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STANDARDS PUBLICATION NO. WC 61

Transfer Impedance Testing (Modified MIL-C-85485 Test Method)

NEMA

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

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NEMA STANDARDS PUBLICATION NO. WC 61-1992

TRANSFER IMPEDANCE TESTING
(MODIFIED MIL-C-85485 TEST METHOD)

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Foreword

In December 1985, the NEMA Electronic Wire and Cable Technical Committee decided to evaluate transfer impedance test procedures. The goal was to establish measurements of shield effectiveness that would provide correlation among manufacturers and end-users. A series of four round robin test programs were performed in conjunction with technical discussions about the merits of different test procedures. This program led to the development of a NEMA Transfer Impedance Test Procedure. The test program and discussions are summarized below.

First Round Robin Test—Results published in minutes of NEMA Ad Hoc Task Force on Transfer Impedance Testing, April 8, 1986. Six manufacturers tested the transfer impedance of coaxial and twisted pair samples shielded with copper tubes. No specific test method was called out, but MIL-C-85485 and the terminated triaxial fixture were the only procedures used. Correlation between test facilities and methods was sufficient to encourage testing of production cables rather than lab constructions.

Second Round Robin Test—Final results published in the minutes of the NEMA Electronic Wire and Cable Technical Committee Meeting, December 10, 1986. Samples of RG-213 and RG-58 from one lot of one source were evaluated by eight manufacturers. Correlation was not good. In some cases, the same manufacturer got varying results on the same cable type. The frequency limitations of both the terminated triaxial and the MIL-C-85485 methods became obvious.

Third Round Robin Test—Results published in Conference Report of Ad Hoc Task Force on Transfer Impedance Meeting, September 28, 1987. Samples of RG-58 and RG-213 shielded with a steel tube were prepared by Belden and tested by seven manufacturers. This shielding was chosen because its transfer impedance could be calculated. Each company prepared its samples for testing per MIL-C-85485. After testing, these samples were circulated to other participants in the program. The data showed that different facilities got close results on the same samples. This implied that measurement equipment was not the significant source of the errors. This was no surprise because this transfer impedance measurement is an insertion loss test. The data demonstrated the theoretical upper frequency limit of the MIL-C-85485 method as described in the referenced paper by A. Martin and M. Mendenhall. That paper and additional testing by the Task Force suggested that the upper frequency limit could be extended from 30 MHz to 100 MHz by testing shorter samples. The most significant source of error in the test was determined to be sample preparation.

Fourth Round Robin Test—Results published in the Conference Report of Ad Hoc Task Force on Transfer Impedance Meeting, March 9, 1988. Spectra-Strip built MIL-C-85485 type 1/3 meter transfer impedance fixtures. These were submitted as a standard for measurement. Four companies tested the fixtures and the correlation up to 100 MHz was excellent. The data established that different test facilities testing identically constructed stable devices would achieve the theoretical results.

Conclusion—This procedure is an effective tool for comparing shield effectiveness. Different shields over the same core, coaxial and twisted pairs, can be quantified and ranked logically. Results are repeatable. However, the method does not have inherent limitations, but within its range, results can be verified with other test methods. This procedure is recommended as an efficient, effective means of evaluating cable shield performance.

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Scope

This standard is intended to provide a reliable surface transfer impedance test method for coaxial cables and shielded multiconductor cables over the frequency range from dc to 100 MHz.

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Section 1
REFERENCED DOCUMENTS

1.1 REFERENCED DOCUMENTS AND PUBLICATIONS

International Electrotechnical Commission

IEC 96/1986 — *Radio-Frequency Cables*

Available from:

American National Standards Institute
11 West 42nd Street
New York, NY 10036

Navy Publishing and Printing
Service Office
700 Robbins Avenue
Philadelphia, PA 19111-5094

MIL-C-24640 — *Military Specification for Cable and Cord, Low Smoke, Lightweight, for Shipboard Use*

MIL-C-24643 — *Military Specification for Cable and Cord, Low Smoke, for Shipboard Use*

MIL-C-85485 — *Wire, Electric, Military Specification for*

Institute of Electrical and Electronics Engineers
347 East 47th Street
New York, New York 10017

EMC-26 No. 2 — *IEEE Transactions on Electromagnetic Compatibility Volume , "A Fast, Accurate and Sensitive Method for Measuring Surface Transfer Impedance," A. R. Martin, M. Mendenhall Pages 66–70, May 1984*

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Section 2
GENERAL

2.1 PRECISION AND BIAS

When samples are prepared and tested in accordance with this procedure, different laboratories using different (but appropriate) equipment can expect to get similar results. The differences found in the NEMA round robin test program which produced this procedure were generally less than 20%. Significant differences in test results were most commonly a result of problems with samples preparation.

Samples shorter than one-third meter are not recommended because of difficulties with accurate sample preparation and termination errors. The one-meter sample is recommended for all measurements up to 30 MHz. The one-third meter samples may be used up to 100 MHz.

2.2 SIGNIFICANCE AND USE

Transfer impedance data generated via this test procedure may be used by both users and manufacturers to classify relative EMI/EMC performance of different shields.

Additionally, EMP response may be related to Transfer Impedance using the following formula:

$$\text{EMP response} = (-185) - 10 \text{ Log} \int_0^F \frac{[Z_t(f)]^2 \, df}{(\alpha^2+f^2)(B^2+f^2)} \text{ (dB)}$$

Where:

Z_t (f) = surface transfer imped. at freq. (f) (ohms/m)

$\alpha = 2.39 \times 10^5$

$B = 4.12 \times 10^7$

f = frequency (Hz)

F = upper frequency limit
- 100 MHz for 1/3 meter length
- 30 MHz for 1 meter length

Assume that Z_t is constant in the frequency range dc to 0.1 MHz.

The integral expression may be approximated by a summation of at least 100 points per decade of frequency.

The MIL-C-85485 test procedure itself does not delineate frequency limitations or caution the tester about potential pitfalls. The method as modified by this test procedure addresses both of these issues. It formulates the relationship between sample length and maximum frequency limit. Correct sample preparation can be verified using shield dc resistance. The NEMA test procedure refines MIL-C-85485 and offers a simple, accurate, and reproducible method for cable shield evaluation.

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Section 3
SAMPLE PREPARATION

3.1 GENERAL

Sample preparation provides the greatest opportunity for introducing error into transfer impedance measurement. By using dc resistance as a benchmark, the validity of the test can be demonstrated. Close adherence to lengths of samples and proper soldering technique will yield good samples. The amount of shield under test is critical. The distance between short circuits, whether 1.0 or .33 meters, must be as accurate as possible. The specific amount of cable beyond these short circuits will not affect the measurement but should be kept as short as possible.

Though MIL-C-85485 specifies Type TNC connectors, other coaxial connectors such as Type BNC or Type N may be substituted as determined by cable size.

3.2 SAMPLE PREPARATION

For a 1 meter sample, approximately 4 feet (1.22 m) of cable shall be used. For 1/3 meter sample, approximately 2 feet (0.61 m) of the cable shall be used. Sample preparation shall be as follows:

Approximately 3 inches (7.6 cm) of the cable jacket shall be removed from one end of the cable (end "A") and the shield pushed back to expose the insulated conductors. The insulation shall be removed from the conductors to within 1 inch (2.54 cm) of the pushed back shield as shown in Figure 3.1.

For multiconductor cable, all the conductors shall be connected together and these connected wires shall be referred to as "the conductor." The shield shall then be pulled forward over the remaining insulation and soldered to the conductor. The shield shall completely enclose the insulated conductor, shall be soldered around 360 degrees of the conductor and all disturbed portions of the shield shall be well-soldered. The conductor shall extend beyond the soldered join and shall be formed and trimmed so as to be able to be soldered into the center pin of the connector such as with a jack to jack adaptor as shown in Figure 3.1.

Excess shield, beyond the solder joint, shall be removed and the center pin shall be attached to the conductor so that the pin is within 1/2 inch (1.27 cm) of the soldered joint. A piece of shrink tubing or other appropriate material shall be applied over the soldered joint to insulate the joint (See Figure 3.1).

The center pin shall then be inserted into the connector as shown in Figure 3.1. A bare or coated copper outer braid having 90% minimum coverage shall be pulled over the entire length of the cable and shall extend halfway over the connector. The outer braid shall then be soldered to the connector, making sure that a 360 degree solder joint is formed (See Figure 3.1). Shrink tubing or other appropriated materials, shall be applied over the entire length of the outer braid ensuring that the outer braid is pressed firmly and consistently to the jacket of the cable (See Figure 3.1).

During the application of the joint insulating material, outer braid and overall material, the exact location of the soldered joint between the shield and conductor shall be noted by marking each layer at that location in a suitable manner (See Figure 3.1). The other end of the cable, with the outer braid and overall material applied, shall be terminated in the following manner: For the 1 meter specimen at a distance of 38 inches (0.96 m) (or 11 inches (.28 m) for the 1/3 meter specimen) from the mark on the tubing which indicates the location of the shield to conductor joint, the material covering the outer braid shall be cut circumferentially. Remove all material further than 38 inches (0.96 m) from that mark (or 11 inches (0.28) for the 1/3 meter sample). The exposed outer braid shall be cut back to within 2 inches (5.08 cm) of the outer covering and the severed braid shall be removed. The remaining 2 inches (5.08 cm) of outer braid shall then be pushed back to expose the cable underneath. A 1/2 inch (1.27 cm) long circumferential section of the cable jacket shall be window-stripped for a distance of 1/2 inch (1.27 cm) to expose the shield under test. The center of the window cut in the cable jacket shall be 39.37±.25 inches (100±0.64 cm) for a maximum frequency of MHz, or 13.12±.25 inches (33.33±0.64 cm) for a frequency of 100 MHz.

The "B" end of the cable shall then be cut and prepared for termination, as shown in Figure 3.2, with a connector such that the distance from the backshell on end "B" to the window in the cable jacket is 1/4 to 1/2 inch (1.27 cm). The connector shall be installed and the outer braid pulled forward over the exposed cable shield. The shield and outer braid shall be soldered together for 360 degrees around the cable as shown in Figure 3.2, Step 2. Any excess outer braid between the solder joint and the connector shall be removed. The joint between the outer braid and shield shall be insulated with shrink tubing or other appropriate material as shown in Figure 3.2.

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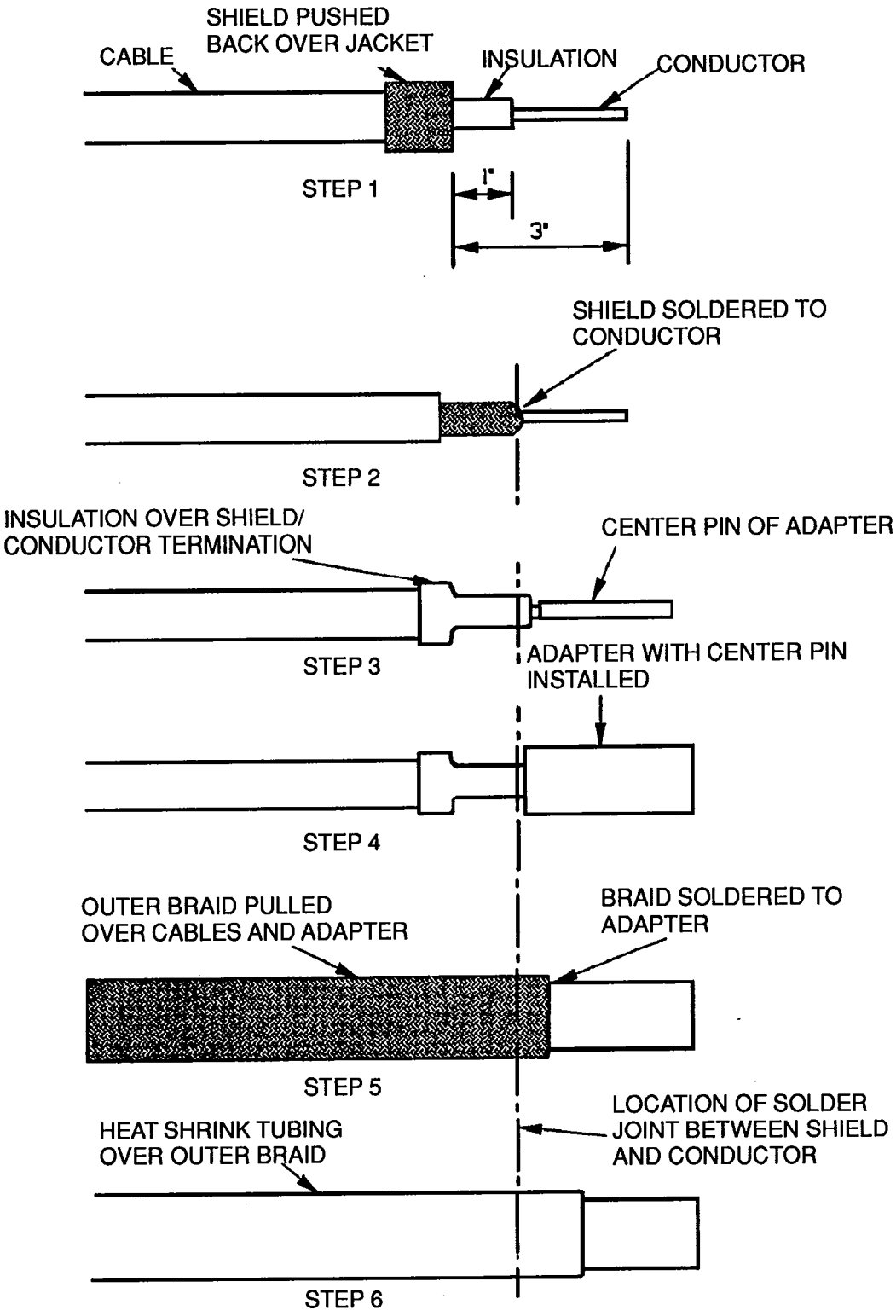

Figure 3-1
CONSTRUCTION OF SAMPLE CABLE

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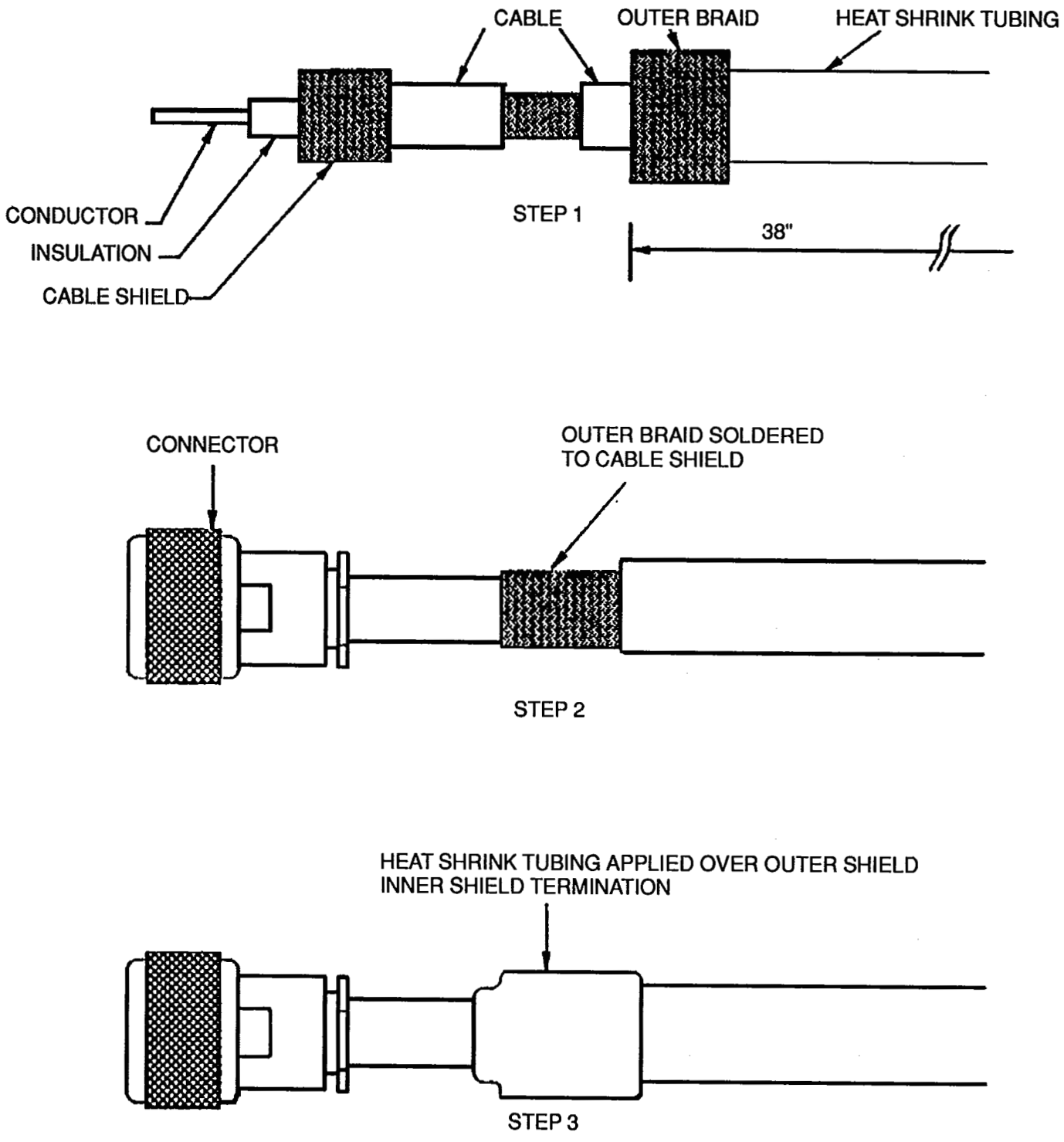

Figure 3-2
DIAGRAM OF CABLE TERMINATION

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3.3 Sample Preparation Verification

Figure 3.3 is the typical Time Domain Reflectometer (TDR) response when end "B" is connected to the TDR. The beginning and end of the sample should be easily determined.

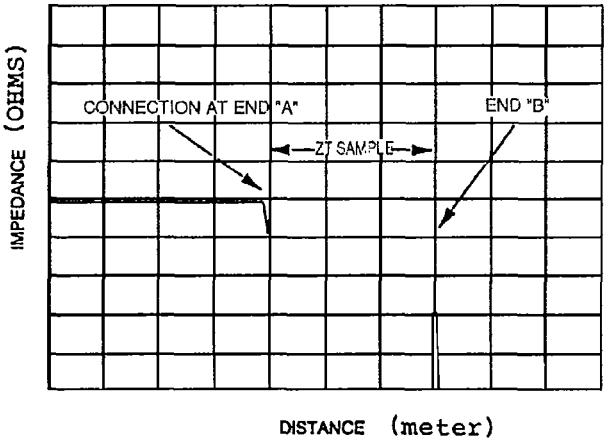

Figure 3-3
END "B" CONNECTION TO TDR—TDR RESPONSE

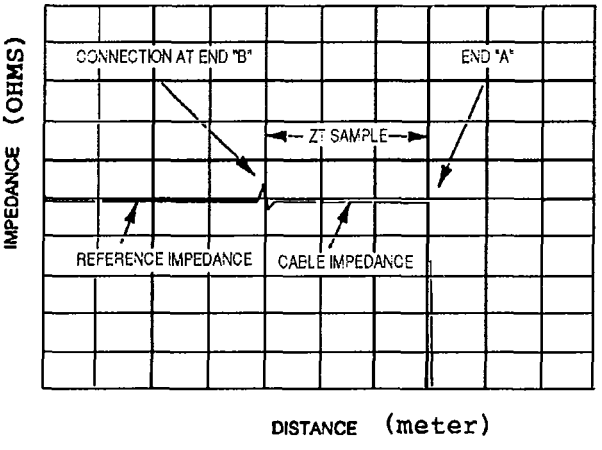

Figure 3-4
END "A" CONNECTION TO TDR—TDR RESPONSE

3.3.1 Circuit Verification

Points where short circuits to the shield under test are made must be soldered circumferentially. Connectors should be applied with utmost care. By examining the sample from both ends with a TDR, one can easily determine whether the connectors themselves have been inadvertently shorted out.

3.3.2 DC Resistance (dcR) of the Shield

dcR can be used to give confidence in a transfer impedance curve. The portion of the Z_t curve below 100 KHz will correspond to both the measured and calculated values for dcR. The dcR can be calculated as shown below.

A single round wire braid which would have response calculated from:

$$R\left(\frac{\Omega}{m}\right)=\frac{N\,d^{2}\,R_s}{\pi\,(D+2d)\cos\alpha}$$

Where:

N = the total number of braid wire ends
d = the diameter of a single strand
D = the diameter under the shield
R_s= the resistivity of the braid material
α = the braid angle

Calculated or measured dcR of the shield under test shall be within 20% of the measured transfer impedance value at 100 KH_z.

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Section 4
TEST PROCEDURE

4.1 General

This measurement procedure is suitable for use with a spectrum analyzer and tracking generator. Other instruments shown to be of equal accuracy to those described below may be used. This test procedure is an attenuation measurement from which the transfer impedance is calculated.

4.2 CABLE MEASUREMENT

Measurements shall be carried out on calibrated equipment. A suggested method of verifying dynamic range is using fixed or variable attenuator with a 1% or greater accuracy.

The end of the cable designated as end "A" shall be attached to the single generator via a 10dB pad during the measurement. End "B" of the cable shall be attached to the detector during the measurement.

4.3 Calculation of Transfer Impedance

Unless otherwise specified, 100 points uniformly spaced throughout a decade of frequency, and including the beginning and end of the decade, shall be taken for each decade of frequency range specified.

Transfer impedance shall be calculated using the following formula:

$$S = A_u - \frac{TY}{h} \text{ dB}$$

Where:

S = resulting trace on the screen (atten. in dB)

A_u = attentuator setting used to produce the calibration trace immediately above trace S

T = difference in attenuation setting for two consecutive settings for two consecutive calibration traces

Y = distance on the screen between traces A_u and S

h = distance on the screen between trace A_u and the calibration trace immediately below trace S

The surface transfer impedance Z_t, shall be given by:

$$Z_t = \frac{Z_0}{2L}\sqrt{P} \text{ ohms/meter}$$

Where:

Z_o = characteristic impedance of the spectrum analyzer and tracking generator

L = length of sample (.33 or 1 meter)

P = $10^{3/10}$

4.4 Verification of Dynamic Range

4.4.1 Connect the equipment as shown in Figure 4.1, substituting the variable attenuator for the sample.

4.4.2 Following the manufacturer's instructions, set up the frequency generator and spectrum analyzer to operate over the frequency range specified for the sample under test. The display sensitivity should be set to 10 dB per division. The output level should be consistent with the range of loss being measured.

4.4.3 Adjust the calibrated attenuator to a value which is at least 5 dB less than the minimum value specified for the sample under test and is an even multiple of 5 dB.

Example: When using equation in Paragraph 4.3, if the minimum specified transfer impedance convert to 51 dB, set the variable attenuator for a value of 45 dB.

4.4.4 Increase the value of the calibrated attenuator in 5 dB increments to a value that is at least 5 dB greater than the maximum value specified for the sample under test.

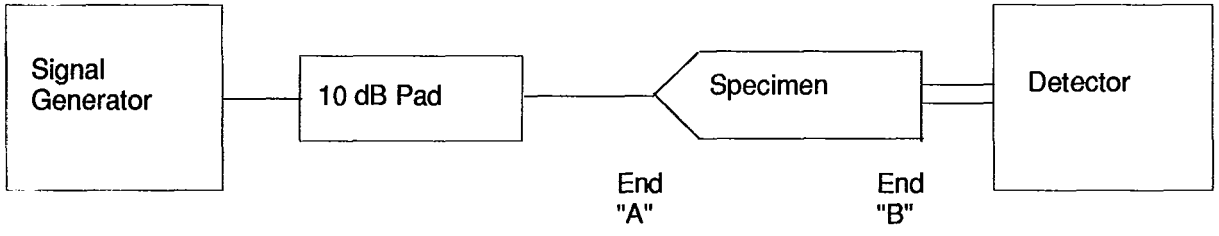

Figure 4-1
CONFIGURATION OF THE MEASUREMENT SYSTEM FOR DETERMINING SURFACE TRANSFER IMPEDANCE

Note— The letters A and B refer to the A and B ends of the specimen, as described in paragraph 4.2.

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA Standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

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

(Standardization Policies and Procedures, p. 1)

Definition of a Standard

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

(Standardization Policies and Procedures, p. 2)

Dimensions

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

(Standardization Policies and Procedures, p. 8)

Categories of Standards

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

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 7 & 16)

Authorized Engineering Information

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

(Standardization Policies and Procedures, pp. 7 & 16)

Identification of Status

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

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

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