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NEMA STANDARDS PUBLICATION NO. WC 63

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Performance Standard for Premise Telecommunications Cables

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA Standards Publication No. WC 63-1994

PERFORMANCE STANDARD FOR PREMISE TELECOMMUNICATIONS CABLES

Published by

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Foreword

The user's attention is called to the possibility that compliance with this Standard may require use of an invention covered by patent rights. By publication of this Standard, no position is taken with respect to the validity of this claim or of any patent rights in connection therewith. The patent holder has, however, filed a statement of willingness to grant a license under these rights on reasonable and non-discriminatory terms and conditions to applicants desiring to obtain such a license. Details may be obtained from the publisher.

This standard has been developed by the High Performance Wire and Cable Section of NEMA in close coordination between manufacturers, users, third party certifying agencies and others having specialized experience. The High Performance Wire and Cable Section of NEMA periodically reviews this standard for any revisions necessary to keep it up to date. Proposed revisions or comments should be submitted to:

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Scope

This standard defines minimum electrical performance characteristics, material and mechanical specifications of premise wiring cables for voice and data applications. Applicable test methods will be discussed.

The products covered in this Standard shall conform to the requirements of Part 68 of the FCC rules and regulations as well as the applicable article of the National Electrical Code and/or safety standards.

The performance requirements contained in this document are for cables as manufactured and not necessarily as installed. This is not an installation document.

This standard covers IEEE 802.3 coaxial, 100 and 150 ohm twisted pair voice and data transmission cables, excluding cable used for "broadband" or RF applications.

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Section 1
REFERENCED STANDARDS

Copies of referenced documents may be obtained from the appropriate sources as follows.

American Society for Testing and Materials (ASTM)
1916 Race Street
Philadelphia, PA 19103

ASTM B3-90	*Soft or Annealed Copper Wire*
ASTM B8-90	*Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft*
ASTM B33-91	*Tinned Soft or Annealed Copper Wire for Electrical Purposes*
ASTM B286-89	*Copper Conductors for Use in Hookup Wire for Electronic Equipment*
ASTM D1248-84	*Polyethylene Plastics Molding & Extrusion Materials*
ASTM D2116-91	*FEP-Fluorocarbon Molding & Extrusion Materials*
ASTM D4566-90	*Electrical Performance Properties of Insulations and Jackets for Telecommunications Wire & Cable, Test for*

Federal Communications Commission (FCC)
Washington, D.C. 20554

Code of Federal Regulations, Title 47, Telecommunications, Chapter 1-FCC, Part 68.

Institute of Electrical & Electronic Engineers (IEEE)
445 Hoes Lane, IEEE Service Center
P.O. Box 1331
Piscataway, NJ 08855-1331

ANSI/IEEE 802.3	*(ISO/IEC 8802-3, Third Edition, 1992), Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method & Physical Layer Specifications*

National Electrical Manufacturers Association (NEMA)
2101 L Street, N.W., Suite 300
Washington, DC 20037

NEMA WC 61-1992	*Standard for Transfer Impedance Testing*

National Fire Protection Association (NFPA)
Batterymarch Park
Quincy, MA 02269

ANSI/NFPA-70-1993	*National Electrical Code (NEC)*

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Naval Publishing and Printing Service Office
700 Robbins Avenue
Philadelphia, PA 19111

MIL-C-17G — *Cables, Radio, Frequency, Flexible and Semirigid, General Specification for*

Underwriters Laboratories Inc.
333 Pfingsten Road
Northbrook, IL 60062

UL 13-90 — *Standard for Power-Limited Circuit Cables*
UL 444-90 — *Standard for Communications Cables*

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Section 2
COAXIAL CABLES

2.1 GENERAL

This section covers the requirements and performance characteristics of coaxial cable to be used in the following baseband local area networks.

a. ISO/IEC 8802-3, TYPE 10BASE5
b. ISO/IEC 8802-3, TYPE 10BASE2

The NEMA Type designations and applications for coaxial designs are described in Table 2-1.

Table 2-1
NEMA TYPE DESIGNATIONS FOR COAXIAL DESIGNS

APPLICATION	**TYPE 10BASE5**
NEMA Type	Description
10B5/1	50 ohm coax, foam core, 0.405 inch OD, listed for NEC non-plenum installations
10B5P/1	50 ohm coax, foam core, 0.375 inch OD, listed for NEC plenum installations

APPLICATION	**TYPE 10BASE2 (Thinnet)**
NEMA Type	Description
10B2/1	50 ohm coax, solid core, tinned copper braid shield, 0.195 inch OD, listed for NEC non- plenum installations
10B2/2	50 ohm coax, foam core, aluminum foil/tinned copper braid shield, 0.185 inch OD, listed for NEC non-plenum installations
10B2P/1	50 ohm coax, solid core, tinned copper braid shield, 0.189 inch OD, listed for NEC plenum installations
10B2P/2	50 ohm coax, foam core, aluminum foil/tinned copper braid shield, 0.168 inch OD, listed for NEC plenum installations

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2.2 MATERIALS

Materials for the principal components of the cable shall be as specified herein. All dimensions for materials are nominal unless otherwise specified. When a material is not specified, a material shall be used that will enable the finished product to meet its performance requirements. Additionally, the manufacturer shall ensure that the product conforms with the National Electrical Code.

2.2.1 Conductors

Center conductors and braid wires shall be manufactured as specified below.

2.2.1.1 BARE COPPER WIRE

Bare copper wire shall conform to soft or annealed wire in accordance with ASTM B3.

2.2.1.2 TIN-COATED COPPER WIRE

Tin-coated copper wire shall conform to soft or annealed copper wire in accordance with ASTM B33.

2.2.1.3 STRANDED INNER CONDUCTORS

Stranded inner conductors shall be in accordance with ASTM B8 or ASTM B286. Tensile strength and elongation of conductors shall be tested prior to stranding. Conductors shall not be coated after stranding (no overcoating). Individual wires, before stranding, shall meet all the requirements of the basic wires.

2.2.2 Insulations

Materials for dielectric cores shall be consistent with applicable specifications given in Sections 2.2.2.1 and 2.2.2.2. They will be applied with uniform thickness and shall have dielectric constants and dissipation factors sufficient to meet electrical requirements.

2.2.2.1 POLYETHYLENE

Polyethylenes shall conform to applicable requirements of ASTM D1248.

2.2.2.2 FLUORINATED ETHYLENE PROPYLENE (FEP)

FEPs shall conform to applicable requirements of ASTM D2116.

2.2.3 Jackets

Materials for jackets shall conform to the requirements of the applicable National Electrical Code cable type.

2.3 ISO/IEC 8802-3 10BASE5

2.3.1 10B5/1 Components/Construction Details

2.3.1.1 INNER CONDUCTOR

Solid uncoated copper wire
Diameter: 0.0855 ± 0.005 inch (2.17 ± 0.013 mm)

2.3.1.2 DIELECTRIC CORE

Foamed polyethylene
Diameter: 0.247 ± 0.005 inch (6.27 ± 0.13 mm)
Eccentricity of center conductor shall be 10% maximum. The conductor shall show no residue of foam when stripped. The adhesion of conductor shall be 20.0 LBF (89.0 N) minimum on a 6 inch (152.4 mm) sample.

2.3.1.3 SHIELD (4 LAYERS OF BRAID AND FOIL)

Reading outward from the dielectric core:

Foil Layer:	0.001 inch (0.025 mm) adhesive/ 0.002 inch (0.051 mm) aluminum/ 0.001 inch (0.025 mm) polyester/ 0.00035 inch (0.009 mm) aluminum/ Tape to be applied longitudinally to core with minimum 0.125 inch (3.18 mm) overlap, adhesive side facing core.
Braid Layer:	Tinned copper Strand diameter: 0.0063 inch (0.16 mm) nominal Picks/inch(mm): 9.7 (0.38) ± 10% Ends: 7 Carriers: 24
Foil Layer:	0.00035 inch (0.009 mm) aluminum/ 0.001 inch (0.025 mm) polyester/ 0.00035 inch (0.009 mm) aluminum. Tape to be applied longitudinally to core with minimum 0.125 inch (3.18 mm) overlap. Percent coverage: 94% minimum Diameter: 0.288 inch (7.32 mm)
Braid Layer:	Tinned copper Strand diameter: 0.0063 inch (0.16 mm) nominal Picks/inch(mm): 5.0 (0.20) ± 10% Ends: 8 Carriers: 24 Percent coverage: 90% minimum Diameter: 0.326 ± 0.007 inch (8.28 ± 0.178)

2.3.1.4 JACKET

Polyvinyl Chloride
Diameter: 0.405 ± 0.007 inch (10.287 ± 0.178 mm)
Color: Yellow
Ring band marking shall be required (see 2.3.4).

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2.3.2 10B5P/1 Components/Construction Details

2.3.2.1 INNER CONDUCTOR

Solid uncoated copper wire
Diameter: 0.055 ± 0.0005 inch (2.17 ± 0.013 mm)

2.3.2.2 DIELECTRIC CORE

Foamed FEP
Diameter: 0.247 ± 0.005 inch (6.27 ± 0.13 mm)
Eccentricity of the center conductor shall be 10% maximum. The conductor shall show no residue of foam when stripped. The adhesion of conductor shall be 20.0 LBF (89.0 N) minimum on a 6 inch (152.4 mm) sample.

2.3.2.3 SHIELD (4 LAYERS OF BRAID AND FOIL)

Reading outward from the dielectric core:

Foil Layer: 0.001 inch (0.025 mm) adhesive/
0.002 inch (0.051 mm) aluminum/
0.001 inch (0.025 mm) polyester/
0.00035 inch (0.009 mm) aluminum/
Tape to be applied longitudinally to core with minimum 0.125 inch (3.18 mm) overlap, adhesive side facing core.

Braid Layer: Tinned copper
Strand diameter: 0.0071 inch (0.18 mm) nominal
Picks/inch (mm): 9.7 (0.38) ± 10%
Ends: 7
Carriers: 24
Percent coverage: 94% minimum
Diameter: 0.293 inch (7.44 mm)

Foil Layer: 0.00035 inch (0.009 mm) aluminum/
0.001 inch (0.025 mm) polyester/
0.00035 inch (0.009 mm) aluminum/
Tape to be applied longitudinally to core with minimum 0.125 inch (3.18 mm) overlap.

Braid Layer: Tinned Copper
Strand diameter: 0.0071 inch (0.18 mm) nominal
Picks/inch (mm): 4.2 (0.165) ± 10%
Ends: 8
Carriers: 24
Percent coverage: 90% minimum
Diameter: 0.326 ± 0.007 inch
(8.28 ± 0.178 mm)

2.3.2.4 JACKET

Fluoropolymer
Diameter: 0.375 ± 0.010 inch (9.53 ± 0.254 mm)
Color: orange
Ring band marking is required: (see 2.3.4)

2.3.3 Electrical Requirements and Characteristics

The sum of the center conductor resistance plus the shield resistance shall not exceed 3.05 ohms/1000 ft. (0.010 ohms/meter) at or corrected to 20EC (68EF).

The velocity of propagation shall not be less than 77% of the speed of light.

The average characteristic impedance shall be 50 ± 2 ohms when measured in accordance with the requirements of MIL-C-17 Time Domain Reflectomers method (TDR). Periodic variations in impedance along a single piece of cable may be up to ±3 ohms sinusoidal centered around the measured average value, with a period less than 6.56 feet (2 m).

The attenuation shall not exceed 3.66 dB/1000 ft. (1.20 dB/100 m) at 5 MHz and 5.18 dB/1000 ft. (1.70 dB/100 m) at 10 MHz.

The transfer impedance of the cable shall not exceed the value shown in Figure 2-1 as a function of frequency.

The nominal capacitance is 26 pF/ft (85 pF/m).

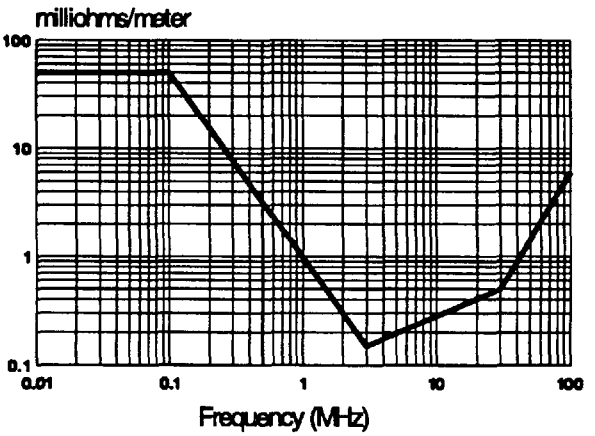

FIGURE 2-1
10BASE5

2.3.4 Ring Band Markings

The cable shall be marked with annular rings in a color contrasting with the background color of the jacket. The rings shall be regularly spaced at 98.4 ± 1.97 inches (2.5 m ± 5 cm) along the entire length of the cable. These annular rings are to be 0.250 – 0.375 inches (6.35 – 9.53 mm) wide and should look solid from a 12 inch (304.8 mm) distance. It is permissible to cover characters of other specified markings where they coincide.

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2.4 ISO/IEC 8802-3 10BASE2

2.4.1 10B2/1 Components/Construction Details

2.4.1.1 INNER CONDUCTOR

19 strands of tinned copper wire;
Diameter: 0.0071 inch (0.18 mm)
Overall diameter: 0.035 ± 0.002 inch (0.89 ± 0.05 mm)

2.4.1.2 DIELECTRIC CORE

Solid polyethylene
Diameter: 0.116 ± 0.006 inch (2.95 ± 0.15 mm)
Eccentricity of center conductor shall be 10% maximum

2.4.1.3 SHIELD

Single braid of tinned copper wire
Strand diameter: 0.005 inch (0.127 mm)
Picks/inch(mm): 10.2 (0.40) ± 10%
Ends: 7
Carriers: 16
Percent coverage: 95% nominal

2.4.1.4 JACKET

Polyvinyl chloride
Diameter: 0.193 ± 0.012 inch (4.90 ± 0.30 mm)

2.4.2 10B2P/1 Components/Construction Details

2.4.2.1 INNER CONDUCTOR

19 strands of tinned copper wire
Diameter: 0.0071 inch (0.18 mm) nominal
Overall diameter: 0.035 ± 0.002 inch (0.89 ± 0.05 mm)

2.4.2.2 DIELECTRIC CORE

Solid FEP
Diameter: 0.116± 0.006 inch (2.95 ± 0.15 mm)
Eccentricity of center conductor shall be 10% maximum

2.4.2.3 SHIELD

Single braid of tinned copper wire
Strand diameter: 0.005 inch (0.127 mm) nominal
Picks/inch(mm): 10.2 (0.40) ± 10%
Ends: 7
Carriers: 16
Percent coverage: 95% minimum

2.4.2.4 JACKET

Fluoropolymer
Diameter: 0.189 ± 0.012 inch (4.80 ± 0.30 mm)

2.4.3 10B2/2 Components/Construction Details

2.4.3.1 INNER CONDUCTOR

19 strands of tinned copper wire
Diameter: 0.0079 inch (0.20 mm) nominal
Overall diameter: 0.037 ± 0.0003 inch (0.94 ± 0.008 mm)

2.4.3.2 DIELECTRIC CORE

Foam polyethylene
Diameter: 0.099 ± 0.007 inch (2.51 ± 0.178 mm)
Eccentricity of center conductor shall be 10% maximum.

2.4.3.3 SHIELD

Foil Layer: 0.0001 inch (0.0025 mm) adhesive/ 0.002 inch (0.051 mm) aluminum/ 0.001 inch (0.025 mm) polyester/ 0.00035 inch (0.009 mm) aluminum. Tape to be applied longitudinally with minimum 0.125 inch (3.18 mm) overlap, adhesive side facing core.

Braid Layer: Tinned copper
Strand diameter: 0.005 inch (0.127 mm) nominal
Picks/inch (mm): 12.5 (0.492) ± 10%
Ends: 6
Carriers: 16
Percent coverage: 93% minimum
Diameter: 0.135 inch (3.429 mm) nominal

2.4.3.4 JACKET

Polyvinyl chloride
Diameter: 0.185 ± 0.004 inch (4.70 ± 0.010 mm)
Color: gray

2.4.4 10B2P/2 Components/Construction Details

2.4.4.1 INNER CONDUCTOR

19 strands of tinned copper wire
Diameter: 0.0079 inch (0.20 mm) nominal
Overall diameter: 0.037 ± 0.0003 inch (0.94 ± 0.008 mm)

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2.4.4.2 DIELECTRIC CORE

Foam FEP
Diameter: 0.099 ± 0.007 inch (2.51 ± 0.178 mm)
Eccentricity of center conductor shall be 10% maximum

2.4.4.3 SHIELD

Foil Layer: 0.001 inch (0.025 mm) adhesive/ 0.002 inch (0.051 mm) aluminum/ 0.001 inch (0.025 mm) polyester/ 0.00035 inch (0.009 mm) aluminum. Tape to be applied longitudinally with minimum 0.125 inch (3.18 mm) overlap, adhesive side facing core.

Braid Layer: Tinned copper
Strand diameter: 0.005 inch (0.127 mm) nominal

Picks/inch(mm): 12.5 (0.492) ± 10%
Ends: 6
Carriers: 16
Percent coverage: 93% minimum
Diameter: 0.135 inch (3.429 mm) nominal

2.4.4.4 JACKET

Fluoropolymer
Diameter: 0.165 ± 0.007 inch (4.19 ± 0.178 mm)
Color: gray

2.4.5 Electrical Requirements and Characteristics

The sum of the center conductor resistance plus the shield resistance shall not exceed 15.24 ohms/1000 ft. (0.050 ohms/meter) at or corrected to 20EC (68EF).

The velocity of propagation shall not be less than 65% of the speed of light.

The average characteristic impedance shall be 50 ± 2 ohms when measured in accordance with the requirements of MIL-C-17 (TDR method). Periodic variations in impedance along a single piece of cable may be up to ±3 ohms sinusoidal centered around the measured average value, with a period less than 6.56 feet (2 meters).

The attenuation shall not exceed 9.88 dB/1000 ft. (3.24 dB/100 m) at 5 MHz and 14.0 dB/1000 ft. (4.59 dB/100 m) at 10 MHz.

The transfer impedance of the cable shall not exceed the value shown in Figure 2-2 as a function of frequency.

The nominal capacitance is 26 pF/ft. (85 pF/m).

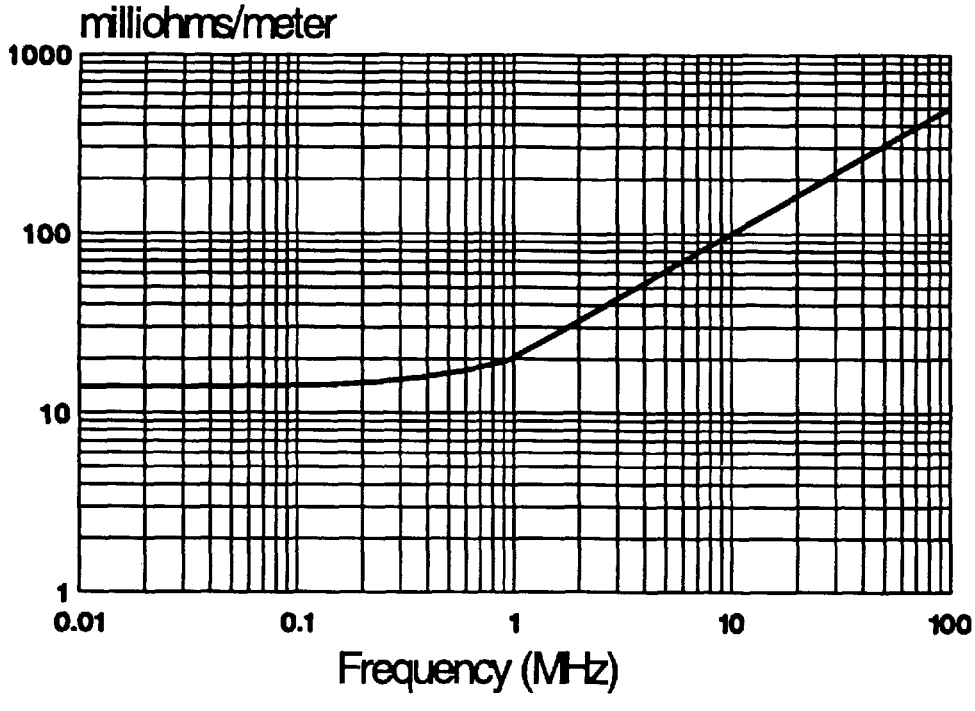

FIGURE 2-2
10BASE2

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Section 3
TWISTED PAIR NOMINAL 100 AND 150 OHM CABLES

3.1 GENERAL

This section covers requirements and performance characteristics of 100 ohm and 150 ohm paired cables.

The NEMA Type designations for twisted pair designs are described in Table 3-1.

3.2 MATERIALS AND MECHANICAL SPECIFICATIONS

3.2.1 Conductors

Conductors shall conform to the requirements listed below except the minimum dimensions shall be in accordance with UL 444.

3.2.1.1 BARE COPPER WIRE

Bare copper wire shall conform to soft or annealed wire in accordance with ASTM B3 except that the requirements for "Dimensions and Permissible Variations" shall be waived.

3.2.1.2 TIN-COATED COPPER WIRE

Tin-coated copper wire shall conform to soft or annealed wire in accordance with ASTM B33 except that the requirements for "Dimensions and Permissible Variations" shall be waived.

3.2.1.3 STRANDED COPPER WIRE

Stranded bare or tin-coated copper wire shall conform to ASTM B8 or B286.

3.2.2 Insulation and Jacket

3.2.2.1 RAW MATERIAL

The copper conductors shall be insulated with one or more layers of solid or expanded material. The core consisting of two or more conductors and other construction components shall be protected with an overall covering generally referred to as an "outer jacket." The insulation, jacket, plus other components such as core wrap, shield, inner jackets, etc. shall be suitable for the intended application environment. The outer jacket must be of a material that adequately protects the cable prior to, during and after installation.

Table 3-1
NEMA TYPE DESIGNATIONS FOR TWISTED PAIR DESIGNS

NEMA TYPE	DESCRIPTION
100-24-STD	100 ohm, #24 AWG, twisted pair, shielded or non-shielded 13.1 dB/100 meter maximum loss at 16.0 MHz
100-22-STD	100 ohm, #22 AWG, twisted pair, shielded or non-shielded 11.2 dB/100 meter maximum loss at 16.0 MHz
100-24-LL	100 ohm, #24 AWG, twisted pair, shielded or non-shielded 8.9 dB/100 meter maximum loss at 16.0 MHz
100-22-LL	100 ohm, #22 AWG, twisted pair, shielded or non-shielded 7.2 dB/100 meter maximum loss at 16.0 MHz
100-24-XF	100 ohm, #24 AWG, twisted pair, shielded or non-shielded 8.2 dB/100 meter maximum loss at 16.0 MHz
100-22-XF	100 ohm, #22 AWG, twisted pair, shielded or non-shielded
150-22-XF	150 ohm, #22 AWG, shielded twisted pair, 13.7 dB/1000 feet maximum loss at 16.0 MHz
150-26-XF	150 ohm, #26 AWG, shielded twisted pair, 20.1 dB/1000 feet maximum loss at 16.0 MHz

Note: STD = Standard, LL = Low loss and XF = Low loss extended frequency

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3.2.2.2 MECHANICAL, PHYSICAL, DIMENSIONAL, SAFETY CONSIDERATIONS

These will be determined primarily by the wide variety of insulation and jacket material choices. The functional electrical characteristics as required by this standard may additionally influence cable design properties such as insulation wall thickness, pair twist lengths, etc.

3.3 ELECTRICAL SPECIFICATIONS

3.3.1 Definitions

3.3.1.1 RESISTANCE

The resistance of a wire is defined as the ratio of the voltage to the resulting current when the wire is attached to the output terminals of a constant voltage, non-time varying (zero frequency) source.

3.3.1.1.1 DC Conductor Resistance

The electrical direct current (DC) resistance shall be measured in the finished cable by means of a device capable of measuring accurately to within 0.5% of the value to be determined.

The measured value, corrected proportionately to the length and expressed in ohms/100 meters, shall be referred to the standard temperature of 20°C (68°F).

For copper conductors, the resistance shall be corrected to the standard temperature by multiplying the measured values by the factor k where:

$$k = \frac{1}{1 + 0.00393\ (t - 20)}$$

Where:

t = the temperature at which measurements are made, expressed in degrees, Celsius (°C).

3.3.1.1.2 DC Resistance Unbalance

The DC resistance unbalance between conductors in the same pair is defined as:

$$R_{UB} = \frac{(R_{max} - R_{min})}{R_{min}} \times 100\,\%$$

Where:

R_{max} = The resistance, in ohms, of the conductor with higher resistance value.

R_{min} = The resistance, in ohms, of the conductor with lower resistance value.

3.3.1.2 INSULATION RESISTANCE

Conductor insulation resistance must be sufficiently high to avoid transmission degradation in cables. This parameter is determined by measuring the resistance existing between any single conductor in the cable and all other conductors and the shield if present.

3.3.1.3 CAPACITANCE

3.3.1.3.1 Mutual Capacitance of a Pair

Mutual capacitance is defined as the effective capacitance between two wires of a pair. In a cable, the mutual capacitance C_m is defined as:

$$C_m = C_{ab} + \frac{C_{ag} \times C_{bg}}{C_{ag} + C_{bg}}$$

Where:

C_{ab} = The capacitance between conductor "a" and conductor "b" with all other conductors in the cable and the shield (if present) connected to ground (guarded).

C_{ag} = The capacitance between conductor "a" and all other conductors in the cable and the shield (if present) with conductor "b" grounded (guarded).

C_{bg} = The capacitance between conductor "b" and all other conductors in the cable and the shield (if present) with conductor "a" grounded (guarded).

The mutual capacitance shall be measured at a frequency of 1 kHz.

3.3.1.3.2 Pair to Ground Capacitance Unbalance

The capacitance unbalance to ground ($C_{UB\ P\text{-}G}$) of a pair of wires/conductors within a cable is defined as:

$$C_{UB\ P\text{-}G} = C_1 - C_2$$

Where:

C_1 = The capacitance between conductor 1 and conductor 2 with conductor 2 connected to all other conductors in the cable, the shield (if present) and ground.

C_2 = The capacitance between conductor 2 and conductor 1 with conductor 1 connected to all other conductors in the cable, the shield (if present) and ground.

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3.3.1.4 CHARACTERISTIC IMPEDANCE

The characteristic impedance is defined as:

$$Z_0 = \sqrt{\frac{R + \omega L}{G + j\,\omega C}}$$

Where:

Z_0 = The complex characteristic impedance in ohms
R = The loop resistance in ohms/unit length
L = The loop inductance in henrys/unit length
G = The mutual conductance in siemens/unit length
C = The mutual capacitance in farads/unit length
ω = The angular frequency in radians/sec.

The characteristic impedance shall be obtained by a least squares function fit of input impedance data. See Appendix A.

3.3.1.5 STRUCTURAL RETURN LOSS

The structural return loss (SRL) figure of merit for a pair compares the complex input impedance to the fitted complex characteristic impedance. It is defined as:

$$SRL = -20 \log_{10} \left| \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \right|$$

Where:

SRL = Structural return loss in decibels
Z_{in} = Complex input impedance in ohms
Z_0 = Complex fitted impedance in ohms

3.3.1.6 INPUT IMPEDANCE

The input impedance is defined as:

$$Z_{in} = \sqrt{Z_{open} \times Z_{short}}$$

Where:

Z_{in} = Complex input impedance in ohms
Z_{open} = Complex measured open circuit impedance in ohms
Z_{short} = Complex measured short circuit impedance in ohms

The input impedance is used to derive the characteristic impedance. Under the conditions described in 3.3.2.6, the input impedance can be used as a characteristic impedance measurement.

3.3.1.7 ATTENUATION

The attenuation for cable where the nominal cable impedance is matched is defined as:

$$\alpha = 10 \log_{10} \frac{P_1}{P_2} = 20 \log_{10} \frac{V_1}{V_2} (dB)$$

Where:

P_1 = The input power
P_2 = The output power
V_1 = The input voltage
V_2 = The output voltage
α = The attenuation in decibels

3.3.1.8 NEAR END CROSSTALK

Near end crosstalk loss (NEXT) is defined as:

$$NEXT = \log_{10} \frac{P_{1N}}{P_{2N}} = 20 \log_{10} \frac{V_{1N}}{V_{2N}} (dB)$$

Where:

NEXT = Near end crosstalk in decibels
P_{1N} = The input power of the disturbing pair
P_{2N} = The output power of the disturbed pair at the near end of the cable
V_{1N} = The input voltage of the disturbing pair
V_{2N} = The output voltage of the disturbed pair at the near end of the cable

3.3.1.8.1 Power Sum Near End Crosstalk (PSNEXT)

Power sum near end crosstalk (PSNEXT) is defined as:

$$PS - NEXT = 10 \log_{10} \sum_{n=1}^{n} 10^{\frac{X_n}{10}}$$

Where:

X = Measured near end crosstalk in decibels
n = number of pairs being measured minus one

3.3.1.9 SURFACE TRANSFER IMPEDANCE

The surface transfer impedance, Z_t (as defined in NEMA WC-61) of the shield of an electrically short, longitudinally uniform cable is defined as the ratio of the longitudinal electromotive force induced in the disturbed circuit to the current flowing in the interfering circuit.

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3.3.2 Test Methods

The transmission measurements of mutual capacitance, capacitance unbalance, characteristic impedance, SRL, attenuation, and NEXT shall be performed on cable samples of 100 m (328 ft) or greater removed from the reel or packages. The test sample shall be stretched along a non-conducting surface, loosely coiled, or supported in aerial spans. On-reel or packaged cable measurements that satisfy the performance requirements are acceptable. In case of conflict, the stretched method shall provide conformance to the minimum requirements of this standard.

3.3.2.1 DC RESISTANCE

3.3.2.1.1 DC conductor resistance shall be measured using the method outlined in ASTM D4566.

3.3.2.1.2 DC resistance unbalance shall be measured using the method outlined in ASTM D4566.

3.3.2.2 INSULATION RESISTANCE

Insulation resistance shall be measured using the method outlined in ASTM D4566.

3.3.2.3 CAPACITANCE

3.3.2.3.1 Mutual capacitance of a pair shall be measured using the method outlined in ASTM D4566.

3.3.2.3.2 Pair to ground capacitance unbalance shall be measured using the method outlined in ASTM D4566.

3.3.2.4 CHARACTERISTIC IMPEDANCE

Characteristic impedance shall be measured using the method outlined in Appendix A.

3.3.2.5 STRUCTURAL RETURN LOSS

Structural return loss shall be obtained from calculations indicated in Appendix A.

3.3.2.6 INPUT IMPEDANCE

The method for measuring input impedance given in Appendix A, Section 2, is the specified characteristic impedance measurement technique for 150 ohm cables. For 100 ohm cables, input impedance can be an alternative characteristic impedance test method. However, curve fitted characteristic impedance and structural return loss are the referee test methods for characteristic impedance.

3.3.2.7 ATTENUATION

Attenuation shall be measured using the method outlined in ASTM D4566. The sample length shall exhibit no less than 3 decibels at the lowest frequency tested and no more than 40 decibels for applicable frequencies. More than one length may be required to test a full range of frequencies.

3.3.2.8 NEAR END CROSSTALK

Near end crosstalk shall be measured using the method defined in ASTM D 4566.

3.3.2.9 SURFACE TRANSFER IMPEDANCE

The surface transfer impedance of a shielded cable shall be measured using the method outlined in NEMA WC 61. Requirements have not been finalized.

3.3.3 Electrical Requirements

The electrical requirements shall be as specified in Tables 3-2, 3-3, and 3-4.

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Table 3-2
ELECTRICAL PERFORMANCE REQUIREMENTS FOR 100 OHM, 24 AWG, STANDARD AND LOW LOSS CABLES AND 100 OHM, 22 AWG, STANDARD AND LOW LOSS CABLES

		Standard*		Low Loss*	
		100-24-STD 24 AWG	100-22-STD 22 AWG	100-24-LL 24 AWG	100-22-LL 22 AWG
Maximum DC Resistance (Ohms/100 m[328 ft.])		9.38	5.91	9.38	5.91
Maximum DC Resistance Unbalance (%)		5		5	
Mutual Capacitance of a Pair (nF/100 m [328 ft]) [For Ref Only]		6.6		5.6	
Maximum Pair to Ground Capacitance Unbalance (pF/100 m [328 ft])		330		330	
Characteristic Impedance (Ohms)	0.772 MHz	102 ± 15%		102 ± 15%	
	1.0 - 16.0 MHz	100 ± 15%		100 ± 15%	
	16.0 - 20.0 MHz	N/S		100 ± 15%	
Structural Return Loss (decibels) (Minimum)	1.0 - 10.0 MHz	12		21	
	10.0 - 16.0 MHz	12 - 10Log(F/10)		21 - 10Log(F/10)	
	16.0 - 20.0 MHz	N/S		21 - 10Log(F/10)	
Attenuation** (decibels/100 m [328 ft]) (Maximum)	0.256 MHz	1.3	1.0	1.1	0.9
	0.512 MHz	1.8	1.5	1.5	1.2
	0.772 MHz	2.2	1.9	1.9	1.5
	1.0 MHz	2.6	2.2	2.2	1.8
	4.0 MHz	5.6	4.9	4.3	3.6
	8.0 MHz	8.5	7.3	6.2	5.1
	10.0 MHz	9.7	8.2	6.9	5.6
	16.0 MHz	13.1	11.2	8.9	7.2
	20.0 MHz	N/S	N/S	10.0	7.9
Worst Pair Near End Crosstalk † (decibels) (Minimum)	0.772 MHz	43		58	
	1.0 MHz	41		56	
	4.0 MHz	32		47	
	8.0 MHz	27		42	
	10.0 MHz	26		41	
	16.0 MHz	23		38	
	20.0 MHz	N/S		36	

* Applies to shielded and unshielded cables.

** Stranded conductors shall be 20% higher than the values shown in the table. Values below .772 MHz are intended for engineering design purposes and are not required for conformance testing.

† Table values for reference only. The minimum NEXT coupling loss for any pair combination at room temperature shall be greater than the value determined using the formula: NEXT (F) ≥ NEXT (0.772) -15 $\log_{10}$(F/-0.772), where F = measured frequency in Mhz. See figure 3–2. PSNEXT is a swept requirement when PSNEXT is required.

The cable attenuation shall be verified at a temperature of 40 degrees Celsius and 60 degrees Celsius and shall meet the requirements of the table above after adjusting for temperature. The maximum attenuation determined using the above table shall be adjusted at elevated temperatures using a factor of 0.4% increase per degree Celsius for low loss cables.

The Power Sum NEXT loss, tested in accordance with ASTM D 4566, within a 25-pair binder group shall be equal to or greater than the values in Tables 3.2 or 3.3 at the discrete frequencies specified. Cables over 4-pair shall be tested for power sum near end cross-talk. Subgroups within any 25-pair group will be considered part of the 25-pair group.

NOTES: NEMA Standard, Low Loss & Extended Frequency Requirements are shown in Figures 3-1 and 3-2.

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NEMA WC*63 94 ■ 6470247 0506894 489 ■

Table 3-3
ELECTRICAL PERFORMANCE REQUIREMENTS FOR 100 OHM, 24 AWG, LOW LOSS EXTENDED FREQUENCY CABLES AND 100 OHM, 22 AWG, LOW LOSS EXTENDED FREQUENCY CABLES

		Low Loss Extended Frequency*	
		100-24-XF	100-22-XF
		24 AWG	22 AWG
Maximum DC Resistance (Ohms/100 m[328 ft.])		9.38	5.91
Maximum DC Resistance Unbalance (%)		5	
Mutual Capacitance of a Pair (nF/100m [328 ft]) Reference Only		5.6	
Maximum Pair to Ground Capacitance Unbalance (pF/100 m [328 ft])		330	
Impedance (Ohms)	0.772 Mhz	102 ± 15%	
	1.0 - 100.0 MHz	100 ± 15%	
Structural Return Loss (dB)	1.0 - 20.0 MHz	23	
	20.0 - 100.0 MHz	23 - 10Log (F/20)	
Attenuation** (dB/100 m [328 ft]) (Maximum)	0.256 MHz	1.1	–
	0.512 MHz	1.5	–
	0.772 MHz	1.8	–
	1.0 MHz	2.0	–
	4.0 MHz	4.1	–
	8.0 MHz	5.8	–
	10.0 MHz	6.5	–
	16.0 MHz	8.2	–
	20.0 MHz	9.3	–
	25.0 MHz	10.4	–
	31.25 MHz	11.7	–
	62.5 MHz	17.0	–
	100.0 MHz	22.0	–
Worst Pair Near End Crosstalk † (dB) (Minimum)	0.772 MHz	64	
	1 MHz	62	
	4 MHz	53	
	8 MHz	48	
	10 MHz	47	
	16 MHz	44	
	20 MHz	42	
	25 MHz	41	
	31.25 MHz	40	
	62.5 MHz	35	
	100 MHz	32	

* Applies to shielded and unshielded cables.

** Stranded conductors shall be 20% higher than the values shown in the table. Values below 0.772 MHz are intended for engineering design purposes and are not required for conformance testing.

† Table values for reference only. The minimum NEXT coupling loss for any pair combination at room temperature shall be greater than the value determined using the formula: NEXT (F) ≥ NEXT (0.772) -15 $\log_{10}$(F/0.772), where F = measured frequency in Mhz. See Figure 3–2.

The cable attenuation shall be verified at a temperature of 40 degrees Celsius and 60 degrees Celsius and shall meet the requirements of the table above after adjusting for temperature. The maximum attenuation determined using the above formula shall be adjusted at elevated temperatures using a factor of 0.4% increase per degrees Celsius for low loss extended frequency cables.

The Power Sum NEXT loss, tested in accordance with ASTM D 4566, within a 25-pair binder group shall be equal to or greater than the values in Tables 3.2 or 3.3 at the discrete frequencies specified. Cables over 4-pair shall be tested for power sum near end cross-talk. Subgroups within any 25-pair group will be considered part of the 25-pair group.

NOTES: Note that this is in addition to the worst pair requirements. Worst pair must meet the requirements for Tables 3-2 or 3-3 at the discrete frequencies specified. NEMA Standard, Low Loss & Extended Frequency Requirements is shown in Figures 3-1 and 3-2.

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Table 3-4
ELECTRICAL PERFORMANCE REQUIREMENTS FOR 150 OHM, SHIELDED, 22 AWG CABLES AND 150 OHM, SHIELDED, 26 AWG CABLES

		150-22-XF 22 AWG	150-26-XF 26 AWG
Maximum DC Resistance (ohms/1000 ft) at 25°C Maximum		17.4	46.0
Minimum Insulation Resistance (megohms-1000 ft)		5,000	
Maximum Pair to Ground Capacitance Unbalance (pF/1000 ft)		457	
Impedance (Ohms)	0.0096 MHz	270 ± 10%	390 ± 15
	0.0384 MHz	185 ± 10%	235 ± 15
	3 to 300 MHz*	150 ± 10%	150 ± 10%
Attenuation (dB/1000 ft) (Maximum)	0.0096 MHz	0.915	1.8
	0.0384 MHz	1.53	2.25
	4.0 MHz	6.71	10.0
	8.0 MHz	9.5	N/S
	10.0 MHz	11.0	13.1
	16.0 MHz	13.4	20.1
	25.00 MHz	18.9	N/S
	31.25 MHz	21.0	N/S
	62.5 MHz	29.9	N/S
	100.0 MHz	37.5	N/
	300.0 MHz	65.3	N/S
Near End Crosstalk (dB) (Minimum)	9.6 kHz – 5 MHz	58.0	52.0
	5 MHz – 16 MHz	58.0 – 15Log (F/5)	52.0 – 15Log (F/5)
	16 MHz – 300 MHz	58.0 – 15Log (F/5)	N/S

* The specification must be met over the entire frequency range.

NOTES: Note that this is in addition to the worst pair requirements. Worst pair must meet the requirements for Tables 3-2 or 3-3 at the discrete frequencies specified. NEMA Standard, Low Loss & Extended Frequency Requirements are shown in Figure 3.

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Appendix A
CHARACTERISTIC IMPEDANCE AND STRUCTURAL RETURN LOSS COMPUTATION FOR UNSHIELDED/SHIELDED TWISTED PAIR CABLES USING S-PARAMETER DATA

A.1 PURPOSE

To obtain input impedance from S-Parameter data or equivalent data and from this information compute the smooth (fitted) characteristic impedance and the structural return loss over the frequency range extending from 772 kHz to 100 MHz.

A.2 OBTAINING THE INPUT IMPEDANCE

A.2.1 Introduction

Input impedance can be obtained either from a single terminated impedance measurement scan or alternatively from the dual open circuit and short circuit scans. The terminated scan is attractive in that either input impedance or return loss (RL) results obtained from it can be viewed or plotted directly with the network analyzer. Using the open/short scans requires personal computer data acquisition procedures and hardware but allows more accurate results at low frequencies where round trip cable loss is less than 20 dB or where the characteristic impedance differs from the load impedance. Function fitting of the input impedance and the computation of the SRL can only be accomplished with a computer based data acquisition procedure.

A.2.2 Equipment Required (or suitable equivalent)

a. Network analyzer
b. S-Parameter test set
c. Calibration standards — open, short, and non-inductive, resistive load
   100 ± 1.0 ohm
   150 ± 1.5 ohm
d. Personal computer with interface card for open/short approach
e. Plotter
f. Appropriate test leads
g. Applicable impedance matching transformer: Unbalanced to balanced type where transformer bandwidth is sufficient to meet test frequency requirements and of proper impedance ratio.

A.2.3 Sample Preparation

a. Refer to 3.3.2.
b. Sample size should be a minimum length of 328 feet (100 meters).
c. Remove appropriate jacket and insulation from both ends of sample (no more than 2.5" of jacket, 2" of shield, 0.75" of insulation).
d. Terminate far end of cables with 100 or 150 ohm matched load resistors.*

* The matched load resistors are not used if the alternative open and short circuit measurements are made instead of the single terminated measurement.

A.2.4 Equipment Set-Up

a. Make proper connections between network analyzer and the S-Parameter set.
b. Allow proper equipment warmup time.
c. Connect proper impedance matching transformer to test port.
d. Connect plotter to network analyzer (if applicable).
e. Connect interface on network analyzer to computer interface card and load acquisition program (if applicable).

A.2.5 Equipment Calibration

a. Set frequency resolution of network analyzer to minimum of 100 points per decade but in no case less than 200 points.

Note: If available, higher resolution is desired for best results/accuracy.

b. Use log frequency sweep mode instead of linear if data is being acquired by the computer for subsequent fitting with impedance function to achieve appropriate low versus high frequency weighting.
c. Perform one-port calibration of analyzer using open/short/terminated measurements upon leads of transformer to determine normalized reflection coefficient scan.
d. Set proper scale (linear vertical) and sweep time (minimum 10 seconds).

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A.2.6 Sample Measurement

a. Connect twisted pair (with far end appropriately terminated in load resistor or if open/short measurements are being made then open or short circuit termination) to impedance matching transformer and sweep across frequency range. The shields and/or other pairs may optionally be grounded to the center tap of the transformer secondary.

b. For on-analyzer evaluation plot results on plotter for hardcopy of results conversion from measured reflection coefficient to impedance is done automatically by the analyzer routines included with the network analyzer controller using the formula:

$$Z_{in} = Z_n \frac{1 + R_0}{1 - R_0}$$

Where:

Z_{in} = Complex input impedance
Z_n = Nominal terminating resistance used during calibration
R_0 = Complex measured reflection coefficient

A.3 LEAST SQUARES FUNCTION FIT TO IMPEDANCE MAGNITUDE AND ANGLE

A.3.1 Calculate a least squares curve to fit to Z_{in} based on the following equation:

$$|Z_0| = K_0 + \frac{K_1}{\sqrt{f}} + \frac{K_2}{f}$$

Where:

Z_0 = the magnitude of the characteristic impedance in ohms
f = frequency in Hz
K_0, K_1, K_2 = least squares fit coefficients

NOTE: This is the referee method. Alternate methods such as those being developed in ASTM D 4566 are also permissible.

The fit coefficients are calculated using the formula:

$$\begin{vmatrix} \sum_{i=1}^{N} |Z_{in}| \\ \sum_{i=1}^{N} \frac{|Z_{in}|}{\sqrt{f_i}} \\ \sum_{i=1}^{N} \frac{|Z_{in}|}{f_i} \end{vmatrix} = \begin{vmatrix} N & \sum_{i=1}^{N} \frac{1}{\sqrt{f_i}} & \sum_{i=1}^{N} \frac{1}{f_i} \\ \sum_{i=1}^{N} \frac{1}{\sqrt{f_i}} & \sum_{i=1}^{N} \frac{1}{f_i} & \sum_{i=1}^{N} \frac{1}{f_i^{3/2}} \\ \sum_{i=1}^{N} \frac{1}{f_i} & \sum_{i=1}^{N} \frac{1}{f_i^{3/2}} & \sum_{i=1}^{N} \frac{1}{f_i^{2}} \end{vmatrix} \times \begin{vmatrix} K_0 \\ K_1 \\ K_2 \end{vmatrix}$$

where all summations are performed over N data points. The Nth order system of equations and unknowns is solved using determinants or matrix inversion techniques. Compute values for the magnitude of the characteristic impedance, $|Z_0|$, according to coefficients obtained from the fit and plot results.

A.3.2 Fit to angle of characteristic impedance (optional)

Fit the same equation as was used for the magnitude of the characteristic impedance to the angle.

$$\angle Z_0 = L_0 + \frac{L_1}{\sqrt{f}} + \frac{L_2}{f}$$

Where:

$\angle Z_0$ = the angle of the characteristic impedance in radians
f = frequency in Hz
L_0, L_1, L_2 = least squares fit coefficients for angle

The coefficients for the impedance angle can be calculated by using the same matrix equation solution procedure as that used for the magnitude of the characteristic impedance. Plot the results as desired.

NOTE: This procedure is necessary only if the angle of the characteristic impedance is of interest or if structural return loss (SRL) Section 4 A.3.1 is being calculated at frequencies low enough to result in significant angle ($\angle$ |10| degrees).

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A.4 Compute Structural Return Loss

Calculate the structural return loss (SRL) by means of the formula:

$$SRL = -20 \log_{10} \left| \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \right|$$

Where:

SRL = Structural return loss
Z_{in} = Complex input impedance in Ohms
Z_0 = Complex fitted impedance in Ohms

Plot the results and check for conformance to appropriate standard over the entire frequency range.

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National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 6)

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National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
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3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 5)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 5)

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Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to the authorized engineering information and not to procedures required for compliance with the standard.

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