Designation: D 4566 – 98

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.

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[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

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

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:

$$G_0 = \frac{G \times 5280}{L} \tag{3}$$

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:

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

where:

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

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

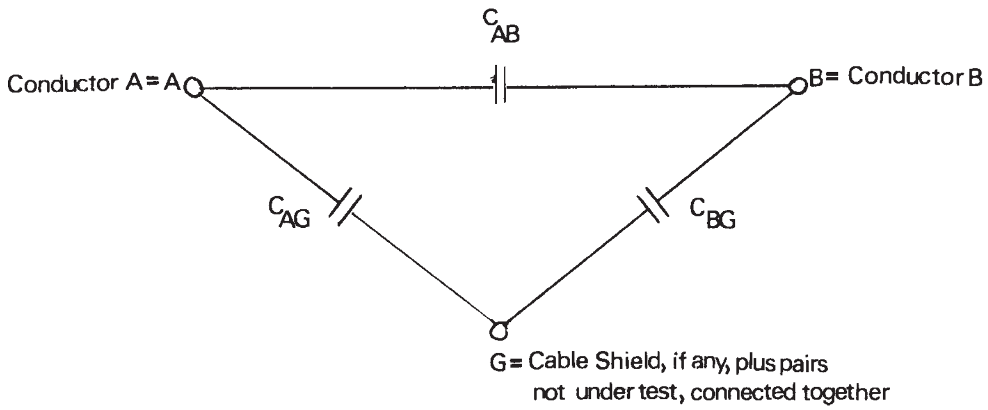


FIG. 1 Mutual Capacitance Relationships

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:

$$\%\, D = \frac{C_0 - C_i}{C_0} - \frac{R_0 - R_i}{R_0} \times 100 \tag{7}$$

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:

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

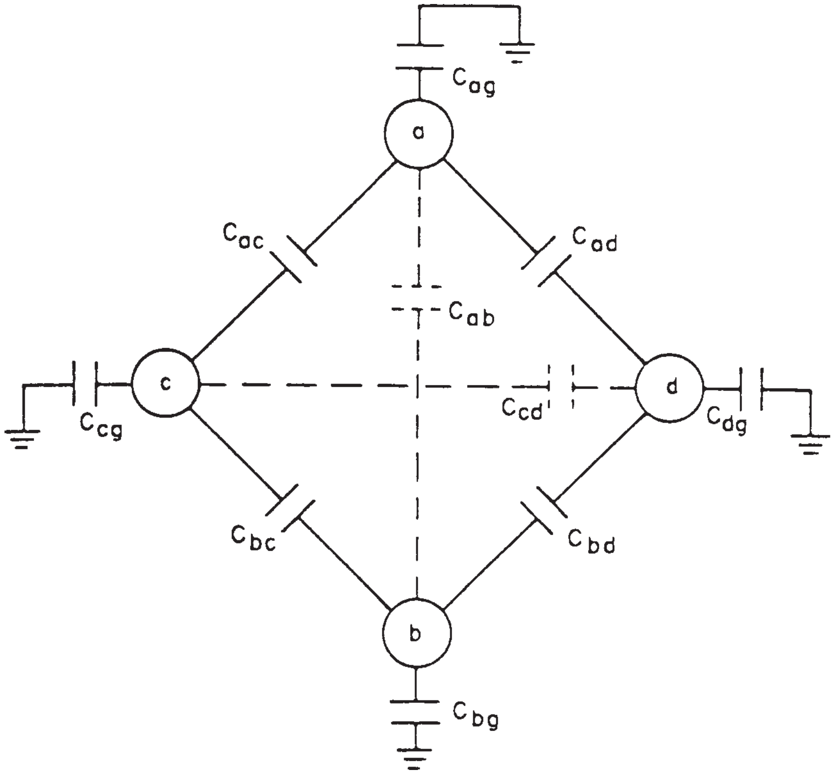


FIG. 2 Conductor Capacitances

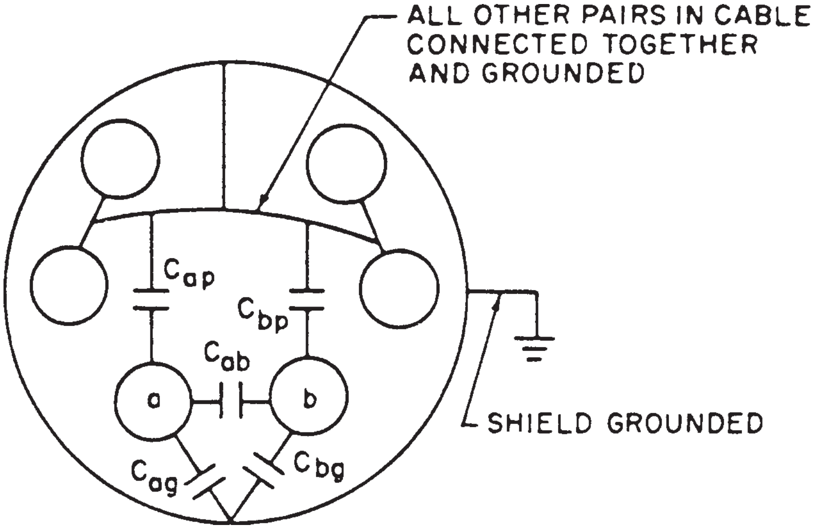


FIG. 3 Pair-to-Ground Capacitance Unbalance

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:

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

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

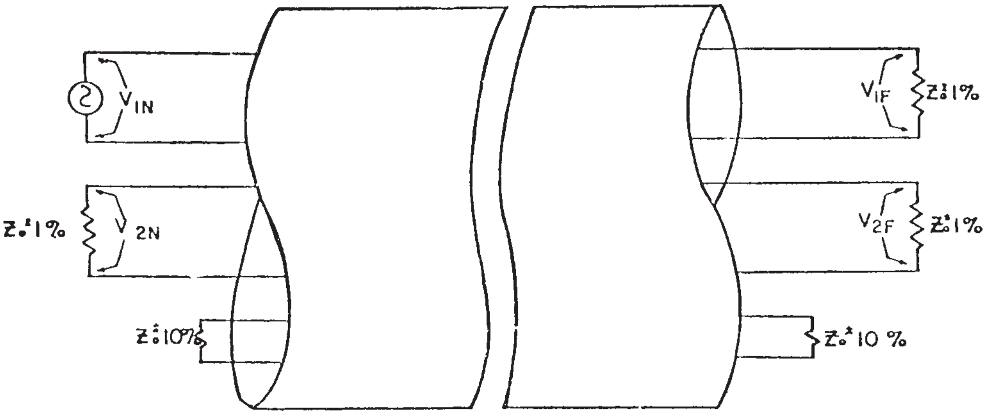
24.1.1 To correct crosstalk values to the nominal characteristic impedance, algebraically add the following factor to the measured value:

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

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 %,



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

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:

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

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:

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

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:

$$FEXT\,dB = \left| 20 \log_{10} \frac{V_{2F}}{V_{1F}} \right| \qquad (16)$$

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:

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

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:

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

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:

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

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

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

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

26.4.2

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

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.

27.3 Unless otherwise specified, measure insulation resistance at or correct to 20°C (68°F). Measurements shall be made using a megohmeter. Measured values are normally converted to a standard length value (normally 1 mile or 1 km). For insulation resistance in megohm-miles, the values would be:

$$IR_0 = \frac{IR_M \times L}{5280} \tag{22}$$

where:
IR_0 = insulation resistance (megohm-mile),
IR_M = insulation resistance, measured (megohms), and
L = specimen length (ft).

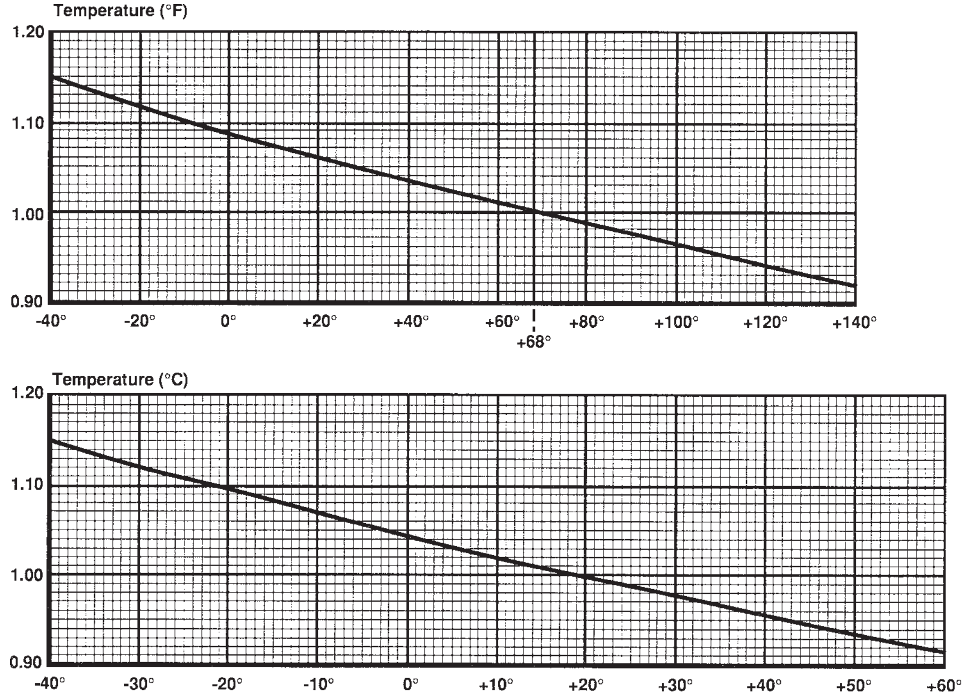
27.4 *Report*:

27.4.1 Report in accordance with Section 46 and include the following:

27.4.1.1 Minimum and average values, and

27.4.1.2 Ambient temperature.

27.5 *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 resistance since the result merely states whether there is conformance to the criteria for success specified in the product specification.



To adjust attenuation data from one temperature to another, proceed as follows:

1. Find the point where the temperature correction factor (TCF) curve is intersected by the vertical line for the temperature of interest. Project this intersection point horizontally and read the temperature correction factor on the vertical scale.

Example:	For Temperature	Read TCF
	40°C (104°F)	0.96
	50°C (122°F)	0.938

2. If adjusting from a non-standard temperature to the reference temperature (20°C or 68°F), *multiply* the known attenuation by the temperature correction factor to determine the attenuation at reference temperature.

Example: Known—attenuation is 2 dB [][@] 40°C (104°F)
Determine—attenuation at 20°C (68°F)

Method: (1) *Read* TCF = 0.96
(2) *Multiply:* 2 dB × 0.96 = 1.92 dB

3. If adjusting from the reference temperature (20°C or 68°F), *divide* the known attenuation by the temperature correction factor to determine the attenuation at the non-standard temperature.

Example: Known—attenuation is 2 dB [][@] 20°C (68°F)
Determine—attenuation at 50°C (122°F)

Method: (1) *Read* TCF = 0.938
(2) *Divide:* 2 dB ÷ 0.938 = 2.13 dB [][@] 50°C (122°F)

NOTE 1—This Graph applies to copper loss correction only, dielectric losses are assumed to be constant with the temperature.

FIG. 5 Attenuation Temperature Correction Factor

28. Fault Rate Test (Air Core Cable Only)

28.1 Just as in the case of in-process fault rate (7.2), fault rate in finished air core cable represents the relationship between the number of faults detected and the conductor footage examined, expressed as a ratio of one fault per given quantity of conductor length.

$$\text{Fault Rate} = \frac{X \text{ faults detected}}{Y \text{ quantity tested}} = \frac{1 \text{ fault}}{Z \text{ quantity length}} \qquad (23)$$

28.2 For finished air core cable, the following method may be used (or required) to establish fault rate:

28.2.1 Select a sample of completed wire or cable and cut a specimen length such that a minimum of 1000 conductor ft (300 conductor m) will be included in the specimen.

28.2.2 With the exception of test ends, expose each insulated conductor to tap water over its entire length (by removing outer covering and immersing the exposed wires, or by filling the specimen with water under pressure).

28.2.3 Measure the insulation resistance for each wire, in accordance with Section 27.

28.2.4 Cut failing lengths of wire into 25-ft (7-m) lengths and retest these to ensure detection of multiple faults.

28.3 Additional specimens may be cut and tested, provided that selected specimens are separated by a minimum of 20 000 cable ft (6100 cable m) from any other tested specimen. Fault rate is then determined by relating faults found to conductor length tested, as stated in 28.1.

28.4 *Report*:

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

28.4.1.1 Conductor footage tested,

28.4.1.2 Number of faults detected (if any), and

28.4.1.3 The fault rate.

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

29. Shorts Test (Continuity Between Wires of a Pair)

29.1 Testing for shorts is normally accomplished using the voltage test method of Section 32 except that testing is expedited by connecting the tip conductors of each pair together, and connecting the ring conductors of each pair together, and then making one tip-to-ring voltage test.

29.2 *Report*:

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

29.2.1.1 Identification and number of shorts detected (if any), and

29.2.1.2 The voltage level.

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

30. Crosses Test (Continuity Between Wires of Different Pairs)

30.1 Testing for crosses is normally accomplished by using the voltage test method of Section 32. If pairs have been separated for other purposes, it may be desirable to test the two wires of each pair (connected together) to all other pairs using the method of Section 32, provided that the shorts test of Section 29 has also been performed.

30.2 *Report*—Report in accordance with 29.2.1.

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

31. Jacket Voltage Breakdown Rating Test

31.1 This test is normally applied only to wire and cable intended as "unprotected" premises wiring to ensure compliance with Federal Communications Commission (FCC) regulations, Part 68, Section 68.213.

31.2 Prepare a specimen of completed wire or cable at least 12 in. (300 mm) long. Completely cover the center 6 in. (150 mm) of the specimen with conductive foil. Connect all of the underlying conductors (including any shield under the jacket) of the wire or cable together.

31.3 Apply a 60 Hz ac potential between the grouped conductors and the foil, gradually increasing the potential to the required value over a 30 s time period, and then maintaining this potential for a period of 1 min. Measure current flow throughout the entire 90 s test period.

31.4 Unless otherwise specified, and to comply with FCC regulations, apply a maximum voltage potential of 1500 V ac; the maximum current flow permitted throughout the 90 s test is 10 mA peak. Other voltage and current limitations may be specified for other than FCC compliance purposes.

31.5 *Report*—Report in accordance with Section 47 and include the following:

31.5.1 The maximum voltage level used in the test, and

31.5.2 The maximum current flow measured during the test period.

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

32. DC Proof Test—Wire-to-Wire

32.1 High voltage breakdown testing of telecommunications wire and cable is traditionally performed (*a*) using a dc voltage source, (*b*) in a dry configuration, and (*c*) on complete production or shipping lengths of wire or cable.

32.1.1 **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.*

32.2 Obtain the dc proof test voltage from a dc source capable of supplying the required voltage. The peak-to-peak ac ripple component of the dc proof test voltage shall not exceed 5 % of the average voltage value under no-load conditions.

32.3 Measure the dc proof test voltage by a method that provides the average value of the voltage applied to the insulated conductor under test. It is recommended that the voltage be measured by the use of a dc meter connected in series with appropriate high-voltage type resistors across the high-voltage circuit. An electrostatic voltmeter of proper range may be used in place of the dc meter-resistor combination. The accuracy of the voltage measuring circuit shall be within ±2 % of full scale.

32.4 Apply the dc proof voltage with a rate-of-rise of approximately 3000 V/s dc. Each insulated conductor shall be tested to every other insulated conductor in the wire or cable assembly.

32.5 Voltage magnitude shall be as specified by the product specification. Unless otherwise specified, apply the voltage for a period of 3 s.

NOTE 3—For automated test sets, conductors are usually fanned out on a test board and the test proceeds automatically; for manual testing, it is usually most convenient to ground all conductors except one, and apply voltage to the ungrounded conductor. As each conductor is successively tested to all others, it is removed from the test configuration.

32.6 *Report*—Report in accordance with 29.2.1.

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

33. DC Proof Test—Core-to-Shield

33.1 This test is performed following the methods of Section 32 except that all conductors in the core are grouped together, and high voltage is applied between these conductors and the grounded shield.

33.2 Voltage magnitude shall be as specified by the product specification. Unless otherwise specified, apply the voltage for a period of 3 s.

33.3 *Report*—Report in accordance with 29.2.1.

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

34. DC Proof Test—Core-to-Support Wire

34.1 This test is normally performed only for non-shielded wire and cable. The test is performed in accordance with Section 32 except that all conductors in the core are grouped together, and high voltage is applied between these conductors and the grounded supporting messenger wire.

34.2 Voltage magnitude shall be as specified by the product specification. Unless otherwise specified, apply the voltage for a period of 3 s.

34.3 *Report*—Report in accordance with 29.2.1.

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

35. DC Proof Test—Core-to-Internal Shield (Screen)

35.1 This test is normally applied to all cables which include an internal shield or screen. The test is performed following the methods of Section 32 except that the conductors in the core are grouped together, and high voltage is applied between these conductors and the grounded screen.

35.2 Voltage magnitude shall be as specified by the product specification. Unless otherwise specified, apply the voltage for a period of 3 s.

35.3 *Report*—Report in accordance with 29.2.1.

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

36. DC Proof Test—Internal Shield (Screen)-to-Shield

36.1 This test is normally applied to all cables that include an internal shield or screen. The test is performed in accordance with Section 32 except that the conductors of the core are left electrically floating and high voltage is applied between the internal screen and the grounded cable shield.

NOTE 4—This test applies only if the internal shield is intended to be electrically isolated from the outer shield.

36.2 Voltage magnitude shall be as specified by the product specification. Unless otherwise specified, apply the voltage for a period of 3 s.

36.3 *Report*—Report in accordance with 29.2.1.

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

37. DC Proof Test—Other Required Isolations

37.1 Depending upon the complexity of the completed wire or cable constructions, product specifications may require that other electrical isolations be verified. As an example, dielectric breakdown testing of the jacket between the shield and armor may be required for a cable having an armor applied over a shielded and jacketed core. All such testing shall be performed in accordance with Section 32, with voltage appropriately applied to the members under test.

37.2 Voltage magnitude shall be as specified by the product specification. Unless otherwise specified, apply the voltage for a period of 3 s.

37.3 *Report*—Report in accordance with 29.2.1.

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

38. Voltage Surge Test

38.1 Voltage surge testing may be required for qualification purposes on new or modified designs of telecommunications wire and cable. Such testing is intended to simulate the effect of lightning strikes. Two types of test shall normally be performed: wire-to-wire and core-to-shield.

38.2 Select a reel of cable for the test. A25-pair 22 AWG cable is most commonly used for voltage surge testing. From the selected reel, cut a sample length long enough to permit the necessary specimen preparation.

38.3 Unless otherwise specified, cut two specimen lengths from the sample, each specimen to be 10 ft (3 m) in length after the end preparation.

NOTE 5—Exercise care throughout the specimen preparation to avoid torn or rough shield edges, unintentional knicks and cuts of insulation, core wrap, shield, etc. Proper specimen preparation is critical to the success of this test.

38.3.1 Remove approximately 18 in. (460 mm) of the outer sheath (outer jacket and armor and inner jacket, if present) from each end of each specimen.

38.3.2 Remove approximately 15 in. (380 mm) of shield from each end of each specimen.

38.3.3 Remove approximately 8 in. (205 mm) of the core wrap at each end of each specimen. Fasten the loose ends of core wrap with plastic insulating tape.

38.3.4 Select pairs for testing at random. Unless otherwise indicated, a minimum of three pairs and a maximum of 10 % of the cable pairs (for large cables) shall be tested. For the core-to-shield test specimen, all pairs selected should be in the outer layer of the core.

38.4 Conduct all testing in air as prescribed by Method D 3426. Unless otherwise specified, only one test shall be made for each type of test performed.

38.4.1 For the wire-to-wire test specimen, apply the specified voltage surge in succession between the wires of conductors of each selected pair. Examine an oscilloscope photograph record for evidence of breakdown failure.

38.4.2 For the core-to-shield test specimen, apply the specified voltage surge in succession between each selected pair and the shield. Examine an oscilloscope photograph record for evidence of breakdown failure.

38.5 *Report*—Report in accordance with Section 46.

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

39. Phase Constant

39.1 The phase constant of a pair of conductors is a measure of the phase shift incurred by the sinusoidal signal as it propagates over the length of a pair. It is affected by the materials and geometry of the insulated conductors. Referring to voltage designated in the top circuit of Fig. 4, the phase constant, β, is defined as:

$$\beta = \angle(V_{1F}) - \angle(V_{1N}) + 2\pi k \tag{24}$$

where:

β = total phase of the length of cable, rad,

$\angle(V_{1N})$ = input angle relative to the same reference angle, and

$\angle(V_{1F})$ = output angle relative to the same reference angle, and

k = multiple of 2π rad.

NOTE 6—This measurement is normally performed at the same time as attenuation (see Section 26).

39.2 *Specimen Preparation*—Prepare the cable ends as described in 25.2.

39.3 *Specimen Measurement*—Measure the phase constant using a sinusoidal signal generator and a phase meter. Equipment such as a network analyzer may be used. For balanced pairs, the transmit and receive ports of the measurement instrument shall afford balanced voltages with respect to ground and balanced currents (commonly accomplished with a transformer). Terminate pairs under test in their nominal characteristic impedance ± 1 %.

39.4 *Determining k*:

39.4.1 *Determining k by Examining Analyzer Display*—Obtain the multiplier, *k*, by interpreting the data acquired over the range of frequencies as appropriate. The phase meter or network analyzer normally yields only the difference between the first and second terms shown on the right hand side of Eq 24. Fig. 6 shows the total phase and the sawtooth representation obtained from a network analyzer. When a network analyzer is used, a trace of the phase constant cycling through the 2π rad (360 degree) range is generally displayed on a CRT display, facilitating the determination of *k*. A frequently used technique in the interactive mode is to start at a low frequency where $k = 0$, by counting the number of $+ 2\pi$ to 0π traversals to obtain the value for *k*.

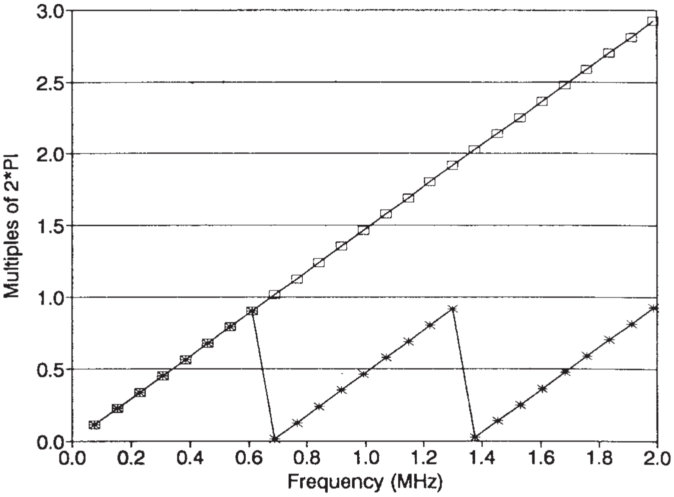


FIG. 6 Determining the Multiple of 2π Radians to be Added to the Phase Measurement

39.4.2 *Determining k Numerically*—Acquire the phase information obtained with the network analyzer digitally by means of an interface with a digital computer as was done with the points plotted in Fig. 6. Follow the data acquisition with a program procedure which starts by establishing a starting slope from several points in the $k = 0$ (multiple of 2π) frequency region. Let the program continue by examining each remaining point in succession. If the next point is not within $\pi/2$ rad of the continuous phase line being established, increment *k* until it is. This approach works even when intermediate values of *k* are passed over, once the correct starting slope is established.

39.5 *Length Function*—Use a procedure called the "length" function which is built into many network analyzers to obtain the total phase. This internal procedure subtracts the specified length, which can be expressed as seconds of delay (actually a constant times frequency), from the internally established total delay and displays the remainder as a residual phase. The displayed phase trace is conveniently kept within the 0 to 2π (or alternately $-\pi$ to $+\pi$) range over the whole frequency range by supplying the appropriate length value to the analyzer.

39.6 *Report*—Report in accordance with Section 47 and include the following data: minimum, maximum, average and standard deviation.

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

40. Phase Delay

40.1 Compute phase delay, τ, from the Phase Constant as measured in accordance with Section 39, by means of:

$$\tau = \frac{\beta}{\omega} \tag{25}$$

where:

τ = phase delay of cable length, s,

β = phase constant from Section 39, rad, and
ω = radian frequency.

Phase Delay (not the same as group delay) is a measure of the amount of time a simple sinusoidal signal is delayed when propagating through the length of a pair or cable and, like the Phase Constant, is affected by the materials and geometry of the insulated conductors.

40.2 *Report*—Report in accordance with Section 47 and include the following data: minimum, maximum, average and standard deviation.

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

41. Phase Velocity

41.1 Compute phase velocity, ν, from the Phase Constant, as measured in accordance with Section 39 by means of:

$$\nu = \frac{\omega}{\beta} \tag{26}$$

where:
ν = phase velocity, distance/s,
ω = radian frequency, rad/s, and
β = phase constant.

Phase velocity (reciprocal of phase delay) is a measure of the velocity with which a sinusoidal signal propagates through a cable.

41.2 Phase velocity is normally reported in unit of length per unit of time such as m/s.

41.3 Phase velocity is sometimes reported as a ratio consisting of the phase velocity from 41.2 divided by the velocity of light in a vacuum (c). It is then reported, for example, as $0.71c$, meaning 0.71 × speed of light. A variation is to report it as a percentage such as, 71 %.

41.4 *Report*—Report in accordance with Section 47 and include the following data: minimum, maximum, average and standard deviation.

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

42. Characteristic Impedance—METHOD 1

42.1 *Characteristic Impedance from the Propagation Constant and Capacitance*—Characteristic impedance for many cable designs can readily be obtained using the propagation constant, consisting of the real attenuation and the imaginary phase constant, and the pair capacitance. The magnitude of the characteristic impedance simplifies to being a function of the delay and capacitance at high frequencies. This method is relatively easy to use for cables with non-polar dielectrics where an easily obtained low frequency capacitance value (See Section 18 for mutual capacitance) is valid over a broad range of frequencies. The additional phase constant information required for this method of characteristic impedance determination is obtained with little additional measurement effort when obtained concurrently with the attenuation measurement procedure in 26.2.

42.1.1 *Important Formulas*—Characteristic Impedance can be stated in terms of the primary cable pair parameters as follows:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{27}$$

where:
Z_0 = the complex characteristic impedance, Ω and Degrees,
R = the ac resistance of the pair length, Ω
L = the inductance of the pair length, H,
G = the conductance of the pair length, S,
C = the capacitance of the pair length, F, and
ω = radian frequency, rad/s.

42.1.1.1 The propagation constant can be stated in terms of the same primary cable pair parameters as follows:

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{28}$$

where:
γ = the complex propagation constant of the length, nepers and radians.

42.1.1.2 The propagation constant can also be stated in terms of the attenuation measured in accordance with Section 26 and the phase constant measured in accordance with Section 39, as follows:

$$\gamma = \alpha + j\beta \tag{29}$$

where:
α = the real part, attenuation of the length, nepers, and
β = the imaginary part, the phase constant for the length, rad.

NOTE 7—It will be noted that the natural unit of attenuation, neper, is equal to 8.686 dB.

42.1.2 *Applicable Formula*—From Eq 27, Eq 28 and Eq 29 it follows that characteristic impedance can be stated in terms of the propagation constant and the shunt primary constants since:

$$Z_0 = \frac{\alpha + j\beta}{G + j\omega C} \tag{30}$$

42.1.3 *Delay Capacitance Procedure*—Measure the three quantities, capacitance, attenuation, and the phase constant, according to Sections 18, 26 and 39. Estimate the fourth quantity, conductance, which is relatively small compared to ωC (in the range of 0.01 % to 3 % depending on dielectric quality). The value of the characteristic impedance is minimally affected by an incorrect estimate of G. For instance, if it is assumed that $G/\omega = 0.0$ when in fact, $G/\omega = 0.03$ then Z_0 will be too large by a mere 0.05 %.

42.1.3.1 When only the reactive portions of Eq 27 are significant, a simpler version of Eq 30, shown here as Eq 31 (the delay-capacitance formula) may be used:

$$|Z_0| = \frac{\tau}{C} \tag{31}$$

where:

$|Z_0|$ = the magnitude of the characteristic impedance, Ω
τ = the delay, s, and
C = the capacitance, F.

42.1.4 *Report*—Report in accordance with Section 46 and include the following data: minimum, maximum, average and standard deviation.

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

43. Characteristic Impedance—METHOD 2—*Characteristic Impedance Obtained from Single Ended Measurements:*

43.1 *Option 1—Open and Short Circuit Measurements*—The open circuit and short circuit measurements have traditionally been employed to obtain the characteristic impedance of a cable pair (either coaxial or balanced). The basis for this measurement approach is the following:

$$Z_0 = \sqrt{Z_{oc}Z_{sc}} \tag{32}$$

where:
Z_0 = the complex characteristic impedance, Ω
Z_{oc} = the complex open circuit impedance, Ω, and
Z_{sc} = the complex short circuit impedance, Ω.

In the ideal sense, Eq 32 applies for frequencies and cable pair lengths varying from a fraction of a wavelength to multiple wavelengths. Measurements for balanced pairs must be made under balanced voltage and current conditions. Accurate characteristic impedance values can be reported directly as computed from Eq 32 for lines where structural effects are negligible.

43.1.1 For electrically long lines (more than ⅛ of a wavelength) the presence of structural variation influences the impedance observed at the measurement end considerably so that it is not the actual Z_0 but rather an input impedance Z_{in}. For this situation, least squares function fitting techniques covered in Section 44 can be used to extract the characteristic impedance from the input impedance.

43.2 *Option 2—Terminated Input Impedance Measurements*—A single terminated impedance measurement is an attractive alternative to the dual open and short circuit measurement procedure in that the resultant input impedance can be viewed directly on an instrument such as a network analyzer. The value of the load impedance does influence the input impedance value at low frequencies and for short lengths where cable loss is small. For the smooth line, this measurement is governed by the following equation:

$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tanh\gamma l}{Z_0 + Z_L \tanh\gamma l} \tag{33}$$

where:
Z_{in} = input impedance, Ω,
Z_0 = characteristic impedance, Ω,
Z_L = the load impedance, Ω,
γ = the propagation constant, nepers and radians, and
l = length of the pair.

Eq 33 indicates that the input impedance is substantially equal to the characteristic impedance if the load impedance is nearly equal to the characteristic impedance, or if the length is such that loss is considerable, in which case $\tanh\gamma l$ is close to unity. A round trip loss of 20 dB and a 15 % difference between the load impedance and pair impedance causes the terminated impedance to differ from the characteristic impedance by 1.4 % at most. A round trip loss of only 12 dB and 15 % impedance difference causes the reading to differ from Z_0 by, at most, 3.5 %

43.3 *Procedure for Method 2, Options 1 and 2—Obtaining the Input Impedance*—Much of the equipment used in the measurement procedure is the same for the open and short circuit approach as for the terminated approach.

43.3.1 *Equipment Required*—The equipment required for the input impedance measurement procedure consists of (*1*) a network analyzer with an *S*-parameter accessory, (*2*) calibration load with the appropriate nominal impedance value (for instance, 100 Ω) with a 1 % tolerance, (*3*) an impedance matching transformer for converting from unbalanced to balanced impedances (for instance, 50:100 Ω or 50:150 Ω) with a suitable frequency range, (*4*) appropriate test leads, and (*5*) a plotter for hard copy output. In addition, if data is being acquired digitally for subsequent processing, (*6*) a computer with an interface card and appropriate data acquisition software is required.

43.3.1.1 *Alternate Measurement Equipment*— A vector impedance meter can be substituted for the network analyzer and *S*-parameter accessory. A matching transformer may still be necessary to achieve a balanced impedance measurement. Equipment setup and calibration procedures will vary according to actual configuration being used.

43.3.2 *Specimen Preparation*:

43.3.2.1 *Choosing a Specimen Length*—Select a specimen length representative of the intended application, taking into consideration the shipping lengths, the loss at the highest measurement frequencies (in the 300 to 1100 ft range for cable intended for Local Area Network (LAN) application) and the low frequency round trip loss which needs to be at least 12 to 20 dB depending on accuracy desired (terminated impedance measurements only).

43.3.2.2 *Preparing the Ends*—Remove appropriate lengths of jacket and insulation from both ends of the specimen ensuring that the exposed portion is short compared to a wavelength at the highest frequencies (no more than 2.5 in. of jacket, 2 in. of shield, 0.75 in. of insulation for measurements extending to 100 MHz).

43.3.2.3 *Far End Termination*—Terminate the far end of the cable pairs with the appropriate load resistors (applicable only to terminated measurement procedure). For the open and short circuit method the corresponding condition must be supplied for each measurement.

43.3.2.4 *Laying Out the Specimen*—Evenly suspend the cable away from any ground surfaces so that the multiple traversals are separated by at least 1 in. and supported frequently to minimize tension to the cable core (applicable to unshielded cables only).

43.3.3 *Equipment Set-Up*—(*1*) Establish proper connections between network analyzer and the *S*-parameter accessory, (*2*) allow proper equipment warm up time, (*3*) connect the appropriate impedance matching transformer to the test port, (*4*) connect the plotter to the network analyzer (if applicable), and (*5*) connect the interface on network analyzer to computer interface card and load the acquisition program (if applicable).

43.3.4 *Equipment Calibration*—(*1*) Set frequency resolution of the network analyzer to a minimum of 100 points per decade (Note: Higher resolution is desired for best results/accuracy), (*2*) choose the log frequency sweep mode instead of the linear sweep mode if data is being acquired by the computer for subsequent fitting with an impedance function to achieve appropriate low versus high frequency weighting, (*3*) perform the three step one-port calibration of the analyzer using open/short/terminated connections at the end of the leads on the secondary (balanced) side of the transformer to determine the normalized reflection coefficient scan, and (*4*) set proper scales (linear vertical) and sweep time (minimum 10 s). See the Annex for calibration equations to be used with calibration data obtained from network analyzers lacking such computation capability internally.

43.3.5 *Specimen Measurement*—Connect twisted pair (with far end appropriately terminated in a load resistor for Option 2, or if Option 1 (open/short measurements are being made) then open or short circuit terminations) to an impedance matching transformer and sweep across the desired frequency range. The shields or other pairs, or both, may optionally be grounded to the center tap of the transformer secondary.

43.3.5.1 *For On-analyzer Evaluation of Terminated Impedance Measurements*—Plot results on plotter for a hardcopy of results. Alternately, for subsequent function fitting and structural return loss (SRL) determination, acquire the terminated input impedance results digitally by means of computer and appropriate software. In many network analyzers, conversion from the measured reflection coefficient, s_{11}, to impedance is done automatically by routines included with the analyzer controller using the formula:

$$Z_{\text{in}} = Z_L \frac{1 + s_{11}}{1 - s_{11}} \tag{34}$$

where:

Z_{in} = the complex input impedance, Ω
Z_L = load resistance used during calibration, Ω, and
s_{11} = the complex measured reflection coefficient.

43.3.5.2 *For Open and Short Data Acquisition Procedure*—Use the computer to acquire the two data scans (both real and imaginary components, or the magnitude and angle of the impedance for each scan). Use Eq 34 to convert from *S*-parameter to the open and short circuit impedances and compute input impedance using Eq 32.

43.4 *Report*—Report in accordance with Section 47 and include the following data: minimum, maximum, average and standard deviation.

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

44. Characteristic Impedance—METHOD 3

44.1 *Least Squares Function Fit of Impedance Magnitude and Angle*—Least squares function fitting consistently works best when the open and short circuit impedance data scans begin at a frequency sufficiently low so as to include frequencies where the cable length is shorter than a quarter wavelength. This approach, which allows averaging over the entire cable length at low frequencies, stabilizes the coefficients of the impedance like function in a manner representative of the actual characteristic impedance function being sought. This may suggest starting the measurement scan at a frequency lower than the range being addressed by a given performance standard (<0.3 MHz for a typical 500 ft cable length). Input impedance smoothness, which is ensured over this portion of the frequency range, contributes to achieving a good overall function fit. Acquiring single terminated impedance scans somewhat compromises the possibility of the low frequency portion of the data being smooth when the termination is different from the cable impedance and the round trip attenuation is minimal. Good fit (where fit resembles a theoretical characteristic impedance curve of a smooth pair) results are possible with terminated scans provided the roughness is moderate in at least a portion of the frequency range.

44.1.1 *Fitting the Input Impedance Magnitude*—For unshielded twisted pair cable and for twisted pair cable with an overshield, calculate a least squares curve fit to Z_{in} based on the following equation:

$$|Z_0| = K_0 + \frac{K_1}{f^{1/2}} + \frac{K_2}{f} + \frac{K_3}{f^{3/2}} \tag{35}$$

where:

$|Z_0|$ = the magnitude of the characteristic impedance, Ω,
f = frequency, Hz, and
K_0, K_1, K_2, K_3 = least squares fit coefficients as indicated in Eq 35.

Calculate the fit coefficients using the formula:

$$\left|\begin{array}{c} \sum_{i=1}^{N} |Z_{\text{in}}| \\ \sum_{i=1}^{N} \frac{|Z_{\text{in}}|}{\sqrt{f_i}} \\ \sum_{i=1}^{N} \frac{|Z_{\text{in}}|}{f_i} \\ \sum_{i=1}^{N} \frac{|Z_{\text{in}}}{f_i^{\,3/2}} \end{array}\right| = \left|\begin{array}{c} N \sum_{i=1}^{N} \frac{1}{\sqrt{f_i}} \sum_{i=1}^{N} \frac{1}{f_i^{3/2}} \\ \sum_{i=1}^{N} \frac{1}{\sqrt{f_i}} \sum_{i=1}^{N} \frac{1}{f_i} \sum_{i=1}^{N} \frac{1}{f_i^{\,3/2}} \sum_{i=1}^{N} \frac{1}{f_i^{\,2}} \\ \sum_{i=1}^{N} \frac{1}{f_i} \sum_{i=1}^{N} \frac{1}{f_i^{\,3/2}} \sum_{i=1}^{N} \frac{1}{f_i^{\,2}} \sum_{i=1}^{N} \frac{1}{f_i^{\,5/2}} \\ \sum_{i=1}^{N} \frac{1}{f_i^{\,3/2}} \sum_{i=1}^{N} \frac{1}{f_i^{\,2}} \sum_{i=1}^{N} \frac{1}{f_i^{\,5/2}} \frac{1}{f_i^{\,3}} \end{array}\right| \times \left|\begin{array}{c} K_0 \\ K_1 \\ K_2 \\ K_3 \end{array}\right| \tag{36}$$

where all summations are performed over N data points.

44.1.1.1 *Log Spaced Data*—Acquire data points that are equally spaced on a log frequency scale when possible. Most network analyzers offer this type of sweep. Convert the data being fitted to log spacing by interpolation when it is equally spaced on a linear frequency scale, or use 1/*f* weighting (this means weighting a 10 MHz data point by 0.1 when a 1 MHz data point is weighted by 1) in performing the summations to simulate log frequency spaced data points. The 4th order system of equations and unknowns (Eq) is solved by the computer, using determinants or matrix inversion techniques.

44.1.1.2 *Fitting With Fewer Terms*—Use fewer terms, such as two or three, when the data spans only one or two decades of frequency. While a four term fit is indicated by Eq 35 and Eq , in some cases fewer terms may suffice. Just accompanying the inductance variation of a cable pair with frequency, calls for the first two terms of Eq 35 when the starting frequency is in the vicinity of 0.5 MHz. If the capacitance is changing with frequency as it does when polar dielectric material is present, two more terms are generally justified.

44.1.1.3 *Four Criteria Indicating Use of Fewer Terms*—Check or have the computer program determine if the fitted function obtained by solving Eq meets the following set of four criteria: (*1*) the fitted function, except when it is only a constant, has negative slope for frequencies below 3 MHz, (*2*) the 10 MHz fitted value is within the impedance range of +5 Ω to −2 Ω of the high frequency asymptote (fitted constant value), (*3*) the area under the fitted function supplied by the frequency dependent terms on a log frequency basis, exclusive of the constant area, is positive (constant component is not above the data), and (*4*) the sum of the negative areas (those due to negative coefficients) is less than the total area due to the frequency dependent terms. If all four criteria are not met, the number of terms in the function (Eq 35) must be reduced by one by omitting the highest order term, or data spanning a wider range of frequencies and generally resulting in a better fit must be obtained and fitted.

NOTE 8—A symptom indicating that too many terms are being used is that the resultant function fit is over responsive. It may exhibit unusual up or down swings at either end of the frequency range. The desired fit needs to exhibit the properties of a smooth pair of the same design. The fit for impedance magnitude should have a monotonic downward behavior with increasing frequency and become asymptotic at very high frequencies. Dropping the last term from Eq 35 amounts to deleting the fourth row and column from Eq , etc. A four term fit works well when the data spans a three plus decade range extending from 0.05 MHz to 100 MHz with a fairly smooth trace in the lowest decade. One term, representing only the average over a narrow measurement frequency range (perhaps a decade) in the asymptotic frequency region, may suffice when SRL estimates are being sought with minimal computing effort.

NOTE 9—The use of fewer terms leading to a reduced computing effort, should not be a consideration with computing capabilities now available. Use of too few terms will compromise the fitted result and possibly jeopardize obtaining a favorable SRL result in portions of the frequency range. From a computational standpoint, the program subroutine doing the calculations for Eq can readily be written in such a way as to allow choosing of the number of terms required for a given cable type and frequency range.

44.1.1.4 *Compute and Plot Fitted Results*— Compute values for the magnitude of the characteristic impedance, $|Z_0|$, according to coefficients obtained from the fit at the desired frequencies and plot the results or tabulate the fitted results, or both, at specification frequencies as desired.

44.1.1.5 *Sample Result with Function Fitting Approach*—Fig. 7 shows a typical result for the function fitting procedure where 401 equally spaced points with log frequency spacing have been least squares fitted using Eq 35. This example shows a fit good to within an Ohm or two at the low frequency end, and passes through the "middle" of data that oscillates considerably because of structural effects at high frequencies. The four fit coefficients and the root mean square of the deviations about the fit appear in the lower left hand corner with units in Ohms. The fitted results for a few round number frequencies appear across the bottom of the plot.

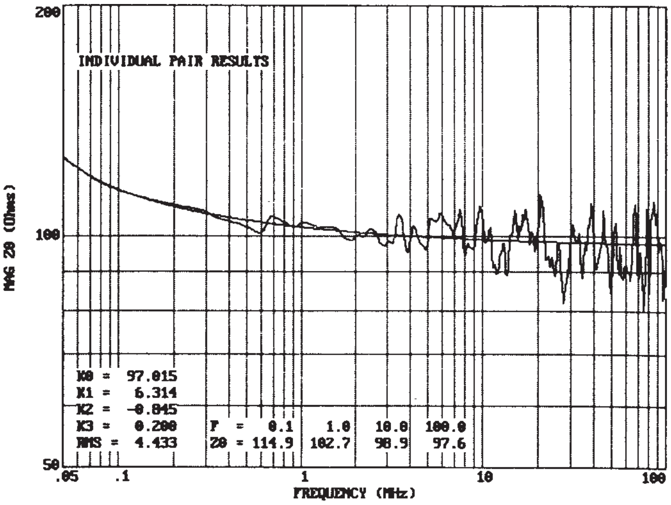


FIG. 7 Unshielded Twisted Pair Input Impedance Data Fitted with Impedance Function

44.1.1.6 *Fitting the Magnitude of the Input Impedance with an Alternate Function*—Fit input impedance traces for relatively smooth pairs such as those with individual shields with a polynomial consisting of log frequency terms. Individually foil shielded pairs exhibit several asymptotic regions. One relatively high impedance region typically starts to develop with increase in frequency in the range of frequencies where the shield is electrically thin. A second lower impedance region develops at higher frequencies where the shield becomes electrically thick. These pairs can not be fitted well over a broad range of frequencies using Eq 35 of 44.1.1 but respond well to a polynomial fit employing a series of log (*f*) terms as indicated in Eq 36. A six term function (an obvious extension of Eq using log terms) fits such an impedance characteristic well over a three to four decade frequency range extending from 50 kHz upward without over-responding to local structural fluctuations. A word of caution is that a six term function of this form will tend to be over responsive when the input impedance is rough.

$$|Z_0| = K_0 + K_1 \log(f) + K_2 \log^2(f) + \cdots + K_5 \log^5(f) \qquad (36)$$

where:

$|Z_0|$ = the magnitude of the characteristic impedance, Ω,
f = frequency, Hz, and
$K_0, K_1 \cdots K_5$ = least squares fit coefficients as indicated in Eq 36.

Calculate the fit coefficients using a formula similar to Eq .

44.1.1.7 *Report*—Report in accordance with Section 47 and include the following data: minimum, maximum, average and standard deviation.

44.1.1.8 *Precision and Bias*—The precision of this test has not been determined by round robin. No statement can be made about the bias of this fit for the characteristic impedance magnitude since the result merely states whether there is conformance to the criteria for success specified in the product specification.

44.2 *Fitting the Angle of Input Impedance (useful when characteristic impedance needs to be specified as a complex quantity)* —Fit the angle of the input impedance using an equation containing the same powers of frequency as those being used for the magnitude of the characteristic impedance discussed under 44.1.1.

$$\angle Z_0 = L_0 + \frac{L_1}{f^{1/2}} + \frac{L_2}{f} + \frac{L_3}{f^{3/2}} \tag{37}$$

where:

$\angle Z_0$ = the angle of the characteristic impedance, rad,

f = frequency, Hz, and

L_0, L_1, L_2, L_3 = 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 10—This procedure is necessary only if the angle of the characteristic impedance is of interest or if structural return loss (SRL), see 43.1, is being calculated at frequencies low enough to result in a significant angle (∠ <10 degrees).

44.2.1 *Fitting the Angle of Input Impedance with an Alternate Function*—Use a function of the same form as Eq 36 to fit the impedance angle for pairs of the type discussed in 42.3.1.5.

44.2.2 *Report*—Report in accordance with Section 47 and include the following data: minimum, maximum, average and standard deviation.

44.2.3 *Precision and Bias*—The precision of this test has not been determined by round robin. No statement can be made about the bias of this fit for the characteristic impedance angle since the result merely states whether there is conformance to the criteria for success specified in the product specification.

45. Structural Return Loss (SRL) and Return Loss (RL)

45.1 Structural return loss (SRL) is obtained from input impedance (square root of open/short impedances). Return loss (RL) is obtained from a terminated impedance scan. The two measures of pair roughness differ in that SRL compares the input impedance obtained from open and short scans with the characteristic impedance while RL compares the terminated impedance with the nominal or load impedance of the pairs (for instance, 100 Ω). Separate characteristic impedance and SRL specifications are often the preferred method of specification because the two effects are more clearly separated. The RL approach is sometimes preferable from a measurement standpoint because it does not require function fitting of the input impedance but uses the load impedance as the reference value, allowing the determination to be accomplished on board the network analyzer, on a stand-alone basis in many instances. In general, a return loss result is less tolerant of roughness than the SRL result since it is sensitive to how well the characteristic impedance is centered about the load impedance.

NOTE 11—When many pairs are considered it is generally true that pairs that pass an SRL requirement on an RL basis will also pass on an SRL basis. However, on an individual pair basis, computing return loss instead of SRL can result in either favorable or unfavorable treatment depending on the direction of the major impedance deviations and where the smooth characteristic impedance lies relative to the reference. The RL approach is a handy alternative only when the pairs pass SRL with considerable margin.

45.2 *Obtaining the Structural Return Loss*—Calculate the SRL for cable pairs, whose characteristic impedance varies appreciably over the desired measurement range, from the input impedance values and fitted impedance function by means of the formula:

$$SRL = -20 \log_{10} \left|\frac{Z_{in} - Z_0}{Z_{in} + Z_0}\right| \tag{38}$$

where:

SRL = Structural Return Loss, dB,

Z_{in} = Input Impedance (complex), Ω, and

Z_0 = Fitted Impedance (complex), Ω.

NOTE 12—On the other hand, using only the magnitude for the fitted results is reasonable when the frequency range starts at a high enough value to result in the fitted angle being within a few degrees of 0.

Perform the indicated calculation using a computer (such as the one used to acquire the data) and plot the results, checking for conformance to the appropriate standard over the entire frequency range. It is important to note that Eq 38 involves complex values for the input impedance and the fitted function. Using only the magnitude for the input impedance will result in favorable SRL results since impedance deviations in the imaginary direction, which are equally strong as those in the real direction, will be overlooked.

45.2.1 *Typical SRL Result*—The SRL result obtained from the use of Eq 38 is shown in Fig. 8 for the same cable pair considered in Fig. 7. This SRL trace shows a decreasing trend with frequency extending over three decades. A straight line has been fitted to the trace to quantify its reference level and downward trend with frequency. It indicates a 1 MHz SRL value of 41.8 dB and a downward slope of about 10.1 dB/decade for this example. Worst values of SRL are as much as 12 dB worse than the fitted line at select frequencies in this example.

45.3 *Obtaining the Return Loss*—Use the appropriate network analyzer function to obtain the RL. The RL may be an

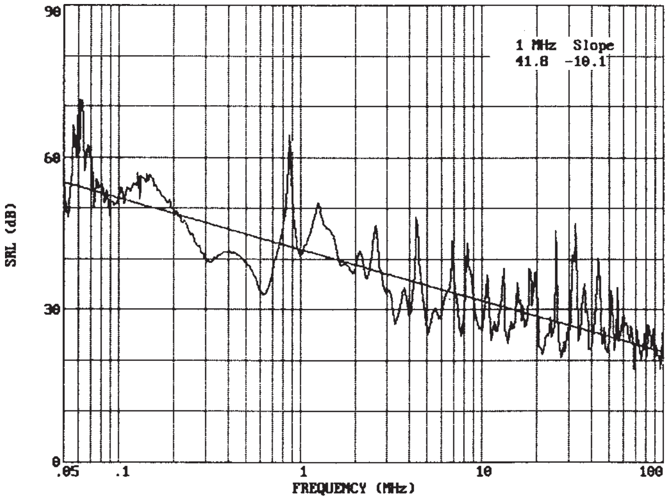


FIG. 8 Typical SRL Trace Computed from Input Impedance Data and Characteristic Impedance

attractive alternative to SRL when it is desirable to evaluate structural effects on the network analyzer without using data acquisition procedures. For pairs whose high frequency characteristic impedance is close to the nominal or load value impedance, the return loss is virtually the same as SRL. The return loss for a pair is defined as:

$$RL = -20 \log_{10} \left|\frac{Z_T - Z_L}{Z_T + Z_L}\right| \tag{39}$$

where:

RL = Return Loss, dB,

Z_T = Terminated Impedance (complex), Ω, and

Z_L = Calibration Load, Ω.

Calculate the RL either on board the network analyzer or using the computer that was used to acquire the data, and plot the results, checking for conformance to the appropriate standard over the entire frequency range. Plots of RL will not exhibit the consistent downward trend such as that apparent in Fig. 8 over such a broad frequency range. They will only exhibit this property for frequencies where the characteristic impedance is centered and is close to the high frequency asymptote.

45.4 *Report*—Report in accordance with Section 46 and include the following data: minimum, maximum, average and standard deviation.

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

46. Longitudinal Conversion Loss (LCL) and Longitudinal Conversion Transfer Loss (LCTL)

These measurements represent conversion from the longitudinal or common mode to the differential mode. LCL consists of the ratio of the differential signal received at the transmit end to the common mode signal applied at the transmit end. LCTL consists of the differential signal received at the end opposite from the transmit end to the common mode signal applied at the transmit end. It will be noted that while the procedure discussed here depicts common mode at the transmit port of the measurement instrument and differential mode at the receive end the measurement circuit is actually reciprocal with the same port impedance at both ends.

46.1 *Equipment Required*—Equipment required consists of (1) a network analyzer of appropriate frequency range with appropriate transmit and receive port impedance (for instance 50 Ohms), (2) transformers, with a center tap on the secondary winding, to convert the network analyzer impedance to the nominal differential mode impedance (for instance 50 to 100 Ohms) of the cable pairs, (3) passive termination for the cable pairs capable of supplying both the appropriate differential and common mode terminations, and (4) a 50 to 75 Ohm minimum loss pad. The bandpass of the transformers shall be appropriate for the frequency range of the measurements. The balance requirements for the transformers are to be better than the anticipated performance of the cable pairs being measured by 15 to 20 dB.

46.2 *Specimen Preparation*:

46.2.1 *Choosing a Specimen Length*—Select a specimen length representative of the intended application (such as 328 ft for horizontal LAN wiring), taking into consideration the shipping lengths and the loss at the highest measurement frequencies

46.2.2 *Preparing the Ends*—Remove appropriate lengths of jacket and insulation from all pairs at both ends of the specimen to allow connection to the transformers and terminations.

46.2.3 *Terminations*— Terminate the cable pair being tested at the near and far ends so as to simultaneously minimize reflections for both the differential and common mode. The nominal differential mode impedance of a multibar cable pair is generally a well known design parameter. The common mode impedance of the pair is heavily influenced by the number of nearby pairs and an overshield if present. The common mode impedance of pairs in many 4 pair unshielded twisted pair (UTP) designs is approximately 75 Ohms when the differential impedance is 100 Ohms. This value can be arrived at by considering the ratio of direct-to-mate capacitance to direct-to-ground capacitance as defined by Fig. 1. The common mode impedance of other designs can be higher or lower depending on the number of other pairs nearby the pair under test and the position of a shield, if present. Individually shielded pairs with a 100 Ohm differential impedance may have a common mode impedance as low as 25 Ohms. Use of improper differential and common mode terminating impedances results in possible mixing of LCL and reflected LCTL for instance. This is similar to the mixing of NEXT and reflected FEXT that results from wrongly terminating crosstalk measurement circuits.

46.2.4 *Laying Out the Specimen*—Evenly suspend the cable away from any ground surfaces so that the multiple traversals are separated by at least 1 in. and supported frequently to minimize tension to the cable core (applicable to unshielded cable only).

46.3 *Equipment Set-Up*—Set up the equipment in accordance with Fig. 9 for LCL and Fig. 8 for LCTL. Generally, the primary side of the transformer presents an impedance that is related to the differential side (secondary) by the square of the turns ratio (for instance, 50 Ohms for a 50 to 100 Ohm transformer). The common mode port of the transformer presents the common mode impedance of the pair under test (for instance, 75 Ohms). In Fig. 9 and Fig. 10 a matching pad is used to convert from the 75 Ohm common mode impedance of 4-pair UTP to the 50 Ohm equipment impedance so as to minimize reflections.

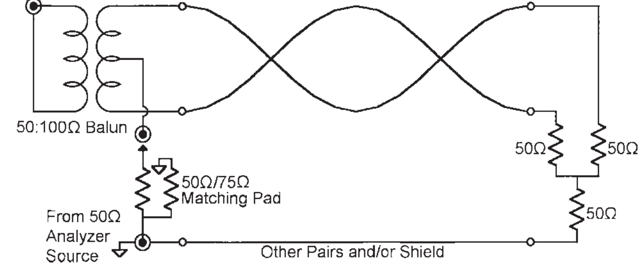


FIG. 9 Longitudinal Conversion Loss (LCL) Circuit

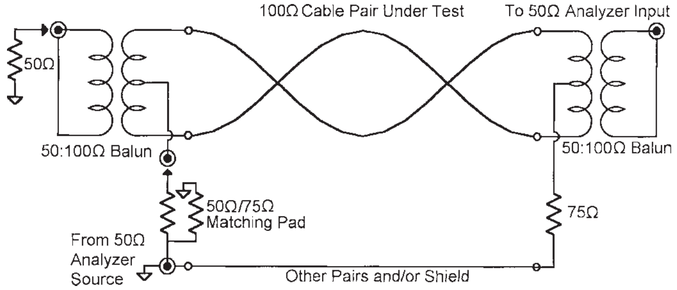


FIG. 10 Longitudinal Conversion Transfer Loss (LCTL) Circuit

46.4 *Number of Swept Frequency Points*—Set the frequency mode preferably to linear mode and to a sufficient number of points to allow detailing of the structure (400 points when several decades of frequency are to be covered). The number of measurement points required for LCL is similar to that needed for NEXT or input impedance of the same length and maximum frequency, where structure is generally present. For LCTL the considerations are similar to those for FEXT where interference patterns can result from mode delay differences.

46.5 *Equipment Calibration*—Calibrate the equipment arrangement by placing a short coaxial between the transmit and receive ports of the network analyzer and doing a simple calibration. Measurements are further corrected by subtracting a correction loss pertaining to the turns ratio loss of the transformer (3.6 dB for 50 to 100 Ohm transformers as indicated by the manufacturer) and by the loss of the minimum loss impedance matching pad (5.7 dB for 50 to 75 Ohm pad) for a total of 9.3 dB.

46.6 *Specimen Measurement*—Measure the pair under test by connecting the ends of the pairs and shield, if any, to the measurement equipment in accordance with Fig. 9 or Fig. 10 as applicable. Aquire the data as desired, graphically or by transferring to a personal computer by way of an interface. The swept loss for LCL or LCTL is corrected by the loss value indicated in 46.5. Minimum margin to a performance specification is also calculated on an individual pair basis. It should be noted that the LCTL is an input to output quantity where no correction has been made for the combination of the differential mode loss and the common mode loss that is a part of this measurement.

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

46.8 *Precision and Bias*—The precision of this test has not been determined by round robin. No statement can be made about the bias of this test for LCL or LCTL since the result merely states there is no conformance to the criteria for success specified in the product specification.

47. Report

47.1 Unless otherwise specified, record the test results of the wire or cable electrical characteristics, with identifying units, on a report form that includes the following:

47.1.1 Identification of the wire or cable sampled and tested by pair count, gage, sheath type, reel number, length, air core, or filled core, etc.,

47.1.2 Date of testing,

47.1.3 Location of testing laboratory and the person responsible for the testing,

47.1.4 Remarks indicating method or procedure used and the deviation, if any, from the standard procedure, and

47.1.5 Indication of the variance in test measurements such as minimum, maximum, average standard deviation (σ), environmental conditions, etc.

47.2 Report test results as calculated or observed values rounded to the nearest unit in the last right hand place of figures used in the wire or cable specification to express the limiting value. (See the rounding method of Practice E 29.)

48. Keywords

48.1 attenuation; capacitance deviation; capacitance difference; capacitance unbalance; characteristic impedance; coaxial capacitance; conductor resistance; conductor resistance unbalance; continuity; crosses; crosstalk loss—far end; crosstalk loss—near end; dc proof test; fault rate test; insulation defect; insulation resistance; jacket voltage breakdown; mutual capacitance; mutual conductance; phase constant; phase delay; phase velocity; shorts test; spark test; structural return loss; voltage surge test

ANNEX

(Mandatory Information)

A1. CALIBRATION PROCEDURE FOR CHARACTERISTIC IMPEDANCE AND SRL DATA ACQUISITION

A1.1 *S-Parameter Calibration of Network Analyzer When Internal Calibration is Not Available*—Extension of the point of calibration from the coaxial *S*-Parameter port to the end of the matching pad (coaxial case) or to the connection point on the balanced secondary side of the impedance matching transformer (balanced pair case) is readily accomplished with a three step calibration procedure. For either coaxial measurements or balanced pairs, separate measurement scans are made with the point of connection open circuited, short circuited and terminated in a calibration resistor, making use of the following three equations with all the variables having complex values:

$$s_{11} = \frac{s_m - s_t}{Ss_m + T} \tag{A1.1}$$

where:

s_{11} = the calibrated s-parameter result,
s_m = the measured s-parameter value,
S_t = the terminated calibration value,

T = the Eq A1.2 calibration term, and
S = the Eq A1.3 calibration term.

The equation for T is defined as:

$$T = \frac{2s_{cs}s_{co} - s_{ct}(s_{cs} + s_{co})}{s_{cs} - s_{co}} \tag{A1.2}$$

where:
s_{co} = calibration value from open circuit calibration scan,
s_{cs} = calibration value from short circuit calibration scan, and
s_{ct} = calibration value from terminated calibration scan.

The equation for S is defined as:

$$S = \frac{2s_{ct} - s_{cs} - s_{co}}{s_{cs} - s_{co}} \tag{A1.3}$$

where:
s_{co} = calibration value from open circuit calibration scan,
s_{cs} = calibration value from short circuit calibration scan, and
s_{ct} = calibration value from terminated calibration scan.

The calculations involved in the 3-step calibration procedure above are accomplished as an internal procedure on many network analyzers. Where this is not the case, the values from the open, short and terminated scans can be obtained with a data acquisition program similar to the one being used to acquire the open and short or terminated data, and stored at the beginning of the data file so as to be available for subsequent processing of actual measurements.

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