Designation: F1835 – 97 (Reapproved 2012)ε1

An American National Standard

Standard Guide for Cable Splicing Installations[1]

This standard is issued under the fixed designation F1835; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε1 NOTE—Reapproved with editorial changes throughout the guide in October 2012.

1. Scope

1.1 This guide provides direction and recommends cable splicing materials and methods that would satisfy the requirements of extensive cable splicing in modular ship construction and offers sufficient information and data to assist the shipbuilder in evaluating this option of cable splicing for future ship construction.

1.2 This guide deals with cable splicing at a generic level and details a method that will satisfy the vast majority of cable splicing applications.

1.3 This guide covers acceptable methods of cable splicing used in shipboard cable systems and provides information on current applicable technologies and additional information that the shipbuilder may use in decision making for the cost effectiveness of splicing in electrical cable installations.

1.4 This guide is limited to applications of 2000 V or less, but most of the materials and methods discussed are adaptable to higher voltages, such as 5-kV systems. The cables of this guide relate to all marine cables, domestic and foreign, commercial or U.S. Navy.

1.5 The values stated in SI units shall be regarded as standard. The values given in parentheses are inch-pound units and are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the application of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B8 Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft

D2671 Test Methods for Heat-Shrinkable Tubing for Electrical Use

2.2 *IEEE Standards:*

IEEE 45 Recommended Practice for Electrical Installations on Shipboard[3]

2.3 *UL Standards:*[4]

UL STD 224 Extruded Insulating Tubing

UL STD 486A Wire Connectors and Soldering Lugs for Use with Copper Conductors

2.4 *IEC Standards:*

IEC 228 Conductors of Insulated Cables[5]

2.5 *Federal Regulations:*

Title 46 Code of Federal Regulations (CFR), Shipping[6]

2.6 *Military Specifications:*

MIL-T-16366 Terminals, Electric Lug and Conductor Splices, Crimp-Style

MIL-T-7928 Terminals, Lug, Splices, Conductors, Crimp-Style, Copper

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *adhesive, n*—a wide range of materials used extensively for bonding and sealing; coating added to the inner wall of heat-shrinkable tubing to seal the enclosed area against moisture. Adhesive is for pressure retention and load-bearing applications (see also *sealant*).

3.1.2 *barrel, n*—the portion of a terminal that is crimped; designed to receive the conductor, it is called the wire barrel.

3.1.3 *butt connector, n*—a connector in which two conductors come together end to end with their axes in line, but do not overlap.

---

[1] This guide is under the jurisdiction of ASTM Committee F25 on Ships and Marine Technology and is the direct responsibility of Subcommittee F25.10 on Electrical.

Current edition approved Oct. 1, 2012. Published October 2012. Originally approved in 1997. Last previous edition approved in 2007 as F1835 – 97 (2007). DOI: 10.1520/F1835-97R12E01.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, http://www.ieee.org.

[4] Available from Underwriters Laboratories (UL), 333 Pfingsten Rd., Northbrook, IL 60062-2096, http://www.ul.com.

[5] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland, http://www.iec.ch.

[6] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://dodssp.daps.dla.mil.

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States

3.1.4 *butt splice, n*—device for joining conductors by butting them end to end.

3.1.5 *circumferential crimp, n*—final configuration of a barrel made when crimping dies completely surround the barrel and form symmetrical indentations.

3.1.6 *compression connector, n*—connector crimped by an externally applied force; the conductor is also crimped by such force inside the tube-like connector body.

3.1.7 *cold-shrink tubing, n*—tubular rubber sleeves that are factory expanded and assembled onto a removable core. No heat is used in installation. Also known as *prestretched tubing* (PST).

3.1.8 *crimp connectors, n*—tubular copper connectors made to match various wire sizes and fastened to the conductor ends by means of a crimping tool.

3.1.9 *crimping die, n*—portion of the crimping tool that shapes the crimp.

3.1.10 *crimping tool, n*—a mechanical device, which is used to fasten electrical connectors to cable conductors by forcefully compressing the connector onto the conductor. This tool may have interchangeable dies or "jaws" to fit various size connectors.

3.1.11 *heat-shrink tubing, n*—electrical insulation tubing of a polyolefin material, which shrink in diameter from an expanded size to a predetermined size by the application of heat. It is available in various diameter sizes.

3.1.12 *primary insulation, n*—the layer of material that is designed to do the electrical insulating, usually the first layer of material applied over the conductor.

3.1.13 *sealant, n*—inner-wall coating optional to shrinkable tubing to prevent ingress of moisture to the enclosed area (see also *adhesive*).

3.1.14 *splice, n*—a joint connecting conductors with good mechanical strength and good conductivity.

3.1.15 *tensile, n*—amount of axial load required to break or pull wire from the crimped barrel of a terminal or splice.

4. Significance and Use

4.1 Splicing of cables in the shipbuilding industry, both in Navy and commercial undertakings, has been concentrated in repair, conversion, or overhaul programs. However, many commercial industries, including aerospace and nuclear power, have standards defining cable splicing methods and materials that establish the quality of the splice to prevent loss of power or signal, ensure circuit continuity, and avoid potential catastrophic failures. This guide presents cable splicing techniques and hardware for application to commercial and Navy shipbuilding to support the concept of modular ship construction.

4.2 This guide resulted from a study that evaluated the various methods of cable splicing, current technologies, prior studies and recommendations, performance testing, and the expertise of manufacturers and shipbuilders in actual cabling splicing techniques and procedures.

4.3 The use of this guide by a shipbuilder will establish cabling splicing systems that are: simple and safe to install; waterproof; corrosion- and impact-resistant; industry accepted with multiple suppliers available; low-cost methods; and suitable for marine, Navy, and IEC cables.

5. General Requirements for Cable Splicing

5.1 Cable splicing requires that cable joints be insulated and sealed with an insulation equal in electrical and mechanical properties to the original cable. Cable splicing shall consist of a conductor connector, replacement of conductor insulation, replacement of the overall cable jacket, and where applicable, reestablishment of shielding in shielded cables and electric continuity in the armor of armored cables.

5.2 *Nonsplice Applications*—Unacceptable areas for cable splices are established by regulations and concern the restriction of being unable to splice cables in defined hazardous areas. Hazardous areas are locations in which fire or explosion hazards may exist as a result of flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings.

6. Cable Splicing

6.1 Cable splicing as presented in this guide uses a system of compression-crimp, tubular-metal connectors for butt connection of cable conductors and insulating systems of shrinkable tubing to reinsulate the individual conductors and replace the overall cable jacket.

6.2 *Crimp Connectors*—For splice connection of conductors, compression-crimped connectors shall be used for joining an electrical conductor (wire) to another conductor. The joint requires proper compression to achieve good electrical performance while not overcompressing and mechanically damaging the conductor. Compression connections are accomplished by applying a controlled force on a barrel sleeve to the conductor with special tools and precision dies.

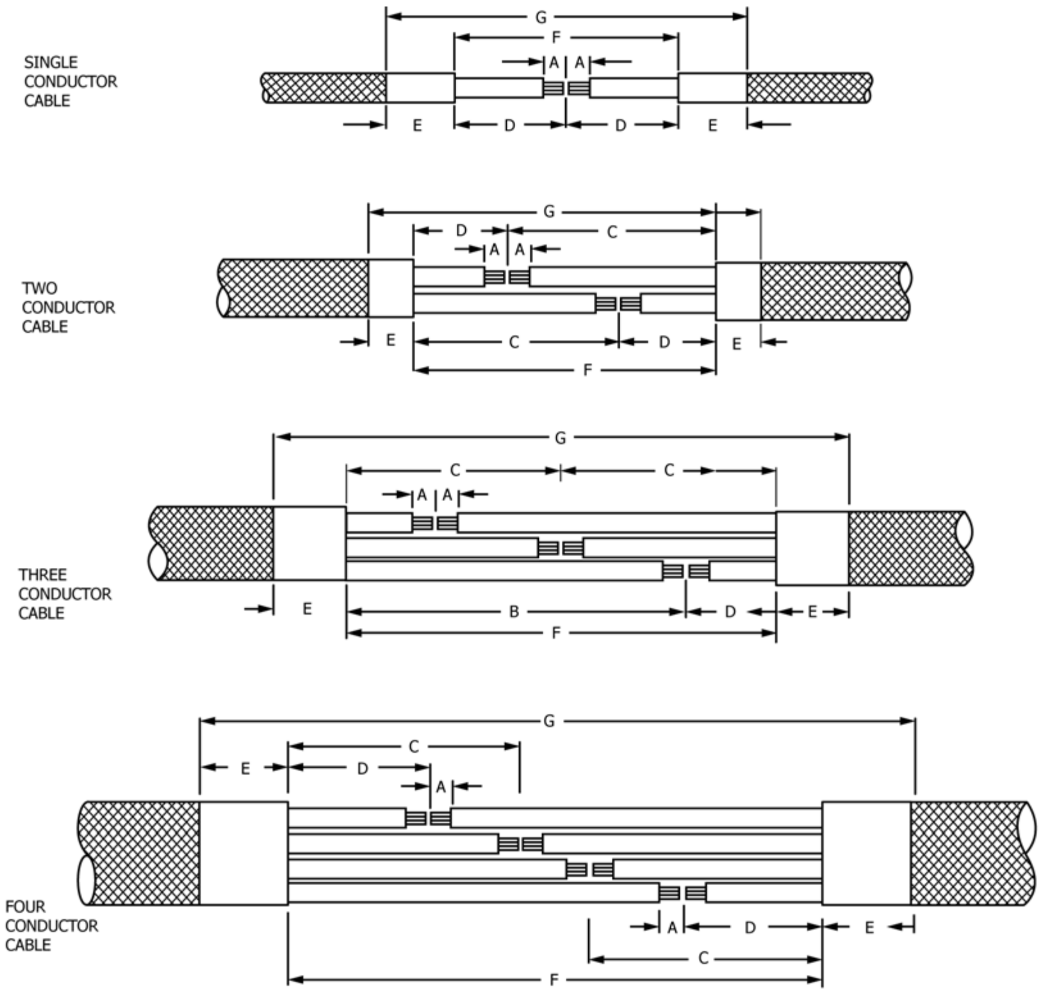
6.3 *Conductor Reinsulation*—Thin-wall shrinkable tubing shall be used to reinsulate the conductor and the installed connector. The insulation tubing, when shrunk or recovered, shall be equal in electrical and mechanical properties to the original conductor insulation. Tubing used for conductor reinsulation does not require an interior adhesive sealant coating.

6.4 *Cable Jacket Reinsulation*—Shrinkable tubing shall be used to envelop the overall splice. To satisfy more abusive conditions that cable jackets are exposed to, a flame-retardant, thick-wall tubing construction with factory applied sealant shall be used.

7. Cable Preparation

7.1 Cables to be spliced shall be prepared to the dimensions specified in Fig. 1 and Fig. 2. Fig. 1 provides cable preparation for power cables from single to four conductor sizes. Dimensions for multiple conductor cables (conductor size of No. 14 or less) are shown in Fig. 2.

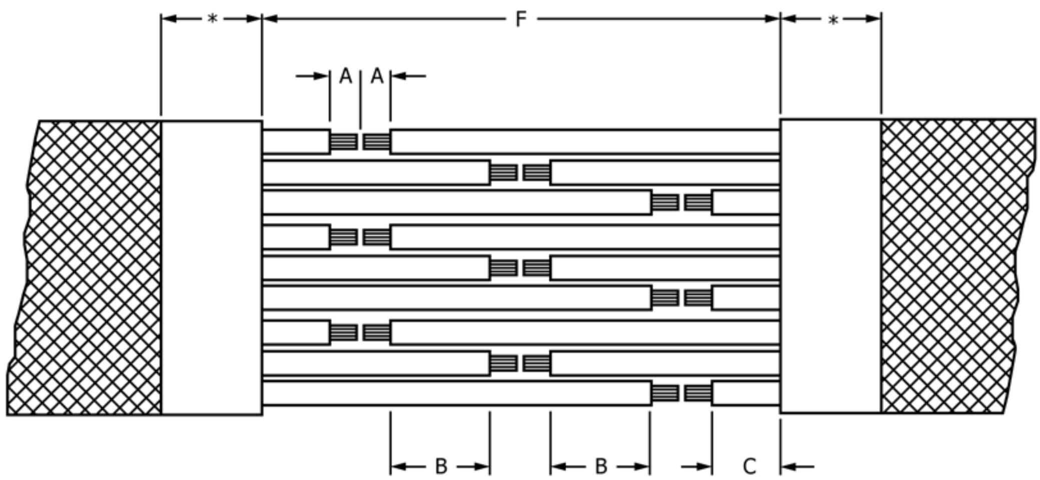
7.2 Care must be exercised when preparing the cable ends so that conductor insulation is not cut when removing the overall cable jacket, shield, or cable armor, where applicable. Similar care is required when removing the individual shield or



CONDUCTOR SIZE (AWG or MCM)	A	B	C	D	E	F				G			
						1/C	2/C	3/C	4/C	1/C	2/C	3/C	4/C
16 to 10	-	203 (8)	127 (5)	50 (2)	76 (3)	102 (4)	178 (7)	254 (10)	330 (13)	254 (10)	330 (13)	406.4 (16)	559 (22)
9 to 4	-	279 (11)	178 (7)	76 (3)	76 (3)	152 (6)	254 (10)	356 (14)	406 (16)	305 (12)	406 (16)	508 (20)	660 (26)
3 to 1/0	-	330 (13)	203 (8)	76 (3)	102 (4)	152 (6)	279 (11)	406 (16)	584 (23)	356 (14)	483 (19)	610 (24)	813 (32)
2/0 to 250	-	381 (15)	254 (10)	127 (5)	102 (4)	254 (10)	381 (15)	508 (20)	635 (25)	457 (18)	584 (23)	711 (28)	914 (36)
300 to 500	-	495 (19.5)	330 (13)	165 (6.5)	102 (4)	330 (13)	495 (19.5)	660 (26)	-	533 (21)	699 (27.5)	864 (34)	-
650 to 2000	-	-	-	254 (10)	102 (4)	508 (20)	-	-	-	711 (28)	-	-	-

LEGEND:
- All dimensions are in millimeters (inches are shown in parenthesis).
- Dimension "A" equals half the connector length plus 3 mm (1/8-inch). Bare copper on each conductor equals "A."

FIG. 1 Splice Dimensions for Power Cables



SPLICES DIMENSIONS FOR CONTROL CABLES

NO. OF CONDUCTORS	1–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–90
DIMENSION F	127 (5)	203 (8)	254 (10)	305 (12)	356 (14)	406 (16)	457 (18)	508 (20)	610 (24)

LEGEND:

- All dimensions are in millimeters (inches).
- 9 Conductor cable shown above.
- "A" equals ½ connector length plus 3 mm (1/8-inch).
- "B" equals 4A (distance from any adjacent butt splice.
- "C" equals 4A (distance from cable sheath from either end).
- "F" equals the length of stripped back cable jacket for wire, unshielded, sizes No. 18 to No. 14.

* For armored cables, it is recommended that the armor be stripped back approximately 75 mm (3-inches) for overlapping of cable jacket replacement with shrink tubing.

FIG. 2 Splice Dimensions for Control-Multiple Conductor Cables

insulation protecting the conductor to prevent cuts or nicks on the individual conductor strands.

7.2.1 Insulation cutting tools that limit depth of cut should be used to prepare cable ends so that underlying insulation is not cut. Similar care is required when removing the individual conductor insulation to protect the conductor copper strands from nicks and cuts.

7.2.2 Cable preparation shall result in stripping the individual conductors so that the bare copper is long enough to reach the full depth of the butt connector plus 3.2 mm (⅛ in.).

7.3 Match the geometrical arrangement between cables to be spliced using conductor color code identification to eliminate crossovers or mismatch when splicing.

7.4 Cable ends shall be in or near their final position before being spliced.

8. Materials and Tools

8.1 *Cable Splicing Materials*—The following sections provide an overview of the various splice materials. In addition, specific recommendations and suggested guidelines are offered that would enhance the cable splicing process.

8.1.1 *Crimp-Type Connectors*—Splice connectors shall be compression-type, butt connectors conforming to the requirements of UL STD 486A and shall be satisfactory to Section 20.11 of IEEE 45.

8.1.1.1 Connector shall be seamless, tin-plated copper.

8.1.1.2 Butt connector shall have positive center wire stops for proper depth of conductor insertion.

8.1.1.3 Connectors shall be marked with wire size for easy identification.

8.1.1.4 Connector shall have inspection holes to allow visual inspection for proper wire insertion.

8.1.1.5 Butt connector for wire sizes No. 10 (AWG) or larger shall be the "long barrel" type to permit multiple crimps on each side of the connector for greater tensile strength. The conductor ends shall be fully inserted to the "stop" at the center of the connector. For smaller conductor sizes (No. 10 AWG or less), a single crimp should be spaced half way between the end of the connector and the center wire stop.

8.1.1.6 Connector shall be color-coded in accordance with Table 1 or Table 2.

8.1.2 *Conductor Reinsulating Material*—To reinsulate the conductor and the installed connector, heat-shrink tubing shall be used (see Table 3).

8.1.2.1 When recovered or shrink, the tubing used shall be equal to or greater than the thickness of the original conductor insulation.

8.1.2.2 Shrink tubing used for conductor reinsulation shall be heat-shrink tubing. The tubing shall be thin-wall cross-linked polyolefin tubing, flame-retardant (FR-1) construction in accordance with UL STD 224 requirements. Performance requirements shall include:

Shrink ratio	2:1
Operating temperature range	–55 to +135°C
Minimum shrinkage temperature	+121°C
Longitudinal shrinkage	±5 %
Electrical rating	600-V continuous operation
Dielectric strength in accordance with Test Methods D2671	19.7 kV/mm (500 V/mil) min

8.1.2.3 Shrink tubing to cover the connection of individual conductors does not require an interior coating of adhesive (mastic) sealant.

8.1.3 *Cable Jacket Replacement Materials*—Several methods and a variety of materials are available that will provide the mechanical protection, moisture-sealing properties, and electrical performance characteristics needed in a cable splice. For a splice reliability and ease of installation replacement of cable jacket and to envelop the splice area, however, either the heat-shrink or the cold-shrink (prestretched) type shall be used.

8.1.3.1 The tubing used, when recovered or shrunk, shall be equal to or greater than the thickness of the original conductor insulation (see Table 3).

8.1.3.2 The tubing used for cable jacket replacement shall be thick wall, also referred to as heavy-duty shrink tubing, cross-linked polyolefin tubing.

8.1.3.3 Shrink tubing shall be flame retardant (FR-1) in accordance with UL STD 224 requirements.

8.1.3.4 Tubing used for rejacketing of a splice bundle shall have an interior coating of adhesive (mastic) sealant.

8.1.3.5 Table 3 provides dimensions for thick-wall tubing used for rejacketing of cables.

TABLE 1 Connector Data (English Units)

Conductor Size AWG or MCM Designation	Connector Overall Length (min)	Depth of Each Side of Barrel (min)	Overall Diameter of Barrel (Approximate)	Color Code[A]	Conductor Nominal Diameter, in.	Number of Crimps/ End[B]
22	5⁄8	1⁄4	0.150	–	0.025	1
20	5⁄8	1⁄4	0.150	–	0.039	1
18	5⁄8	1⁄4	0.150	–	0.049	1
16	5⁄8	1⁄4	0.150	–	0.061	1
14	5⁄8	1⁄4	0.150	–	0.077	1
12	3⁄4	5⁄16	0.212	–	0.092	1
10	3⁄4	5⁄16	0.212	–	0.108	1
8	1 3⁄4	13⁄16	1⁄4	red	0.146	2
6	2 3⁄8	1 1⁄8	5⁄16	blue	0.184	2
4	2 3⁄8	1 1⁄8	5⁄16	gray	0.226	2
3	2 5⁄8	1 1⁄4	3⁄8	white	0.254	2
2	2 5⁄8	1 1⁄4	7⁄16	brown	0.282	2
1	2 7⁄8	1 3⁄8	1⁄2	green	0.317	4
1⁄0	2 7⁄8	1 3⁄8	1⁄2	pink	0.363	4
2⁄0	3 1⁄8	1 1⁄2	9⁄16	black	0.407	4
3⁄0	3 1⁄8	1 1⁄2	5⁄8	orange	0.457	4
4⁄0	3 3⁄8	1 5⁄8	11⁄16	purple	0.514	4
250 MCM	3 3⁄8	15⁄8	3⁄4	yellow	0.577	4
300 MCM	4 1⁄8	2	13⁄16	white	0.628	4
350 MCM	4 1⁄8	2	7⁄8	red	0.682	4
500 MCM	4 5⁄8	2 1⁄4	1 1⁄16	brown	0.742	4
600 MCM	5 3⁄4	2 13⁄16	1 1⁄4	green	0.893	4
750 MCM	6	2 15⁄16	1 3⁄8	black	0.998	4
1000 MCM	6 1⁄8	3	1 1⁄2	white	1.180	4

[A] Recommended colors for connectors; however, variances do exist between manufacturers.
[B] For conductors No. 1 or larger, the type of crimping tool used determines the number of crimps to be made. Number and location of compression points (crimps) shall be in accordance with the manufacturer's recommendations.

TABLE 2 Connector Data (Metric)

Conductor Size AWG or MCM Designation	Connector Overall Length (min)	Depth of Each Side of Barrel (Min)	Overall Diameter of Barrel (Approximate)	Color Code[A]	Conductor Nominal Diameter, mm	Number of Crimps/End[B]
22	16.0	6.5	4.0	–	0.6	1
20	16.0	6.5	4.0	–	1.0	1
18	16.0	6.5	4.0	–	1.5	1
16	16.0	6.5	4.0	–	2.0	1
14	16.0	6.5	4.0	–	2.0	1
12	19.0	8.0	5.5	–	2.5	1
10	19.0	8.0	5.5	–	3.0	1
8	45.0	21.0	6.5	red	4.0	2
6	60.0	29.0	8.0	blue	5.0	2
4	60.0	29.0	8.0	gray	6.0	2
3	67.0	32.0	9.5	white	6.5	2
2	67.0	32.0	9.5	brown	7.5	2
1	73.0	35.0	13.0	green	8.0	4
1/0	73.0	35.0	13.0	pink	9.0	4
2/0	80.0	39.0	14.5	black	10.0	4
3/0	80.0	39.0	14.5	orange	11.5	4
4/0	86.0	41.0	17.5	purple	13.0	4
250 MCM	86.0	41.0	17.5	yellow	15.0	4
300 MCM	105.0	51.0	22.0	white	16.0	4
350 MCM	105.0	51.0	22.0	red	17.5	4
500 MCM	118.0	57.0	27.0	brown	19.0	4
600 MCM	146.0	72.0	32.0	green	23.0	4
750 MCM	153.0	75.0	35.0	black	25.5	4
1000 MCM	156.0	76.0	38.0	white	30.0	4

[A] Recommended colors for connectors; however, variances do exist between manufacturers.
[B] For conductors No. 1 or larger, the type of crimping tool used determines the number of crimps to be made. Number and location of compression points (crimps) shall be in accordance with manufacturer's recommendations.

TABLE 3 Shrink Tubing Data

Heat Shrink Thin-Wall Tubing for Conductor Reinsulation				
		Expanded I.D. (min)	Fully Recovered I.D. (max)	Fully Recovered Wall Thickness
		1.2 (0.046)	0.6 (0.023)	0.40 (0.016)
		1.6 (0.063)	0.8 (0.032)	0.43 (0.017)
		2.4 (0.093)	1.2 (0.046)	0.51 (0.020)
		3.2 (0.125)	1.6 (0.062)	0.51 (0.020)
		4.8 (0.187)	2.4 (0.093)	0.51 (0.020)
		6.4 (0.250)	3.2 (0.125)	0.64 (0.025)
		9.5 (0.375)	4.8 (0.187)	0.64 (0.025)
		12.7 (0.500)	6.5 (0.250)	0.64 (0.025)
		19.0 (0.750)	9.5 (0.375)	0.76 (0.030)
		25.5 (1.000)	12.7 (0.500)	0.89 (0.035)
		38.0 (1.500)	19.0 (0.750)	1.00 (0.040)
		50.8 (2.000)	25.4 (1.000)	1.20 (0.045)
		76.2 (3.000)	38.0 (1.500)	1.30 (0.050)
		102.0 (4.000)	51.0 (2.000)	1.40 (0.055)
Heat Shrink Thick-Wall Tubing for Cable Jacket Replacement				
Range of Cable Diameter[A]		Expanded I.D. (min)	Fully Recovered I.D. (max)	Fully Recovered Wall Thickness (Nominal)
... to 7.5	(... to 0.30)	10.0 (0.40)	3.8 (0.150)	1.5 (0.060)
5.5 to 13.0	(0.22 to 0.50)	19.0 (0.75)	6.0 (0.220)	2.7 (0.105)
10.0 to 22.0	(0.40 to 0.87)	28.0 (1.10)	9.5 (0.375)	3.0 (0.120)
14.0 to 28.0	(0.55 to 1.10)	38.0 (1.50)	13.0 (0.500)	3.6 (0.140)
22.0 to 44.5	(0.87 to 1.75)	51.0 (2.00)	19.5 (0.750)	3.5 (0.155)
38.0 to 70.0	(1.50 to 2.75)	76.0 (3.00)	32.0 (1.250)	3.5 (0.155)
51.0 to 98.0	(2.00 to 3.85)	102.0 (4.00)	44.5 (1.750)	3.5 (0.155)
Cold Shrink Tubing for Cable Jacket Replacement				
Range of Cable Diameter[A]			Fully Recovered I.D. (max)	Fully Recovered Wall Thickness (Nominal)
2.5 to 9.9	(0.10 to 0.39)[B]		6.5 (0.25)	3.8 (0.15)
9.9 to 18.0	(0.39 to 0.70)		6.5 (0.25)	3.8 (0.15)
12.5 to 25.0	(0.51 to 1.00)		8.5 (0.34)	4.0 (0.16)
17.5 to 33.0	(0.69 to 1.30)		11.0 (0.46)	4.3 (0.17)
24.0 to 48.0	(0.95 to 1.90)		15.0 (0.62)	4.5 (0.18)
32.5 to 63.5	(1.28 to 2.50)		21.0 (0.84)	4.5 (0.18)

Legend—All dimensions are in millimetres (inches).

[A] "Range of Cable Diameter" refers to the actual "Splice Bundle Diameter" that may be slightly larger than the cable diameter.
[B] Requires slip-on adapters.

8.1.3.6 Tubing shall have the following performance requirements:

Shrink ratio	3:1
Operating temperature range	–55 to +135°C
Minimum shrinkage temperature (for heat-shrink tubing)	+121°C
Longitudinal shrinkage	±5 %
Electrical rating	600-V continuous operation
Dielectric strength in accordance with Test Methods D2671	7.9 kV/mm (200 V/mil) min

8.1.4 *Shield Terminations*—Cables that require continued shielding shall have at least a 13-mm (½-in.) overlap between the replacement shielding material and the permanent shielding and shall be attached with either solder-type connectors or a mechanical connection using inner and outer compression (crimp-type) rings.

8.2 *Splicing Tools:*

8.2.1 *Cable Preparation*—The basic tools required for cable splice preparation include a cable cutter, measuring tape or ruler, and a wire insulation stripper. Following the cable preparation, the types of tools required to complete a cable splice include the crimp tool for compression of the butt connectors and a heat source for reducing heat-shrinkable tubing.

8.2.2 *Crimping Tools*—The crimp compression method for making electrical cable splices as recommended in this guide consists of compressing a butt connector onto the wire very tightly so that good metal-to-metal contact is achieved. A crimping tool is necessary so that the process is controlled, the crimp is made easily and correctly and can be reproduced reliably.

8.2.2.1 This guide recommends the use of compression systems that coordinate connectors, crimping tools and dies, and include built-in installation and inspection features that prevent improper field connections.

8.2.2.2 The crimping tool shall be a single-cycle type, requiring full-cycle compression before release. Full-cycle control requires the crimping tool to be closed to its fullest extent, thereby completing the crimping cycle before the tool can be opened.

8.2.2.3 Mechanical-type (manual) compression tools used for crimping connectors shall be one-cycle devices and require full compression before release.

8.2.2.4 Hydraulic crimping devices shall have an emergency release mechanism to abort the crimp cycle if necessary.

8.2.2.5 Crimp tool shall allow easy visual field check for proper tool adjustment with butting surfaces.

8.2.2.6 Crimping tool and crimp dies shall result in circumferential-shaped configuration.

8.2.3 *Heat Guns*—Heat-shrink tubing installation requires that the source of heat be controllable. Limited electric heat guns and hot air blowers that are portable and provide even controlled heat at nozzle temperatures of 260 to 399°C (500 to 750°F) are recommended devices for installing heat-shrink tubing. Propane torches shall be used with extreme care. Torches shall not be used to shrink thin-wall tubing.

9. Quality Assurance

9.1 *General Guidelines for Quality Assurance*—For extensive cable splicing activities, such as found with modular ship construction techniques, that a material control program and a personnel training program that includes certification of personnel for both splicing installation and inspection are recommended. Quality control issues are of major significance and should be controlled and monitored by the shipbuilder before, during, and following cable splicing. A cable splicing program as envisioned for modular ship construction should include use of only approved materials and devices, only qualified personnel to make the electrical cable splices, and should establish inspection procedures using only qualified inspectors to verify proper installation.

9.2 *Material Control*—Since crimping is a mechanical process and, by controlling the material and dimensional properties of the conductor, the butt connector, and the crimp tool, the reliability of the crimped connection may be controlled closely. An in-process quality assurance program based on controlled distribution of materials and tools should be established. For installation tools, the program should include inspections to assure that:

9.2.1 Splicing equipment shall be inspected before the first use each month to verify the performance of insulation removal devices and of crimping tools.

9.2.2 Crimp tool dies shall be checked before the first use each month for correct tolerances.

9.3 *Material Procurement; Recommended Use of Kits*—A material control program should adopt the use of cable splice kits. Splice kits may be procured directly from a number of qualified manufacturers or can be assembled by the shipbuilder from quantity-purchased materials for the various types and sizes of materials necessary. All kits shall be for one-to-one cable splices. For selection of cable-splice kit, the following minimum information should be established:

9.3.1 Number of conductors in the cable.

9.3.2 Size (gage) of each conductor,

9.3.3 Ground wire size, if included.

9.3.4 Shielded or nonshielded; individual, overall.

9.3.5 Only one splice per kit is recommended, with basic materials of the kit to include butt connectors, conductor reinsulation material, cable jacket replacement material, and shield braid sleeve connectors, when required.

10. Installation

10.1 *Installation Guidelines*—Various factors and conditions are significant in contributing to a successful splice. These items are summarized in this section as installation guidelines for the use of shipbuilders and others. These basic factors should be emphasized in any quality assurance or training programs established in support of a major cable splicing program.

10.2 *Splice Locations*—There are no significant differences in installing vertical splicing and horizontal splicing, however after splicing is completed on a cable, the cable should be supported as close as possible to the splice. For extensive splicing at section interfaces, it is recommended that individual cable connections be staggered and where appropriate, the cables fanned out from one row to a double row for space to ease installation and avoid derating of cables.

10.3 *Important Splicing Factors:*

10.3.1 The crimping device shall be matched properly to the splice connector and wire size.

10.3.2 Splicing material should be kept as clean as possible during application so that foreign matter or contaminants are not within the splice. Lightly abrade and solvent clean the cable jacket a minimum of 153 mm (6-in.) from the jacket cutback edge.

10.3.3 Proper installation requires that the shrink tubing should be centered over the installed splice connector and the cable jacket replacement over the splice area.

10.4 *Dimensions:*

10.4.1 Length of the replacement insulation tubing shall be 57.2 mm (2¼ in.) longer than the butt-crimp connector length (see Table 1 and Table 2).

10.4.2 The replacement jacket shall overlap the original cable jacket by either 76.2 or 101.6 mm (3 or 4 in.) min at each end as shown in Fig. 1 or Fig. 2.

10.4.3 Shrink-tubing dimensions shall be as shown in Table 3 for conductor reinsulation or for cable jacket replacement.

10.5 *Heating*—For heat-shrinkable tubing, apply heat and begin shrinking at the center of the tubes and move toward the ends. For jacket replacement, apply heat at the center of the tube and toward each end until the tube is smooth and wrinkle-free and recovered enough to assume the final configuration. When a fillet of adhesive is visible at each end, discontinue heating. Additional heating will not make the tube shrink tighter.

10.6 *Inspection Checkpoints*—For quality control and the assurance of a splicing program, there are a number of check points at which inspections can be made to verify proper installation of the cable splice. These include steps in preparation for, during the overall splice process, and post-inspection following completion of a splice.

10.6.1 The following suggests various check points in the splicing process that a quality assurance inspection program could include:

10.6.1.1 Cable ends are properly positioned, that is, staggered configuration and prepared properly to dimensions for size and number of conductors that will be spliced.

10.6.1.2 Splices are assembled properly, positioned in the crimp tool, and crimped.

10.6.1.3 Verify the use of an approved, complete-cycle crimping tool with dies matched to the splice connector and conductor.

10.6.1.4 Verify that the splice connectors are spaced properly.

10.6.1.5 Connectors are insulated properly.

10.6.2 Following conductor insulation replacement, the verification process should include inspection that:

10.6.2.1 All tubings are shrunk in place permanently.

10.6.2.2 All insulation tubings meet the overlap requirements for conductor replacement.

10.6.2.3 Tubings are not nicked or split or charred if heat-shrink tubing was used.

10.6.3 *Post-Splice Inspection*—Following the completion of a cable splice, post-splice inspections also can be undertaken to check the splice quality. Some check points that should be considered in an inspection program are:

10.6.3.1 Verification that jacket tubing meets the minimum overlap requirements.

10.6.3.2 Verification that the jacket replacement tubing is shrunk permanently in place without damage, such as cut or split.

10.6.3.3 Adhesive should be visible at each end for heat-shrink tubing used in cable sheath replacement.

10.6.3.4 That replacement armor is positioned and secured properly or a jumper is installed to maintain electrical continuity for splices made in armored cable.

10.6.4 For heat-shrink with integral (encased) shield for splicing of shielded cables, the following apply:

10.6.4.1 Sleeve/shield must be recovered along its entire length.

10.6.4.2 Sleeve must be recovered tightly around cable jacket.

10.6.4.3 Sealing rings must have flowed along cable jacket.

10.6.4.4 Sleeve must not have discolored to the degree that joint cannot be inspected.

10.6.4.5 Strands must not be poking through the sleeve.

10.7 Additionally, standard shipboard tests for cable installations should include final inspection and testing for continuity, resistance to ground (insulation resistance), and electrical performance of all completed splices.

11. Keywords

11.1 cable splicing; crimp connectors; circumferential crimp; electrical cable splicing; insulation sleeving

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL INFORMATION ON CABLE SPLICING SELECTION AND PERFORMANCE CONSIDERATIONS

X1.1 Background

X1.1.1 A number of studies have evaluated available splicing materials and techniques that would support extensive cable splicing mandated in modular ship construction. These investigations affirmed that suitable materials and several installation techniques are available for the various shipboard applications that exist and that these splicing systems would guarantee the integrity of spliced cables to be the equal of a continuously installed cable.

X1.2 Marine Cable

X1.2.1 In the U.S. shipbuilding industry, commercial vessels are constructed typically with IEEE 45-type cables or U.S. Navy military specification cables. Naval combatants and auxiliary ships typically use the Mil Spec cables. Additionally, commercial merchant vessels use a PVC/nylon insulated cable derived from a standard building wire-type construction, as well as a wide variety of nonstandard cables listed by Underwriters Laboratories, Inc. under the Marine Shipboard Cable Program. Foreign vessels typically use cable constructed in accordance with International Electrotechnical Commission (IEC) requirements. These international standards govern the construction and installation of electrical cables on merchant ships and on a general comparison with U.S. practices (IEEE 45 or Mil Spec) are found to be comparable and without significant differences in design.

X1.3 Connectors

X1.3.1 *Commercial Versus Military Specification Connectors*—A difference in minimum performance requirements of the splice crimp connectors exists between commercial and Mil-Spec-type connectors. The tensile strength requirements for crimped connectors most widely used are those specified in UL 486A or as required in Military Specifications in accordance with MIL-T-7928 or MIL-T-16366.

X1.3.1.1 Comparison of the minimum pull-out force test values listed in these documents shows that, in general, the specified requirements for the Mil-Spec are twice that of the values specified in UL STD 486A.

X1.3.1.2 Tensile strength or minimum pull-out force is the measure of the pulling force required to destroy the crimped connection (joint) between conductors; however, destruction may not necessarily occur at the crimp joint and may occur in one of the following ways:

(*a*) Slip of the wire from the crimped connector.

(*b*) Slip of some strands, rupture of the others at the crimp joint.

(*c*) Rupture of the wire at the crimp joint.

(*d*) Rupture of the wire outside of the crimped termination.

X1.3.1.3 Although IEEE 45 and the Code of Federal Regulations Title 46 recommends the use of connectors listed by UL STD 486A, this guide adopts that crimp butt connectors used for the marine shipboard environment should have minimum requirements exceeding the basic commercial requirements. The more stringent requirements defined in the military specification certainly are more appropriate to guarantee the mechanical connection between conductors.

X1.3.2 *Crimp Configurations*—The crimp die of the tool determines the completed crimp configuration. There are a variety of configurations in use, such as a simple nest and indent die, or the more complicated four indent die. Several different configurations may work equally well for some applications, while for others, a certain shape is superior. Since cable splicing for modular construction would require extensive splices at section interfaces for multiple cable runs (banks), therefore, the area (volume of splices) required should be minimized to the maximum extent possible. The optimal technique to fulfill this requirement is the use of the circumferential compression of butt connectors. Circumferential-shaped compression applies equal force around the connector sleeve and results in each conductor strand receiving equal compression and carrying an equal amount of current loading. This type of joint eliminates loose strands, and therefore, is virtually free of electrical-caused noise. In general, connectors compressed into a circumferential joint will have a higher pull-out strength and a lower electrical resistance than the common indented (bathtub) crimped connector. For the best results and to satisfy minimum splice area, a circumferential-shaped compression applying equal force around the sleeve should be used. Note, however, that to assure positive joints, each connector for this type of operation is designed for only one or a very limited number of conductor sizes.

X1.4 Splicing Systems

X1.4.1 The cable splicing method presented in this guide uses a compression-crimp, tubular-metal connector for butt connection of cable conductors in conjunction with the use of shrinkable tubing as both the conductor reinsulating material and overall cable sheath (jacket) replacement. This guide is considered the most effective procedure for the greatest number of applications of cable materials.

X1.4.2 Although other insulating systems are available and considered appropriate for particular applications, they have not been addressed in detail in this guide. The use of various layers of insulating materials, such as shrinkable-tubing, tape, or molding compounds require varying levels of skill, differences in time, and relative cost. The six splicing systems evaluated were:

X1.4.2.1 Cold shrink.

X1.4.2.2 Heat shrink.

X1.4.2.3 Molded—vulcanized.

X1.4.2.4 Molded—resin, room temperature cure.

X1.4.2.5 Molded—resin, heat cure.

X1.4.2.6 Tape.

X1.4.3 The most significant factor that the shipbuilder must address is that the choice of a splicing system must be compatible to both the application/environment and cable jacket material. Information furnished in Tables X1.1-X1.3 provide comparisons for the various splicing systems to application factors, compatibility to cable-jacketing materials, and environment/location of the splice.

X1.4.3.1 Table X1.1 shows compatibility of splicing systems to the various types of cable jacket materials found in shipboard applications.

X1.4.3.2 Acceptability of the six splicing systems with regard to environmental or application location is shown in Table X1.2.

X1.4.3.3 Table X1.3 evaluates application factors for the six systems and offers a comparison between systems as to the required skill level of the installer and the time required for installation.

X1.4.4 *Shrink Tubing Methods*—Shrinkable tubing materials are recommended for the vast majority of cable splice applications. These materials provide the electrical and mechanical properties equivalent to the original cable conductor insulation and jacketing material.

X1.4.4.1 The addition of a sealant is felt necessary since the cable's jacket may be nonuniform, damaged, or scratched. Deviation from eccentricity or small paths for moisture could lead to splice failure; therefore, the sealant provides an additional safety factor considered necessary. The addition of sealant to the area of overlap on the original cable jacket during splice installation is required for either heat-shrink or cold-shrink tubing.

X1.4.5 *Molding Compounds Methods*—A variety of materials including rubber-based compounds, epoxies, silicones, and polyurethane are available for molded-type cable splices. Vulcanized splices are made with molding presses and require the use of heat. Ambient-temperature cured materials are sometimes referred to as "room temperature" cure since no external heat is applied for the polymerization reactions.

X1.4.5.1 For the marine environment, molded splices mainly are used for outboard, weather-exposed, or underwater applications. This type of splice is molded in matched metal molds, which may be attached to heating platens to expedite forming. For molded splices, the manufacturers' recommendations on surface cleaning and preparation of the casting compounds and primer should be followed explicitly.

X1.4.6 *Tape and Coating Compounds*—Taping is more skill/workmanship intensive as compared to the shrinkable tubing or molding compound methods. The basic types of tapes and their primary function is as follows:

X1.4.6.1 Insulating and binder-type tapes are pressure-sensitive tapes used as primary insulation directly over the connector/conductor and as a binder tape over the conductors for cables with two or more conductors. These tapes have a dielectric strength that permits use as a primary insulator over base connectors or conductors.

X1.4.6.2 Filler tape is used both to fill the indents on large connectors and to provide a smooth taping surface over which the cable jacket material can be applied. Filler tape should not be used if beyond the manufacturer's shelf life recommendations.

X1.4.6.3 Outer sheathing tape is a pressure-sensitive vinyl tape used as sheathing over the filler tape. Sheathing tape is a relatively heavy tape that is used to cover the splice area and provides protection against abrasion and wear.

X1.4.6.4 Care should be exercised to keep adhesive tapes (insulating, binder, and sheathing) clean since they are difficult to apply when the adhesive becomes coated with dirt. Contaminants also will cause degradation to the tape's electrical properties. All tapes must be applied tightly and smooth and should be applied such that the buildup to reinsulate the individual conductor or produce the overall splice is of uniform cross section.

X1.4.6.5 To complete a tape splice, a coating material, normally a liquid cement compound, shall be brushed on in several thin coats to provide overall seal to the splice.

TABLE X1.1 Splicing System—Application/Environment

Application/ Environment	Splicing System					
	Cold Shrink	Heat Shrink	Molded (Vulcanized)	Resin (Room Temperature Cure)	Resin (Heat Cure)	Tape
Weather deck	Yes	Yes	Yes	Yes	Yes	Yes
Outboard[A]	Yes	Yes	Yes	Yes	Yes	No
Enclosed space	Yes	Yes	Yes	Yes	Yes	Yes
Engine room and machinery space	Yes	Yes	Yes	Yes	Yes	No
Fuel tank (internal)	No	No	No	No	No	No
Hazardous areas[B]	No	No	No	No	No	No

Legend—"Yes" indicates acceptable while "No" indicates not acceptable.

[A] Below water line.

[B] Regulations prohibit splices in hazardous areas.

TABLE X1.2 Splicing System—Cable Jacket Compatibility

Cable Jacket Compatibility	Splicing System: Cold Shrink	Heat Shrink	Molded (Vulcanized)	Resin (Room Temperature Cure)	Resin (Heat Cure)	Tape
EPDM	Yes	Yes	No	Yes	Yes	Yes
H.D. polyethylene	No	Yes	No	No	No	No
Hypalon	Yes	Yes	Yes	Yes	Yes	Yes
Low halogen polyolefin[A]	Yes	Yes	No	Yes	Yes	Yes
Neoprene	Yes	Yes	Yes	Yes	Yes	Yes
Nitrile	Yes	Yes	Yes	Yes	Yes	Yes
Polyurethane	Yes	Yes	No	Yes	Yes	Yes
PVC	Yes	Yes	No	Yes	Yes	Yes
Silicone	Yes	Yes	Yes	Yes	Yes	Yes

Legend—"Yes" indicates compatibility while "No" means not compatible.

[A] Recommendation based on splice not necessarily being of low halogen material.

TABLE X1.3 Comparison of Splicing Systems

Application Factors	Splicing System: Cold Shrink	Heat Shrink	Molded (Vulcanized)	Resin (Room Temperature Cure)	Resin (Heat Cure)	Tape
Cable preparation	Cut-backs, abrade, solvent wipe	Cut-backs, abrade, solvent wipe	Cut-backs, abrade, solvent wipe	Cut-backs, abrade, solvent wipe	Cut-backs, abrade, solvent wipe	Cut-backs, abrade, solvent wipe
Application time	1	2	5	3	5	5
Cure time	NA	NA	Yes	Yes	Yes	NA
Skill level	1	2	5	2*	5	5
Special tools	No	Yes (heat source)	Yes	No	Yes	No
Critical shelf life	No	No	Yes	Yes	Yes	No
Inspection of installed splice	Centered, adhesive bead	Adhesive bead, bond, centered, burn	Tack-free bond	Tack-free bond	Tack-free bond	Workmanship, dimensions

Legend:
NA stands for "not applicable."
Numericals (1 to 5) represent from least (1) to greatest (5).
*—For premeasured resin kit.
Critical shelf life is defined as less than two years.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/