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An American National Standard

Standard Test Methods for Electrical Performance Properties of Insulations and Jackets for Telecommunications Wire and Cable[1]

This standard is issued under the fixed designation D 4566; 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.

1. Scope

1.1 These test methods cover procedures for electrical testing of thermoplastic insulations and jackets used on telecommunications wire and cable and for the testing of electrical characteristics of completed products. To determine the procedure to be used on the particular insulation or jacket compound, or on the end product, reference should be made to the specification for that product.

1.2 The test methods appear in the following sections of this standard:

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1.3 The values stated in inch-pound units are to be regarded as the standard. SI units are for information only.

1.4 *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 applicability of regulatory limitations prior to use. Specific hazard statements are given in Sections 6 and 32.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 193 Test Method for Resistivity of Electrical Conductor Materials[2]

D 150 Test Methods for A-C Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials[3]

D 1711 Terminology Relating to Electrical Insulation[3]

D 3426 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Using Impulse Waves[4]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[5]

2.2 *ANSI Standard:*

ANSI/IEEE Standard 100 IEEE Standard Dictionary of Electrical and Electronics Terms[6]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *air core*, *n*—refers to products in which the air spaces between cable core components (pairs, etc.) remain in their unfilled or natural state.

[1] These test methods are under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and are the direct responsibility of Subcommittee D09.18 on Solid Insulations, Non-Metallic Shieldings, and Coverings for Electrical and Telecommunications Wires and Cables.

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[2] *Annual Book of ASTM Standards*, Vol 02.03.

[3] *Annual Book of ASTM Standards*, Vol 10.01.

[4] *Annual Book of ASTM Standards*, Vol 10.02.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

[6] Available from the Institute of Electrical and Electronic Engineers, Inc., 345 E. 47th St., New York, NY 10017.

3.1.2 *armored wire or cable*, *n*—wire or cable in which the shielded or jacketed or shielded and jacketed wire or cable is completely enclosed by a metallic covering designed to protect the underlying telecommunications elements from mechanical damage.

3.1.3 *cable, telecommunications*, *n*—products of six or more pair.

3.1.4 *filled core*, *n*—those products in which air spaces are filled with some materials intended to exclude air or moisture, or both.

3.1.5 *pair*, *n*—two insulated conductors combined with a twist.

3.1.6 *phase constant* (β), *n*—a number derived from the shift incurred by an electrical sinusoidal signal as it propagates along the length of a pair of conductors.

3.1.7 *sheath*, *n*—the jacket and any underlying layers of shield, armor, or other intermediate material down to but not including the core wrap.

3.1.8 *shielded wire or cable*, *n*—wire or cable in which the core (or inner jacket) is completely enclosed by a metallic covering designed to shield the core from electrostatic or electromagnetic interference, or both.

3.1.9 *wire, telecommunications*, *n*—products containing less than six pair.

ELECTRICAL TESTS OF INSULATION—IN-PROCESS

4. Scope

4.1 In-process electrical tests are used primarily as process control tools in an attempt to minimize the number and magnitude of problems detected at final test of completed cable.

5. Significance and Use

5.1 Electrical tests, properly interpreted, provide information with regard to the electrical properties of the insulation. The electrical test values give an indication as to how the insulation will perform under conditions similar to those observed in the tests. Electrical tests may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

6. Spark Test

6.1 The spark test is intended to detect defects in the insulation of insulated wire conductors. Spark testers are commonly used to detect insulation defects (faults) at conductor insulating operations, at pair twisting operations, and (occasionally) at operations for assembly or subassembly of conductors. In selected instances, spark tests may be used to detect defects in the jackets of shielded wire and cable, and in such cases, spark testers appear on cable jacketing lines. The basic method calls for a voltage to be applied between a grounded conductor and an electrode that is in mechanical contact with the surface of the material being tested. The wire or cable under test usually moves continuously against the electrode. When the dielectric medium is faulty (for example, excessively thin or missing, as in a pin-hole or when mechanically damaged), the impressed voltage will produce an arc to the grounded conductor. This arcing or sparking will usually activate one or more indicators (such as, warning buzzers or lights, counters, etc.) and, when appropriately interlocked, may halt the production or movement of the item through the sparker. For telecommunications products, the number of faults are usually only counted while production continues. Jacket defects may be flagged when detected. Jacket defects and units of insulated wire containing an excessive number of faults may be repaired or disposed of.

6.2 **Caution:—** *Lethal voltages may be present during this test. It is essential that the test apparatus, and all associated equipment that may be electrically connected to it, be properly designed and installed for safe operation. Solidly ground all electrically conductive parts that any person might come into contact with during the test. Provide means for use at the completion of any test to ground any parts which: were at high voltage during the test; may have acquired an induced charge during the test; may retain a charge even after disconnection of the voltage source. Thoroughly instruct all operators in the proper way to conduct tests safely. When making high voltage tests, particularly in compressed gas or in oil, the energy released at breakdown may be sufficient to result in fire, explosion, or rupture of the test chamber. Design test equipment, test chambers, and test specimens so as to minimize the possibility of such occurrences and to eliminate the possibility of personal injury.*

6.3 Unless otherwise limited by detailed specification requirements, spark testers used may generate either an ac or dc test voltage; if ac, various frequencies may be used. For safety to personnel, spark test equipment is usually current-limited to levels normally considered to be nonlethal. Unless otherwise specified, the test voltage level employed shall be at the discretion of the manufacturer.

6.4 Unless otherwise limited by detailed specification requirements, various types of electrodes may be used, at the discretion of the manufacturer. Bead chains, water, ionized air and spring rods are among electrode types that have been successfully employed. The length of the electrode is also variable; unless otherwise limited by detailed specification requirements, electrode size and length shall be such that the tester will operate successfully for any particular rate of travel of the product through the tester that is used. In spite of current limitations, electrodes are normally provided with grounded metallic screens or shields to guard against accidental personnel contact.

6.5 Both ends of the conductor of insulated wire, or both ends of the metallic shield under a cable jacket are grounded, and then attached to the ground side of the tester. Attach the high voltage side of the tester to the sparker electrode. Set the test voltage at the level specified. Unless otherwise specified, energize the spark tester whenever the product to be tested is moving through the electrode. Take appropriate action (for example, flag defects, count defects, adjust the process, etc.) when and if defects are detected.

6.6 *Report*:

6.6.1 Report the following information recorded on suitable forms (that is, production reports):

6.6.1.1 Machine number and type (that is, extruder, twister, etc.),

6.6.1.2 Date of production test,

6.6.1.3 Insulation type (air core or filled core), conductor gage and footage,

6.6.1.4 Voltage level, and

6.6.1.5 Number of indicated faults.

6.7 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this spark test since the result merely states whether there is conformance to the criteria for success specified in the product specification.

7. Insulation Defect or Fault Rate—In-Process

7.1 For purposes of in-process control, it may be desirable to monitor and record in-process faults at a particular operation (such as, extruders, twisters, etc.) and relate the number of defects found to the quantity of product produced.

7.2 When appropriate, and using records of the quantity of product produced versus the number of insulation defects counted, a fault rate may be established as a ratio as follows:

$$\text{Fault Rate} = \frac{\text{faults detected}}{\text{quantity (ft or m) produced}} = \frac{1}{X} \quad (1)$$

7.3 Fault rates may be determined for any particular time frame as desired; however, minimum industry practice is to keep fault rate records covering periods approximating 1 month, with cumulative records kept for 6-month periods (for example, for the first 6 months of the year, the fault rate was 1/40 000 ft, meaning 1 fault/40 000 conductor ft.)

7.4 *Report*—Report in accordance with 6.6.

7.5 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for insulation defect or fault rate since the result merely states whether there is conformance to the criteria for success specified in the product specification.

8. DC Proof Test—In-Process

8.1 For purposes of in-process control, it may be desirable to dc proof test product at one or more stages of processing prior to the final test operation. Such testing is normally at the discretion of the manufacturer.

8.2 Conduct wire-to-wire dc proof tests in accordance with Section 32 following, at whatever stage of production may be appropriate and designated by the factory management.

8.3 *Report*—Report in accordance with Section 47 except that 47.1.5 does not apply.

8.4 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this dc proof test since the result merely states whether there is conformance to the criteria for success specified in the product specification.

ELECTRICAL TESTS OF COMPLETED WIRE AND CABLE

9. Scope

9.1 Electrical tests of completed wire and cable may include verification of some or all of the properties in accordance with Sections 11-45.

10. Significance and Use

10.1 Electrical tests, properly interpreted, provide information with regard to the electrical properties of the insulation or of the jacket, or both. The electrical test values give an indication as to how the wire or cable, or both, will perform under conditions similar to those observed in the tests. Electrical tests may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

11. Conductor Continuity

11.1 Continuity of the conductors of a telecommunications wire and cable is a critical characteristic.

11.2 Unless otherwise specified or agreed upon, conductor continuity shall be verified using a dc potential of 100 V or less. Manual continuity checkers commonly take the form of a battery voltage source of 9 V, in series with a visible or audible indicator with hand-held test leads. Automatic test equipment, also available to test properly terminated wire and cable, normally provides an indication (lights or printout) when continuity does not exist.

11.3 Prepare each end of the wire or cable for test. This usually involves stripping some insulation from each conductor at each end and separating the conductors at one or both ends. When automatic test equipment is used, terminate the individual conductors at a test fixture (both ends are normally terminated since this automatic test is often performed in conjunction with other tests). When manual continuity checking is performed, it is usually suitable to connect all conductors to a common termination (for example, wrap stripped ends with a length of copper wire, immerse one end in an electrically conductive liquid, etc.) at one end of the wire or cable.

11.4 In succession, apply the voltage source to one end of each conductor. Using test equipment indicators, verify the continuous circuit paths or detect the discontinuities.

11.5 After defective conductors are repaired, continuity checks must be repeated.

11.6 *Report*—Report in accordance with Section 47.

11.7 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for conductor continuity since the result merely states whether there is conformance to the criteria for success specified in the product specification.

12. Continuity of Other Metallic Cable Elements

12.1 In addition to the metallic conductors intended for information transmission, telecommunications wire and cable may contain one or more additional metallic elements in the form of a shield, an armor, or an internal shield or screen that separates a cable into compartments, etc. Depending upon the particular product design, these elements may or may not be in contact with each other (cross-continuity). The continuity of each of these elements is normally considered to be a critical parameter.

12.2 Unless otherwise specified or agreed upon, verify the individual continuity of each shield, armor, screen (internal shield), or other metallic cable element of the cable construction using a dc potential of 100 V or less, in accordance with Section 11. When metallic elements under test are insulated, the insulation is normally removed to the extent necessary for testing. If continuity between any of these metallic elements is required, it shall be verified; if such continuity is expected but not required, it may be verified at the discretion of the manufacturer. If continuity between any of these metallic elements is not permitted, verify isolation in accordance with Section 37.

12.3 *Report*—Report in accordance with Section 47.

12.4 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for continuity of other metallic cable elements since the result merely states whether there is conformance to the criteria for success specified in the product specification.

13. Conductor Resistance

13.1 The resistance of each of the conductors used in telecommunications wire and cable is usually a key characteristic; however, conductor resistance is normally verified only on a quality assurance sampling basis for finished products. Complete shipping units (full reels or other) of wire or cable, or both (not specimen lengths) shall constitute the basic sample. When the selected sample reel is a cable containing a great many conductors, the conductors of the sample cable are also checked on a sampling basis (that is, sampling of the sample).

13.2 Unless otherwise specified or agreed upon, measure the dc resistance of conductors at or correct to 68°F (20°C). Temperature correction shall be performed as described in Test Method B 193. The dc resistance is considered to vary directly with cable length.

13.3 Conductor resistance measurements are commonly made using volt/ohm meters or Wheatstone bridges having an accuracy of ±0.5 %. Various types of automatic or semiautomatic equipment may also be used.

13.4 Follow the general procedures of 11.3-11.5 except that the voltage source shall be the test instrument, and instrument readings obtained for each tested conductor shall be recorded. Note that data for resistance unbalance testing (Section 15) is normally obtained during this procedure; consequently, care must usually be taken to record data separately in pair groupings. See Section 15 for details.

13.5 Upon completion of measurements, manipulate the recorded data as appropriate (for example, determine averages, adjust for temperature and length, etc.) and compare with the requirements of detailed specifications.

13.6 *Report*:

13.6.1 Report in accordance with Section 47 and include the following:

13.6.1.1 Minimum, maximum and average values, and

13.6.1.2 Ambient temperature.

13.7 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for conductor resistance since the result merely states whether there is conformance to the criteria for success specified in the product specification.

14. Resistance of Other Metallic Cable Elements

14.1 It is occasionally important to know the resistance of other metallic elements (most often shield resistance) within telecommunications wire and cable. When required, this information may be obtained following 13.2-13.4, measuring cable construction elements as appropriate.

14.2 *Report*—Report in accordance with Section 47 and include the ambient temperature.

14.3 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for resistance of other metallic cable elements since the result merely states whether there is conformance to the criteria for success specified in the product specification.

15. Conductor Resistance Unbalance (Pairs)

15.1 The difference in resistance between two conductors of any pair can be a key characteristic in telecommunications; however, resistance unbalance is normally verified only on a quality assurance sampling basis for finished products.

15.2 The Conductor Resistance Unbalance is usually determined at the same time that conductor resistance measurements are made; consequently, 13.2-13.4 apply and resistance data is recorded in pair groupings.

15.3 The absolute difference in resistance unbalance is calculated by subtracting the lesser resistance from the greater resistance. Absolute resistance unbalance is normally expressed in Ω/1000 ft or Ω/km. A more useful and generally used expression for resistance unbalance is percent resistance unbalance, where

$$\text{\% Resistance Unbalance} = \frac{(\text{max resistance} - \text{min resistance})}{(\text{min resistance})} \times 100 \tag{2}$$

15.4 Telecommunications wire and cable users are generally interested in two resistance unbalance values: cable average and maximum individual pair unbalance. Cable average in absolute or percentage terms is determined by standard averaging techniques, while the maximum individual pair unbalance in absolute or percentage terms is determined by simple inspection of the data. Data values are then compared with detailed specification requirements to verify conformance.

15.5 *Report*—Report in accordance with Section 47 and include the average and maximum values.

15.6 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for conductor resistance unbalance (pairs) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

16. Mutual Conductance

16.1 The mutual conductance of a pair in a wire or cable is proportional to the mutual capacitance, the average value of the effective dissipation factor of the insulating system, and the frequency. Although it is one of the primary transmission characteristics, mutual conductance is the least consistent; the conductance of an individual pair may vary as much as 10 to 15 % from the nominal values at carrier frequencies. Fortunately, the effect of conductance on the secondary parameters is negligible at voice frequency, and contributes less than 1 % to the secondary parameters at 1 MHz, so the inconsistency is of little consequence. Although conductance also varies with temperature, the correction is insignificant in comparison with other sources of variation, so it is usually neglected.

16.2 Because of the factors mentioned in 16.1, mutual conductance is normally measured only infrequently, and readings are usually taken on short specimen lengths (an exact 32-ft specimen is convenient). When an impedance bridge is used for measurements, conductance and capacitance may be read directly from the instrument balance settings. Various types of automatic or semiautomatic equipment may also be used.

16.3 Unless otherwise specified, obtain mutual conductance readings at 23 ± 3°C and 1000 ± 100 Hz. Measured values are normally converted to a standard length value (normally one mile or one km). For conductance in microsiemens per mile, the values would be:

$$G_0 = \frac{G \times 5280}{L} \quad (3)$$

where:
G_0 = mutual conductance, µS/mile,
G = conductance reading, µS, and
L = specimen length, ft.

16.4 *Report*—Report in accordance with Section 47 and include the maximum value.

16.5 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for mutual conductance since the result merely states whether there is conformance to the criteria for success specified in the product specification.

17. Coaxial Capacitance (Capacitance to Water)

17.1 Coaxial capacitance for insulated wire is defined as the capacitance existing between the outer surface of the round metallic conductor and the outer surface of the insulating dielectric applied over that conductor.

NOTE 1—For a more general definition, refer to Test Methods D 150 or to Terminology D 1711.

17.2 In-process measurements of coaxial capacitance are made by passing the insulated conductor through a water bath while measurements are made between the grounded conductor and the water. Automatic feedback of data is then used to control the insulating equipment. Such measurements are generally not suitable for product acceptance.

17.3 For purposes of measuring coaxial capacitance in completed wire, a sample length of insulated wire is immersed in a water bath and the direct capacitance is measured between the conductor and the water. Unless otherwise specified, a minimum specimen length of 1000 ft (305 m) shall be used. Unless otherwise specified, perform measurements at a water temperature of 20 ± 2°C and a test frequency of 1000 ± 100 Hz using capacitance or impedance bridges, capacitance meters, etc. Unless otherwise prohibited, other equipment yielding equivalent results may be used.

17.4 *Report*—Report in accordance with Section 47 and include the minimum, maximum, and average values.

17.5 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for coaxial capacitance (capacitance to water) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

18. Mutual Capacitance

18.1 Mutual capacitance is defined as the effective capacitance between the two wires of a pair. In a multi-pair cable, AC mutual capacitance is defined as:

$$C_M = C_{AB} + \frac{(C_{AG})(C_{BG})}{C_{AG} + C_{BG}} \quad (4)$$

where:
C_{AB}, C_{AG} and C_{BG} are as illustrated in Fig. 1.

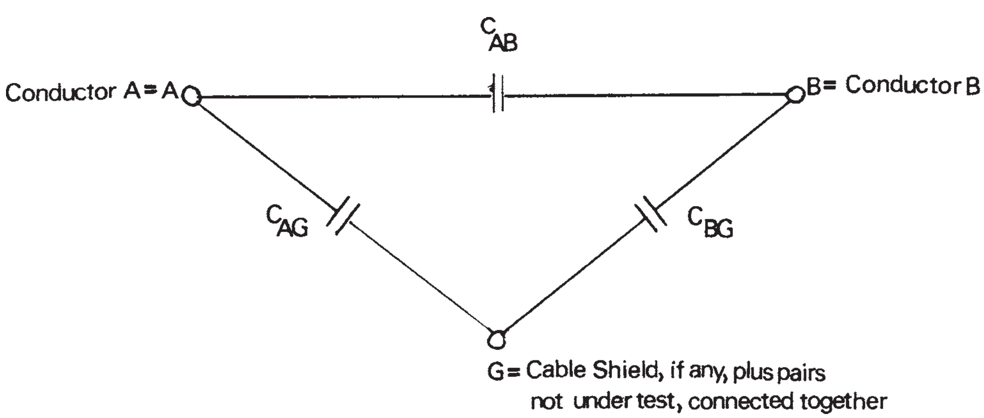


FIG. 1 Mutual Capacitance Relationships

18.2 Mutual capacitance is a critical characteristic in telecommunications wire and cable; consequently, unless otherwise specified or agreed upon between the producer and the user, each lot of product is checked to verify this parameter.

18.3 Before measuring, cable to be tested must be prepared by removing the jacket(s) and shield or armor, when present, from both ends of the cable to expose approximately 2 ft (600 mm) of the cable core. Conductors at one end of the cable are then fanned out to ensure that no conductors are shorted or grounded. Insulation is then stripped for approximately 1 to 3 in. (25 to 75 mm) from the conductors at the other end of the cable. All conductors are then shorted together and to ground to dissipate any static charge that may have accumulated.

18.4 Unless otherwise specified, mutual capacitance is understood to mean capacitance at an ac frequency of 1000 ± 100 Hz, and this test frequency shall be used if measurement is made using a bridge technique. Other test methods yielding comparable results shall be considered as acceptable if not specifically prohibited.

18.5 Mutual capacitance readings are commonly made manually using impedance bridges or capacitance meters; various types of automatic or semiautomatic equipment may also be used.

18.6 Specification limits are generally placed on the cable average mutual capacitance and on the individual pair mutual capacitance. Limits for individual pairs can be verified only by making measurements of individual pairs, and such measurements are normally made for cables of 25 or fewer pairs; for larger cables, individual measurements are often made only on a quality assurance sampling basis. Cable averages can be obtained by averaging individual pair readings. Average mutual capacitance can also be measured by grouping a number of pairs together (electrically in parallel circuits), measuring the capacitance of the group and dividing the total capacitance by the number of pairs tested to obtain a grouped average. When grouped readings are made, no more than 25 pairs should be grouped for any one reading. Conversely, grouped readings should not be used for cables containing 25 or fewer pairs.

18.7 Unless otherwise specified, measure mutual capacitance at 23 ± 3°C. Measured values are normally converted to a standard length value (normally 1 mile or 1 km). For mutual capacitance in nanofarads/mile, the values would be:

$$C_0 = \frac{C \times 5280}{L} \tag{5}$$

where:

C_0 = mutual capacitance, nF/mile,
C = mutual capacitance, measured, nF, and
L = specimen length, ft.

NOTE 2—This method is applicable for lengths of 10 000 ft (3.05 km) or less. Special correction factors are required for longer lengths.

18.8 *Report*:

18.8.1 Report in accordance with Section 47 and include the following:

18.8.1.1 Minimum, maximum, and average values, and

18.8.1.2 Standard deviation.

18.9 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for mutual capacitance since the result merely states whether there is conformance to the criteria for success specified in the product specification.

19. Capacitance Deviation

19.1 The desired intent of most telecommunications cable specifications is to have an individual pair mutual capacitance and a reel average mutual capacitance as close to the specified nominal requirement as possible. It is also intended that differences between reels of cable of different wire gages and of different pair counts should be kept to a minimum. The capacitance deviation for any reel of cable is defined as the calculated root mean square deviation of the mutual capacitance of all the measured pairs of the reel of cable from the average mutual capacitance for that reel of cable.

19.2 Using the methods described in Section 18, measure the individual pair mutual capacitances. (Note that this method cannot be applied to *grouped* mutual capacitance readings.) Calculate the capacitance deviation from the measured data using the following equation:

$$D = \frac{\sigma}{\bar{x}} \times 100\ (\%) \tag{6}$$

where:

D = % RMS deviation from average,
σ = $\sqrt{\frac{\Sigma x^2}{N} - \left(\frac{\Sigma x}{N}\right)^2}$,
$\bar{x}$ = $\frac{\Sigma x}{N}$, and
x = individual mutual capacitance values (nF/mile, nF/kft, nF/km, etc.)

19.2.1 The calculated percentage deviation for any measured cable shall comply with the requirements of the product specification.

19.3 *Report*—Report in accordance with Section 47 and include the percent deviation.

19.4 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for capacitance deviation since the result merely states whether there is conformance to the criteria for success specified in the product specification.

20. Capacitance Difference (Filled Core only)

20.1 This test may be used to provide some assurance that a filled cable is adequately filled across the entire cross-section of the cable core. This test can be applied only to cables that are manufactured with a clearly discernible center layer of pairs.

20.2 Using the methods described in Sections 13 and 18, measure the conductor resistance and mutual capacitance of individual pairs selected at random, keeping separate records for pairs from the inner layer and for pairs from the outer layer. When measuring compartmental core cables, make measurements in each compartment separately. Unless otherwise permitted, the number of inner and outer pair readings shall each be at least 5 % of the total pair count, or 25 readings, whichever is less.

20.3 Calculate the average conductor resistance and average mutual capacitance for the innermost pairs (center layer) and record as (R_i and C_i, respectively). Repeat this calculation for the outermost pairs and record as (R_0 and C_0, respectively).

20.4 Calculate the percent difference, D, in the average mutual capacitance for the innermost and outermost pairs using the following equation:

$$\% D = \frac{C_0 - C_i}{C_0} - \frac{R_0 - R_i}{R_0} \times 100 \quad (7)$$

20.4.1 The calculated percentage difference for any measured cable shall comply with the requirements of the product specification.

20.5 *Report*—Report in accordance with Section 47.

20.6 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for capacitance difference since the result merely states whether there is conformance to the criteria for success specified in the product specification.

21. Capacitance Unbalance—Pair to Pair

21.1 The capacitances involved and the definition of pair-to-pair capacitance unbalance are illustrated in Fig. 2, where *a* and *b* represent the two conductors of a pair and *c* and *d* represent the two conductors of another pair.

21.1.1 The capacitances, namely C_{ac}, C_{ad}, C_{bc} and C_{bd} are the direct capacitances between conductors. Direct capacitance is defined in ANSI/IEEE Standard 100 – 1984.

21.1.2 The capacitances C_{ag}, C_{bg}, C_{cg} and C_{dg} are the direct capacitances between wires *a*, *b*, *c* and *d* respectively, and all other conductors in the cable that are connected to the shield and grounded.

21.2 Measure the pair-to-pair capacitance unbalance at a frequency of 1000 ± 100 Hz using a capacitance unbalance bridge. Various types of automatic or semiautomatic equipment may also be used.

21.3 In cables of 25 pairs or less and in each group of multigroup cables, the unbalances to be considered are all of the following:

21.3.1 Between pairs adjacent in a layer,

21.3.2 Between pairs in the center, when there are four pairs or less, and

21.3.3 Between pairs in adjacent layers, when the number of pairs in the inner (smaller) layer is six or less. Here, the center is counted as a layer.

21.4 If a capacitance unbalance bridge is not available, the direct capacitances (refer to 21.1) C_{ac}, C_{ad}, C_{bc} and C_{bd} can be measured using a voice-frequency capacitance bridge or comparable equipment. The pair-to-pair capacitance unbalance, C_{upp}, can then be calculated using the following equation:

$$C_{upp} = (C_{ad} + C_{bc}) - (C_{ac} + C_{bd}) \quad (8)$$

21.5 Unless otherwise specified, correct the maximum, average, and root mean square capacitance unbalance values for each length other than 1000 ft (or 1000 m) to 1000 ft (or 1000 m) by dividing the value of unbalance for the length measured by the square root of the ratio of the length measured to 1000.

$$Y_1 = \frac{Y}{\sqrt{X/1000}} \quad (9)$$

where:

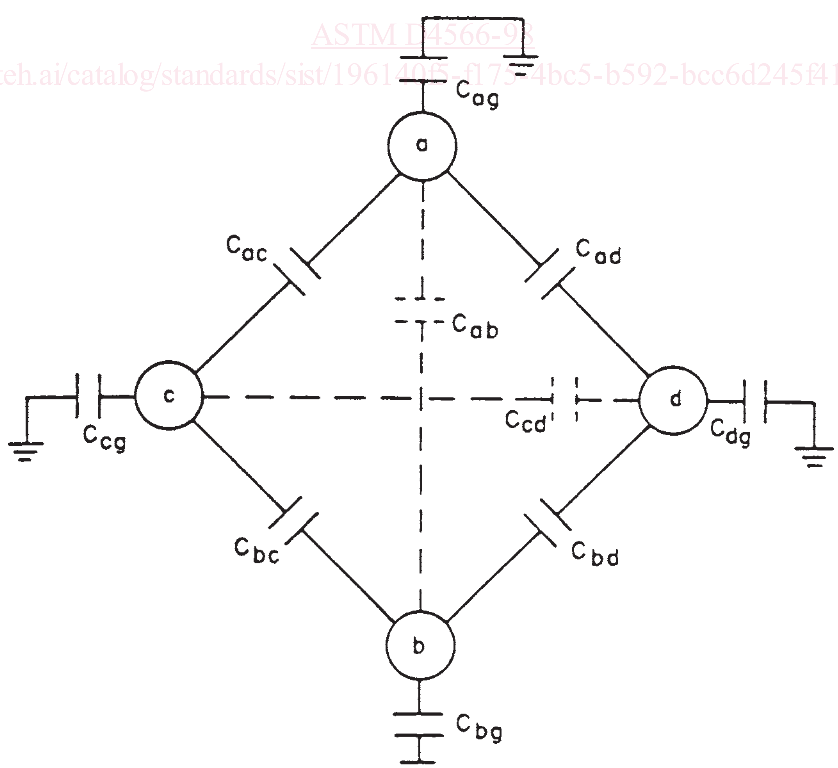


FIG. 2 Conductor Capacitances

Y_1 = unbalance corrected to 1000 ft (1000 m),
Y = unbalance of cable length, and
X = cable length, ft (m).

21.6 *Report*—Report in accordance with Section 47 and include the maximum, average, and root mean square values.

21.7 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for capacitance unbalance (pair-to-pair) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

22. Capacitance Unbalance—Pair-to-Ground

22.1 The capacitances involved and the definition of pair-to-ground capacitance unbalance are illustrated in Fig. 3, where *a* and *b* represent the two conductors of a pair. The capacitances, namely C_{ag} and C_{bg}, are the direct capacitances between conductors *a* and *b* respectively and the shield. The capacitances C_{ap} and C_{bp} are the direct capacitances between conductors *a* and *b* respectively and all other pairs.

22.2 Using a capacitance unbalance bridge, measure the pair-to-ground capacitance unbalance at a frequency of 1000 ± 100 Hz. Various types of automatic or semiautomatic equipment may also be used.

22.3 If a capacitance unbalance bridge is not available, the direct capacitances (refer to 22.1) C_{ag}, C_{bg}, C_{ap}, and C_{bp} can be measured using a voice-frequency capacitance bridge or comparable equipment. The pair-to-ground capacitance unbalance, C_{upg}, can then be calculated using the following equation:

$$C_{upg} = (C_{ag} + C_{ap}) - (C_{bg} + C_{bp}) \tag{10}$$

22.4 Unless otherwise specified, correct the maximum and average capacitance unbalance values for each length other than 1000 ft (or 1000 m) to 1000 ft (or 1000 m) by dividing the value of unbalance for the length measured by the ratio of the length measured to 1000.

$$Y_1 = \frac{Y}{X/1000} \tag{11}$$

where:
Y_1 = unbalance corrected to 1000 ft (1000 m),
Y = unbalance of cable length, and
X = cable length, ft (m).

22.5 *Report*—Report in accordance with Section 46 and include the maximum and average values.

22.6 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for capacitance unbalance (pair-to-ground) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

23. Capacitance Unbalance—Pair-to-Support Wire

23.1 This particular procedure is applied only to self-supported (that is, integral messenger wire) non-shielded telecommunications wire and cable.

23.2 Unbalances shall be measured as described in Section 22 except that the grounded support wire replaces the shield in all measurements. The maximum allowable unbalance shall comply with the requirements of the product specification.

23.3 *Report*—Report in accordance with Section 47 and include the maximum value.

23.4 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for capacitance unbalance (pair-to-support wire) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

24. Crosstalk Loss—Near End

24.1 Near-end crosstalk loss (NEXT) is usually defined and measured as an input-to-output crosstalk (that is, the power input to the disturbing pair is compared to the output power coupled into the disturbed pair at the end of the cable which includes the disturbing source). Referring to Fig. 4, the NEXT shall be defined as:

$$Xm = \left| 20 \log_{10} \frac{V_{2N}}{V_{1N}} \right| \tag{12}$$

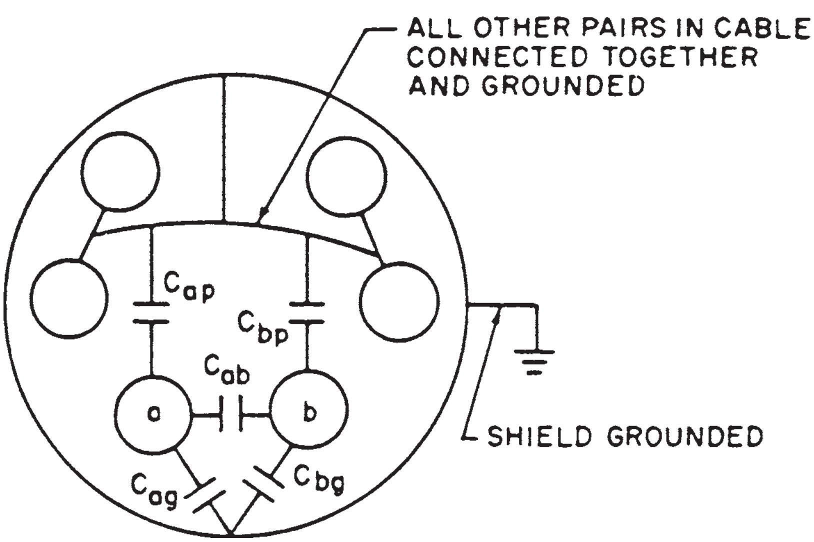
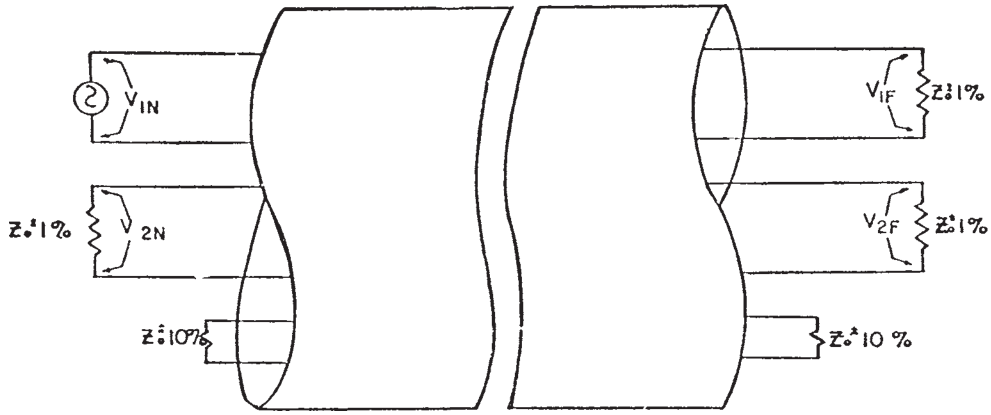


FIG. 3 Pair-to-Ground Capacitance Unbalance



NOTE 1—1. Source impedance = $Z_0 \pm$ 1 %. 2. Z_0 at 150 kHz (FEXT) or 3. Z_0 at 772 or 1576 kHz (NEXT). 4. Terminating resistors Z_0 shall be noninductive.

FIG. 4 Test Circuit for Crosstalk Measurements

where:

V_{1N} = disturbing pair input voltage, and
V_{2N} = disturbed pair output voltage, near end.

24.1.1 To correct crosstalk values to the nominal characteristic impedance, algebraically add the following factor to the measured value:

$$20 \log_{10} \frac{4 Z_0 Z}{(Z_0 + Z)^2} \tag{13}$$

where:

Z_0 = nominal characteristic impedance, and
Z = terminating impedance

24.2 Cable ends shall be prepared for test as described in 18.3.

24.3 Unless otherwise specified, (*a*) the equipment used for crosstalk testing shall be balanced to ground and the pairs under test shall be terminated in their nominal characteristic impedance ±1 %, (*b*) pairs not under test shall be terminated at both ends in their nominal characteristic impedance ±10 %, and (c) the input to the disturbing pair shall be approximately 10 dBm. The circuit of Fig. 4, or equal, shall be used. If the crosstalk values are impedance-corrected (as illustrated in 24.1) to the nominal characteristic impedance, the pairs under test may be terminated in their nominal characteristic impedance ±25 %. However, in case of conflict, data derived with the pairs terminated in their nominal characteristic impedance ±1 % shall be used.

24.3.1 For accurate readings, each pair in the cable under test must be terminated; however, if readings are taken on a sampling of the pairs, the pairs not under test usually can be left unterminated, since any error introduced by this shortcut will be minor and in the conservative direction (that is, readings will be worse than if all pairs had been terminated).

24.4 Measure the NEXT between pairs, as required by the detailed product specification using a signal generator and a level meter. Various types of automatic or semiautomatic equipment may also be used.

24.5 Measured values are normally corrected to a standard length value (normally 1000 ft or 1000 m). Correction of measured values is not required if lengths of 1000 ft (305 m) or more are used. If lengths less than 1000 ft (305 m) are measured then correct the readings to 1000 ft (305 m) by using the following equation:

$$N_x = N_o - 10 \log_{10} \frac{1 - e^{-4\alpha 1_x}}{1 - e^{-4\alpha 1_o}} \tag{14}$$

where:

N_x = near end crosstalk, dB/1000 ft (305 m),
N_o = near end crosstalk, dB/cable length,
α = attenuation, nepers/cable length,
1_o = cable length, ft (m),
1_x = reference length, 1000 ft (305 m), and
e = 2.71828.

24.6 Some specifications require near end crosstalk to be reported as power sum (P.S.) near end crosstalk. This requirement normally applies to cables containing 50 or more pairs. P.S. NEXT can be calculated from readings obtained in 24.4 as follows:

$$\text{P.S. NEXT} = 10 \log_{10} \sum_{n=1}^{n} 10^{\frac{(-dB)n}{10}} \tag{15}$$

where:

dB = measured near end crosstalk, dB, and
n = number of pairs being measured minus 1, (for example, for a 50 pair cable each pair will have 49 measurements).

24.7 *Report*:

24.7.1 Report in accordance with Section 47 and include the following:

24.7.1.1 Minimum and average values,

24.7.1.2 Standard deviation, σ, and

24.7.1.3 Power sum near end crosstalk (if applicable).

24.8 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for near end crosstalk (NEXT) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

25. Crosstalk Loss—Far End

25.1 Referencing Fig. 4, the far-end crosstalk loss (FEXT) shall be defined as:

$$FEXT\ dB = |20 \log_{10} \frac{V_{2F}}{V_{1F}}| \quad (16)$$

where:
V_{1F} = disturbing pair output voltage, and
V_{2F} = disturbed pair output voltage, far end.

25.2 Cable ends shall be prepared as described in 18.3 (except both ends must be stripped) and terminated as described in 24.3.

25.3 Measure the output-to-output FEXT for any binder group in completed cable at the specified frequency (±1 %) using a signal generator and a level meter. Various types of automatic or semiautomatic equipment may also be used. The measured values shall be corrected to the normal characteristic impedance as illustrated in 24.1.

25.4 Take measurements between adjacent and alternate adjacent pairs in the same layer, and center to first layer within each binder group. Calculate the root mean square FEXT using the following formula:

$$\text{rms FEXT } dB = |20 \log_{10} \sqrt{\frac{\sum_{K=1}^{N} \left[\left(\frac{V_{2F}}{V_{1F}} \right)^2 \right]_K}{N}}| \quad (17)$$

where:
N = number of measurements performed.

25.5 Unless otherwise specified, FEXT shall be measured at 23 ± 3°C. Measured values are normally converted to a standard length value (normally 1000 ft or 1000 m). To convert FEXT of the tested length to FEXT of 1000 ft, algebraically add the following factor to the calculated FEXT:

$$10 \log_{10} \left(\frac{\text{Measured length (ft)}}{1000} \right) dB \quad (18)$$

25.6 Some specifications require far end crosstalk to be reported as power sum (P.S.) far end crosstalk. P.S. FEXT can be calculated from readings obtained in 25.4 (except measurements must be made on all pair combinations) using the formula presented in 24.6.

25.7 *Report*—Report in accordance with Section 47 and include the minimum and root mean square values.

25.8 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for far end crosstalk (FEXT) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

26. Attenuation

26.1 Attenuation is a measure of the loss in signal strength over a length of wire or cable and is affected by the materials and geometry of the insulated conductors. Referring to Fig. 4, attenuation shall be defined as:

$$\alpha = 20 \log_{10} \left(\frac{V_{1F}}{V_{1N}} \right) \quad (19)$$

where:
α = measured attenuation of cable length, dB,
V_{1N} = input voltage level, and
V_{1F} = output voltage level.

26.2 Cable ends shall be prepared as described in 25.2.

26.3 Measure attenuation using a signal generator and a level meter. Various types of automatic or semiautomatic equipment may also be used. Unless otherwise specified, the equipment used for measuring attenuation shall be balanced to ground and the pairs under tests shall be terminated in their nominal characteristic impedance ± 1 %.

26.4 Unless otherwise specified, measure attenuation at or correct to 20°C (68°F). Temperature corrections can be made using the following equations:

26.4.1

$$\alpha_{20} = \frac{\alpha_\tau}{[1 + 0.0022\,(T - 20)]} \quad (20)$$

where:
α_τ = measured attenuation,
τ = temperature, °C, and
α_{20} = attenuation corrected to 20°C.

26.4.2

$$\alpha_{68} = \frac{\alpha_\tau}{[1 + 0.0012\,(T - 68)]} \quad (21)$$

where:
α_τ = measured attenuation,
τ = temperature, °F, and
α_{68} = attenuation corrected to 68°F.

26.5 Alternatively, the information and instructions given in Fig. 5 may be used for performing temperature corrections. Measured values are normally converted to a standard length value (normally 1 mile, 1000 ft, or 1 km). Attenuation is considered to vary directly with length.

26.6 Upon completion of measurements, mathematically manipulate the recorded data as appropriate (for example, determine averages, adjust for temperature and length, etc.) and compare with the requirements of detailed specifications.

26.7 *Report*:

26.7.1 Report in accordance with Section 47 and include the following:

26.7.1.1 Minimum, maximum, and average values, and

26.7.1.2 Ambient temperature.

26.8 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for attenuation since the result merely states whether there is conformance to the criteria for success specified in the product specification.

27. Insulation Resistance

27.1 Before measuring, prepare cable ends in accordance with 18.3.

27.2 Each insulated conductor shall be measured with all other insulated conductors and the shield grounded. Measurements shall be made with a dc potential of not less than 100 or more than 550 V applied for 1 min. The test may be terminated within the minute as soon as the measurement demonstrates that the specified value has been met or exceeded.