Designation: D 4566 – 05

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 the product.

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

Test Method	Sections
Electrical Tests of Insulation—In-Process	4-8
DC proof test	8
Insulation defect or fault rate	7
Spark test	6
Electrical Tests of Completed Wire and Cable	9-51
Attenuation	24
Attenuation, effects due to aging	31
Attenuation, effects due to elevated temperature	29
Attenuation, effects due to humidity	30
Attenuation to crosstalk ratio—far end (ACR-F)	28
Attenuation to crosstalk ratio—near end (ACR-N)	26
Capacitance deviation	19
Capacitance difference	20
Capacitance unbalance, Pair-to-ground (CUPG)	22
Capacitance unbalance, Pair-to-pair (CUPP)	21
Capacitance unbalance, Pair-to-support wire	23
Characteristic Impedance—Method 1 Propagation constant and capacitance	47
Characteristic Impedance—Method 2, Single-ended measurements	48
Characteristic Impedance—Method 3 Least Squares Function Fit	49
Coaxial capacitance (capacitance to water)	17
Conductor continuity	11
Conductor resistance (CR)	13
Conductor resistance unbalance (CRU of pairs)	15
Continuity of other metallic elements	12
Crosses test (continuity between wires of different pairs)	35
Crosstalk loss, far-end	27
Crosstalk loss, near-end	25
DC proof test, Core-to-internal shield (screen)	40
DC proof test, Core-to-shield	38
DC proof test, Core-to-support wire	39
DC proof test, Internal shield (screen)-to-shield	41
DC proof test, Other required isolations	42
DC proof test, Wire-to-wire	37
Fault rate test (air core only)	33
Insulation resistance (IR)	32
Jacket voltage breakdown rating test	36
Mutual capacitance (CM)	18
Mutual conductance	16
Phase Constant	44
Phase Delay	45
Phase Velocity	46
Resistance of other metallic cable elements	14
Shorts test (continuity between wires of a pair)	34
Structural Return Loss and Return Loss	50
Unbalance attenuation (conversion losses)	51
Voltage surge test	43

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 37.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

B 193 Test Method for Resistivity of Electrical Conductor Materials

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

D 1711 Terminology Relating to Electrical Insulation

D 2633 Test Methods for Thermoplastic Insulations and Jackets for Wire and Cable

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

D 5423 Specification for Forced-Convection laboratory Ovens for Evaluations of Electrical Insulation

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

---

[1] These test methods are under the jurisdiction of ASTM Committee D09 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.

Current edition approved March 1, 2005. Published April 2005. Originally approved in 1986. Last previous edition approved in 1998 as D 4566 – 98.

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

2.2 *ANSI Standard:*

ANSI/IEEE Standard 100 IEEE Standard Dictionary of Electrical and Electronics Terms[3]

2.3 *IEC Standard:*

IEC 61156-1 Multicore and Symmetrical Pair/Quad Cables for Digital Communications—Part 1: Generic Specification[3]

2.4 *ITU-T Standard:*

ITU-T Recommendation G117 Transmission Aspects of Unbalance About Earth[3]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this standard, refer to Terminology D 1711.

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *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.

3.2.3 *cable, telecommunications*, *n*—products of six or more pairs.

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

3.2.5 *low frequency cable*, *n*—cable used for transmitting signals at a frequency of 2 MHz or less.

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

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

3.2.8 *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.

3.2.9 *wire, telecommunications*, *n*—products containing less than six pairs.

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 spark tester electrode. For telecommunications products, the number of faults is 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 **Warning**—*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 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 non-lethal. 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

---

[3] Available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80113-5776.

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 an insulated wire, or both ends of a 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:

$$\text{Fault Rate} = \frac{N}{L} = \frac{1}{X} \tag{1}$$

where:

N = the number of faults detected,

L = the length of the product over which the faults are detected, and

X = the average length of the product per fault.

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 37 following, at whatever stage of production may be appropriate and designated by the factory management.

8.3 *Report*—Report in accordance with Section 52 except that 52.1.5 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 through 51.

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 test 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 a 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. Use test equipment indicators to 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 52.

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, 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 42.

12.3 *Report*—Report in accordance with Section 52.

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 (CR)

13.1 The conductor resistance (CR) in telecommunications wire and cable is 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 conductor resistance (CR) at or corrected to 20°C (68°F). 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 through 11.5 for end preparation followed by measurement using the voltage supplied by the test instrument. Record instrument readings obtained for each tested conductor. 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 52 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 through 13.4, measuring cable construction elements as appropriate.

14.2 *Report*—Report in accordance with Section 52 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 (CRU of Pairs)

15.1 The difference in resistance between two conductors of any pair can be a key characteristic in telecommunications; however, Conductor Resistance Unbalance (CRU) 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 through 13.5 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:

$$\mathrm{CRU} = \frac{R_{max} - R_{min}}{R_{min}} \cdot 100\ \% \qquad (2)$$

where:

CRU = the conductor resistance unbalance in %,

R_{max} = the maximum conductor resistance of a conductor in a pair, and

R_{min} = the minimum conductor resistance of a conductor in a pair.

NOTE 1—Care should be taken to identify the method for determining conductor resistance unbalance. IEC 61156-1 defines conductor resistance unbalance as the ratio of the difference in resistance of two conductors to the sum of their resistances. Therefore, the IEC values are less than half of those defined in 15.3.

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 52 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. 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 constraints mentioned in 16.1, mutual conductance is only measured rarely, 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 a test frequency of 1000 ± 100 Hz. Measured values are normally converted to a standard length value (normally one mile or one km). For conductance in micro-Siemens per mile, the values would be:

$$G_o = \frac{G \times 5280}{L} \quad \mu\text{S / mile} \tag{3}$$

$$G_o = \frac{G \times 1000}{L} \quad \mu\text{S / km}$$

where:

G_o = mutual conductance, µS/mile (km),
G = conductance reading, µS, and
L = specimen length, ft (m).

16.4 *Report*—Report in accordance with Section 52 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 2—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 of insulated wire is immersed in a water bath and the direct capacitance is measured between the conductor and the water. 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 52 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 (CM)

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

$$\text{CM} = C_{AB} + \frac{C_{AG} \cdot C_{BG}}{C_{AG} + C_{BG}} \quad \text{nF / cable length} \tag{4}$$

where:

CM = the mutual capacitance, and
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, the 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

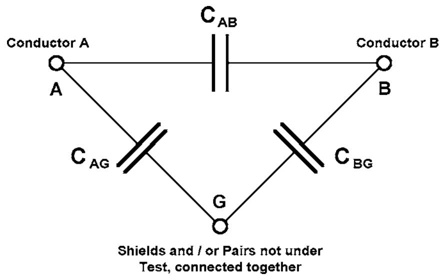


FIG. 1 Mutual Capacitance Relationships

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 a test frequency of 1000 ± 100 Hz, and this test frequency shall be used if measurement is made using a bridge technique. Other test methods yielding comparable results shall be considered as acceptable if not specifically prohibited.

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

18.6 Specification limits are generally placed on the cable average mutual capacitance and on the individual pair mutual capacitance. Limits for individual pairs can be verified only by making measurements of individual pairs, and such measurements are normally made for cables of 25 or fewer pairs; for larger cables, individual measurements are often made only on a quality assurance sampling basis. Cable averages can be obtained by averaging individual pair readings. Average mutual capacitance can also be measured by grouping a number of pairs together (electrical 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 nano-Farad/mile, the values would be:

$$C_o = \frac{C \times 5280}{L} \quad \text{nF / mile} \tag{5}$$

$$C_o = \frac{C \times 1000}{L} \quad \text{nF / km}$$

where:

C_o = mutual capacitance, nF/mile (nF/km),
C = mutual capacitance, measured, nF, and
L = specimen length, ft (m).

NOTE 3—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 52 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 = % root mean square (rms) deviation from average,
σ = $\sqrt{\Sigma\frac{x^2}{N} - \left(\frac{\Sigma x}{N}\right)^2}$
$\bar{x}$ = $\frac{\Sigma x}{N}$
x = individual mutual capacitance values (nF/mile, nF/kft, nF/km, etc.), and
$\bar{x}$ = average mutual capacitance value (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 52 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 cable, 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_1 and C_1, respectively). Repeat this calculation for the outermost pairs and record as (R_o and C_o, respectively).

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

$$D = \frac{C_o - C_1}{C_o} - \frac{R_o - R_1}{R_o} \cdot 100\ \% \tag{7}$$

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 52.

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 (CUPP)

21.1 The capacitances involved and the definition of capacitance unbalance pair-to-pair (CUPP) 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 and shields in the cable that are connected to grounded.

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

21.3 In cables of 25 pairs or less and in each group of multi-group 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 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 capacitance unbalance, pair-to-pair (CUPP), can then be calculated using the following equation:

$$\text{CUPP} = (C_{AD} + C_{BC}) - (C_{AC} + C_{BD}) \qquad \text{pF @ cable length} \tag{8}$$

21.5 Unless otherwise specified, correct the maximum, average, and root mean square unbalance values for each length other that 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.

$$Y_1 = \frac{Y}{\sqrt{X/1000}} \qquad \text{pF @ 1000 ft (1000 m)} \tag{9}$$

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 52 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 (CUPG)

22.1 The capacitances involved and the definition of capacitance unbalance, pair-to-ground (CUPG) are illustrated in Fig. 3, where A and B represent the two conductors of a pair. The capacitances, namely C_{AG} and C_{BG} are the direct capacitances between conductors A and B respectively and the shield. The

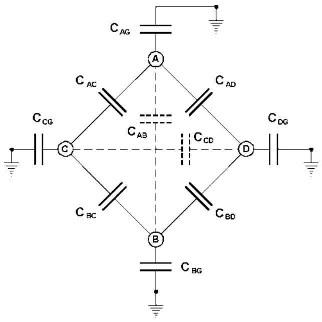
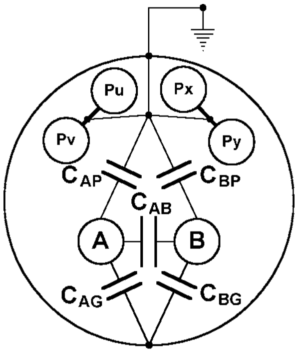


FIG. 2 Conductor Capacitances



All Pairs and / or Shields connected together and grounded

FIG. 3 Pair-to-Ground Capacitance Unbalance

capacitances C_{AP} and C_{BP} are the direct capacitances between conductors A and B respectively and all other pairs P, consisting of the conductors' u, v and x, y respectively.

22.2 Using a capacitance unbalance bridge, measure the pair-to-ground capacitance unbalance at a test frequency of 1000 ± 100 Hz. Various types of automatic and 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 capacitance unbalance, pair-to-ground, CUPG, can then be calculated using the following equation:

$$\text{CUPG} = (C_{AG} + C_{AP}) - (C_{RG} - C_{RP}) \qquad \text{pF / cable length} \qquad (10)$$

22.4 Unless otherwise specified correct the maximum and average capacitance unbalance values for each length, other that 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.

$$Y_1 = \frac{Y}{X / 1000} \qquad (11)$$

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 52 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 unbalances shall comply with the requirements of the product specification.

23.3 *Report*—Report in accordance with Section 52 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. Attenuation

24.1 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, the surrounding jacket material and/or eventual shield(s). Referring to Fig. 5, attenuation shall be defined as:

$$\alpha_i = \frac{1}{L_o} \cdot \left| 20 \cdot \log_{10} \frac{V_{iN}}{V_{iF}} \right| \qquad \text{dB / length unit} \qquad (12)$$

where:

L_o = the measured length of the cable in length units, and
α_i = the attenuation of the pair i.

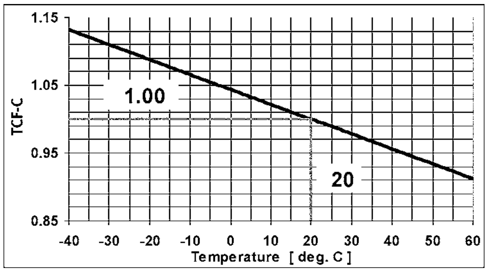
24.2 Cable ends shall be prepared as described in 25.2.

24.3 The equipment used for measuring attenuation, unless otherwise specified, shall be *(a)* balanced to ground or *(b)* a network analyzer with an S-parameter test set in conjunction with balance to unbalanced impedance matching transformers (baluns). In the case *(a)* the test equipment shall have a nominal input and output impedance corresponding to the nominal characteristic impedance ±1 % of the pairs under test. The input power to the pair under test shall be approximately 10 dBm. The circuit of Fig. 5, or equal, shall be used.

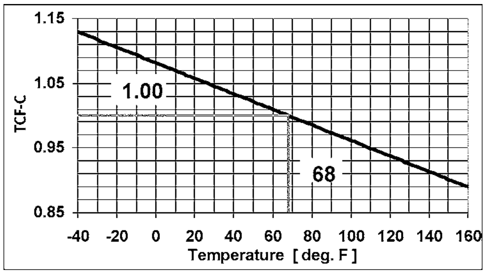
24.4 Unless otherwise specified, measure attenuation at or corrected to 20°C (68°F). Temperature corrections can be made using the following equations, taking into account the copper conductor resistance increase with temperature:

$$\alpha_{20} = \frac{\alpha_T}{[1 + 0.0022 \cdot (T - 20)]} = \frac{\alpha_T}{\text{TCF in °C}} \qquad \text{dB / length unit} \qquad (13)$$

$$\alpha_T = \alpha_{20} \cdot \text{TCF in °C} \qquad \text{dB / length unit}$$

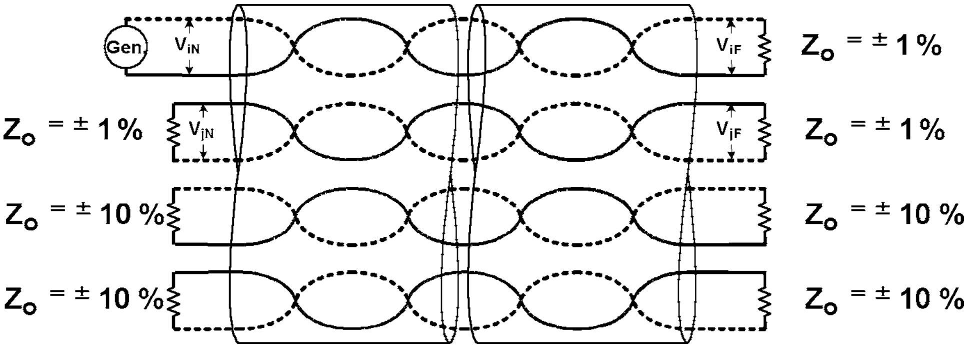


(a) Attenuation temperature correction factor for temperatures given in °C



(b) Attenuation temperature correction factor for temperatures given in °F

FIG. 4 Attenuation Temperature Correction Factor



NOTE 1—Source Impedance = Z_o ± 1 %.

NOTE 2—Pairs not under test terminated with resistors = Z_o ± 10 %.

NOTE 3—Terminating resistors Z_o shall be non-inductive.

FIG. 5 Test Circuit for Crosstalk Measurements

where:

α_{20} = the attenuation corrected to 20°C,
α_T = the measured attenuation at temperature T,
T = the measured temperature, °C, and
TCF in °C = the temperature correction factor at temperature T.

$$\alpha_{68} = \frac{\alpha_T}{[1 + 0.0022 \cdot (T - 68)]} = \frac{\alpha_T}{\text{TCF in °F}} \quad \text{dB / length unit} \tag{14}$$

$$\alpha_T = \alpha_{68} \cdot \text{TCF in °F} \quad \text{dB / length unit}$$

where:

α_{68} = the attenuation corrected to 68°F,
α_T = the measured attenuation at temperature T,
T = the measured temperature, °F, and
TCF in °F = the temperature correction factor at temperature T.

NOTE 4—When the temperature coefficient of the attenuation increase is higher than the increase due to resistance increase of the copper conductors alone, the coefficient has to be determined, see Section 29.

24.5 Alternately, the information given in Fig. 4(a) and Fig. 4(b) 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. The correction factors are based on Eq 13 and 14.

24.6 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.

24.7 *Report*:

24.7.1 Report in accordance with Section 52 and include the following:

24.7.1.1 Minimum, maximum, and average values, and

24.7.1.2 Ambient temperature.

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

25. Crosstalk Loss—Near End

25.1 Near-end crosstalk loss (NEXT) is usually defined and measured as an input-to-output crosstalk coupling between two pairs on the same end of the cable. Hence, NEXT is the logarithmic ratio of the input power of the disturbing pair *i* to the output power of the disturbed pair *j* on the same end of the cable. Referencing Fig. 5, the NEXT shall be defined as:

$$\mathrm{NEXT}_{ij} = \left| 20 \cdot \log_{10} \frac{V_{iN}}{V_{jN}} \right| \quad \mathrm{dB} \tag{15}$$

where:

NEXT_{ij} = the NEXT measured, dB,

i = the disturbing pair,

j = the disturbed pair,

V_{iN} = the input voltage to the disturbing pair at the near end, and

V_{jN} = the output voltage of the disturbed pair at the near end.

25.1.1 To correct crosstalk values to the nominal characteristic impedance, when the terminating and characteristic impedance are different, Eq 15 is changed as follows:

$$\mathrm{NEXT}_{ij} = \left| 20 \cdot \log_{10} \frac{V_{iN}}{V_{jN}} \right| + 20 \cdot \log_{10} \frac{4Z_o \cdot Z}{(Z_o + Z)^2} \quad \mathrm{dB} \tag{16}$$

where:

Z_o = nominal characteristic impedance of cable, and

Z = terminating impedance at the far end of both pairs.

25.2 Cable ends shall be prepared for test as described in 18.3 for low frequency cables. For cables intended to be used at frequencies beyond 2 MHz, the cable ends shall be kept to the minimum length that will permit a connection to the test equipment.

25.3 The equipment used for measuring crosstalk, unless otherwise specified, shall be *(a)* balanced to ground or *(b)* a network analyzer (NWA) with an *S*-parameter test set in conjunction with balance to unbalanced impedance matching transformers (baluns). The pairs under test shall be terminated in their nominal characteristic impedance ±1 %. Pairs not under test shall be terminated at both ends in their nominal characteristic impedance ±10 %. The input power to the disturbing pair shall be approximately 10 dBm. The circuit of Fig. 5, or equal, shall be used. If crosstalk values are impedance-corrected to the nominal characteristic impedance as outlined in 25.1.1, 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.

25.3.1 For low frequency cables and discrete frequency measurements, the following shortcut may be used. For accurate readings, each pair must be terminated; however, if readings are taken on a sampling of specific pairs, the pairs not under test usually can be left unterminated, since any error introduced by this shortcut will be minor.

NOTE 5—This is not necessarily true in the higher frequency ranges with swept frequency measurements.

25.4 Measure the NEXT between pairs, as required by the detailed product specification using the choice of equipment indicated in 25.3. Other types of automatic or semiautomatic equipment are acceptable.

25.5 For low frequency cables, the measured values are normally corrected to a standard length value (normally 1000 ft or 1000 m). Length 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, correct the reading to 1000 ft (305 m) by using the following equation:

$$\mathrm{NEXT}_{ijLx} = \mathrm{NEXT}_{ijLo} - 10 \cdot \log_{10} \frac{1 - e^{-4 \cdot \alpha \cdot L_x}}{1 - e^{-4 \cdot \alpha \cdot L_o}} \quad \mathrm{dB} \tag{17}$$

where:

i = the disturbing pair,

j = the disturbed pair,

α = average attenuation of disturbing and disturbed pair Neper/unit length,

L_o = the measured cable length, ft (m),

L_x = the reference cable length, 1000 ft (305 m), and

e = 2.71828.

NOTE 6—This length correction is based upon the assumption of a strict length correlation of the crosstalk. This may be assumed only for large pair count cables on a statistical basis.

25.6 If the detailed product specification requires the near end crosstalk to be reported as power sum (P.S.), the P.S. NEXT can be calculated from readings obtained in 25.4 as follows:

$$\text{P.S. NEXT}_j = \left| 10 \cdot \log_{10} \sum_{\substack{i=1 \\ i \neq j}}^{i=n} 10^{\frac{-\mathrm{NEXT}_{ij}}{10}} \right| \quad \mathrm{dB} \tag{18}$$

where:

i = the disturbing pair,

j = the disturbed pair, and

n = number of pairs.

25.7 *Report*—Report in accordance with Section 52 and include the following. The report differentiates between discrete frequency measurements at specified frequencies and swept frequency measurements with a dense frequency distribution at measurement points.

25.7.1 Measurements at specified frequencies:

25.7.1.1 Minimum and average values, and

25.7.1.2 Power sum near end crosstalk (if applicable).

25.7.2 Swept frequency measurements:

25.7.2.1 *NEXT*—Generally graphic representation of measurements, including specification limits of the measured NEXT values.

25.7.2.2 *P.S. NEXT*—Generally graphic representation of measurements, including specification limits of the calculated P.S. NEXT 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 near end crosstalk (NEXT) since the result merely states whether there is conformance to the criteria for success specified in the product specification.

26. Attenuation to Crosstalk Ratio, Near-End (ACR-N)

26.1 The attenuation to near end crosstalk ratio is limited to swept frequency measurements.

26.2 The attenuation to crosstalk ratio-near-end is defined as:

$$\mathrm{ACR{-}N}_{ij} = \mathrm{NEXT}_{ijL_x} - \alpha_i \cdot L_o \qquad \text{dB @ measured cable length} \tag{19}$$

where:

i = the disturbing pair,

j = the disturbed pair,

L_o = the measured cable length, ft (m),

ACR-N = the attenuation to near-end crosstalk ratio of the pair j, exposed to the disturbing pair i, expressed in dB at the measured cable length, and

α = the attenuation of the pair j in dB per unit-length.

NOTE 7—The attenuation to crosstalk ratio, near-end is also frequently called attenuation to crosstalk ratio (ACR).

26.3 Some detail specifications specify the power sum of the attenuation to crosstalk ratio-near-end.

26.3.1 The power sum of the attenuation to crosstalk ratio-near-end of the pair j, due to the disturbing pair i is calculated from the difference of the NEXT and the attenuation of the disturbed pair: Hence, the P.S. ACR-N is calculated as follows:

$$\mathrm{P.S.\ ACR{-}N}_j = \left| 10 \cdot \log_{10} \sum_{\substack{i=1 \\ i \neq j}}^{i=n} 10^{\frac{-(\mathrm{NEXT}_{ijLx} - \alpha_i \cdot L_o)}{10}} \right| \tag{20}$$

$$= \left| 10 \cdot \log_{10} \sum_{\substack{i=n \\ i \neq j}}^{i=1} 10^{\frac{-\mathrm{NEXT}_{ijLx}}{10}} \right| - \alpha_j \cdot L_o$$

dB @ measured cable length

where:

i = the disturbing pair,

j = the disturbed pair,

L_o = the measured cable length, ft (m), and

n = the number of pairs in the cable.

26.4 *Report*—Report in accordance with Section 52. The reporting is generally done in graphical form, that is, the calculated ACR-N or P.S. ACR-N as a function of frequency with the specified reference values indicated as well. Individual failure points may be listed upon request.

26.5 *Precision and Bias*—The precision of these tests has not been determined. No statement can be made about the bias of these tests for ACR-N or P.S. ACR-N since the results merely state whether there is conformance to the criteria for success specified in the product specification.

27. Crosstalk Loss—Far End

27.1 Referencing Fig. 5, the far-end or the input-to-output crosstalk loss (FEXT) shall be defined as:

$$\mathrm{FEXT}_{ij} = \left| 20 \cdot \log_{10} \frac{V_{iN}}{V_{jF}} \right| \qquad \text{dB} \tag{21}$$

where:

i = the disturbing pair,

j = the disturbed pair,

V_{iN} = the input voltage to the disturbing pair at the near end, and

V_{jF} = the output voltage of the disturbed pair at the far end.

27.2 Referencing Fig. 5, the equal level far-end crosstalk loss or the output-to-output far-end crosstalk loss (EL FEXT) is defined as:

$$\mathrm{EL\ FEXT}_{ij} = \left| 20 \cdot \log_{10} \frac{V_{iF}}{V_{jF}} \right| \qquad \text{dB} \tag{22}$$

where:

i = the disturbing pair,

j = the disturbed pair,

V_{iF} = the output voltage to the disturbing pair at the far end, and

V_{jF} = the output voltage of the disturbed pair at the far end.

27.2.1 Low frequency measurements:

27.2.1.1 The EL FEXT shall be measured for each binder group in the completed cable at the specified frequency (±1 %), using a signal generator and a level meter (see Fig. 5). Various types of automatic or semi-automatic equipment are also acceptable. The measured values shall be impedance corrected to the nominal characteristic impedance, if the pairs under test are terminated in their characteristic impedance $Z = Z_o \pm 25\ \%$. This should be done according to the following equation:

$$\mathrm{EL\ FEXT}_{ij} = \left| 20 \cdot \log_{10} \frac{V_{iF}}{V_{jF}} \right| + 20 \cdot \log_{10} \frac{4 \cdot Z_o \cdot Z}{(Z_o + Z)^2} \qquad \text{dB} \tag{23}$$

where:

i = the disturbing pair,

j = the disturbed pair,

V_{iF} = the output voltage of the disturbing pair at the far end,

V_{jF} = the output voltage of the disturbed pair at the far end,

Z_o = the characteristic of the cable, and

Z = the impedance of the termination.

27.2.1.2 If a root mean square (rms) value is required for the EL FEXT, make measurements between adjacent and alternate adjacent pairs in the same layer, and center to the first layer in each binder group. Calculate the root mean square EL FEXT using the following equation:

$$\mathrm{rms\ EL\ FEXT} = \left| 20 \cdot \log_{10} \sqrt{\frac{\sum_{k=1}^{k=n} \left[\left(\frac{V_{iF}}{V_{jF}} \right)^2 \right]_k}{n}} \right| \qquad \text{dB} \tag{24}$$

where:

i = the disturbing pair,
j = the disturbed pair,
n = the number of measurements performed,
k = the current number of the measured crosstalk combinations,
V_{iF} = the output voltage of the disturbing pair, and
V_{jF} = the output voltage of the disturbed pair.

27.2.1.3 Unless otherwise specified the EL FEXT or output-to-output FEXT shall be measured at 23 ± 3°C.

27.2.1.4 If the measurements are taken at a different length than the standard reference length, convert the measurements to the standard length using the following equation:

$$\text{EL FEXT}_{L_x} = \text{EL FEXT}_{L_o} - 10 \cdot \log_{10}\left(\frac{L_x}{L_o}\right) \quad \text{dB @ referenced length} \tag{25}$$

where:
L_x = the length to be referenced, and
L_o = the measured length of the cable.

NOTE 8—This length correction is based upon the assumption of a strict length correlation of the crosstalk. This may be assumed only for large pair count cables on a statistical basis.

27.2.2 High frequency measurements (measurements at frequencies greater than 2 MHz):

27.2.2.1 The termination of the pairs under measurement, as well as all the other pairs in the cable shall be terminated in the nominal characteristic impedance ±1 %. The input power shall be approximately 10 dBm.

27.2.2.2 The cable ends shall be kept to the minimum length which allows a connection to the test equipment.

27.2.2.3 The EL FEXT is generally calculated. It is the difference of input-to-output FEXT and the attenuation of the disturbing pair, where both values are measured with the same frequency points in the corresponding swept frequency measurements:

$$\text{EL FEXT}_{ij} = \left|20 \cdot \log_{10}\frac{V_{iF}}{V_{jF}}\right| = \left|20 \cdot \log_{10}\frac{V_{iN}}{V_{jF}}\right| - \left|20 \cdot \log_{10}\frac{V_{iN}}{V_{iF}}\right| \tag{26}$$

dB @ measured cable length

$$\text{EL FEXT}_{ij} = \left|20 \cdot \log_{10}\frac{V_{iN}}{V_{jF}}\right| - \alpha_i \cdot L_o = \text{FEXT}_{ijL_o} - \alpha_i \cdot L_o$$

dB @ measured cable length

27.2.2.4 Unless otherwise specified, the EL FEXT shall be based on measurements at or corrected to 20 °C (68 °F).

27.3 Some detail specifications require the EL FEXT to be reported as a power sum (P.S.). P.S. EL FEXT shall be calculated from readings and calculations obtained in 27.2 except the measurements must be made on all pair combinations using the following equation:

$$\text{P.S. EL FEXT}_j = \left|10 \cdot \log_{10}\sum_{\substack{i=1\\ i\neq j}}^{i=n} 10^{\frac{-\text{FEXT}_{ijLo} - \alpha_i \cdot L_o}{10}}\right| \tag{27}$$

dB @ measured cable length

where:
n = the number of pairs in the cable.

27.4 *Report*—Report in accordance with Section 52 and include the minimum and root mean square values.

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

28. Attenuation to Crosstalk Ratio, Far-End (ACR-F)

28.1 The attenuation to crosstalk ratio-far-end is important for some high frequency applications. The determination of these values is therefore limited to swept frequency measurements.

28.2 The attenuation to crosstalk ratio-far end is defined as:

$$\text{ACR}-\text{F}_{ij} = \text{FEXT}_{ijL_o} - \alpha_i \cdot L_o \quad \text{dB @ measured cable length} \tag{28}$$

where:
ACR-F = the attenuation to crosstalk ratio-far end of the pair j expressed in dB @ measured cable length,
i = the disturbing pair,
j = the disturbed pair,
L_o = the reference length of the cable in length units, and
α_i = the attenuation of the pair j in dB per unit-length.

NOTE 9—The attenuation to crosstalk ratio-far end is also sometimes called misleadingly EL FEXT. However, it has to be stressed that this is wrong as ACR-F is not based upon an equal level concept of the outputs of the disturbing and disturbed pairs.

28.3 Some detail specifications specify the power sum of the attenuation to crosstalk ratio-far end.

28.4 The attenuation to crosstalk ratio-far end of the pair j, due to the disturbing pair i, is calculated from the difference of the FEXT and the attenuation of the disturbed pair. Hence, the P.S. ACR-F is calculated as follows:

$$\text{P.S. ACR}-\text{F}_j = \left|10 \cdot \log_{10}\sum_{\substack{i=1\\ i\neq j}}^{i=n} 10^{\frac{-(\text{FEXT}_{ijLo} - \alpha_i \cdot L_o)}{10}}\right| \tag{29}$$

$$= \left|10 \cdot \log_{10}\sum_{\substack{i=1\\ i\neq j}}^{i=n} 10^{\frac{-\text{FEXT}_{ijLo}}{10}}\right| - \alpha_j \cdot L_o$$

dB @ measured cable length

where:
n = the number of pairs in the cable.

28.5 *Report*—Report in accordance with Section 52. The reporting is generally in graphical form, that is, the calculated ACR-F or P.S. ACR-F as a function of frequency with the specified reference values indicated as well. Individual failure points may be listed upon request.

28.6 *Precision and Bias*—The precision of these tests has not been determined. No statement can be made about the bias of these tests for ACR-F or P.S. ACR-F since the results merely state whether there is conformance to the criteria for success specified in the product specification.

29. Effects of Elevated Temperature on Attenuation

29.1 *Test Chamber*—Either an air-circulating oven or an environmental chamber can be used as follows:

29.1.1 Air circulating oven conforming to Specification D 5423, Type II with vents either open or closed.

29.1.2 *Environmental Chamber*—The chamber shall provide the physical space to accommodate mounting hardware for cable sample(s) that are coiled or in other configurations according to 29.2. The physical space shall be adequate to provide environmental air flow across all samples under test. The chamber shall provide instrumentation, controls and sensors required to provide a running log of time, temperature and humidity for the duration of a test cycle. Temperature and relative humidity (RH) shall be maintained within ±2°C and ±5 % RH respectively for the duration of a test cycle.

29.2 *Sample Preparation*—Sample length shall be 100 m ± 10 cm. The ends of the cable shall be placed such that they are accessible outside of the oven. The length of sample outside the oven shall be less than 2 m for each end. Alternately, fixed connections inside the oven or chamber may be provided to connect the cable under test.

29.2.1 *Cable Configuration*—Cables shall be configured as follows:

29.2.1.1 Cable coils having a minimum 18 cm (7 in.) internal diameter (ID) with the adjacent wraps touching, or,

29.2.1.2 Cable positioned to have a minimum 18 cm (7 in.) internal diameter (ID) with the adjacent wraps separated by a minimum of 2.5 cm (1 in.).

29.3 *Test Equipment*—The equipment used for measuring attenuation (insertion loss) over the specified frequency range shall be a network analyzer with an *S*-parameter test set and unbalanced to balanced impedance matching transformers. For measurements at frequencies less than 1 MHz, alternate equipment such as impedance bridges may be utilized.

29.4 *Test Procedure*—Measure the initial attenuation of the cable per Section 24 at or corrected to 20°C (68°F) and at 50 ± 5 % relative humidity after a minimum conditioning period of 4 h. The measurement frequency range shall be as specified by the individual product specification.

29.4.1 Increase the temperature of the oven or chamber to the specified temperature ±2°C. At this temperature, the relative humidity is unspecified. The cables shall be exposed to this condition for a minimum of 4 h and a maximum of 24 h. Measure the attenuation per Section 24.

29.5 *Treatment of Data*:

29.5.1 For coils per 29.2.1.1, a smoothing (curve fitting) of the measurement data to compensate for inter-coil coupling shall be carried out using the general equation of the form:

$$\alpha = a + b \cdot \sqrt{f} + c \cdot f + \frac{d}{\sqrt{f}} \qquad \text{dB / 100 m} \tag{30}$$

where:

a, b, c, d = regression coefficients (see Section 49 on curve fitting application),

α = the measured attenuation (dB/100 m), and

f = the frequency (MHz).

29.5.2 For sample configurations, per 29.2.1.2, smoothing (curve fitting) of data is not required due to the absence of inter-coil coupling.

29.6 *Temperature Coefficient*—If desired, the temperature coefficient of temperature increase κ can now be determined, using the equation:

$$\kappa = \frac{(\alpha_{T2} - \alpha_{T1})}{\alpha_{T1} \cdot (T_2 - T_1)} \qquad 1 / °\text{C} \tag{31}$$

When smoothing (curve fitting) of the data is necessary, the value of the temperature coefficient, κ, can be determined using the following equation:

$$\kappa = \frac{(a_{T2} - a_{T1}) + (b_{T2} - b_{T1}) \cdot \sqrt{f} + (c_{T2} - c_{T1}) \cdot f + \frac{(d_{T2} - d_{T1})}{\sqrt{f}}}{\left[a_{T1} + b_{T1} \cdot \sqrt{f} + c_{T1} \cdot f + \frac{d_{T1}}{\sqrt{f}}\right] \cdot (T_2 - T_1)} \tag{32}$$

$$1 / °\text{C}$$

where:

α_{T1} = attenuation at the reference temperature, dB/100 m,

α_{T2} = attenuation at the elevated temperature of interest, dB/100 m,

T_1 = referenced temperature, °C,

T_2 = elevated temperature of interest, °C,

$a_{T1}, b_{T1}, c_{T1}, d_{T1}$ = regression coefficients obtained at the referenced temperature, and

$a_{T2}, b_{T2}, c_{T2}, d_{T2}$ = regression coefficients obtained at the elevated temperature of interest.

29.7 *Report*—Report in accordance with Section 52 and include the following:

29.7.1 Attenuation at or corrected to 20°C (68°F) and the specified temperature, at the frequency of interest, shall be reported together with the description of the test sample configuration. If desired, temperature coefficient shall be reported.

29.8 *Precision and Bias*—The precision and bias of these tests have not been determined.

30. Effects of Humidity on Attenuation

30.1 *Test Chamber*—The chamber shall be as specified in 29.1.2.

30.2 *Sample Preparation*—Sample shall be prepared as specified in 29.2.

30.2.1 *Cable Configuration*—Cables shall be configured as specified in 29.2.1.

30.3 *Test Equipment*—Test Equipment shall be as specified in 29.3.

30.4 *Test Procedure*—Measure the initial attenuation of the cable per Section 24 at or corrected to 20°C (68°F) and at 50 ± 5 % relative humidity (RH) after a minimum conditioning period of 4 h. The measurement frequency range shall be as specified by the individual product specification.

30.4.1 Increase the temperature of the chamber to the specified temperature ±2°C while maintaining 50 % relative humidity. The cables shall be exposed to this condition for a minimum of 120 h and a maximum of 168 h. Measure the attenuation per Section 24.

30.5 *Treatment of Data*:

30.5.1 For coils per 29.2.1.1, a smoothing (curve fitting) of the measurement data to compensate for inter-coil coupling shall be carried out using the general equation of the form:

$$\alpha = a + b \cdot \sqrt{f} + c \cdot f + \frac{d}{\sqrt{f}} \qquad \text{dB / 100 m} \tag{33}$$

where:

a, b, c, d = regression coefficients (see Section 49 on curve fitting application),

α = the measured attenuation (dB/100 m), and

f = the frequency (MHz).

30.5.2 For sample configurations, per 29.2.1.2, smoothing (curve fitting) of data is not required due to the absence of inter-coil coupling.

30.6 The attenuation percentage increase, λ, due to temperature and humidity can be calculated with the following equation:

$$\lambda = \frac{(\alpha_{T2,RH2} - \alpha_{T1,RH1})}{\alpha_{T1,RH1}} \cdot 100~\% \tag{34}$$

The attenuation percentage increase, λ, may also be expressed as a function of frequency, using the constants of the curve fitting technique per 29.6.

$$\lambda = (a_{T2,RH2} - a_{T1,RH1}) + (b_{T2,RH2} - b_{T1,RH1}) \cdot \sqrt{f} + (c_{T2,RH2} - c_{T1,RH1}) \cdot f + \frac{(d_{T2,RH2} - d_{T1,RH1})}{\sqrt{f}} \Big/ \left[a_{T1,RH1} + b_{T1,RH1} \cdot \sqrt{f} + c_{T1,RH1} \cdot f + \frac{d_{T1,RH1}}{\sqrt{f}} \right] \cdot 100~\% \tag{35}$$

where:

$\alpha_{T1,RH1}$ = attenuation at the reference temperature and relative humidity, dB/100 m,

$\alpha_{T2,RH2}$ = attenuation at the elevated temperature and humidity of interest, dB/100 m,

T_1 = referenced temperature, °C,

T_2 = elevated temperature of interest, °C,

$a_{T1,RH1}$, $b_{T1,RH1}$, $c_{T1,RH1}$, $d_{T1,RH1}$ = regression coefficients obtained at the referenced temperature and humidity, and

$a_{T2,RH2}$, $b_{T2,RH2}$, $c_{T2,RH2}$, $d_{T2,RH2}$ = regression coefficients obtained at the elevated temperature and humidity of interest.

30.7 *Report*—Report in accordance with Section 52 and include the following:

30.7.1 Attenuation at or corrected to 20°C (68°F) and the specified temperature, at the frequency of interest, shall be reported together with the description of the test sample configuration.

30.8 *Precision and Bias*—The precision and bias of these tests have not been determined.

31. Effects of Aging on Attenuation

31.1 *Test Chamber*—An air-circulating oven shall be used as specified in 29.1.1.

31.2 *Sample Preparation*—Sample shall be prepared as specified in 29.2.

31.2.1 *Cable Configuration*—Cables shall be configured as specified in 29.2.1.

31.3 *Test Equipment*—Test Equipment shall be as specified in 29.3.

31.4 *Test Procedure*—Measure the initial attenuation of the cable (per Section 24) at or corrected to 20°C (68°F) and at 50 ± 5 % relative humidity (RH) after a minimum conditioning period of 4 h. The measurement frequency range shall be as specified by the individual product specification.

31.4.1 Increase the temperature of the oven to 100 ± 2°C unless otherwise specified. At this temperature, the relative humidity is unspecified. The cables shall be exposed to this condition for 168 h. After 168 h, allow cables to cool down to ambient conditions for a minimum of 24 h. Measure the attenuation per Section 24.

31.5 *Treatment of Data*:

31.5.1 For coils per 29.2.1.1, a smoothing (curve fitting) of the measurement data to compensate for inter-coil coupling shall be carried out using the general equation of the form:

$$\alpha = a + b \cdot \sqrt{f} + c \cdot f + \frac{d}{\sqrt{f}} \qquad \text{dB / 100 m} \tag{36}$$

where:

a, b, c, d = regression coefficients (see Section 49 on curve fitting application),

α = the measured attenuation (dB/100 m), and

f = the frequency (MHz).

31.5.2 For sample configurations, per 29.2.1.2, smoothing (curve fitting) of data is not required due to the absence of inter-coil coupling.

31.6 *Report*—Report in accordance with Section 52 and include the following:

31.6.1 Attenuation at or corrected to 20°C both before and after aging, at the frequency of interest, shall be reported together with the description of the test sample configuration and the aging temperature/duration conditions.

31.7 *Precision and Bias*—The precision and bias of these tests have not been determined.

32. Insulation Resistance (IR)

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

32.2 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.

32.3 Unless otherwise specified, measure insulation resistance at or corrected to 20°C (68°F). Temperature correction shall be performed as described in Test Methods D 2633. Measurements shall be made using a meg-Ohm-meter. Measured values are normally converted to a standard length value (normally 1 mile or 1 km). For insulation resistance in Meg-Ohm·miles (Meg-Ohm·km), the values would be:

$$IR_o = \frac{IR_M \cdot L}{5280} \qquad \text{Meg}-\text{Ohm}\cdot\text{mile} \tag{37}$$

$$IR_o = \frac{IR_M \cdot L}{1000} \qquad \text{Meg}-\text{Ohm}\cdot\text{km}$$

where:

IR_O = the insulation resistance, Meg-Ohm, reference length of cable,
IR_M = the insulation resistance, measured Meg-Ohm, cable length , and
L = specimen length, ft (m).

32.4 *Report*:

32.4.1 Report in accordance with Section 52 and include the following:

32.4.1.1 Minimum and average values, and

32.4.1.2 Ambient temperature.

32.5 *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.

33. Fault Rate (Air Core Only)

33.1 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.

$$\text{Fault Rate} = \frac{N}{L} = \frac{1}{X} \tag{38}$$

where:
N = the number of faults detected,
L = the length of the measured product length, and
X = the average length per fault.

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

33.2.1 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.

33.2.2 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).

33.2.3 Measure the insulation resistance for each wire, in accordance with Section 32.

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

33.3 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.

33.4 *Report*:

33.4.1 Report in accordance with Section 52 and include the following:

33.4.1.1 Conductor footage tested,

33.4.1.2 Number of faults detected (if any), and

33.4.1.3 The fault rate.

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

34. Shorts Test (Between Wires of a Pair)

34.1 Testing for shorts is normally accomplished using the dc proof test wire-to-wire of Section 37 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.

34.2 *Report*:

34.2.1 Report in accordance with Section 52 and include the following:

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

34.2.1.2 The voltage level.

34.3 *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.

35. Crosses Test (Between Wires of Different Pairs)

35.1 Testing for crosses is normally accomplished using the dc proof test wire-to-wire of Section 37. 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 37, provided that the shorts test of Section 34 has also been performed.

35.2 *Report*—Report in accordance with 34.2.1.

35.3 *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.

36. Jacket Voltage Breakdown Rating Test

36.1 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.

36.2 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.

36.3 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.

36.4 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.

36.5 *Report*—Report in accordance with Section 52 and include the following:

36.5.1 The maximum voltage level used in the test, and

36.5.2 The maximum current flow measured during the test period.

36.6 *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.

37. DC Proof Test—Wire-to-Wire

37.1 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.

37.1.1 **Warning**—*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.*

37.2 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.

37.3 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.

37.4 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.

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

NOTE 10—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.

37.6 *Report*—Report in accordance with 34.2.1.

37.7 *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 wire-to-wire since the result merely states whether there is conformance to the criteria for success specified in the product specification.

38. DC Proof Test—Core-to-Shield

38.1 This test is performed following the methods of Section 37 except that all conductors in the core are grouped together, and high voltage is applied between these conductors and the grounded shield.

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

38.3 *Report*—Report in accordance with 34.2.1.

38.4 *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 core-to-shield since the result merely states whether there is conformance to the criteria for success specified in the product specification.

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

39.1 This test is normally performed only for non-shielded wire and cable. The test is performed in accordance with Section 37 except that all conductors in the core are grouped together, and high voltage is applied between these conductors and the grounded supporting messenger wire.

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

39.3 *Report*—Report in accordance with 34.2.1.

39.4 *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 core-to-shield since the result merely states whether there is conformance to the criteria for success specified in the product specification.

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

40.1 This test is normally applied to all cables which include an internal shield or screen. The test is performed in accordance with Section 37 except that the conductors in the core are grouped together, and high voltage is applied between these conductors and the grounded screen.

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

40.3 *Report*—Report in accordance with 34.2.1.

40.4 *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 core-to-internal screen since the result merely states whether there is conformance to the criteria for success specified in the product specification.

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

41.1 This test is normally applied to all cables which include an internal shield or screen. The test is performed in accordance with Section 37 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 11—This test applies only if the internal shield is intended to be electrically isolated from the outer shield.

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

41.3 *Report*—Report in accordance with 34.2.1.

41.4 *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 internal shield (screen)-to-shield since the result merely states whether there is conformance to the criteria for success specified in the product specification.

42. DC Proof Test—Other Required Isolations

42.1 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 37, with voltage applied to the members under test.

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

42.3 *Report*—Report in accordance with 34.2.1.

42.4 *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-other required isolations since the result merely states whether there is conformance to the criteria for success specified in the product specification.

43. Voltage Surge Test

43.1 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.

43.2 Select a reel of cable for the test. A 25-pair 22 AWG cable is most commonly used for voltage surge testing. Cut a sample length long enough to permit the necessary specimen preparation from the selected reel.

43.3 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 12—Prepare the specimen carefully to avoid torn or rough shield edges or unintentional nicks and cuts of insulation, core wrap, shield, etc. Proper specimen preparation is critical to the success of this test.

43.3.1 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.

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

43.3.3 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.

43.3.4 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.

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

43.4.1 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.

43.4.2 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.

43.5 *Report*—Report in accordance with Section 52.

43.6 *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.

44. Phase Constant

44.1 The phase constant of a pair of conductors is a measure of the phase shift incurred by a 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:

$$\beta = \angle(V_{iF}) - \angle(V_{iN}) + 2\pi k \qquad \text{radian / cable length} \qquad (39)$$

where:

β = the total phase angle over the length of cable, radian,
i = the measured pair,
$\angle(V_{iN})$ = the input angle relative to a reference angle,
$\angle(V_{iF})$ = the output angle relative to the same reference angle, and
k = the multiple of 2π radian.

NOTE 13—This measurement is normally performed at the same time as attenuation (see Section 24).

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

44.3 *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 port 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 %.

44.4 *Determining k*:

44.4.1 *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 39. 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 radians (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*.

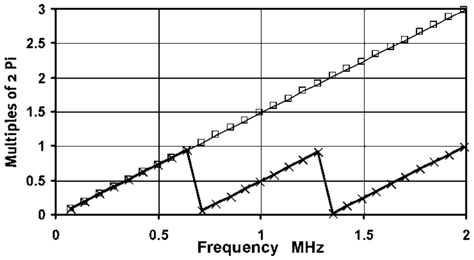


FIG. 6 Determining the Multiple of 2π Radians to be Added to the Phase Measurement

44.4.2 *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 shown 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 $\pi/2$ radians 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.

44.5 *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.

44.6 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

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

45. Phase Delay

45.1 Compute phase delay, τ, from the phase constant as measured in accordance with Section 44, by means of:

$$\tau = \frac{\beta}{\omega} \quad \text{s / measured cable length} \tag{40}$$

where:

τ = the phase delay of cable length, s per measured cable length,
β = the phase constant from Section 44, radian, and
ω = the 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.

45.2 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

45.3 *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.

46. Phase Velocity

46.1 Compute phase velocity, ν, from the phase constant, as measured in accordance with Section 44 by means of:

$$\nu = \frac{\omega}{\beta} \quad \text{cable length / s} \tag{41}$$

where:

ν = the phase velocity of measured cable length/s,
ω = the radian frequency, radian/s and
β = the phase constant, radian.

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

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

46.3 Phase velocity is sometimes reported as the normalized velocity of propagation (NVP), which is the ratio of the phase velocity from 46.2 to the velocity of light in a vacuum (c). It is then reported, for example, as NVP = 0.71 or expressed as a percentage of the speed of light as NVP = 71 %. A variation is to report the velocity of propagation as a fraction of the speed of light, such as $0.71c$.

46.4 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

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

47. Characteristic Impedance—Method 1

47.1 *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 Section 24.

47.1.1 *Important Equations*—Characteristic Impedance of a cable pair can be stated in terms of the primary transmission parameters as follows:

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \Re e(Z_o) + \Im m(Z_o) \qquad \textit{Ohm, radian} \qquad (42)$$

where:

Z_o = the complex characteristic impedance, Ohm and radian,
R = the ac resistance of the pair length, Ohm,
L = the inductance of the pair length, Henry,
G = the conductance of the pair length, Siemens,
C = the capacitance of the pair length, Farad,
ω = radian frequency, radian/s,
$\Re e$ = the real part of complex characteristic impedance, and
$\Im m$ = the imaginary part of complex characteristic impedance.

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

$$\gamma = \sqrt{(R + j\omega L) \cdot (G + j\omega C)} \qquad \text{Neper, radian} \qquad (43)$$

where:

γ = the complex propagation constant of the length of cable, Neper and radian.

47.1.1.2 The propagation constant can also be stated in terms of the attenuation measured in accordance with Section 24 and the phase constant measured in accordance with Section 44, as follows:

$$\gamma = \alpha + j\beta \qquad \text{Neper, radian} \qquad (44)$$

where:

α = the real part, attenuation of the length of cable, Neper, and
β = the imaginary part, the phase constant for the length of cable, radian.

NOTE 14—It will be noted that while the natural unit of attenuation is Neper, it is often expressed in dB which is equal to the value in Neper times 8.686.

47.1.2 *Applicable Equations*—From Eq 42-44, it follows that characteristic impedance can be stated in terms of the propagation constant and the shunt primary constants since:

$$Z_o = \frac{\alpha + j\beta}{G + j\omega C} \qquad \text{Ohm, radian} \qquad (45)$$

47.1.3 *Delay Capacitance Procedure*—Measure the three quantities, capacitance, attenuation, and the phase constant, according to Sections 18, 24 and 44. 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_o will be too large by a mere 0.05 %. When only the reactive portions of Eq 43 are significant, a simpler version of Eq 45, shown here as Eq 46 (the delay-capacitance equation) may be used:

$$|Z_o| = \frac{\tau}{C} \qquad (46)$$

where:

Z_o = the magnitude of the characteristic impedance, Ohm,
τ = the delay, s per cable length, and
C = the capacitance, Farad per cable length.

47.1.4 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

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

48. Characteristic Impedance—Method 2 Single Ended Measurements

48.1 *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 unbalanced or balanced). The basis for this measurement approach is the following:

$$Z_o = \sqrt{Z_{oc} Z_{sc}} \qquad \text{Ohm, radian} \qquad (47)$$

where:

Z_o = the complex characteristic impedance, Ohm, radian,
Z_{oc} = the complex open circuit impedance, Ohm, radian, and
Z_{sc} = the complex short circuit impedance, Ohm, radian.

In the ideal sense, Eq 46 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 for lines can be reported directly as computed from Eq 47 when structural effects are negligible.

48.1.1 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_o but rather an input impedance Z_{in}. For this situation, least squares function fitting techniques, covered in Section 49, can be used to extract the characteristic impedance from the input impedance.

48.2 *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:

$$Z_{in} = Z_o \frac{(Z_L + Z_o \tanh(\gamma l))}{(Z_o + Z_L \tanh(\gamma l))} \quad \text{Ohm, radian} \qquad (48)$$

where:

Z_{in} = the input impedance, Ohm, radian,
Z_o = the characteristic impedance, Ohm, radian,
Z_L = the load impedance, Ohm, radian,
γ = the propagation constant, Neper and radian, per length unit, and
l = the length of the pair in length units.

Eq 48 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 tanhγl 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_o by, at most, 3.5 %.

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

48.3.1 *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 Ohms) with a 1 % tolerance, *(3)* an impedance matching transformer for converting from unbalanced to balanced impedances (for instance, 50:100 Ohms or 50:150 Ohms) 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.

48.3.1.1 *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.

48.3.2 *Specimen Preparation*:

48.3.2.1 *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 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).

48.3.2.2 *Preparing the Ends*—Remove appropriate lengths of jacket and insulation from both ends of the specimen insuring 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, and 0.75 in. of insulation for measurements extending to 100 MHz).

48.3.2.3 *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.

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

48.3.3 *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 or printer to the network analyzer (if applicable); and *(5)* Connect the interface on network analyzer to the computer interface card and load the acquisition program (if applicable).

48.3.4 *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 Annex A1 for calibration equations to be used with calibration data obtained from network analyzers lacking such computation capability internally.

48.3.5 *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 may optionally be grounded to the center tap of the transformer secondary.

48.3.5.1 *For On-analyzer Evaluation of Terminated Impedance Measurements*—Edit results on plotter or printer for a hardcopy of results. Alternately, for 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 equation:

$$Z_{in} = Z_L \cdot \frac{1 + s_{11}}{1 - s_{11}} \qquad (49)$$

where:

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

48.3.5.2 *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 49 to convert from *S*-parameter to the open and short circuit impedances and compute input impedance using Eq 47.

48.4 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

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

49. Characteristic Impedance—Method 3

49.1 *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 assured 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 measurements provided the roughness is moderate in at least a portion of the frequency range.

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

$$|Z_o| = K_o + \frac{K_1}{\sqrt{f}} + \frac{K_2}{f} + \frac{K_3}{f \cdot \sqrt{f}} \quad \text{Ohm} \tag{50}$$

where:

Z_o = the magnitude of the characteristic impedance, Ohm,

f = the frequency, MHz, and

K_o, K_1, K_2, K_3 = the least squares fit coefficients as indicated in Eq 50.

Calculate the curve fit coefficients using the equation:

$$\begin{vmatrix} \sum_{i=1}^{N} |Z_{in}| \\ \sum_{i=1}^{N} \frac{|Z_{in}|}{\sqrt{f_i}} \\ \sum_{i=1}^{N} \frac{|Z_{in}|}{f_i} \\ \sum_{i=1}^{N} \frac{|Z_{in}}{f_i^{3/2}} \end{vmatrix} = \begin{vmatrix} N & \sum_{i=1}^{N} \frac{1}{\sqrt{f_i}} & \sum_{i=1}^{N} \frac{1}{f_i^{3/2}} & \\ \sum_{i=1}^{N} \frac{1}{\sqrt{f_i}} & \sum_{i=1}^{N} \frac{1}{f_i} & \sum_{i=1}^{N} \frac{1}{f_i^{3/2}} & \sum_{i=1}^{N} \frac{1}{f_i^{2}} \\ \sum_{i=1}^{N} \frac{1}{f_i} & \sum_{i=1}^{N} \frac{1}{f_i^{3/2}} & \sum_{i=1}^{N} \frac{1}{f_i^{2}} & \sum_{i=1}^{N} \frac{1}{f_i^{5/2}} \\ \sum_{i=1}^{N} \frac{1}{f_i^{3/2}} & \sum_{i=1}^{N} \frac{1}{f_i^{2}} & \sum_{i=1}^{N} \frac{1}{f_i^{5/2}} & \frac{1}{f_i^{3}} \end{vmatrix} \times \begin{vmatrix} K_0 \\ K_1 \\ K_2 \\ K_3 \end{vmatrix} \tag{51}$$

where all summations are performed over N data points.

49.1.1.1 *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 51) is solved by the computer, using determinants or matrix inversion techniques.

49.1.1.2 *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 50 and Eq 51, 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 50 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.

49.1.1.3 *Four Criteria Indicating Use of Fewer Terms*—Check or have the computer program determine if the fitted function obtained by solving Eq. 51 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 Ohm to −2 Ohm 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 50) must be reduced by one by omitting the highest order term or a wider range of frequencies must be used. This will generally result in a more suitable curve.

NOTE 15—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 50 amounts to deleting the fourth row and column from Eq 51, 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 16—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 51 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.

49.1.1.4 *Compute and Edit Fitted Results*—Compute values for the magnitude of the characteristic impedance, Z_o, according to coefficients obtained from the fit at the desired frequencies and edit the results or tabulate the fitted results at specification frequencies as desired.

49.1.1.5 *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 cannot be fitted well over a broad range of frequencies using Eq 50 but respond well to a polynomial fit employing a series of log(*f*) terms as indicated in Eq 52. A six term function (an obvious extension of Eq 50 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.

$$|Z_o| = K_o + K_1 \cdot \log(f) + K_2 \cdot \log^2(f) + ... + K_5 \cdot \log^5(f) \qquad \text{Ohm} \qquad (52)$$

where:

Z_o = the magnitude of the characteristic impedance, Ohm,

f = the frequency, MHz, and

$K_o, K_1 ... K_5$ = the least squares fit coefficients as indicated in Eq 52.

Calculate the fit coefficients using an equation similar to Eq 50.

49.1.1.6 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

49.1.1.7 *Precision and Bias*—The precision of this test has not been determined. 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.

49.2 *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 49.1.1.

$$\angle Z_o = L_o + \frac{L_1}{\sqrt{f}} + \frac{L_2}{f} + \frac{L_3}{f \cdot \sqrt{f}} \qquad \text{radian} \qquad (53)$$

where:

$\angle Z_o$ = the angle of the characteristic impedance, radian,

f = the frequency, MHz, and

L_o, L_1, L_2, L_3 = the 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. Edit the results as desired.

NOTE 17—This procedure is necessary only if the angle of the characteristic impedance is of interest or if structural return loss (SRL), see 50.1, is being calculated at frequencies low enough to result in a significant angle ($\angle < -10$ degrees). It should be noted that the separate curve fitting of real and imaginary data is, from a strictly mathematical standpoint, incorrect. Therefore, data obtained in this way do not reflect the real phase relations. However, compared to the complexity of curve fitting complex data, this simplification is acceptable in the cases considered here.

49.2.1 *Fitting the Angle of Input Impedance with an Alternate Function*—Use a function of the same form as Eq 52 to fit the impedance angle for pairs of the type discussed in 49.1.1.5.

49.2.2 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

49.2.3 *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.

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

50.1 Structural return loss (SRL) is obtained from input impedance (square root of open/short impedances). Return Loss (RL) is obtained from a terminated impedance measurement. While SRL gives an indication primarily of the roughness of the transmission line, the return loss is an indication of the reflected signal. Hence the two measures differ in their importance, thus-*(a)* SRL is primarily used as a manufacturing and quality control tool during and after manufacturing processes, and *(b)* Return loss (RL) is an important parameter from the application point of view. Separate characteristic impedance and RL specifications are the preferred method of specification. The RL approach 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. 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 18—SRL measurements are mainly used to verify and analyze equipment performance with respect to conductor and insulation diameter, capacitance and uniformity of tensions.

NOTE 19—On an individual pair basis, computing return loss instead of SRL can result in an 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.

50.2 *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 equation:

$$\text{SRL} = -20 \log_{10} \left| \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \right| \qquad \text{dB} \qquad (54)$$

where:
SRL = the structural return loss, dB,
Z_{in} = the complex input impedance, Ohm, radian, and
Z_o = the curve fitted complex impedance, Ohm, radian.

NOTE 20—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 edit the results, checking for conformance to the appropriate standard over the entire frequency range. It is important to note that Eq 54 involves complex values for the input impedance and the fitted function (see also Note 17).

50.2.1 *SRL Result*—The SRL result obtained from the use of Eq 53 shows a decreasing trend over frequency. If a straight regression line is curve fitted to the trace to quantify its reference level and downward trend with frequency, it will indicate a downward slope of about 10 dB/decade.

50.3 *Obtaining the Return Loss*—Use the appropriate network analyzer function to obtain the RL. The return loss for a pair is defined as:

$$\mathrm{RL} = -20 \log_{10} \left| \frac{Z_T - Z_L}{Z_T + Z_L} \right| \qquad \mathrm{dB} \tag{55}$$

where:
RL = the return loss, dB,
Z_T = the terminated complex impedance, Ohm, and radian, and
Z_L = the calibration load, Ohm and radian.

Calculate the RL either on board the network analyzer or using the computer that was used to acquire the data, and edit the results, checking for conformance to the appropriate standard over the entire frequency range. Graphs of RL will not exhibit the consistent downward trend as SRL over such a broad frequency range. In fact, RL normally increases with frequency up to a plateau level and decreases with a constant slope in a log-frequency graph at higher frequencies.

50.4 *Report*—Report in accordance with Section 52 and include the following data: minimum, maximum, average and standard deviation.

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

51. Unbalance Attenuation (Mode Conversion Losses)

51.1 These measurements represent mode conversion losses within one pair. The unbalance attenuation is defined as the logarithmic ratio of the common mode power to the differential mode power.

$$\alpha_{\substack{u,n\\u,f}} = 20 \cdot \log \left| \frac{\sqrt{P_{\substack{n,com\\f,com}}}}{\sqrt{P_{diff}}} \right| \tag{56}$$

$$= 20 \cdot \log \left| \frac{\sqrt{V_{\substack{n,com\\f,com}}}}{\sqrt{V_{diff}}} \right| + 10 \cdot \log \left| \frac{Z_{diff}}{Z_{com}} \right| \qquad \mathrm{dB}$$

where:
α_u = the unbalance attenuation, dB,
P_{diff} = the matched differential mode power, Watt,
P_{com} = the matched common mode power, Watt,
V_{diff} = the voltage in the differential mode circuit, Volt,
V_{com} = the voltage in the common mode circuit, Volt,
Z_{diff} = the characteristic impedance of the differential mode circuit, Ohm,
Z_{com} = the characteristic impedance of the common mode circuit, Ohm, and
n, f = the indices to designate the near end and far end, respectively.

51.2 *Equipment Required*—*(a)* a network analyzer or generator/receiver combination suitable for the required frequency and dynamic range shall be selected, *(b)* for unbalance attenuation measurements, the two baluns (balanced to unbalanced impedance matching transformer) shall have a common mode port, centered over the balanced output, *(c)* passive terminations for the cable pairs are required, capable of supplying both the appropriate differential and common mode terminations, and *(d)* metal drum, big enough to hold 100 m of unscreened cables in one layer for measurement (optional). Performance requirements of the baluns shall be as specified in the product specification.

51.3 *Specimen Preparation*—The unbalance attenuation is frequency and length dependent. Therefore, the measurement shall be carried out on a length of 100 ± 1 m. For unscreened twisted pair cables, it is mandatory to create a defined return (common mode) path. This is normally achieved by grounding all other pairs. However, the cable under test may be wound onto a metal drum. This drum may have a suitable thread, wide enough to have the cable in the groove of the thread. In this case, the drum, the adjacent pairs and screens, if present, should be grounded.

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

51.3.2 *Terminations*—Terminate the cable pair being tested at the near and far ends so as to simultaneously minimize reflections of both the differential and common mode. This is accomplished by proper termination of the pairs. Use of improper differential and common mode terminating impedances results in possible mixing of near-end and reflected far-end unbalance attenuation, for instance. This is similar to the mixing of NEXT and reflected FEXT that may result from wrongly terminating crosstalk measurement circuits.

51.4 *Calibration*—*(a)* for the reference line calibration (0 dB-line) over the whole specified frequency range, the same coaxial cables used for the measurements shall be used by connecting them between the analyzer output and the input, *(b)* two identical baluns shall be used for the measurements. The baluns shall be connected back to back (see Fig. 7) on the symmetrical output side, and their attenuation measured over the specified frequency range. The connection between the two baluns shall be made with negligible loss. These measurements give the differential mode loss, α_{diff}, of the baluns. It is assumed that the intrinsic losses, differential and common mode losses, respectively, of the baluns are equal.

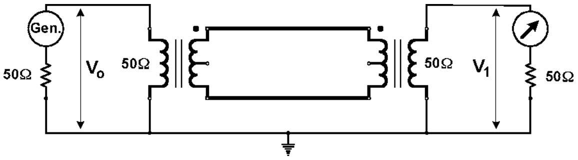


FIG. 7 Test Set-Up for the Measurement of the Differential Mode Loss of the Baluns

$$\alpha_{diff} = \frac{1}{2} \cdot \left(20 \cdot \log_{10}\left|\frac{V_1}{V_o}\right|\right) \quad \text{dB} \qquad (57)$$

where:

α_{diff} = the differential mode loss of the balun, dB.

The same baluns are connected together as in *(b)* above, while terminating the unbalanced ports with the nominal impedance and connecting the generator and receiver to the common mode port (center tap) of the baluns. Fig. 8 indicates the set-up for the measurement of the common mode loss of the baluns. From this measurement, we obtain the common mode loss α_{com} of the baluns, again under the assumption that both baluns have identical common mode loss, as indicated in Eq 58.

$$\alpha_{com} = \frac{1}{2} \cdot \left(20 \cdot \log_{10}\left|\frac{V_1}{V_o}\right|\right) \quad \text{dB} \qquad (58)$$

where:

α_{com} = the common mode loss of the balun, dB.

(c) The operational attenuation of the balun α_{balun} takes into account the common mode and differential mode losses of the balun:

$$\alpha_{balun} = \alpha_{diff} + \alpha_{com} \quad \text{dB} \qquad (59)$$

where:

α_{balun} = the operational attenuation or intrinsic loss of the balun, dB.

NOTE 21—More precise results can be obtained using either poling of the baluns for α_{diff} and α_{com}, and averaging the results, or using three baluns. In the latter case, the assumptions of Eq 57 and 58 are not required.

The voltage ratio of the balun can be expressed by the turns ratio of the balun and the operational attenuation of the balun:

$$20 \cdot \log_{10}\left|\frac{V_{diff}}{V_o}\right| = 10 \cdot \log_{10}\left|\frac{Z_{diff}}{Z_o}\right| - \alpha_{balun} \quad \text{dB} \qquad (60)$$

$$20 \cdot \log_{10}\left|\frac{V_{diff}}{V_1}\right| = 10 \cdot \log_{10}\left|\frac{Z_{diff}}{Z_1}\right| - \alpha_{balun} \quad \text{dB}$$

where:

V_{diff} = the differential mode voltage at the input of the DUT (device under test), Volt,
V_o = the voltage at the output of the generator, Volt,
Z_{diff} = the characteristic impedance of the differential mode circuit, Ohm,
Z_o = the output impedance of the generator, Ohm,
V_1 = the voltage at the input of the load, Volt, and
Z_1 = the input impedance of the load, Ohm.

51.5 *Measurement*—All pairs/quads of the cable shall be measured at both ends of the DUT. The attenuation unbalance shall be measured over the specified frequency range and at the same frequency points as for the calibration procedure. For cables having a nominal impedance of 100 Ohm, the value of Z_{com} is approximately 75 Ohm for small pair count unscreened pair cables, approximately 50 Ohm for common screened pair cables and high pair count unscreened pair cables, and 25 Ohm for individually screened pair cables. These values should be used for correction purpose. The impedance of the common mode circuit Z_{com} can be measured more precisely either with a time domain reflectometer (TDR) or a network analyzer. The two conductors of the pair are connected together at both ends and the impedance is measured between these conductors and the return path. The absolute value of the common mode impedance can also be approximated, using the capacitance values according to Fig. 1, using the following equation:

$$[M<]reale(Z) \approx R_{com} \approx \frac{C_{AB}}{2} \cdot \left(\frac{1}{C_{AG}} + \frac{1}{C_{BG}}\right) \quad \text{Ohm} \qquad (61)$$

51.6 *Cable under Test*—The ends of the DUT shall be prepared so that the twisting of the pairs/quads is maintained up to the terminals of the test equipment. The DUT shall have a length of 100 ± 1 m. All pairs not under test, and the shields, if present, shall be connected to ground at both ends of the cable.

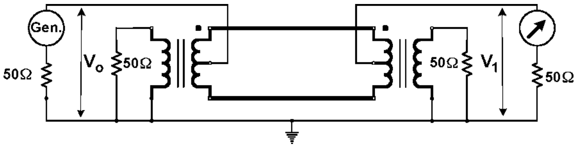


FIG. 8 Test Set-Up for the Measurement of the Common Mode Loss of the Baluns

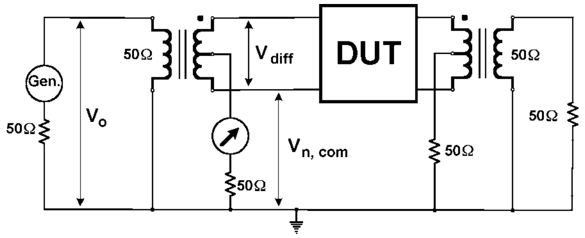


FIG. 9 Test Set-Up for Unbalance Attenuation Near End (TCL)

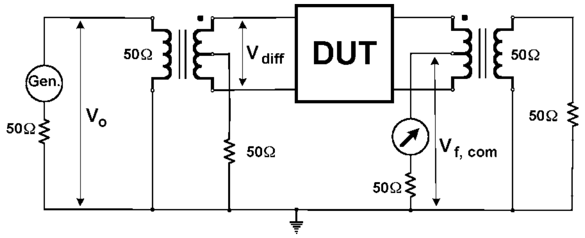


FIG. 10 Test Set-Up for Unbalance Attenuation Far End (TCTL)

51.7 *Test Set-Up for Unbalance Measurements—Definitions: (a)* definition of the measurement for unbalance attenuation near end (for more detailed information see Annex A2):

$$\alpha_{meas} = 20 \cdot \log_{10} \left| \frac{V_{n,\,com}}{V_o} \right| \quad \text{dB} \qquad (62)$$

where:

α_{meas} = the measured attenuation, dB,

V_{com} = the voltage in the common mode circuit, Volt, and

n, f = the indices to designate the near end and far end, respectively.

(b) definition of the measurement for unbalance attenuation far end (for more detailed information see Annex A2):

$$\alpha_{meas} = 20 \cdot \log_{10} \left| \frac{V_{f,\,com}}{V_o} \right| \quad \text{dB} \qquad (63)$$

51.8 *Expression of Test Result*—The unbalance attenuation is defined as the logarithmic ratio of the common mode power to the differential mode power (see also Eq 56). Usually, when measuring with *S*-parameter test-sets, instead of the differential mode voltage in the DUT, the output voltage of the generator is measured. Taking the operational attenuation of the balun into account, the equation above can be written as follows for the unbalance attenuation near or far end, respectively:

$$\alpha_{\substack{u,\,n\\u,\,f}} = 10 \cdot \log_{10} \left| \frac{P_{\substack{n,\,com\\f,\,com}}}{P_{diff}} \right| = 10 \cdot \log_{10} \left| \frac{P_{\substack{n,\,com\\f,\,com}}}{P_o} \right| - \alpha_{balun} \qquad (64)$$

$$= 20 \cdot \log_{10} \left| \frac{V_{\substack{n,\,com\\f,\,com}}}{V_o} \right| + 10 \cdot \log_{10} \left| \frac{Z_o}{Z_{com}} \right| - \alpha_{balun} \quad \text{dB}$$

$$\alpha_{\substack{u,\,n\\f,\,n}} = \alpha_{meas} + 10 \cdot \log_{10} \left| \frac{Z_o}{Z_{com}} \right| - \alpha_{balun} \quad \text{dB} \qquad (65)$$

The equal level unbalance attenuation at far end is then:

$$\text{EL } \alpha_{u,f} = \alpha_{meas} + 10 \cdot \log_{10} \left| \frac{Z_o}{Z_{com}} \right| - \alpha_{balun} - \alpha_{diff\,cable} \quad \text{dB} \qquad (66)$$

$$\text{EL } \alpha_{u,f} = \text{EL TCTL} \qquad dB$$

where:

EL $\alpha_{u,f}$ = the equal level unbalance attenuation at far end or the EL TCTL (equal level transverse conversion transfer loss), dB, and

$\alpha_{diff\,cable}$ = the differential mode attenuation of the cable, dB.

NOTE 22—Two equal level attenuations far-end can be defined. Besides the one defined in Eq 66, it is also possible to define the EL $\alpha_{u,f}$ as follows (see also A2.2):

$$\text{EL } \alpha_{u,f} = \text{EL LCTL} = \alpha_{u,f} + 10 \cdot \log_{10} \left| \frac{Z_o}{Z_{diff}} \right| - \alpha_{balun} - \alpha_{com\,cable} \qquad (67)$$

However, this definition is normally not used, as the measurement of the common mode attenuation of an unshielded twisted pair is prone to much error and there is no test method defined for it.

51.9 *Report*—Report in accordance with Section 52.

51.10 *Precision and Bias*—The precision of this test has not been determined. No statement can be made about the bias of this test for unbalance attenuation, near-end (TCL/LCL), unbalance attenuation, far-end (TCTL/LCTL) or the corresponding equal level values (EL TCTL/EL LCTL), since the results merely state whether there is conformance to the criteria for success specified in the product specification.

52. Report

52.1 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:

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

52.1.2 Date of testing,

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

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

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

52.2 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.)

53. Keywords

53.1 aging; attenuation; attenuation to crosstalk ratio near-end; attenuation to crosstalk ratio far-end; capacitance deviation; capacitance difference; capacitance unbalance pair-to-pair; capacitance unbalance pair-to-ground; capacitance unbalance pair-to-support wire; characteristic impedance; coaxial capacitance; conductor resistance; conductor resistance unbalance; continuity; conversion loss; crosses; crosstalk loss—far end; crosstalk loss—near end; dc proof test; equal level far-end crosstalk; equal level unbalance attenuation far-end; equal level unbalance attenuation near-end; equal level longitudinal conversion transfer loss (EL LCTL); equal level transverse conversion transfer loss (EL TCTL); fault rate test; humidity; insulation defect; insulation resistance; jacket voltage breakdown; longitudinal conversion loss (LCL); longitudinal conversion transfer loss (LCTL); mutual capacitance; mutual conductance; phase constant; phase delay; phase velocity; shorts test; spark test; structural return loss; transverse conversion loss (TCL); transverse conversion transfer loss (TCTL); unbalance attenuation far-end; unbalance attenuation near-end; voltage surge test

ANNEXES

(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:

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

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:

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

where:

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

The equation for S is defined as:

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

where:

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

A2. UNBALANCE ATTENUATION

A2.1 *General*—Symmetric pairs may be operated in the differential mode (balanced) or the common mode (unbalanced). In the differential mode, one conductor carries the current and the other conductor carries the return current. The return path (common mode) should be free of any current. In the common mode, each conductor of the pair carries half of the current and the return path, the sum of both these currents. All pairs not under test and any screens, if present, represent the return path for the common mode voltage.

A2.1.1 Under ideal conditions, both modes are independent of one another. In reality, both modes influence each other. Differences in the diameter of the insulation, unequal twisting and different distances of the conductors to the screen are some reasons for the unbalance of a pair. The asymmetry is caused by the transverse-asymmetry and by the longitudinal-asymmetry. The transverse-asymmetry is caused by longitudinally distributed unbalances to earth of the capacitance and conductance. The longitudinal-asymmetry is caused by the inductance and resistance unbalances between the two conductors of the pair.

A2.2 *Unbalance Attenuation Near End and Far End*:

A2.2.1 Unbalance attenuation is measured as the logarithmic ratio of the common mode power to the differential mode power at the near end and at the far end of the cable. The unbalance attenuation is also often referred to as conversion loss:

LCL = longitudinal conversion loss
LCTL = longitudinal conversion transfer loss
TCL = transverse conversion loss
TCTL = transverse conversion transfer loss

A2.2.2 Additionally, the equal level unbalance attenuations far end, are defined as follows:

EL LCTL = equal level longitudinal conversion transfer loss
EL TCTL = equal level transverse conversion transfer loss

A2.2.3 The equal level unbalance attenuation is defined as an output-to-output measurement of the logarithmic ratio of the common mode power to the differential mode power, or vice versa. The output-to-output measurements correspond to the difference of the input-to-output measurement and the respective attenuation:

$$\text{EL LCTL} = \text{LCTL} - \alpha_{\text{com}} \quad \text{dB} \qquad \text{(A2.1)}$$

$$\text{EL TCTL} = \text{TCTL} - \alpha_{\text{diff}} \quad \text{dB}$$

where:

α_{diff} = the operational differential mode attenuation of the cable, dB, and
α_{com} = the operational common mode attenuation of the cable, dB.

A2.2.4 As it is not a common practice to measure the output-to-output ratios directly, the above differences are utilized to determine the equal level unbalance attenuation. The measurement of the common mode attenuation of balanced cables is prone to error, and the differential attenuation of the cables has to be measured anyway. Therefore, the measurement of the equal level unbalance attenuation far end is limited here to the equal level transverse conversion transfer loss.

A2.2.5 The unbalance attenuation near end or far end is related to the conversion losses as indicated in Tables A2.1 and A2.2, respectively:

TABLE A2.1 Unbalance Attenuation Near End

Power fed at the near end into the differential mode and coupled power measured at the near end in the common mode	TCL
Power fed at the near end into the common mode and coupled power measured at the near end in the differential mode	LCL

TABLE A2.2 Unbalance Attenuation Far End

Power fed at the near end into the differential mode and coupled power measured at the far end in the common mode	TCTL
Power fed at the near end into the common mode and coupled power measured at the far end in the differential mode	LCTL
Same as TCTL but the measured common mode power is related to the differential mode power at the far end (equal level)	EL TCTL

A2.2.6 Table A2.3 indicates the common and differential mode circuit of the input, and the receive signal for the different types of unbalance attenuation.

A2.2.7 Using the concept of operational attenuation, the generator and receiver on one port network are interchangeable without any change in the results. Therefore, the measurements of TCL are identical to those of LCL.

A2.2.8 However, the measurement of LCTL or TCTL is inherently a two-port measurement. Therefore, the measurements of LCTL are only identical to those of TCTL, if the longitudinal distribution of the unbalances is homogeneous, and if the velocity of propagation of differential and common mode signals is identical. In this case, the twisted pair corresponds to a reciprocal and impedance symmetrical two port network.

A2.2.9 If differential mode transmission is considered, then the loss due to conversion of the differential mode signal into common mode signal only is of interest. This yields an additional advantage. Feeding the power into the differential mode ports of the balun yields the benefit that the balun then represents a matched generator, which avoids the need of any additional matching pads.

A2.2.10 The differential mode impedance of multiple pair cables is a well-known design parameter. However, the common mode impedance depends largely upon the design of the cable and is influenced primarily by the insulation thickness, the dielectric constant of the insulation, the proximity and number of neighboring pairs, and finally by the presence of shields. Thus, the common mode impedance of nominally 100

TABLE A2.3 Measurement Set-Up

Unbalance Attenuation		Set-Up			
		Near End		Far End	
		Common Mode Circuit	Differential Mode Circuit	Common Mode Circuit	Differential Mode Circuit
Near End	TCL	Receiver	Generator	—	—
	LCL	Generator	Receiver	—	—
Far End	TCTL	—	Generator	Receiver	—
	LCTL	Generator	—	—	Receiver

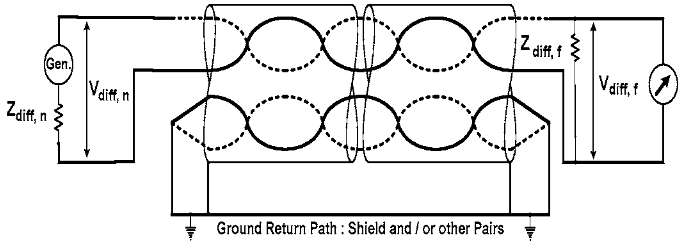


FIG. A2.1 Differential Mode Transmission in a Symmetric Pair

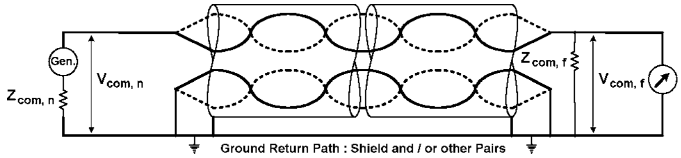


FIG. A2.2 Common Mode Transmission in a Symmetric Pair

Ohm cables can vary within the range of 25 to 75 Ohm, depending on cable construction. For STP (individually screened twisted pair) cables, it is approximately 25 Ohm. For FTP (common screened twisted pair) cables, it is approximately 50 Ohm. For UTP (unscreened twisted pair) cables, it is approximately 75 Ohm (see also 51.5).

A2.2.11 The baluns used for measuring are matching generally the input impedance of the *S*-parameter test set to the differential mode impedance of the cable under test (DUT). It is, however, impractical to measure first for each cable the common mode impedance to match it then to the corresponding common mode impedance terminations used on the balun. Therefore, the terminations at the common mode port are made throughout in 50 Ohm, 60 Ohm or 75 Ohm for 100 Ohm, 120 Ohm or 150 Ohm nominal impedance cables respectively, to match the common mode impedance of the balun and the pair under test (DUT). For cables with a nominal impedance of 100 Ohm, the 50 Ohm termination is presented by the input impedance of the network analyzer. This proceeding entails, due to eventual impedance mismatches, a variation of the unbalance attenuation due to the reflected signal. Thus, a return loss of 10 dB yields an uncertainty of about ±1 dB.