CHAPTER 6

WIRE AND CABLE

This chapter contains descriptions of various types of wire, cable and connectors with the characteristics of the materials used in their manufacture. In addition, information on termination and marking of cables and conductors is included. It is the intent of this chapter to provide detailed step-by-step installation and/or fabrication methods for various wire and conductor applications.

NOTE

It should be noted that the installation instructions provided in this chapter do not take into consideration the criteria established in NAVELEXINST 011120.1, "Shore Electronics Engineering Installation Guidance for Equipment and Systems Processing Classified Information". In those instances where this chapter is in conflict with NAVELEXINST 011120.1, the NAVELEX instructions shall govern.

6.1 CABLE SELECTION

Generally, all elements relating to cable selection can be broadly categorized as electrical or physical. Electrical considerations range from the more obvious ampere and voltage requirements to the more obscure factors such as capacitance, isolation of circuits, and cross-talk. (Standard Navy installation procedure dictates that no more than a 2 percent voltage drop across the entire length of a power cable is allowed.) The physical elements include consideration of tensile strength. The following paragraphs discuss some of these elements. It should be noted that use of aluminum cable has been banned in building construction by many communities.

6.1.1 Voltage

The operating voltage for a given circuit is a primary factor in the choice of insulating material. Incorrect selection of the insulating material may result in insulation breakdown and arcing between cables or conductors. Cable specifications given by manufacturers contain voltage ratings that conform to National Electric Code (NEC) requirements.

6.1.2 Current

Circuit current requirements are used to determine the conductor size. The maximum current-carrying capacity for a given size conductor is determined by the heat dissipation that can be tolerated in a given application. The NEC lists allowable current-carrying capacities for copper and aluminum conductors of different sizes and with different types of insulation. The conductors listed are normally used for power circuits. If the ambient room temperature is greater than 30° C (86° F), the values must be reduced by multiplying the current-carrying value by the applicable correction factor. The values contained in the NEC tables apply to installations consisting of three conductors or less. If more than three conductors are used, the values must be reduced as shown in other NEC tables.

Table 6-1 lists the current-carrying capacity of conductors normally used for equipment hook-up. The current-carrying capacity decreases when the conductor is enclosed in conduit or routed through areas where air circulation is restricted or where high temperatures prevail.

6.1.3 Frequency

When conductors are selected for DC or low frequency applications, frequency need not be considered. However, when conductors are used as RF transmission lines, skin effect (tendency of current to flow near the outer surface of a conductor) becomes a consideration. Copper-clad steel or copper tubing can be used to advantage in such applications. The specific resistance of the wire also increases at radio frequencies and results in signal attenuation.

6.1.4 Environment

The degree of protection required for a conductor depends upon the environment of the installation. Cables are required to have a special covering when installed in gasoline, oil, or ammunition storage areas or other locations where they may be subjected to abrasion, chemicals, or gases.

6.1.5 Effect on Circuit

Circuits carrying video, pulse-train, or other low-level signals are adversely affected by cables with high capacitances or improperly matched impedances. Shielded wire with excellent characteristics at audio frequencies may be unsuitable for video or pulse-train applications.

6.2 CABLE SUBSTITUTION

In order to expedite completion of electronic installations, it is sometimes necessary to make field expedient cable and wire substitutions. Substitutions of this type shall be performed only as an emergency measure, and then only with the approval of the project engineer.

6.2.1 Substandard Installations

Installed materials that are found to be substandard must be tagged immediately to ensure replacement at the earliest possible date. Information to be included on the tag shall cover: the reason for the substandard installation, the original requirements, what was installed, and the date of installation. If standard tags are not available, a tag shall be improvised that contains the required information.

6.2.2 Preferred Substitutions

If substitution is necessary, cables that exceed the design requirements shall be selected. This procedure ensures that the substitution will not result in hazards to personnel and equipment.

6.3 ENVIRONMENTAL CONSIDERATIONS

6.3.1 Animal Life

Cables installed at permanent bases and, to a lesser degree, interconnecting cables between mobile vans are subject to damage by rodents and insects. The particular species involved will vary with location and season, but some type of infestation must always be expected. Cables covered by lead sheathing and armor are not always adequately protected. Rodents (rats, mice, squirrels) have sometimes destroyed even these protective coverings. Beetles and termites are equally destructive. To prevent damage, protective sheaths are often painted or impregnated with arsenic or other poisons and repellents.

To further protect installed cables, all trenches shall be provided with covers and seals in areas where serious infestations are to be expected. Information on the type and seriousness of infestations to be encountered in specific areas may be obtained from local commercial telephone companies and local representatives of the United States Department of Agriculture.

Although not harmful to a cable installation, the presence of snakes and black widow spiders in trenches and ducts create a hazard to personnel. Therefore, caution must always be exercised when work is performed on existing cable installations.

6.3.2 Sunlight

Some synthetic rubber sheaths and insulations are subject to damage by prolonged exposure to sunlight. Loss of flexibility and surface cracks result. If prolonged exposure cannot be avoided, the following preventive measures are recommended:

a. Perform frequent inspections.

b. Treat cable surface with a silicone compound such as DC-4. (Excess compound should be wiped off to prevent accumulation of dirt.)

c. Paint cables with a rubber base preservative paint. The paint may be applied to the cable with a cloth mitten or glove. Approved paints of this type are available in supply channels under FSN 8030-656-1032 (Spec-ORDJR-OME-PD-124) and 8030-201-1103 (MIL-P-1152OD).

d. Select cables that are resistant to sunlight such as ALPETH Cable manufactured by the Western Electric Company.

Project specifications shall include the preventive measures to be taken to protect cables from damage because of sunlight.

6.3.3 Ozone

Ozone (O_3) is a form of oxygen which, unlike oxygen in its normal state (O_2), is harmful to rubber and rubber compounds. The ozone enters the atmosphere and causes smog when stack- and automobile-exhaust gases are decomposed by sunlight. The preventive measures mentioned in the preceding paragraph also aid in the prevention of ozone damage to cables.

6.3.4 Extreme Climatic Conditions

Extreme cold, salt air, hot humid air, and other climatic conditions must be considered when the type of cable to be used is determined. These conditions govern the insulation and sheath requirements of the cable.

6.4 CONDUCTORS

6.4.1 Configurations of Conductors

a. Solid. Solid conductors offer the advantage of a minimum outside circumference for a given cross-sectional area. When bent, solid wire retains its shape, which makes it desirable for use in formed coils and hook-up wire. Larger size solid conductors are too rigid for most applications; therefore, stranded wire is generally used when a large conductor is required. Table 6-2 lists the characteristics of solid, bare wire between sizes 44 and 0000.

b. Stranded. Conductors consisting of small strands of wire are often used in place of solid conductors because they are more flexible than their solid equivalents. The size and number of strands are chosen so that the stranded conductor has the same current-carrying capacity as a solid conductor with the same AWG number. Conductors with differing degrees of flexibility are obtained by varying the size, number, and twist (lay) of the strands. The lay of the strands can either be concentric or bunched. The conductor in a concentric lay is composed of a central strand surrounded by one or more layers of spirally wound strands. The strands in a bunched lay are twisted together in the same direction without regard to geometrical arrangement. A listing of uninsulated, stranded copper wire is contained in Table 6-3.

6.4.2 Materials and Types of Conductors

a. General. Conduction, by solid metals, of electricity is accomplished by the movement of electrons along the conductor. Hence, the more free electrons, the better the conductivity. The relative order of conductiveness of materials is listed below:

Silver	Zinc
Copper	Beryllium
Gold	Cobalt
Aluminum	Nickel
Magnesium	Potassium
Calcium	Cadmium
Sodium	Iron

b. Copper-Clad Steel. Where mechanical strength and low cost are of prime importance, steel conductors are often used. The main disadvantages of steel are relatively poor conductivity and susceptibity to corrosion. A copper coating can be fused to the outside of the steel conductor to overcome these disadvantages. Steel conductors treated in this manner (copper-clad steel) are widely used for antennas; overhead telephone, telegraph, and signal cables; aerial-cable messenger; guy wires; and ground rods (see Table 6-4).

c. Bus Bar. The most frequent application of bus bar is in grounding networks and in electric-power switchgear, boxes, and busways. Bus bars are made of either aluminum or copper and are usually rectangular or round. Solid or hollow-centered stock may be used. The most common configuration is a rectangular bar that is from 1/8 to 1/2 inch thick and from 1 to 6 inches wide. The large surfaces of bus bar simplify the making of bolted or brazed joints.

6.5 INSULATION AND SHEATHS

The following paragraphs describe the commonly used types of insulation for wire and cable. The characteristics of various types of insulations are detailed in the NEC.

In addition, conductors are often provided with protective coverings to avoid environmental and mechanical damage. This sheath will consist of any variety of chemical compounds and/or metals depending on the type and degree of protection the particular application requires.

6.5.1 Rubber-Type Insulations

All rubber-type insulation is compounded, in one form or another, with other chemicals to withstand the rigors of its intended application. These various compounds offer rubber-type insulations with a wide range of operating temperatures and widely varied environmental application. Specific types, and their use, are detailed in the NEC.

6.5.2 Thermoplastic Insulations

Thermoplastic insulation is a synthetic organic material that is molded, cast, or extruded around a conductor. Various chemical compounds are mixed with the base material to provide the desired operating temperature and environmental characteristics.

a. Polyvinyl Chloride (PVC). Polyvinyl chloride insulations consist of a mixture of plastic resins and other ingredients. Their properties can be adjusted over a wide range by the selection of these ingredients. In general, this type of insulation is limited to applications where the voltage is less than 600 volts and the temperature range is between -60° C to +80° C (-76° F to +176° F) in dry locations, or -60° C to +60° C (-76° F to +140° F) in wet locations. All PVC type insulations have good resistance to moisture, oil, solvents, chemicals, and ozone. PVC is normally used as an outer jacket for cables since it does not support combustion. Wires with this insulation are used primarily for indoor applications or for electronic and low-voltage power circuits in protected areas. PVC is also used as an outer protective sheath.

b. Polyethylene. Since polyethylene insulation has excellent dielectric properties, it is used extensively in the manufacture of coaxial cables. Its flexibility is not seriously impaired until a temperature below -70° C (-94° F) is reached. Its resistance to damage because of sunlight, weather, chemicals, and fire is good; however, it is flammable and does not support combustion. Use of polyethylene insulation for cables permits a voltage rating as high as 35 KV.

c. Teflon. This material is an ideal insulation because of its high resistance to most chemicals and environmental influences. Temperatures as high as 260° C (500° F) can be tolerated without an appreciable change in its electrical properties. Teflon finds wide applications in high frequency circuits at voltages up to 1000 volts.

CAUTION

If fumes of heated Teflon resins or fibers are inhaled in sufficient quantities, influenza-like symptoms may follow. These symptoms do not ordinarily occur until several hours after exposure and pass off within 36 to 48 hours. Teflon can be processed without hazard with the use of proper ventilation. Particular care should be taken to avoid contaminating cigarette or pipe tobacco with Teflon. Unusually heavy concentration of harmful vapor could be inhaled when smoking contaminated tobacco.

d. Varnished Cambric. Varnished cambric consists of cotton fabric coated with multiple layers of varnish and is applied to the conductor in the form of tape. It is frequently used as insulation on short-distance, high voltage power lines and in electronic equipment. This insulator requires a covering such as lead sheath if it is to be used in wet locations. Voltage ratings up to 28 kV and temperature ratings as high as 85° C (185° F) are typical for this insulation.

e. Enamel. Wire is passed through successive baths of quick-drying enamel until the required insulator thickness is attained. It is frequently used as an insulator on magnet wire. Temperatures as high as 105° C (221° F) can be tolerated. Kinks and sharp bends in the wire must be avoided to prevent cracking and flaking.

f. Formvar (Vinyl Acetal). Formvar is a trade name for a wire coating that is applied in the same manner as enamel. Its advantage over enamel is the resiliency of the coating. It will not crack or flake when bent or kinked. The maximum operating temperature of this insulator is 105° C (221° F).

g. NEC approved insulations. The NEC specifies the recommended use of specific insulations for building wiring, and lists designations, dimensions, and types of conductor insulations.

6.5.3 Nonmetallic Sheaths

Nonmetallic sheaths protect the insulation against flame, sunlight, abrasion, chemicals, and moisture. These sheaths are inferior to metal sheaths in resistance to mechanical injury. Nonmetallic sheaths can be used as a covering for metallic sheaths to protect against corrosion and electrolysis. Three basic types of nonmetallic sheaths are available: rubber, plastic, and fabric.

a. Natural and Synthetic Rubber Sheaths. The most common sheath materials are natural and synthetic rubber. Many different compounds, each having advantages for a specific application, are available. Neoprene is the most widely used rubber compound for sheaths. Butyl rubber jacketed cables are primarily used in high-temperature applications, but these cables are also suitable for use at very low temperatures. Cables with these types of sheath are classified as direct burial cables and can be buried directly in the earth. Natural rubber is occasionally used on cables requiring flexibility at low temperatures.

b. Plastic Sheaths. The types of plastics used for sheaths are identical to those used for insulation. Polyvinyl chloride (PVC) is the most widely used because of its excellent physical properties and its relatively low cost.

c. Fabric Sheaths. Hook-up wire and cables used in building construction are frequently encased in tubular-woven fabric sheaths. The most common fabrics used are cotton, rayon, nylon, and fiberglass. The fabrics are sometimes impregnated with a sealer, such as asphaltic material or clear plastic, to make the insulated conductor stronger and more impervious to moisture and chemicals. Fabric sheaths are quite flexible and have good resistance to abrasion.

6.5.4 Metallic Sheaths

Metallic sheaths protect the insulated conductors and other nonmetallic sheaths from mechanical damage, provide increased safety to human life, and protect cables subject to induced potentials. These sheaths are usually made of galvanized steel, however other metals are available for special uses.

a. Corrugated Metallic Duct. Corrugated-metallic duct is a metal tube with an inside diameter substantially larger than the cable outside diameter. The corrugations are spaced at intervals to grip the cable and to retain cable flexibility. This type of sheathing is similar to corrugated flexible conduit and is available in steel, aluminum, and other metals. An additional nonmetallic sheath may be provided to afford greater protection from water, gas, chemical, oil, and mechanical damage.

b. Interlocked Armor. Interlocked armor sheaths are spirally-wound metal strips that are interlocked to provide mechanical protection for the entire cable. Galvanized steel is the most commonly used material; however, aluminum, copper, bronze, and stainless steel armors are available for special applications.

The interlocked construction produces a relatively flexible cable that can be installed or repositioned easily. A cover of PVC or polyethylene material makes this sheath water-tight. Interlocked armor is not designed to take longitudinal stresses; consequently, long unsupported vertical or horizontal runs must be avoided.

c. Round-Wire Armor. Round-wire armor consists of one or more layers of steel wire applied over a cable core. The armor wire is usually applied over a bedding of asphalt-impregnated jute. Round-wire armor is used where high tensile strength and high resistance to abrasion and mechanical damage are required. Round-wire armored cables are widely used in submarine installations.

6.6 TYPES OF WIRE AND CABLE

There are few official standards for the internal wiring of electronic equipment. However, there are numerous standards dictating the specific requirements for the various types of wire and cable. Therefore, proper selection of wire and cable must be based on a thorough knowledge of the intended application with a review of the cable or wire characteristics following. Answers to the following questions will aid considerably in the selection process.

- Will the device or equipment be complex enough to require wire identification (color coding, etc.) to aid in construction, installation or servicing?

- Will a metallic shield on some conductors be needed to reduce pick-up? (Shields must be grounded if positive single-joint grounding is to be attained).

- Will there be motion, shock, or vibration during normal use of the equipment thereby necessitating stranded conductors?

- What will be the probable maximum continuous ambient temperature?

- What is the possibility of corona on high-voltage leads?

- What will be the full-load conditions? (Dictates wire size)

- Will shielding be required to protect conductor from direct heat radiation from electron tubes, power resistors, etc. ?

- What will be the maximum voltage to ground? (Dictates insulation thickness)

The types of wire and cable most commonly encountered at Naval Shore Stations are briefly described.

6.6.1 Hook-Up Wire

Hook-up wire is the term employed to describe those conductors utilized in the internal wiring of electrical and electronic equipment. Military specifications MIL-W-76 and MIL-W-16878 cover the various types available.

a. MIL-W-76 Wire and Cable, Hook-Up, Electrical, Insulated. This specification applies to single conductor, synthetic-resin insulated wire with a temperature limit of 80^{o} C (176^{o} F). Wire covered under this specification has a voltage range 300 to 2500 volts. Type characteristics as prescribed in this Military Specification, are outlined in Table 6-5.

b. MIL-W-16878 Wire, Electrical, Insulated, High Temperature. This specification applied to wire having a maximum operating temperature of 200^{o} C and a voltage range of 600 to 3000 volts. Type characteristics, as prescribed in this military specification, are outlined in Table 6-6.

6.6.2 High Voltage Pulse Cable

The special coaxial cables used for the transmission of high voltage pulses are listed below:

RG-25/U	RG-28B/U	RG-88A/U
RG-25A/U	RG-56/U	RG-88B/U
RG-26/U	RG-60/U	RG-156/U
RG-26A/U	RG-64/U	RG-157/U
RG-27/U	RG-64A/U	RG-158/U
RG-27A/U	RG-74A/U	RG-190/U
RG-28/U	RG-77A	RG-193/U
RG-28A/U	RG-88/U	RG-194/U

These cables differ in that they have two layers of dielectric material instead of one. The outer dielectric material is semiconducting and evenly distributes the electrical stresses within the dielectric. Because of the semiconductivity of this material it must be peeled back when attaching connectors. Additional information regarding pulse cable characteristics and the applicable connectors will be supplied in later chapters.

6.6.3 Shielded Cable

See paragraph 6.5.4.

6.6.4 Direct Burial Cable

Direct burial cable is offered in a wide variety of configurations to meet specific needs. However, it should be noted that most cables of this type are of a multipurpose nature and may also be used in conduit, ducting, or aerially. When cable is used to carry high voltages a protective covering of steel armor is provided to prevent mechanical damage. Cable-manufacturer catalogs should be reviewed to obtain specific characteristics.

6.6.5 Miscellaneous Conductors and Cables

a. Ribbon Conductor. The use of ribbon and printed circuit conductors for applications in new equipment is becoming more prevalent. The two basic types are:

- Molded-vinyl flat cable (figure 6-1) where parallel conductors are bonded to form a flat cable. Individual conductors may be stripped out to make separate terminations. This cable may be folded or coiled to allow the servicing of slide mounted equipment.

- Printed circuits where the conductors consist of flat copper strips that are laminated between sheets of insulating material such as Mylar or Kel-F. This type of conductor is usually tailored to fit an individual equipment and is not normally fabricated in the field.

b. Tinsel Wire. Tinsel wire (figure 6-2) is used for applications such as test leads, headset cables, and microphone cables where an ultra-flexible cable is required. Tinsel wire consists of strands of copper or bronze wire that is wrapped around multiple cotton or synthetic fiber filaments.

c. Resistance Wire. Resistance wire is used to terminate antenna systems, in the construction of special resistors and attenuators, and as an isolation element between circuits. Standard resistance wire is made of copper, nichrome, constantan, or other alloys. The resistive properties of resistance wire vary widely with temperature; therefore, the ambient temperature must be considered when a determination of the resistance is made.

A table of resistance materials is given in Table 6-7. The mil-foot referred to is a unit of volume measures for conductors. It is equal to a one-foot length of wire with an area of one circular mil.

For example, a two-foot length of KARMA wire with an area of two circular mils would have a resistance of 2 x 0.5 x 800 = 800 ohms.

d. Litz Wire. Litz wire is used in the construction of coils and loop antennas that are designed for use below 2 MHz. This wire consists of individually cloth- or enamel-insulated, very fine strands of wire. The insulation must be removed from each strand of wire before soldering. Fine sandpaper or commercial stripping solutions such as General Cement Strip-X may be used.

Table 6-1. Current-Carrying Capacity of Equipment Hook-Up Wire

WIRE SIZE		COPPER CONDUCTOR ($100^{\circ}C$) NOMINAL	MAXIMUM CURRENT IN AMPERES			
			COPPER WIRE		ALUMINUM WIRE	
AWG	CIRCULAR MILS	RESISTANCE (OHMS/1000 FT)	WIRING IN FREE AIR	WIRING CONFINED	WIRING IN FREE AIR	WIRING CONFINED
32	63.2	188.0	0.53	0.32		
30	100.5	116.0	0.86	0.52		
28	159.8	72.0	1.4	0.83		
26	254.1	45.2	2.2	1.3		
24	404.0	28.4	3.5	2.1		
22	642.4	22.0	7.0	5.0		
20	1022	13.7	11.0	7.5		
18	1624	6.50	16	10		
16	2583	5.15	22	13		
14	4107	3.20	32	17		

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Table 6-2. Characteristics of Solid Bare Wire

SIZE	DIAMETER	CROSS-SECTIONAL AREA		RESISTANCE-OHMS/1000 FEET @ 20° C (68°F)			
(AWG)	INCHES	CIR MILS	SQ IN X 10^{-6}	HARD COPPER	MEDIUM COPPER	SOFT COPPER	ALUMINUM
4/0	0.4600	211,600	166,200	0.05045	0.05019	0.04901	0.0804
3/0	0.4096	167,800	131,800	0.06362	0.06330	0.06182	0.101
2/0	0.3648	133,100	104,500	0.08021	0.07980	0.07793	0.128
0	0.3249	105,600	829,100	0.1022	0.1016	0.09825	0.161
1	0.2893	83,690	65,730	0.1289	0.1282	0.1239	0.203
2	0.2576	66,360	52,120	0.1625	0.1617	0.1563	0.2562
3	0.2294	52,620	41,330	0.2050	0.2039	0.1971	0.3231
4	0.2043	41.740	32,780	0.2584	0.2571	0.2485	0.4074
5	0.1819	33,090	25,990	0.3260	0.3243	0.3134	0.5139
6	0.1620	26,240	20,610	0.4110	0.4088	0.3952	0.6479
7	0.1443	20,820	16,350	0.5180	0.5153	0.4981	0.8165
8	0.1285	16,510	12,970	0.6532	0.6498	0.6281	1.030
9	0.1144	13,090	10,280	0.8341	0.8199	0.7925	1.299
10	0.1019	10,380	8,155	1.039	1.033	0.9988	1.637
11	0.0907	8,230	6,460	1.31	1.30	1.26	2.07
12	0.0808	6,530	5,130	1.65	1.64	1.59	2.60
13	0.0720	5,180	4,070	2.09	2.07	2.00	3.28
14	0.0641	4,110	3,230	2.63	2.61	2.52	4.14
15	0.0571	3,260	2,560	3.31	3.29	3.18	5.21
16	0.0508	2,580	2,030	4.18	4.16	4.02	6.59
17	0.0453	2,050	1,610	5.26	5.23	5.05	8.28
18	0.0403	1,620	1,280	6.64	6.61	6.39	10.5
19	0.0359	1,290	1,010	8.37	8.32	8.05	13.2
20	0.0320	1,020	804	10.5	10.5	10.1	16.6
21	0.0285	812	638	13.3	13.2	12.8	20.9
22	0.0253	640	503	16.9	16.8	16.2	26.6
23	0.0226	511	401	21.1	21.0	20.3	33.3
24	0.0201	404	317	26.7	26.6	25.7	42.1
25	0.0179	320	252	33.7	33.5	32.4	53.1
26	0.0159	253	199	42.7	42.4	41.0	67.2
27	0.0142	202	198	53.5	53.2	51.4	84.3
28	0.0126	159	125	67.9	67.6	65.3	107
29	0.0113	128	100	84.5	84.0	81.2	133
30	0.0100	100	78.5	108	107	104	170
31	0.0089	79.2	62.2	136	135	131	213
32	0.0080	64.10	50.3	168	168	162	269
33	0.0071	50.4	39.6	214	213	206	339
34	0.0063	39.7	31.2	272	270	261	428
35	0.0056	31.4	24.6	344	342	331	540
36	0.0050	25.0	19.6	431	429	415	681
37	0.0045	20.2	15.9	533	530	512	858
38	0.0040	16.0	12.6	674	671	648	1080
39	0.0035	12.2	9.62	880	876	847	1360
40	0.0031	9.61	7.55	1,120	1,120	1,080	1720
41	0.0028	7.84	6.16	1,380	1,370	1,320	2160
42	0.0025	6.25	4.91	1,720	1,720	1,660	2720
43	0.0022	4.84	3.80	2,230	2,200	2,140	3440
44	0.0020	4.00	3.14	2,700	2,680	2,590	4320

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Table 6-3. Characteristics of Stranded Bare Copper Wire (Sheet 1 of 2)

AWG GAUGE	STRANDING*	TYPE STRANDING	DIAMETER INCHES	CIRCULAR MILS	WEIGHT PER 1000 FT	FEET PER LB
40	Solid	-----	0.0031	10	0.0291	34410
39	Solid	-----	0.0035	13	0.0377	26500
38	Solid	-----	0.004	16	0.0475	21010
37	Solid	-----	0.0045	20	0.0599	16660
36	Solid	-----	0.005	25	0.0758	13210
35	Solid	-----	0.0056	31	0.0954	10480
34	Solid	-----	0.0063	40	0.111	8311
33	Solid	-----	0.0071	50	0.159	6591
32	Solid	-----	0.008	63	0.1913	5230
	4/38	Bunched	0.010	64	0.200	5000
	7/40	Concentric	0.010	70	0.204	4916
31	Solid		0.0089	80	0.241	4145
	3/35	Concentric	0.012	96	0.285	3510
	6/38	Bunched	0.013	96	0.290	3480
30	Solid		0.010	101	0.305	3287
	7/38	Concentric	0.012	112	0.314	3190
	4/36	Bunched	0.0104	100	0.321	3120
	3/34	Bunched	0.013	120	0.370	2681
29	Solid		0.0113	127	0.382	2607
	5/36	Bunched	0.011	125	0.375	2670
28	Solid		0.0126	160	0.484	2067
	6/36	Bunched	0.016	150	0.411	2430
	7/36	Concentric	0.015	175	0.546	1830
	16/40	Bunched	0.012	158	0.480	2185
27	Solid		0.0152	202	0.610	1639
	8/36	Bunched	0.017	200	0.643	1560
	7/35	Concentric	0.017	224	0.670	1493
26	Solid		0.0159	254	0.769	1330
	10/36	Bunched	0.019	250	0.769	1256
	7/34	Concentric	0.019	278	0.773	1235
	19/38	Concentric	0.019	304	0.784	1025
	26/40	Bunched	0.018	257	0.758	1495
25	Solid		0.0179	320	0.969	1031
	8/34	Bunched	0.019	317	1.001	990
	12/36	Concentric	0.020	300	0.960	1063
24	Solid		0.0201	404	1.22	818
	19/36	Concentric	0.025	475	1.505	665
	16/36	Bunched	0.025	400	1.307	765
	7/32	Concentric	0.025	441	1.382	724
	12/34	Concentric	0.0255	476	1.504	668
23	10/32		0.032	632	1.97	508
	16/34	Bunched	0.0250	640	1.95	513
	63/40	Bunched	0.027	623	2.02	495
22	Solid	----	0.0254	642	1.94	514
	26/36	Bunched	0.032	650	2.04	490
	27/36	Bunched	0.030	675	2.18	459
	7/30	Concentric	0.031	707	2.18	464
	7/30	Concentric	0.031	707	2.17	462
	45/38	Bunched	0.031	720	2.21	453
	19/34	Concentric	0.032	760	2.32	431
21	Solid	----	0.0284	806	2.49	401
	19/33	Concentric	0.036	950	2.50	400
20	Solid		0.032	1022	3.09	323
	41/36	Bunched	0.039	1025	3.25	308
	10/30	Bunched	0.039	1010	3.12	320
	26/34	Bunched	0.039	1025	3.26	307
	19/32	Concentric	0.040	1197	3.77	265
	7/28	Concentric	0.039	1120	3.32	301

* 4/38 indicates 4 strands of 38-gauge wire (typical).

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Table 6-3. Characteristics of Stranded Bare Copper Wire (Sheet 2 of 2)

AWG GAUGE	* STRANDING	TYPE STRANDING	DIAMETER INCHES	CIRCULAR MILS	WEIGHT PER 1000 FT	FEET PER LB
	37/36	Concentric	0.039	1000	3.16	316
	104/40	Bunched	0.039	1038	3.40	294
	105/40	Bunched	0.036	1038	3.40	306
	27/34	Bunched	0.038	1073	3.12	180
19	Solid	----	0.036	1290	3.90	256
18	Solid	----	0.0403	1620	4.92	203
	65/36	Bunched	0.049	1625	5.03	198
	19/30	Concentric	0.049	1909	5.90	170
	16/30	Bunched	0.049	1616	4.97	202
	7/26	Concentric	0.049	1778	5.31	183
	41/34	Bunched	0.049	1640	4.92	203
	26/32	Bunched	0.050	1642	5.20	193
16	Solid	----	0.0508	2580	7.82	128
	26/30	Bunched	0.060	2656	8.19	122
	19/29	Concentric	0.057	2413	7.32	136
	96/36	Bunched	0.060	2400	7.70	130
	7/24	Concentric	0.060	2828	8.90	114
	168/38	Rope	0.065	2640	8.93	112
	98/36	Rope	0.065	2450	7.95	126
14	Solid	----	0.0641	4110	12.4	80
	19/27	Concentric	0.072	3828	11.94	84
	41/30	Bunched	0.072	4141	12.65	79
	105/34	Bunched	0.076	4200	12.95	77
	7/22	Concentric	0.076	4494	13.70	73
	168/36	Rope	0.80	4200	13.51	74
13	Solid	----	0.0737	5178	15.88	63
12	Solid	----	0.080	6530	19.7	50
	19/25	Concentric	0.090	6080	18.7	54
	65/30	Bunched	0.090	6565	20.25	49
	7/21	Concentric	0.085	5671	17.30	58
	266/36	Rope	0.100	6650	21.2	47
10	Solid	----	0.102	10380	31.4	32
	37/26	Concentric	0.120	10443	28.1	36
	82/29	Concentric	0.120	10414	30.25	33
	105/30	Bunched	0.120	10500	33.65	29
	19/22	Concentric	0.128	12205	37.2	26.9
	49/27	Bunched	0.120	9875	33.2	
8	Solid	----	0.1285	16510	50.0	20
	133/29	Rope	0.169	16891	51.6	19
	168/30	Rope	0.169	16968	52.3	30.1
6	Solid	----	0.162	26250	79.4	12
	133/27	Rope	0.213	26800	80.8	12
4	Solid	----	0.204	41620	143.0	7
	133/25	Rope	0.255	42560	141.0	7.1
2	Solid	----	0.258	66560	200.0	5
	665/30	Rope	0.315	67165	206.0	4.8
1	817/30	Rope	0.381	81700	263	3.9
	259/25	Rope	0.385	83000	290	3.4
0	1045/30	Rope	0.410	105545	349	2.9
00	1330/30	Rope	0.445	134330	427	2.3
000	1661/30	Rope	0.545	166930	542	1.8
0000	2104/30	Rope	0.615	211452	686	1.4

* 4/38 indicates 4 strands of 38-gauge wire (typical).

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Table 6-4. Copper-Clad Steel Conductors

	SIZE DESIGNATION			NOM DIA	NOMINAL WEIGHT		TOTAL AREA	MINIMUM BREAKING STRENGTH (lb)			MAXIMUM DC RESISTANCE 20°C (68°F) (ohms/m ft)	
	Inch	No. of Wires	AWG of each Wire	Inches	lb/ MFt	lb/ Mile	Square Inches	Grade 40 HS	Grade 30 HS	Grade 30 EHS	Grade 40	Grade 30
SOLID	..	1	....	.0800	17.76	93.77	0.005027	770	....	....	4.133	....
	..	1	12	.0808	18.12	95.68	0.005129	785	....	....	4.051	....
	..	1	10	.1019	28.81	152.1	0.008155	1130	1231	1460	2.547	3.396
	..	1	....	.1040	30.01	158.5	0.008495	1177	1283	1325	2.445	3.260
	..	1	9	.1144	36.33	191.8	0.01028	1368	1491	1790	2.020	2.693
	..	1	....	.1280	45.47	240.1	0.01287	1647	1802	2188	1.614	2.152
	..	1	8	.1285	45.81	241.9	0.01297	1660	1815	2204	1.602	2.136
	..	1	7	.1443	57.77	305.0	0.01635	2011	2207	2681	1.270	1.694
	..	1	6	.1620	72.85	384.6	0.02061	2433	2680	3247	1.008	1.343
	..	1	....	.1650	75.55	398.6	0.02133	2523	2780	3368	0.9715	1.295
	..	1	5	.1819	91.86	485.0	0.02599	2938	3250	3913	0.7990	1.065
	..	1	4	.2043	115.8	611.6	0.03278	3541	3934	4672	0.6337	0.8447
STRANDED	..	3	12	.174	54.80	289.3	0.01539	2236	....	....	1.361	....
	..	3	10	.220	87.13	460.0	0.02446	3221	3509	4160	0.8559	1.141
	..	3	9	.247	109.9	580.1	0.03085	3898	4250	5129	0.6788	0.9049
	..	3	8	.277	138.5	731.5	0.03890	4730	5174	6282	0.5383	0.7176
	..	3	7	.311	174.7	922.4	0.04905	5732	6291	7922	0.4269	0.5691
	..	3	6	.349	220.3	1163	0.06185	6934	7639	9754	0.3385	0.4513
	..	3	5	.392	277.8	1467	0.07800	8373	9262	11,860	0.2685	0.3579
	5/16	7	10	.306	203.7	1076	0.05708	7121	7758	9196	0.3676	0.4900
	11/12	7	9	.343	256.9	1356	0.07198	8616	9393	11,280	0.2915	0.3885
	3/8	7	8	.385	323.9	1710	0.09077	10,460	11,440	13,890	0.2312	0.3081
	7/16	7	7	.433	408.4	2157	0.1145	12,670	13,910	16,890	0.1833	0.2444
	1/2	7	6	.486	515.0	2719	0.1443	15,330	16,890	20,460	0.1454	0.1938
	9/16	7	5	.546	649.4	3429	0.1820	18,510	20,470	24,650	0.1153	0.1537
	5/8	7	4	.613	818.9	4324	0.2295	22,310	24,780	29,430	0.09143	0.1219
	9/16	19	9	.572	700.0	3696	0.1954	23,390	25,500	30,610	0.1078	0.1437
	21/32	19	8	.642	882.7	4660	0.2464	28,380	31,040	37,690	0.08550	0.1140
	23/32	19	7	.721	1113	5877	0.3107	34,390	37,740	45,850	0.06780	0.09039
	13/16	19	6	.810	1403	7410	0.3917	41,600	45,830	55,530	0.05377	0.07168
	7/8	19	5	.910	1770	9344	0.4940	50,240	55,570	66,910	0.04264	0.05685

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Table 6-5. MIL-W-76 Type Characteristics

TYPE	OUTER COVERING	DESCRIPTION (SINGLE CONDUCTOR)	VOLTAGE RATING	CONDUCTOR SIZE
HW	None	Stranded tinned copper, heavy wall thermoplastic insulation. 80° C.	2500 V 600 V	22-16 AWG 14-8 AWG
MW	Nylon Jacket	Stranded tinned copper, medium wall thermoplastic insulation, clear nylon jacket overall. 90° C.	1000 V	24-12 AWG
MW	Nylon Jacket Shielded	Stranded tinned copper, thermoplastic insulation, tinned copper shield overall, jacket over shield. 90° C.	1000 V	24-12 AWG
MW	Shielded	Stranded tinned copper insulation, tinned copper shield overall. 80° C.	1000 V	24-12 AWG
MW	None	Stranded or solid tinned copper, thermoplastic insulation. 80° C.	1000 V	24-12 AWG
LW	Nylon Jacket	Stranded tinned copper, light wall thermoplastic insulation, clear nylon jacket overall. 90° C.	300 V	30-20 AWG
LW	None	Stranded tinned copper, light wall thermoplastic insulation. 80° C.	300 V	30-20 AWG

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Table 6-6. MIL-W-16878 Type Characteristics

TYPE	OUTER COVERING	DESCRIPTION (SINGLE CONDUCTOR)	VOLTAGE RATING	CONDUCTOR SIZE
ET	None	Stranded silver plated copper, extruded Teflon insulation. .006" wall. 200^{o} C.	250 V	32-22 AWG
EE	None	Stranded silver plated copper, extruded Teflon insulation. .016" wall. 200^{o} C.	1000 V	30-8 AWG
E	None	Stranded silver plated copper, extruded Teflon insulation. .010" wall. 200^{o} C.	600 V	30-10 AWG
D	Clear Nylon	Stranded tinned copper, .032" vinyl thermoplastic insulation with clear nylon jacket overall. 115^{o} C.	3000 V	24-0 AWG
D	None	Stranded tinned copper, .032" vinyl thermoplastic insulation. 105^{o} C.	3000 V	24-0 AWG
C	Nylon	Stranded tinned copper, .016" vinyl thermoplastic insulation with clear nylon jacket overall. 115^{o} C.	1000 V	24-12 AWG
C	None	Stranded tinned copper, .016" vinyl thermoplastic insulation. 105^{o} C.	1000 V	24-12 AWG
B	Nylon	Stranded tinned copper, .010" vinyl thermoplastic insulation with clear nylon jacket overall. 115^{o} C.	600 V	32-14 AWG
B	None	Stranded tinned copper, .010" vinyl thermoplastic insulation. 105^{o} C.	600 V	32-14 AWG

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Table 6-7. Properties of Resistance Metals and Alloys.

MATERIAL	RESISTIVITY	
	Ohms Per Mil Foot	Temperature Coefficient
Karma	800	±.00002
Radiohm	800	.00007
Nichrome	675	.00015
Nichrome V	650	.00011
Chromax	600	.00036
Nirex	590	.000125
Comet	570	.00055
Nilvar	494	.00135
Stainless Type 304	438	.00094
142 Alloy	420	.0025
Advance	294	±.00002
Therlo	294	.0038
Manganin	290	±.000015
146 Alloy	275	.0032
152 Alloy	260	.0036
Duranickel	260	.001
Midohm	180	.00018
33 Alloy	162	.0024
R-63 Alloy	130	.003
Hytemco	120	.0045
Magno (Gr. D Nickel)	105	.0036
Permanickel	100	.0036
95 Alloy	90	.00049
Gr. E Nickel	85	.0000146
Gr. A Nickel	60	.0050
Lohm	60	.0008
High Brass	50	.0016
99 Alloy	48	.0060
Low Brass	30	.0015
30 Alloy	30	.0015
Commercial Bronze	25	.0000184

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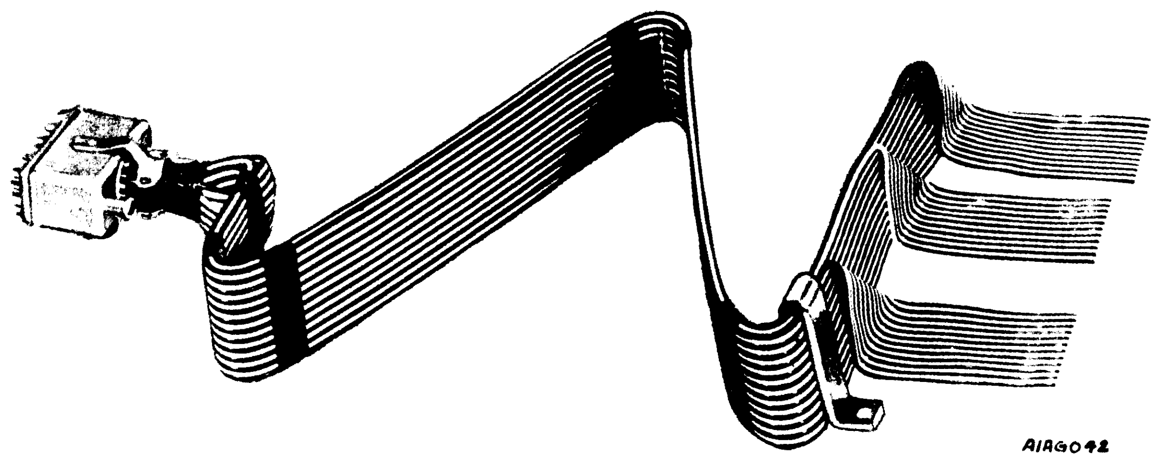

Figure 6-1. Molded Flat Cable

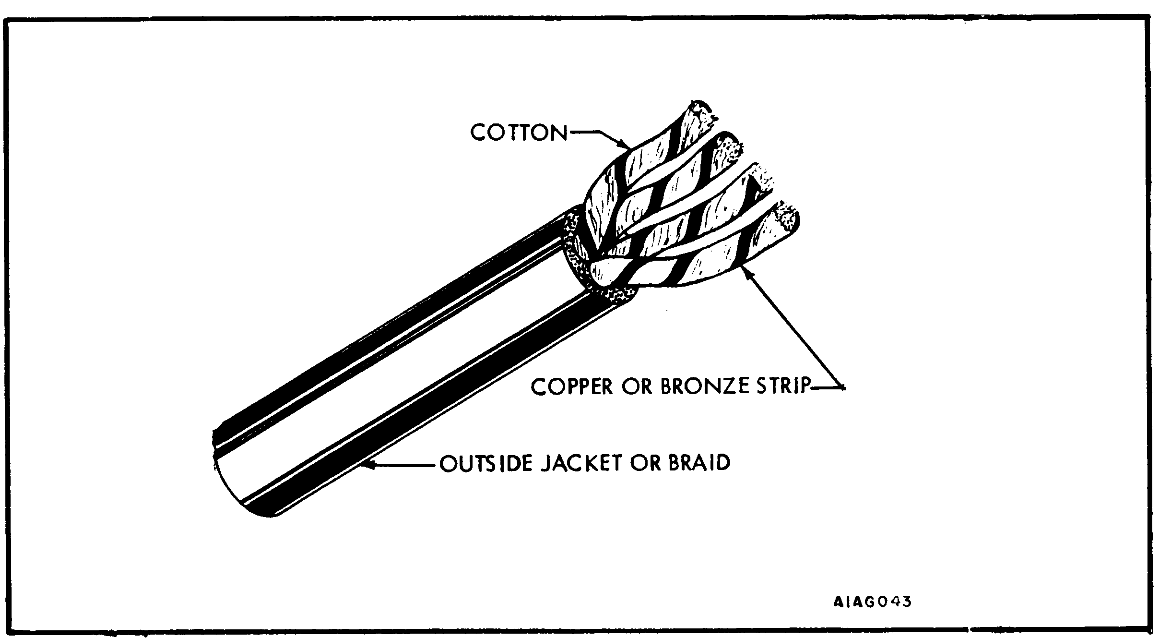

Figure 6-2. Tinsel Wire