IEC TR 61156-1-2

Edition 1.0 2014-09

TECHNICAL REPORT

AMENDMENT 1

Multicore and symmetrical pair/quad cables for digital communications – Part 1-2: Electrical transmission characteristics and test methods of Symmetrical pair/quad cables

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FOREWORD

This amendment has been prepared by subcommittee 46C: Wires and symmetric cables, of IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

The text of this amendment is based on the following documents:

Enquiry draft	Report on voting
46C/993/DTR	46C/1000/RVC

Full information on the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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2 Normative references

Add, after IEC 60050-726, the following new references:

IEC 60169-15, *Radio-frequency connectors – Part 15: R.F. coaxial connectors with inner diameter of outer conductor 4,13 mm (0,163 in) with screw coupling – Characteristic impedance 50 ohms (Type SMA)*

IEC 61169-16, *Radio-frequency connectors – Part 16: Sectional specification – RF coaxial connectors with inner diameter of outer conductor 7 mm (0,276 in) with screw coupling – Characteristics impedance 50 ohms (75 ohms) (type N)*

3 Terms, definitions, symbols, units and abbreviated terms

3.1 Terms and definitions

Change the introductory wording as follows:

For the purposes of this document, the terms and definitions given in IEC 60050-726, IEC TR 62152 and the following apply:

Add the following new definition:

3.1.1
single-ended
measurement with respect to a fixed potential, usually ground

8 Unbalance attenuation

8.3 Theoretical background

In Formula (140), replace $T_{u,n}$ *by* $T_{u,f}$.

In Formula (143), replace in the exponential term $\beta_{diff} \pm \beta_{com}$ *by* $\beta_{diff} + \beta_{com}$.

Add, after Clause 8, the following new Clause 9:

9 Balunless test method

9.1 Overall test arrangement

9.1.1 Test instrumentation

The test procedures hereby described require the use of a vector network analyser or similar test equipment. The analyser shall have the capability of full 4-port calibration and should include isolation calibrations. The analyser should cover at least the full frequency range of the cable or cabling under test (CUT).

Measurements are to be taken using a mixed mode test set-up, which is often referred to as an unbalanced, modal decomposition or balun-less set-up. This allows measurements of balanced devices without use of an RF balun in the signal path. With such a test set-up, all balanced and unbalanced parameters can be measured over the full frequency range.

Such a configuration allows testing with both a common or differential mode stimulus and responses, ensuring that intermodal parameters can be measured without reconnection.

A 16 port network analyser is required to measure all combinations of a 4 pair device without external switching; however, the network analyser should have a minimum of 2 ports to enable the data to be collated and calculated.

It should be noted that the use of a 4-port analyser will involve successive repositioning of the measurement ports in order to measure any given parameter.

A 4-port network analyser is recommended as a minimum number of ports, as this will allow the measurement of the full 16 term mixed mode S-parameter matrix on a given pair combination without switching or reconnection in one direction.

In order to minimise the reconnection of the CUT for each pair combination, the use of an RF switching unit is also recommended.

Each conductor of the pair or pair combination under test should be connected to a separate port of the network analyser, and results are processed either by internal analysis within the network analyser or by an external application.

Reference loads and through connections are needed for the calibration of the set-up. Requirements for the reference loads are given in 9.1.5. Termination loads are needed for termination of pairs, used and unused, which are not terminated by the network analyser. Requirements for the termination loads are given in 9.1.7.

9.1.2 Measurement precautions

To assure a high degree of reliability for transmission measurements, the following precautions are required:

a) Consistent and stable resistor loads should be used throughout the test sequence.

b) Cable and adapter discontinuities, as introduced by physical flexing, sharp bends and restraints should be avoided before, during and after the tests.

c) Consistent test methodology and termination resistors should be used at all stages of transmission performance qualifications.

   The relative spacing of conductors in the pairs should be preserved throughout the tests to the greatest extent possible.

d) The balance of the cables should be maintained to the greatest extent possible by consistent conductor lengths, pair twisting and lay up of the screen to the point of load.

e) The sensitivity to set-up variations for these measurements at high frequencies demands attention to details for both the measurement equipment and the procedures.

9.1.3 Mixed mode *S*-parameter nomenclature

The test methods specified in this document are based on a balun-less test set-up in which all terminals of a device under test are measured and characterized as single-ended (SE) ports, i.e. signals (RF voltages and currents) are defined relative to a common ground. For a device with 4 terminals, a diagram is given in Figure 14.

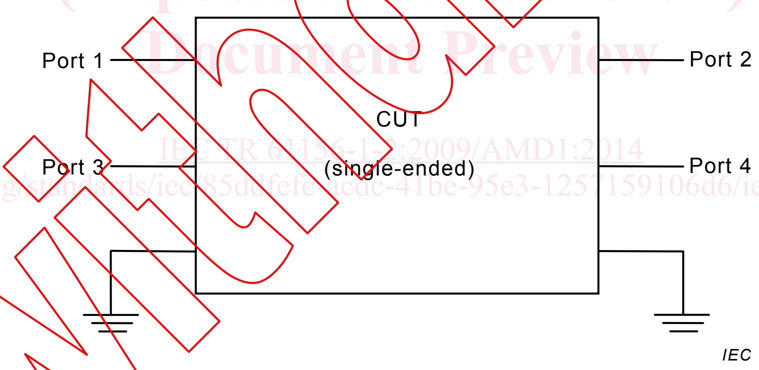

Figure 14 – Diagram of a single-ended 4-port device

The 4-port device in Figure 14 is characterized by the 16 term SE *S*-matrix given in Equation (146), in which the *S*-parameter S_{ba} expresses the relation between a single-ended response on port "b" resulting from a single ended stimulus on port "a".

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{34} & S_{44} \end{bmatrix} \tag{146}$$

For a balanced device, each port is considered to consist of a pair of terminals (= a balanced port) as opposed to the SE ports defined above, see Figure 15.

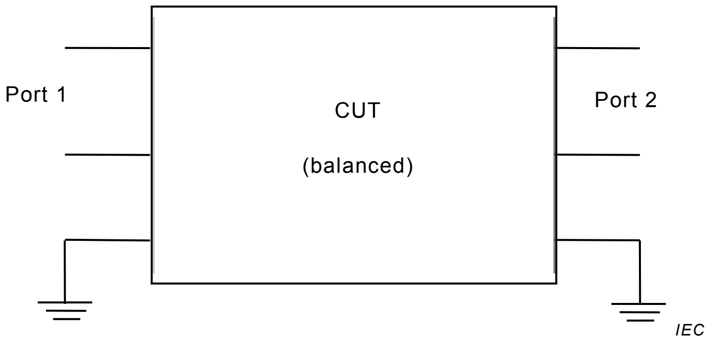

Figure 15 – Diagram of a balanced 2-port device

In order to characterize the balanced device, both the differential mode and the common mode signals on each balanced port shall be considered. The device can be characterized by a mixed mode S-matrix that includes all combinations of modes and ports, e.g. the mixed mode S-parameter S_{DC21} that expresses the relation between a differential mode response on port 2 resulting from a common mode stimulus on port 1. Using this nomenclature, the full set of mixed mode S -parameters for a 2-port can be presented as in Table 4.

Table 4 – Mixed mode S-parameter nomenclature

		Differential mode stimulus		Common mode stimulus	
		Port 1	Port 2	Port 1	Port 2
Differential mode response	Port 1	S_{DD11}	S_{DD12}	S_{DC11}	S_{DC12}
	Port 2	S_{DD21}	S_{DD22}	S_{DC21}	S_{DC22}
Common mode response	Port 1	S_{CD11}	S_{CD12}	S_{CC11}	S_{CC12}
	Port 2	S_{CD21}	S_{CD22}	S_{CC21}	S_{CC22}

A 4-terminal device can be represented both as a 4-port SE device as in Figure 14 characterized by a single ended S-matrix (Equation (146)) and as a 2-port balanced device as in Figure 15 characterized by a mixed mode S-matrix (see Table 4). As applying a SE signal to a port is mathematically equivalent to applying superposed differential and common mode signals, the SE and the mixed mode characterizations of the device are interrelated. The conversion from SE to mixed mode S-parameters is given in Annex A. Making use of this conversion, the mixed mode S-parameters may be derived from the measured SE S-matrix.

9.1.4 Coaxial cables and interconnect for network analysers

Assuming that the characteristic impedance of the network analyser is 50 Ω, coaxial cables used to interconnect the network analyser, switching matrix and the test fixture should be of 50 Ω characteristic impedance and of low transfer impedance (double screen or more).

These coaxial cables should be as short as possible. (It is recommended that they do not exceed 1 000 mm each.)

The screens of each cable shall be electrically bonded to a common ground plane, with the screens of the cable bonded to each other at multiple points along their length.

To optimize dynamic range, the total interconnecting cable insertion loss should be minimised. (It is recommended that the interconnecting cable loss does not exceed 3 dB at 1 000 MHz.)

9.1.5 Reference loads for calibration

The N-nonnector shall be seen as a possible sample. Other connectors can be used for similar purposes such as e.g. SMA-connectors. Some test equipment even use no standardized fixtures.

To perform a one or 2-port calibration of the test equipment, a short circuit, an open circuit and a reference load are required. These devices should be used to obtain a calibration.

The reference load should be calibrated against a calibration reference, which should be a 50 Ω load, traceable to an international reference standard. One 50 Ω reference load should be calibrated against the calibration reference. The reference load for calibration should be placed in an N-type connector according to IEC 61169-16 or a SMA-connector according to IEC 60169-15, meant for panel mounting, which is machined-flat on the back side, see Figure 16. For frequencies higher than 1 GHz, a SMA-connector should be used.

The load should be fixed to the flat side of the connector. A network analyser should be calibrated, 1-port full calibration, with the calibration reference. Thereafter, the return loss of the reference load for calibration should be measured. The verified return loss should be ≥46 dB at frequencies up to 100 MHz and ≥40 dB at frequencies above 100 MHz and up to the limit for which the measurements are to be carried out.

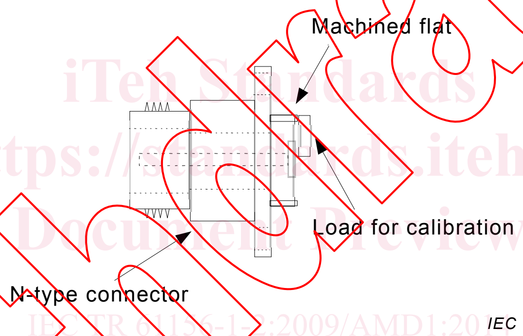

Figure 16 – Possible solution for calibration of reference loads

For short and open, the inductance and capacitance should be minimised.

9.1.6 Calibration

Isolation measurements should be used as part of the calibration.

The calibration should be equivalent to a minimum of a full 4-port SE calibration for measurements where the response and stimulus ports are the same (S_{xx11} and S_{xx22}), and a minimum of a full 4-port SE calibration for measurements where the response and stimulus ports are different (S_{xx12} and S_{xx21}).

An individual calibration should be performed for each signal path used for the measurements. If a complete switching matrix and a 4-port network analyser test set-up is used, a full set of measurements for a 4-pair device (i.e. 16 single-ended ports), will require 28 separate 4-port calibrations, although many of the measurements within each calibration are in common with other calibrations. A software or hardware package may be used to minimise the number of calibration measurements required.

The calibration should be applied in such a way that the calibration plane should be at the ends of the fixed connectors of the test fixture.

The calibration may be performed at the test interface using appropriate calibration artefacts, or at the ends of the coaxial test cable using coaxial terminations.

Where calibration is performed at the test interface, open, short and load measurements should be taken on each SE port concerned, and through and isolation measurements should be taken on every pair combination of those ports.

Where calibration is performed at the end of the coaxial test cables, open, short and load measurements should be taken on each port concerned, and through and isolation measurements should be taken on every pair combination of those ports. In addition, the test fixture shall then be de-embedded from the measurements. The de-embedding techniques should incorporate a fully populated 16 port S-matrix. It is not acceptable to perform a de-embedded calibration using only reflection terms (S_{11}, S_{22}, S_{33}, S_{44}) or only near-end terms (S_{11}, S_{21}, S_{12}, S_{22}).

De-embedding using reduced term S-matrices may be used for post processing of results.

9.1.7 Termination loads for termination of conductor pairs

9.1.7.1 General

When this document is used for the measurement of performance against standards, the differential mode terminations applied to the device under test (DUT) shall provide the differential mode and common mode reference termination impedances specified in standards for the cabling system where the DUT is used.

50 Ω wires to ground terminations should be used on all active pairs under test. 50 Ω differential mode to ground terminations should be used on all inactive pairs and on the opposite ends of active pairs for near-end crosstalk (NEXT) and far-end crosstalk (FEXT) testing. Inactive pairs for return loss testing should be terminated with 50 Ω differential mode to ground terminations. See Figure 17.

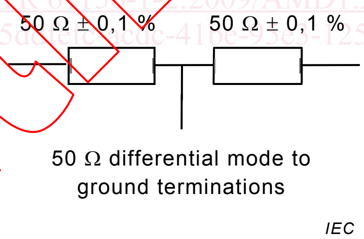

Figure 17 – Resistor termination networks

Small geometry chip resistors should be used for the construction of resistor terminations. The two 50 Ω DM terminating resistors should be matched to within 0,1 % at DC, and 2 % at 1 000 MHz (corresponding to a 40 dB return loss requirement at 1 000 MHz). The length of connections to impedance terminating resistors should be minimized. Use of soldered connections without leads is recommended.

9.1.7.2 Verification of termination loads

The performance of impedance matching resistor termination networks should be verified by measuring the return loss of the termination and the residual NEXT between any two resistor termination networks at the calibration plane.

For the return loss measurement, a 2-port SE calibration is required using a reference load verified according to 9.1.5.

After calibration, connect the resistor termination network and perform a full 2-port SE *S*-matrix measurement. The measured SE *S*-matrix should be transformed into the associated mixed mode *S*-matrix to obtain the *S*-parameters S_{DD11} and S_{CC11} from which the differential mode return loss RL_{DM} and the common mode return loss RL_{CM} are determined. The return loss of the resistor termination network should meet the requirements of Table 5.

For the residual NEXT measurement, a 4-port SE calibration is required. After calibration, connect the resistor termination networks and perform a full 4-port SE *S*-matrix measurement. The measured *S*-matrix should be transformed into the associated mixed mode *S*-matrix to obtain the *S*-parameter S_{DD21} from which the residual NEXT of the terminations, $NEXT_{residual\_term}$, is determined. The residual NEXT should meet the requirements of Table 5.

For the TCL measurement, a 2-port SE calibration is required using a reference load verified according to 9.1.5.

After calibration, connect the resistor termination network and perform a full 2-port SE *S*-matrix measurement. The measured SE *S*-matrix should be transformed into the associated mixed mode *S*-matrix to obtain the *S*-parameter S_{CD11} from which the differential mode TCL is determined. The TCL of the resistor termination network should meet the requirements of Table 5.

Table 5 – Requirements for terminations at calibration plane

Parameter	Frequency MHz	Requirement up to maximum frequency
SE port (50 Ω) return loss (dB)	$1 \leq f \leq f_{max}$	≥74-20 log(f) dB 40 dB max 20 dB min
DM port (100 Ω) return loss (dB)		≥74-20 log(f) dB 40 dB max 20 dB min
DM port to port residual NEXT (dB)		≥140-20 log(f) dB 104 dB max 80 dB min
DM port TCL of loads (dB)		≥ 60-10 log(f) dB 50 dB max 20 dB min

9.1.8 Termination of screens

If the CUT is screened, screened measurement cables shall be applied.

The screen or screens of these cables should be fixed to the ground plane as close as possible to the calibration plane.

9.2 Cabling and cable measurements

9.2.1 Insertion loss and EL TCTL

9.2.1.1 Object

When this document is used for the measurement of performance against standards, the differential mode terminations applied to the DUT shall provide the differential mode and common mode reference termination impedances specified in standards for the cabling system where the DUT is used.

The object of this test is to measure the insertion loss (IL) and equal-level transverse conversion transfer loss (EL TCTL) of a cable or cabling pair. Insertion loss is defined as the attenuation that is caused by the cable or cabling pair. EL TCTL is defined as the unbalance attenuation at far end.

9.2.1.2 Cable and cabling insertion loss and EL TCTL

Cable or cabling should be tested for insertion loss in one direction and EL TCTL in both directions.

9.2.1.3 Test method

Insertion loss is evaluated from the mixed mode parameter S_{DD21} and EL TCTL is evaluated from the mixed mode parameter S_{CD21} for each conductor pair. The mixed mode S-parameters are derived by transformation of the SE S-matrix.

9.2.1.4 Test set-up

The test set-up consists of a network analyser and two test fixtures. An illustration of the test set-up, which also shows the termination principles, is shown in Figure 18. Resistor termination networks in accordance with 9.1.7 should be applied for all inactive pairs.

9.2.1.5 Procedure

9.2.1.5.1 Calibration

A full 4-port SE calibration should be performed at the calibration planes in accordance with 9.1.6. Reference loads used for calibration should be in accordance with 9.1.5.

9.2.1.5.2 Measurement

The CUT should be arranged in an appropriate test set-up according to Figure 18, including proper termination of the active, inactive pairs and screen. A full SE S-matrix measurement should be performed. The measured SE S-matrix should be transformed into the associated mixed mode S-matrix to obtain the S-parameter S_{DD21} from which insertion loss is determined and S_{CD21} from which TCTL is determined.

$$\mathrm{IL}(f) = -20 \cdot \log_{10}(|S_{DD21}|) = -20 \cdot \log_{10}\left(\left|\frac{1}{2}(S_{31} - S_{41} - S_{32} + S_{42})\right|\right) \quad (147)$$

$$\mathrm{TCTL}(f) = -20 \cdot \log_{10}(|S_{CD21}|) = -20 \cdot \log_{10}\left(\left|\frac{1}{2}(S_{31} + S_{41} - S_{32} - S_{42})\right|\right) \quad (148)$$

$$\mathrm{EL\ TCTL}(f)=\mathrm{TCTL(f)}\text{-}\mathrm{IL}(f) = -20 \cdot \log_{10}\left(\left|\frac{(S_{31}+S_{41}-S_{32}-S_{42})}{(S_{31}-S_{41}-S_{32}+S_{42})}\right|\right) \quad (149)$$

Test all conductor pairs and record the results.