

Rayon—this is a synthetic used for yarn serving and braid applications generally in the same applications where cotton can be used. See section 8.

Silica—silica fibers produced from melted quartz offer properties similar to fiber glass but even higher heat resistance (above 2000°F). They offer possibilities as yarn servings. See section 8.

Silicone rubber—silicone rubber extrusions offer retention of good electrical properties, resilience, and flexibility after long-time heat aging at class H temperatures and higher. Excellent ozone resistance, low temperature flexibility, long life, low moisture absorption, weather resistance, radiation resistance, and corona resistance are other characteristics. Resistance to some oils, solvents, and strong acids is relatively poor. Aircraft wires, nuclear cable, lighting wire, power cable, control cable, shipboard cable, heat and cold appliance wires, lead wires, etc., are uses. See section 16.

Silk—used very little today as yarn serving and braid. See section 8.

Varnished Cambric—tape wraps of varnished cambric for insulation of wires and cable offer properties that lie between those of rubber and impregnated paper. This applies to dielectric strength, flexibility, resistance to moisture and heat, and handling cable connections and terminations. It provides greater moisture resistance than paper and higher voltage ratings than rubber. In dry locations, it may be used without a lead sheath. It can be used for low and moderate voltage cables. See section 12.

PRODUCERS OF PRODUCTS COVERED IN THIS SECTION

Code Product

Listed According to Insulation and Jacketing Materials Used

A1	Acrylic
B1	Asbestos
C1	Buna N
D1	Buna S
E1	Butyl rubber
F1	Cellulose acetate
G1	Ceramic
H1	Chlorosulfonated polyethylene
I1	Cotton
J1	Fluoroelastomers
K1	Fluorinated ethylene propylene
L1	Foamed dielectric
M1	Gas filled
N1	Glass fiber
O1	Irradiated polyethylene
P1	Mica
Q1	Mineral (magnesium oxide) insulated
R1	Natural rubber
S1	Neoprene
T1	Nylon
U1	Oil filled
V1	Paper
W1	Polyester fiber
X1	Polyester film
Y1	Polyethylene
Z1	Polypropylene
A2	Polytetrafluoroethylene
B2	Polytrifluorochloroethylene
C2	Polyvinylchloride
D2	Quartz fiber
E2	Rayon
F2	Silicone rubber
G2	Silk
H2	Varnished cambric

Listed According to Application, Function, Type, or Form

A3	Aerial
B3	Aircraft and missile
C3	Alloy
D3	Apparatus
E3	Appliance
F3	Armored
G3	Automotive
H3	Bare
I3	Building
J3	Cable terminations
K3	Cable
L3	Coaxial
M3	Coiled
N3	Communication
O3	Control
P3	Cord sets
Q3	Direct burial
R3	Electronic
S3	Fixture
T3	Harnesses and assemblies
U3	Heating
V3	High temperature
W3	High voltage
X3	Hook-up
Y3	Ignition
Z3	Lead covered
A4	Lighting
B4	Line
C4	Machine tool

