Electron-Ion Collider, Brookhaven National Laboratory			
Doc No. EIC-SEG-STD-002	**Author:** Lauren Strange	**Effective Date:** July 31, 2024	**Review Frequency:** 5 years
Design Standard: EIC Tray Cable Guide			**Revision:** 00

Electron-Ion Collider Design Standard

EIC Tray Cable Guide

July 31, 2024

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REVISION HISTORY

Revision #	Effective Date	List of Reviewers	Summary of Change
00	7/31/2024		Initial release

LIST OF ACRONYMS

BNL	Brookhaven National Laboratory
DLO	Diesel Locomotive Cable
EIC	Electron-Ion Collider
NEC	National Electric Code
NFPA	National Fire Protection Association
UL	Underwriters Laboratories
CSA	Canadian Standards Association
NRTL	Nationally Recognized Testing Laboratory
ESA	Electrical Safety Advisor

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EIC Tray Cable Guide

1. PURPOSE AND SCOPE

The purpose of this document is to provide guidance for all technical EIC tray cabling. The cabling process is detailed in Figure 1.

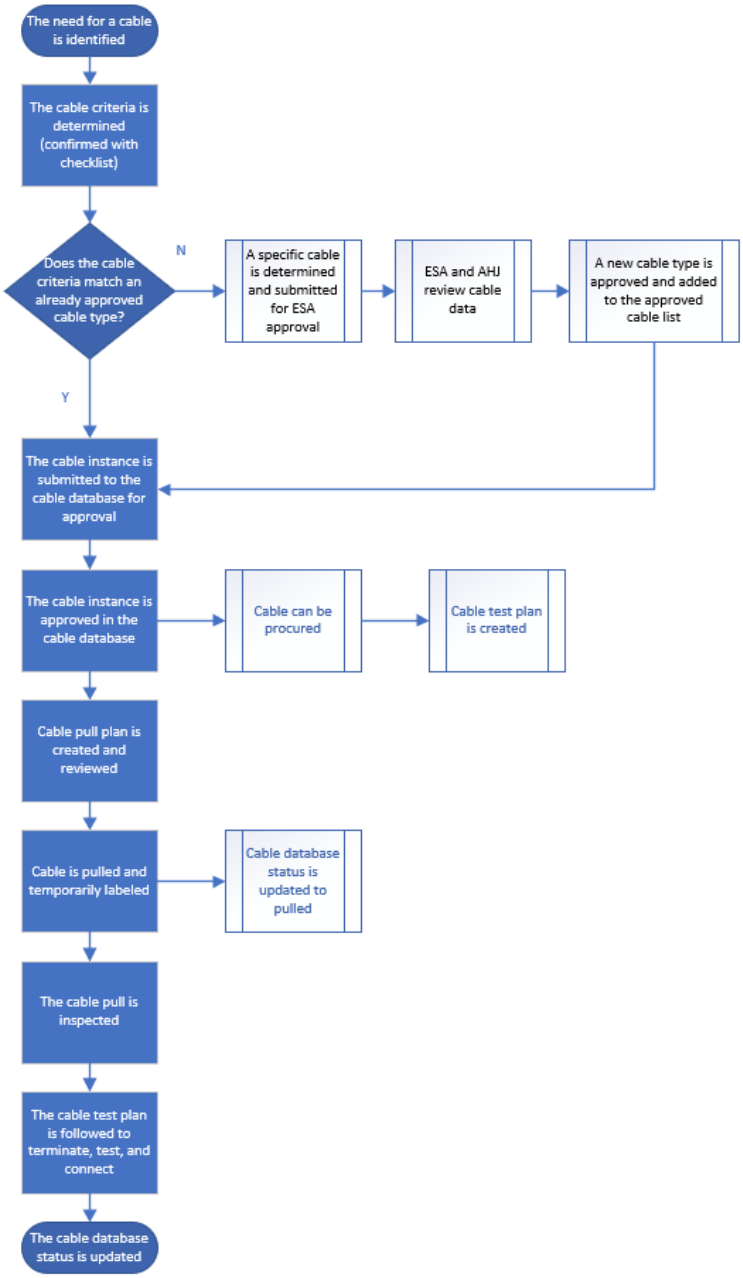

Figure 1. Cable Process

2. DEFINITIONS

Definitions that are relevant to the requirements are listed below:

National Fire Protection Association (NFPA): International nonprofit advocate's aim is to reduce the effect of fire and other hazards through developing standards and codes, training, research and education. The NFPA is the largest authority on fire prevention and develops, publishes, and disseminates more than 300 codes and standards to minimize the possibility and effects of fire and other risks.

National Electrical Code (NEC): The National Electrical Code, also called the NFPA 70 is the standard in the United States for safe installation of electrical wiring, cabling and equipment. Created by the NFPA, it is part of their national fire codes. While the NEC is not US law, it is commonly used as the basis for the majority of state and local building codes due to it being thorough and widespread in its use.

Underwriters Laboratories (UL): Underwriters Laboratories® is an independent product safety certification organization that tests products and writes safety standards.

Canadian Standards Association (CSA): The CSA is worldwide recognized product tester although its focus is on products sold within Canada. It is responsible for testing and providing certification for electrical as well as mechanical, plumbing, gas and a multitude of other devices.

3. DETERMINING CABLE CRITERIA

3.1. General Cable Specification Requirements

All cable selections must meet the requirements discussed in this section. Exceptions must be submitted to the EIC Electrical Safety Advisor (ESA) for approval.

3.1.1. NEC Type Compliance

Cable types must have a NEC / UL rating from Table 3-1. NEC permitted substitutions can be found in the appendix.

Table 3-1. NEC Listed Cable Types

UL Rating	NEC 2023 Article	Description
MV	315	Medium Voltage Cable (2,001-35,000VAC & 2,001-2,300 VDC)
TC, TC-ER	336	Power and control tray cable
PLTC, CL3P, CL2P, CL3R, CL2R, CL3, CL2	725	Remote-control, signaling, and power-limited circuits that are not an integral part of a device or of utilization equipment
OFNP, OFNR, OFNG, OFN, OFCP, OFCR, OFCG, OFC	770	Fiber cable conductive and non-conductive
CMP, CMR, CMG, CM	800	Communications circuit cable

3.1.2. Electrical Ratings

Cable voltage rating should be appropriate for cable use. All general tray cables must have a minimum voltage rating of 300V. Cables routing in the same signal section (table 4-1) must be rated at or above the section's minimum voltage rating.

Cable ampacities and deratings for uncovered trays must follow Table 3-2. All NEC tables referenced can be found in the appendix.

Table 3-2. NEC Cable Ampacities

Voltage	Cable Type	NEC 2023 Code
<=2,000V	1 conductor	392.80(A)(2)
	2 or 3 conductors	392.80(A)(1): Table 310.16 & 310.18
	>3 conductors	392.80(A)(1)(a)
>2,000V	any conductor	392.80(B)

3.2. Cable Specification Requirements by Location

3.2.1. Environmental

Plenum Areas:

Cable types routing in plenum areas (spaces between raised floors and dropped ceilings) of buildings must be NFPA 262, UL 910, or CSA FT6 compliant. Acceptable UL rated types end with "P" in Table 3-1.

Riser Areas:

Cables routing vertically between floor of a multi-story structure must be UL 1666 or CSA FT4 compliant. Acceptable UL rated types end with "R" in Table 3-1.

General-Purpose:

All other general-purpose cables must be UL 1685, UL 1581, or CSA FT1 compliant. Acceptable UL rated types are in Table 3-1.

Indoor Tray:

Plenum, riser, and general-purpose cable NEC classified installation types are permitted to be supported by cable trays.

Outdoor Tray:

Cables installed in outdoor cable trays must be Type PLTC and UV resistant.

3.3. Cable Property Requirements and Guidelines

3.3.1. Radiation Resistant Jacket Material

Cables installed in EIC tunnel beamline area [1] must have a jacket and insulation material with a useable radiation dose >10Mrad (x10^6). Materials meeting this criterion are shown in the appendix. Beamline locations with a radiation dose that exceeds 10Mrad need to be further evaluated.

3.3.2. Jacket and Insulation Color

a) A red jacket is reserved and required for coaxial cables rated at or over 2,400V
b) Cables for life safety systems much have an orange jacket
c) Grounded-conductors must comply with NEC, details can be found in the appendix.
d) AC insulation color requirements can be found in the appendix.

3.3.3. Conductors equal to or greater than 1/0AWG DC

DC cables requiring a conductor equal to or greater than 1/0AWG should be DLO with tinned copper Class I stranded conductors.

3.3.4. Additional Considerations

Additional cable properties to consider can be found in the appendix.

3.4. Criteria Checklist

A cable criteria checklist and example cable manual can be found in the appendix.

4. CABLE DATABASE

4.1. Cable Type Approval

All cable types used for EIC must be submitted to the cable type database [2] and approved by the EIC ESA. The cable data required for approval can be found in the appendix.

4.2. Cable Instance Approval

All technical EIC cable instances must be submitted to the cable database [3] and approved by the EIC ESA before cable procurement and installation. The cable instance data required can be found in the appendix.

4.2.1. Signal Section Classifications

Each cable instance routing in a tray requires the signal section to be defined. Signal sections must be separated by a solid fixed barrier of a material compatible with the cable tray to prevent signal interference and ensure NEC code compliance. Signal sections are defined in Table 4-1.

Table 4-1. EIC Cable Signal Sections

Signal Section	Abbreviation	Cable Function	Minimum Voltage Rating	Cable Use Example
AC Distribution	AC	<600V AC	300V	AC power circuits
Medium Voltage AC Distribution	MAC	600V - 15kV	600V	AC power circuits
Low voltage DC	DC	<600V DC	600V	Power supply leads
High power DC	HPDC	>600V	2,001V	High-voltage power supply leads
Ramped DC	RDC	>600V	2,001V	RCS power supply leads
High voltage	HV	>600V	5,000V	Coax: Bias, ion pump, cold cathode gauge

Communication	COM	<50V	300V	controls, network
Motor drive	MD	<120V	300V	stepper motors
High Frequency	HF	<50V coax	300V	cavity signal
PASS	PASS	<120V	300V	ODH cable
High power RF	HPRF	N/A	N/A	hardline cavity power

4.3. Cable Status Tracking

Once a cable instance is approved in the database, the cable status can be tracked. The cable status includes but is not limited to cable procured, cable onsite, cable pulled, cable source end terminated, cable destination end is terminated, cable is tested (ready for operation).

5. CABLE ROUTING REQUIREMENTS

All cable routing must meet the requirements discussed in this section. Exceptions must be submitted to the ESA for approval.

5.1. General

Cable routing must comply with the below criteria:

1. Cables must have a self-laminating label containing the cable I.D and conduit name(s) (if applicable) on either end and 10ft from either end prior to the final cable label installed during cable terminations.
2. Cable bend radius must comply with manufacture recommendations.
3. Cables should always maintain separation according to Signal Sections in Table 4-1.
4. DC lead cables shall route with appropriate pairing (+,-).
5. Cables outside of tray must have horizontal support every 3ft.
6. Cables outside of tray must have vertical support every 4ft .
7. All cables must have adequate strain relief within 2ft of the termination point.

5.2. Tray

Cable routing in cable tray must comply with the below criteria:

1. Cables must be separated by signal section with a solid fixed barrier of a material compatible with the cable tray.
2. All cables must be adequately supported and secured while exiting a tray.
3. All routing must comply with the NEC code, associated codes can be found in article 392.

5.3. Conduit

Cable routing in conduit must comply with the below criteria:

1. Only one signal section type is allowed in each conduit.
2. DC cables shall route with pairing (+,-) must route together or in their own conduit.
3. All cables must have a heat analysis performed prior to each pull through a conduit >2ft.
4. All conduits must comply with the NEC code. Associated codes can be found in the appendix.

6. CABLE TERMINATION REQUIREMENTS

6.1. Permanent Cable Labels

After the cable end is terminated, a permanent label must be installed containing at least the cable I.D, signal section, from location, and to location. DC cables must include the polarity.

Spare or unused cables must have a label containing "SPARE", the cable I.D, from location, and to location.

6.2. Cable Test Plan

Each cable instance must have an associated cable test plan [4]. The cable test plan should include but is not limited to how the cable will be inspected, specific test plans required to confirm the cable is functional (e.g., continuity, insulation leakage), termination details, and associated hazards.

7. REFERENCES

[1] EIC tunnel beamline area
[2] Cable type database (pending hyperlink)
[3] Cable database (pending hyperlink)
[4] Cable test plan

8. APPENDIX

3.1.1. NEC permitted substitutions

The table below is for informational purposes only. Consult official current NEC code for the most current values.

Table 722.135(E) Cable Substitutions

Cable Type	Permitted Substitutions
CL3P	CMP
CL2P	CMP, CL3P
CL3R	CMP, CL3P, CMR
CL2R	CMP, CL3P, CL2P, CMR, CL3R
PLTC	None
CL3	CMP, CL3P, CMR, CL3R, CMG, CM, PLTC
CL2	CMP, CL3P, CL2P, CMR, CL3R, CL2R, CMG, CM, PLTC, CL3
CL3X	CMP, CL3P, CMR, CL3R, CMG, CM, PLTC, CL3, CMX
CL2X	CMP, CL3P, CL2P, CMR, CL3R, CL2R, CMG, CM, PLTC, CL3, CL2, CMX, CL3X
FPLP	CMP
FPLR	CMP, FPLP, CMR
FPL	CMP, FPLP, CMR, FPLR, CMG, CM
OFNP	None
OFCP	OFNP
OFNR	OFNP
OFCR	OFNP, OFCP, OFNR
OFNG, OFN	OFNP, OFNR
OFCG, OFC	OFNP, OFCP, OFNR, OFCR, OFNG, OFN
CMUC	None

Table 805.154 Cable Substitutions

Cable Type	Permitted Substitutions
CMR	CMP
CMG, CM	CMP, CMR
CMX	CMP, CMR, CMG, CM

3.1.2. NEC Ampacities

393.80:

The table below is for informational purposes only. Consult official current NEC code for the most current values.

(A) Ampacity of Cables, Rated 2000 Volts or Less, in Cable Trays.

Informational Note: See 110.14(C) for conductor temperature limitations due to termination provisions.

(1) Multiconductor Cables. The ampacity of multiconductor cables, nominally rated 2000 volts or less, installed according to the requirements of 392.22(A) shall be as given in Table 310.16 and Table 310.18, subject to 392.80(A)(1)(a), (A)(1)(b), (A)(1)(c), and 310.14(A)(2).

(a) The adjustment factors of 310.15(C)(1) shall apply only to multiconductor cables with more than three current-carrying conductors. Adjustment factors shall be limited to the number of current-carrying conductors in the cable and not to the number of conductors in the cable tray.

(b) Where cable trays are continuously covered for more than 1.8 m (6 ft) with solid unventilated covers, not over 95 percent of the ampacities of Table 310.16 and Table 310.18 shall be permitted for multiconductor cables.

(c) Where multiconductor cables are installed in a single layer in uncovered trays, with a maintained spacing of not less than one cable diameter between cables, the ampacity shall not exceed the ambient temperature-corrected ampacities of multiconductor cables, with not more than three insulated conductors rated 0 through 2000 volts in free air, in accordance with 310.14(B).

Informational Note: See Informative Annex B, Table B.2(3).

(2) Single-Conductor Cables. The ampacity of single-conductor cables shall be as permitted by 310.14(A)(2). The adjustment factors of 310.15(C)(1) shall not apply to the ampacity of cables in cable trays. The ampacity of single-conductor cables, or single conductors cabled together (triplexed, quadruplexed, and so forth), nominally rated 2000 volts or less, shall comply with 392.80(A)(2)(a) through (A)(2)(d).

(a) Where installed according to the requirements of 392.22(B), the ampacities for 600 kcmil and larger single-conductor cables in uncovered cable trays shall not exceed 75 percent of the ampacities in Table 310.17 and Table 310.19. Where cable trays are continuously covered for more than 1.8 m (6 ft) with solid unventilated covers, the ampacities for 600 kcmil and larger cables shall not exceed 70 percent of the ampacities in Table 310.17 and Table 310.19.

(b) Where installed according to the requirements of 392.22(B), the ampacities for 1/0 AWG through 500 kcmil single-conductor cables in uncovered cable trays shall not exceed 65 percent of the ampacities in Table 310.17 and Table 310.19. Where cable trays are continuously covered for more than 1.8 m (6 ft) with solid unventilated covers, the ampacities for 1/0 AWG through 500 kcmil cables shall not exceed 60 percent of the ampacities in Table 310.17 and Table 310.19.

(c) Where single conductors are installed in a single layer in uncovered cable trays, with a maintained space of not less than one cable diameter between individual conductors, the ampacity of 1/0 AWG and larger cables shall not exceed the ampacities in Table 310.17 and Table 310.19.

Exception to (c): For solid bottom cable trays, the ampacity of single conductor cables shall be determined by 310.14(B).

(d) Where single conductors are installed in a triangular or square configuration in uncovered cable trays, with a maintained free airspace of not less than 2.15 times one conductor diameter (2.15 × O.D.) of the largest conductor contained within the configuration and adjacent conductor configurations or cables, the ampacity of 1/0 AWG and larger cables shall not exceed the ampacities of two or three single insulated conductors rated 0 through 2000 volts supported on a messenger in accordance with 310.15.

Informational Note: See Table 310.20.

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The table below is for informational purposes only. Consult official current NEC code for the most current values.

Table 310.16 Ampacities of Insulated Conductors with Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried)

Size AWG or kcmil	Temperature Rating of Conductor [See Table 310.4(1)]						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, XHWN, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, PFA, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, XHWN, XHWN-2, XHHN, Z, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, XHWN, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, XHWN, XHWN-2, XHHN	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
18*	—	—	14	—	—	—	—
16*	—	—	18	—	—	—	—
14*	15	20	25	—	—	—	—
12*	20	25	30	15	20	25	12*
10*	30	35	40	25	30	35	10*
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	555	665	750	470	560	630	2000

Notes:
1. Section 310.15(B) shall be referenced for ampacity correction factors where the ambient temperature is other than 30°C (86°F).
2. Section 310.15(C)(1) shall be referenced for more than three current-carrying conductors.
3. Section 310.16 shall be referenced for conditions of use.
*Section 240.4(D) shall be referenced for conductor overcurrent protection limitations, except as modified elsewhere in the *Code*.

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The table below is for informational purposes only. Consult official current NEC code for the most current values.

Table 310.18 Ampacities of Insulated Conductors with Not More Than Three Current-Carrying Conductors in Raceway or Cable

	Temperature Rating of Conductor [See Table 310.4(1)]				
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PFA, SA	Types PFAH, TFE	Type Z	
Size AWG or kcmil	COPPER		NICKEL OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM	Size AWG or kcmil
14	34	36	39	—	14
12	43	45	54	30	12
10	55	60	73	44	10
8	76	83	93	57	8
6	96	110	117	75	6
4	120	125	148	94	4
3	143	152	166	109	3
2	160	171	191	124	2
1	186	197	215	145	1
1/0	215	229	244	169	1/0
2/0	251	260	273	198	2/0
3/0	288	297	308	227	3/0
4/0	332	346	361	260	4/0

Notes:
1. Section 310.15(B) shall be referenced for ampacity correction factors where the ambient temperature is other than 40°C (104°F).
2. Section 310.15(C)(1) shall be referenced for more than three current-carrying conductors.
3. Section 310.18 shall be referenced for conditions of use.

The table below is for informational purposes only. Consult official current NEC code for the most current values.

393.80(B):

(1) Multiconductor Cables (2001 Volts or Over). The ampacity of multiconductor cables shall be as given in Table 315.60(C)(9) and Table 315.60(C)(10), subject to the following:

(1) Where cable trays are continuously covered for more than 1.8 m (6 ft) with solid unventilated covers, not more than 95 percent of the ampacities of Table 315.60(C)(9) and Table 315.60(C)(10) shall be permitted for multiconductor cables.

(2) Where multiconductor cables are installed in a single layer in uncovered cable trays, with maintained spacing of not less than one cable diameter between cables, the ampacity shall not exceed the allowable ampacities of Table 315.60(C)(5) and Table 315.60(C)(6).

(2) Single-Conductor Cables (2001 Volts or Over). The ampacity of single-conductor cables, or single conductors cabled together (triplexed, quadruplexed, and so forth), shall comply with the following:

(1) The ampacities for 1/0 AWG and larger single-conductor cables in uncovered cable trays shall not exceed 75 percent of the ampacities in Table 315.60(C)(3) and Table 315.60(C)(4). Where the cable travs are covered for more than 1.8 m (6 ft) with solid unventilated covers, the ampacities for 1/0 AWG and larger single-conductor cables shall not exceed 70 percent of the ampacities in Table 315.60(C)(3) and Table 315.60(C)(4).

(2) Where single-conductor cables are installed in a single layer in uncovered cable trays, with a maintained space of not less than one cable diameter between individual conductors, the ampacity of 1/0 AWG and larger cables shall not exceed the ampacities in Table 315.60(C)(3) and Table 315.60(C)(4).

(3) Where single conductors are installed in a triangular or square configuration in uncovered cable trays, with a maintained free air space of not less than 2.15 times the diameter (2.15 × O.D.) of the largest conductor contained within the configuration and adjacent conductor configurations or cables, the ampacity of 1/0 AWG and larger cables shall not exceed the ampacities in Table 315.60(C)(1) and Table 315.60(C)(2).

3.3.1. Radiation Resistant Jacket Material

Table 8-1. Cable Jacket Materials for Radiation Areas

Material	**Useable Mrad [1,2]**
Chlorosulfonated polyethylene (Hypalon)	11
Cross-linked Polyethylene (XLPE)	10
Cross-linked Polyolefin (XLPO)	11
Ethylene vinyl acetate (EVA)	11
Polychloroprene rubber (Neoprene)	11
Polyethylene (PE)	10
Polyethylene terephthalate copolymers (Hytrel)	11
Polyimide (Kapton)	500
Polyolefin- Propylene Elastomers (EPR, EPDM)	14
Polyolefin-Thermoplastic Propylene (PP)	10
Polyurethane rubber (PUR)	90
Polyvinylchloride (PVC)	11
Styrene-butodiene rubber (SBR)	13

[1] United States Nuclear Regulatory Commission, "Literature Review of Environmental Qualification of Safety-Related Electric Cables", Brookhaven National Laboratory, Upton, NY, 1996

[2] NARA Technical Reports Server, "Nuclear and Space Radiation Effects on Materials - Space Vehicle Design Criteria", NASA, 1970

3.3.2. Jacket and Insulation Color

The table below is for informational purposes only. Consult official current NEC code for the most current values.

400.22 Grounded-Conductor Identification. One conductor of flexible cords that is intended to be used as a grounded circuit conductor shall have a continuous marker that readily distinguishes it from the other conductor or conductors. The identification shall consist of one of the methods indicated in 400.22(A) through (F).

(A) Colored Braid. A braid finished to show a white or gray color and the braid on the other conductor or conductors finished to show a readily distinguishable solid color or colors.

(B) Tracer in Braid. A tracer in a braid of any color contrasting with that of the braid and no tracer in the braid of the other conductor or conductors. No tracer shall be used in the braid of any conductor of a flexible cord that contains a conductor having a braid finished to show white or gray.

Exception: In the case of Types C and PD and cords having the braids on the individual conductors finished to show white or gray. In such cords, the identifying marker shall be permitted to consist of the solid white or gray finish on one conductor, provided there is a colored tracer in the braid of each other conductor.

(C) Colored Insulation. A white or gray insulation on one conductor and insulation of a readily distinguishable color or colors on the other conductor or conductors for cords having no braids on the individual conductors.

For jacketed cords furnished with appliances, one conductor having its insulation colored light blue, with the other conductors having their insulation of a readily distinguishable color other than white or gray.

Exception: Cords that have insulation on the individual conductors integral with the jacket.

The insulation shall be permitted to be covered with an outer finish to provide the desired color.

(D) Colored Separator. A white or gray separator on one conductor and a separator of a readily distinguishable solid color on the other conductor or conductors of cords having insulation on the individual conductors integral with the jacket.

(E) Tinned Conductors. One conductor having the individual strands tinned and the other conductor or conductors having the individual strands untinned for cords having insulation on the individual conductors integral with the jacket.

(F) Surface Marking. One or more ridges, grooves, or white stripes located on the exterior of the cord so as to identify one

400.23 Equipment Grounding Conductor Identification. A conductor intended to be used as an equipment grounding conductor shall have a continuous identifying marker readily distinguishing it from the other conductor or conductors. Conductors having a continuous green color or a continuous green color with one or more yellow stripes shall not be used for other than equipment grounding conductors. Cords or cables consisting of integral insulation and a jacket without a nonintegral equipment grounding conductor shall be permitted to be green. The identifying marker shall consist of one of the methods in 400.23(A) or (B).

Conductor Color

a) For A/C systems >2000V the color code is:
   Phase A – Brown taped stripe (or one stripe)
   Phase B – Orange taped stripe (or two stripes)
   Phase C – Yellow taped stripe (or three stripes)
   Neutral – Gray or White taped stripe (or three stripes)
   Ground – Green taped stripe
   Or
   Phase A – One stripe
   Phase B – Two stripes
   Phase C – Three stripes
   Neutral – Gray or White taped stripe
   Ground – Green taped stripe
b) For A/C systems >250V and less than 601V, the color code is:
   Phase A – Brown
   Phase B – Orange
   Phase C – Yellow
   Neutral – Gray or White
   Ground – Green
c) For A/C systems >50V and less than 251V, the color code is:
   Phase A – Black
   Phase B – Red (Orange, if High-Leg Delta)
   Phase C – Blue
   Neutral – White
   Ground - Green

3.3.4 Additional Cable Considerations

Comparison	Difference
solid vs stranded conductor	solid is a better conductor but stiffer and more physically challenging to work with
tinned soft copper vs bare copper	tinned soft copper is better for higher temperatures and humid environments
conductor pairing	paired conductors reduce interference between other conductors
conductor installation color coding	standard color coding can help prevent incorrect connections
cable flexibility	Increased flexibility (especially for coax) can reduce the chance of damage during the pull and minimalizes route contains

3.4 Cable Criteria Check List

Is the NEC/UL compliance appropriate for the cable path?
Does the conductor size accommodate NEC deratings?
Does the voltage rating meet the requirement for the planned signal section? ref
Is the cable shielding adequate to prevent any signal interference?
Is the jacket and installation material suitable for the cable path?
Is the cable bend radius and flexibility feasible for the cable path?
Do the jacket and installation color match lab guidelines?

Example cable type manual:

Product: 9514

High Perform Instr, 4 Pr #22 Str TC, PVC Ins E2, OS, PVC Jkt, PLTC

Request Sample

Product Description

High Performance Instrumentation, 4 Pair 22AWG (7x30) Tinned Copper, PVC Insulation E2 Color Code, Overall Beldfoil® Shield, PVC Outer Jacket, PLTC

Technical Specifications

Product Overview

Suitable Applications:	Instrumentation, Sensors, Valves, Positioners, 4-20mA, 0-10V

Construction Details

Conductor

Element	No. of Elements	Size	Stranding	Material
Pair(s)	4	22 AWG	7x30	TC - Tinned Copper

Insulation

Element	Material	Nom. Thickness	Nom. Insulation Diameter	Color Code
Pair(s)	PVC - Polyvinyl Chloride	0.017 in (0.43 mm)	0.062 in (1.6 mm)	ICEA Chart E2

Outer Shield

Shield Type	Material	Coverage	Drainwire Type
Tape	Bi-Laminate (Alum+Poly)	100%	22 AWG (7x30) TC

Outer Jacket

Separator	Material	Nom. Thickness	Nom. Diameter	Ripcord
Cotton Serve	PVC - Polyvinyl Chloride	0.042 in (1.1 mm)	0.356 in (9.04 mm)	Yes

Overall Cable Diameter (Nominal):	0.356 in (9.04 mm)

Electrical Characteristics

Electricals

Element	Nom. Conductor DCR	Nom. Capacitance Cond-to-Cond	Nom. Capacitance Cond-to-Other (Conds + Shield)	Max. Current
Pair(s)	18.2 Ohm/1000ft	26 pF/ft (85 pF/m)	45 pF/ft (150 pF/m)	3.4 Amps per Conductor at 25°C

Voltage

UL Voltage Rating
300 V (PLTC, CMG)

Mechanical Characteristics

Temperature

UL Temperature	Operating
105°C	-30°C to +105°C

Table Notes:	AWM 80°C

Bend Radius

Stationary Min.	Installation Min.
3.6 in (91 mm)	3.6 in (91 mm)

Max. Pull Tension:	82 lbs (37 kg)
Bulk Cable Weight:	60 lbs/1000ft

Standards and Compliance

Environmental Suitability:	Indoor/Outdoor, Indoor, Outdoor, Sunlight Resistance
Flammability / Reaction to Fire:	UL 1685 UL Loading, FT4, T-29-520, IEEE 1202
NEC / UL Compliance:	Article 725, Article 727, Article 800, CMG, ITC, PLTC
AWM Compliance:	AWM 2464
CEC / C(UL) Compliance:	CMG
European Directive Compliance:	EU CE Mark, EU Directive 2015/863/EU (RoHS 2 amendment), EU Directive 2011/65/EU (RoHS 2), EU Directive 2012/19/EU (WEEE)
APAC Compliance:	China RoHS II (GB/T 26572-2011)

History

Update and Revision:	Revision Number: 0.608 Revision Date: 01-04-2024

4.1 Cable Type Data Required for Approval

Table 8-2. Cable Type Data for Approval

Field	Field Options
Manufacturer	
Part number	
Type	Multi Multi-conductor or Multi-paired cable, PwrDC, ArmPwrDC, Coax, Hardline, Rigid, Triax, Cat6, TCtypeK, SMfiber, MMfiber
Conductor Size	
Conductor Material	Tin-plated copper, Copper, Copper-plated aluminum, Silver-plated copper covered steel
Conductor Number (no ground)	
Ground Wire	T/F
Pairing	twisted pair, unpaired, triad, paired, N/A
Shielding	shielded pairs, unshielded, overall single, shielded pairs, overall single, overall double, solid, individually shielded, overall shielded, overall shielded, N/A
Voltage Rating (V)	
Conductor Insulation Material	
Outer Jacket Material	
UL Temperature Rating (◦C)	
NEC Cable Class	320 – AC, 328 - MV, 330 – MC, 336 – TC, 725 – CL2, CL3, PLTC, 760 – FPL, 770 – OFC, OFN, 800 – CM, 820 – CATV, 830 – BM
Fire-Resistance Level	general purpose, riser, plenum
Outer Diameter (in)	
Conductor CSA (in2)	
Cable Weight (lb/ft)	
Spec Sheet	
Other	
Calculated Fields:	
Tray Rated	T/F
Flame Test	UL 1685 / UL 1581 / CSA FT1, UL 1666 / CSA FT4, NFPA 262 / UL 910 / CSA FT6
NEC Cable Type	

4.2 cable instance data required

Table 8-3. Cable Instance Data for Approval

Basic	**Required/Optional**	**Description**
WBS	Required	
Signal Section	Required	
Cable Type	Required	
Request Procurement Support	Required	T/F
Quantity	Required	
Function	Required	
Polarity	Optional	
From (power/signal source)		
From Location	Optional	rack/panel name or general location
From Device	Required	the specific device name
From Termination Type	Required	termination type part number
From Termination Wiring Drawing	Optional	associated drawing number
To (power/signal destination)		
To Location	Optional	rack/panel name or general location
To Device	Required	the specific device name
To Termination Type	Required	termination type part number
To Termination Wiring Drawing	Optional	associated drawing number
Routing		
Path Restriction	Optional	physical length, electrical length, polarity pairing, special care, etc.
Request Installation Support	Required	T/F
IF TRUE		
Estimated Length	Optional	
Date to Pull By	Required	
Terminated Length	Required	
Routing notes	Optional	
IF FALSE		
Estimated Length	Optional	
Conduit(s)	Required	
Tray(s)	Required	
Terminated Length	Required	
Routing notes	Optional	
MISC		
Comments	Optional	

5.3 NEC Conduit Fill Codes

The table below is for informational purposes only. Consult official current NEC code for the most current values.

Chapter 9 Tables

Table 1 Percent of Cross Section of Conduit and Tubing for Conductors and Cables

Number of Conductors and/or Cables	Cross-Sectional Area (%)
1	53
2	31
Over 2	40

Informational Note No. 1: Table 1 is based on common conditions of proper cabling and alignment of conductors where the length of the pull and the number of bends are within reasonable limits. It should be recognized that, for certain conditions, a larger size conduit or a lesser conduit fill should be considered.

Informational Note No. 2: When pulling three conductors or cables into a raceway, if the ratio of the raceway (inside diameter) to the conductor or cable (outside diameter) is between 2.8 and 3.2, jamming can occur. While jamming can occur when pulling four or more conductors or cables into a raceway, the probability is very low.

Notes to Tables

(1) See Informative Annex C for the maximum number of conductors and fixture wires, all of the same size (total cross-sectional area including insulation) permitted in trade sizes of the applicable conduit or tubing.

(2) Table 1 applies only to complete conduit or tubing systems and is not intended to apply to sections of conduit or tubing used to protect exposed wiring and cable from physical damage.

(3) Equipment grounding or bonding conductors, where installed, shall be included when calculating conduit or tubing fill. The actual dimensions of the equipment grounding or bonding conductor (insulated or bare) shall be used in the calculation.

(4) Where conduit or tubing nipples, not including connectors, having a maximum length not to exceed 600 mm (24 in.) are installed between boxes, cabinets, and similar enclosures, the nipples shall be permitted to be filled to 60 percent of their total cross-sectional area, and 310.15(C)(1) adjustment factors need not apply to this condition.

(5) For conductors not included in Chapter 9, such as multiconductor cables and optical fiber cables, the actual dimensions shall be used.

(6) For combinations of conductors of different sizes, use actual dimensions or Table 5 and Table 5A for dimensions of conductors and Table 4 for the applicable conduit or tubing dimensions.

(7) When calculating the maximum number of conductors or cables permitted in a conduit or tubing, all of the same size (total cross-sectional area including insulation), the next higher whole number shall be used to determine the maximum number of conductors permitted when the calculation results in a decimal greater than or equal to 0.8. When calculating the size for conduit or tubing permitted for a single conductor, one conductor shall be permitted when the calculation results in a decimal greater than or equal to 0.8.

(8) Where bare conductors are permitted by other sections of this *Code*, the dimensions for bare conductors in Table 8 shall be permitted.

(9) A multiconductor cable, optical fiber cable, or flexible cord of two or more conductors shall be treated as a single conductor for calculating percentage conduit or tubing fill area. For cables that have elliptical cross sections, the cross-sectional area calculation shall be based on using the major diameter of the ellipse as a circle diameter. Assemblies of single insulated conductors without an overall covering shall not be considered a cable when determining conduit or tubing fill area. The conduit or tubing fill for the assemblies shall be calculated based upon the individual conductors.

(10) The values for approximate conductor diameter and area shown in Table 5 are based on worst-case scenario and indicate round concentric-lay-stranded conductors. Solid and round concentric-lay-stranded conductor values are grouped together for the purpose of Table 5. Round compact-stranded conductor values are shown in Table 5A. If the actual values of the conductor diameter and area are known, they shall be permitted to be used.