

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Multicore and symmetrical pair/quad cables for digital communications –
Part 1: Generic specification**

**Câbles multiconducteurs à paires symétriques et quartes pour transmissions
numériques –
Partie 1: Spécification générique**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES
FOR DIGITAL COMMUNICATIONS –****Part 1: Generic specification**

FOREWORD

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International Standard IEC 61156-1 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 cables are classified in the study of generic cabling for information technology being produced by ISO/IEC JTC1/SC 25.

This third edition cancels and replaces the second edition published in 2002 and it includes its Corrigendum 1 (2004) This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) inclusion of definitions and test methods in support of the MICE table in ISO 24702;
- b) inclusion of definitions and test methods in support of new cable categories 6_A and 7_A;
- c) inclusion of definitions in support of PoEP.

This bilingual version, published in 2008-03, corresponds to the English version.

The text of this standard is based on the second edition, its Amendment 3 and on the following documents:

FDIS	Report on voting
46C/815/FDIS	46C/823/RVD

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

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The list of all the parts of the IEC 61156 series, under the general title *Multicore and symmetrical pair/quad cables for digital communication*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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- withdrawn;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.

The contents of the corrigendum of August 2015 have been included in this copy.

MULTICORE AND SYMMETRICAL PAIR/QUAD CABLES FOR DIGITAL COMMUNICATIONS –

Part 1: Generic specification

1 Scope

This part of IEC 61156 is applicable to communication systems such as ISDN, local area networks and data communication systems and specifies the definitions, requirements and test methods of multicore, symmetrical pair and quad cables.

This standard is also applicable to cables used for customer premises wiring.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60028, *International standard of resistance for copper*

IEC 60050-726, *International Electrotechnical Vocabulary (IEV) – Part 726: Transmission lines and wave guides*

IEC 60068-2-1, *Environmental testing – Part 2: Tests – Tests A: Cold*

IEC 60169-22, *Radio-frequency connectors – Part 22: RF two-pole bayonet coupled connectors for use with shielded balanced cables having twin inner conductors (Type BNO)*

IEC 60189-1:1986, *Low-frequency cables and wires with PVC insulation and PVC sheath – Part 1: General test and measuring methods*¹⁾

IEC 60304, *Standard colours for insulation for low-frequency cables and wires*

IEC 60332-1-1, *Tests on electric and optical fibre cables under fire conditions – Part 1-1: Test for vertical flame propagation for a single insulated wire or cable – Apparatus*

IEC 60332-2-1, *Tests on electric and optical fibre cables under fire conditions – Part 2-1: Test for vertical flame propagation for a single small insulated wire or cable – Apparatus*

IEC 60332-3-10, *Tests on electric cables under fire conditions – Part 3-10: Test for vertical flame spread of vertically-mounted bunched wires or cables – Apparatus*

IEC 60332-3-24, *Tests on electric cables under fire conditions – Part 3-24: Test for vertical flame spread of vertically-mounted bunched wires or cables – Category C*

IEC 60708, *Low-frequency cables with polyolefin insulation and moisture barrier polyolefin sheath*

¹⁾ There exists a 2007 edition of 60189-1.

IEC 60754-2, *Test on gases evolved during combustion of electric cables – Part 2: Determination of the degree of acidity of gases evolved during the combustion of materials taken from electric cables by measuring pH and conductivity*

IEC 60794-1-2:2003, *Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures*

IEC 60811-1-1:1993, *Common test methods for insulating and sheathing materials of electric cables and optical cables – Part 1: Methods for general application – Section 1: Measurement of thickness and overall dimensions – Tests for determining the mechanical properties*

IEC 60811-1-2:1985, *Common test methods for insulating and sheathing materials of electric and optical cables – Part 1: Methods for general application – Section Two: Thermal ageing methods*

IEC 60811-1-3:1993, *Common test methods for insulating and sheathing materials of electric and optical cables – Part 1: Methods for general application – Section Three: Methods for determining the density – Water absorption tests – Shrinkage test*

IEC 60811-1-4:1985, *Common test methods for insulating and sheathing materials of electric and optical cables – Part 1: Methods for general application – Section Four: Test at low temperature*

IEC 60811-3-1:1985, *Common test methods for insulating and sheathing materials of electric and optical cables – Part 3: Methods specific to PVC compounds – Section One: Pressure test at high temperature – Tests for resistance to cracking*

IEC 60811-4-2:2004, *Insulating and sheathing materials of electric cables – Common test methods – Part 4-2: Methods specific to polyethylene and polypropylene compounds – Tensile strength and elongation at break after conditioning at elevated temperature – Wrapping test after conditioning at elevated temperature – Wrapping test after thermal ageing in air – Measurement of mass increase – Long-term stability test – Test method for copper-catalyzed oxidative degradation*

IEC 61034 (all parts), *Measurement of smoke density of cables burning under defined conditions*

IEC 61196-1-105, *Coaxial communication cables – Part 1-105: Electrical test methods – Test for withstand voltage of cable dielectric*

IEC 62012-1:2004, *Multicore and symmetrical pair/quad cables for digital communications to be used in harsh environments – Part 1: Generic specification*

IEC 62153-4-3, *Metallic communication cables test methods – Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method*

IEC 62153-4-4, *Metallic communication cables test methods – Part 4-4: Electromagnetic compatibility (EMC) – Shielded screening attenuation, test method for measuring of the screening attenuation a_s up to and above 3 GHz*

IEC 62153-4-5, *Metallic communication cables test methods – Part 4-5: Electromagnetic compatibility (EMC) – Coupling or screening attenuation – Absorbing clamp method*

IEC 62255 (all parts), *Multicore and symmetrical pair/quad cables for broadband digital communications (high bit rate digital access telecommunication networks) – Outside plant cables*

ITU-T Recommendation G.117:1996, *Transmission aspects of unbalance about earth*

ITU-T Recommendation O.9:1999, *Measuring arrangements to assess the degree of unbalance about earth*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60050-726, apply.

3.1

resistance unbalance

difference in resistance of the conductors within a pair or one side of a quad or between pairs or quads

NOTE Resistance unbalance is expressed as a percentage (%).

3.2

capacitance unbalance to earth

arithmetic difference of the capacitance to earth of the conductors of a pair or one side of a quad

NOTE Capacitance unbalance is expressed in pF/m.

3.3

mutual capacitance

electrical charge storage parameter of a pair of conductors (or with respect to the side of a quad)

NOTE 1 Mutual capacitance is one of the four primary transmission line parameters: mutual capacitance, mutual inductance, resistance and conductance.

NOTE 2 Mutual capacitance is expressed in pF/m.

3.4

velocity of propagation (phase velocity)

speed at which a sinusoidal signal propagates on a pair in the cable

NOTE Velocity of propagation is expressed in m/s.

3.5

delay (phase delay)

time duration between the instants that the wave front of a sinusoidal travelling wave, defined by a specified phase, passes two given points in a cable

NOTE Phase delay is expressed in s/m.

3.6

differential phase delay (skew)

difference in phase delay between any two pairs in the cable

NOTE Differential phase delay (skew) is expressed in s.

3.7

attenuation

decrease in magnitude of power of a signal that propagates along a pair of a cable

NOTE Attenuation is expressed in dB/m.

3.8

unbalance attenuation

magnitude of power of a signal that propagates between the common-mode circuit and the differential-mode circuit of a cable

NOTE Unbalance attenuation is expressed in dB.

3.9

near-end crosstalk

NEXT

magnitude of the signal power coupling from a disturbing pair at the near end to a disturbed pair measured at the near end

NOTE Near-end crosstalk is expressed in dB.

3.10

far-end crosstalk

FEXT

magnitude of the signal power coupling from a disturbing pair at the near end to a disturbed pair measured at the far end

NOTE Far-end crosstalk is expressed in dB.

3.11

power sum of crosstalk

PS

summation of the crosstalk power from all disturbing pairs into a disturbed pair

NOTE 1 The summation is applicable to near-end and far-end crosstalk.

NOTE 2 The power sum of crosstalk is expressed in dB.

3.12

attenuation to crosstalk ratio, near-end

ACR-N

arithmetic difference between the near-end crosstalk and the attenuation of the disturbed pair

NOTE Attenuation to crosstalk ratio, near-end, is expressed in dB.

3.13

attenuation to crosstalk ratio, far-end

ACR-F

arithmetic difference between the far-end crosstalk and the attenuation of the disturbed pair

NOTE Attenuation to crosstalk ratio, far-end, is expressed in dB.

3.14

alien (exogenous) near-end crosstalk

ANEXT

near-end crosstalk where the disturbing and disturbed pairs are contained in different cables

NOTE Alien (exogenous) near-end crosstalk is expressed in dB.

3.15

alien (exogenous) far-end crosstalk

AFEXT

far-end crosstalk where the disturbing and disturbed pairs are contained in different cables

NOTE Alien (exogenous) far-end crosstalk is expressed in dB.

3.16**power sum of alien (exogenous) crosstalk*****PSA***

summation of the alien (exogenous) crosstalk power from all disturbing pairs into a disturbed pair in different cables

NOTE 1 The summation is applicable to near-end and far-end alien (exogenous) crosstalk.

NOTE 2 The power sum of alien (exogenous) crosstalk is expressed in dB.

3.17**characteristic impedance*****Z_C***

impedance at the input of a homogeneous line of infinite length

NOTE 1 The asymptotic value at high frequencies is denoted as Z_{∞} .

NOTE 2 The characteristic impedance of a homogeneous cable pair is given by the quotient of a voltage wave and current wave which are propagating in the same direction, either forwards or backwards.

NOTE 3 Characteristic impedance is expressed in Ω .

3.18**mean characteristic impedance*****Z_{Cm}***

impedance calculated as the geometric mean of the product of the impedances obtained at the input terminals of a cable pair when the far end is terminated by an open- and short-circuit load

NOTE Mean characteristic impedance is expressed in Ω .

3.19**input impedance*****Z_{in}***

impedance at the input terminals of a cable pair

NOTE 1 The pair is terminated with its reference impedance, Z_R (system nominal impedance), at the near and far end. See IEC/TR 62152.

NOTE 2 Input impedance is expressed in Ω .

3.20**fitted input impedance**

impedance calculated from a least squares function fitting algorithm

NOTE Fitted input impedance is expressed in Ω .

3.21**return loss*****RL***

ratio of reflected power to input power at the input terminals of a cable pair

NOTE Return loss is expressed in dB.

3.22**balun**

balanced to unbalanced impedance matching transformer

3.23**bundled cable**

grouping or assembly of several individual cables that are systematically laid up

NOTE Bundled cables are also referred to as speed-wrap, whip, or loomed cables.

3.24

current-carrying capacity

capacity of a conductor that results in a specified increase of the surface temperature of the conductor beyond the ambient temperature

NOTE The conductor may be bare, insulated or enclosed in a cable.

3.25

hygroscopic

characteristic of a material to absorb moisture from the atmosphere

3.26

wicking

longitudinal flow of a liquid in a material due to capillary action

3.27

coupling attenuation

ratio between the transmitted power through the conductors and the maximum radiated peak power, conducted and generated by the exited common-mode currents

4 Installation considerations

The cables shall be designed to meet the installation conditions encountered for each area as follows.

a) Equipment cables

The cables are used between work stations and peripheral equipment (for example, printer).

b) Work area cables

The cables are used between the work station and the communication outlets.

c) Horizontal floor wiring cables

The cables are used between the work area communication outlet and the communication closet.

d) Riser cables and building back-bone cables

The cables are used for horizontal installation or vertically between floors.

e) Campus cables

These cables are used to interconnect buildings and shall be suitable for outdoor installation. The cables should be sheathed and protected in accordance with IEC 62255.

5 Materials and cable construction

5.1 General remarks

The choice of materials and cable construction shall be suitable for the intended application and installation of the cable. Particular care shall be taken to meet any special requirements for EMC (Electromagnetic Compatibility) or fire performance.

5.2 Cable construction

The cable construction shall be in accordance with the details and dimensions given in the relevant detail specification.

5.2.1 Conductor

The conductor shall consist of annealed copper, uniform in quality and free from defects. The properties of the copper shall be in accordance with IEC 60028.

The conductor may be either solid or stranded. The solid conductor shall be circular in section and may be plain or metal-coated. The solid conductor shall be drawn in one piece. Joints in the solid conductor are permitted, provided that the breaking strength of a joint is not less than 85 % of the breaking strength of the unjointed solid conductor.

The stranded conductor shall consist of strands circular in section and assembled without insulation between them by concentric stranding or bunched.

NOTE A bunched strand is not recommended for insulation displacement connection (IDC) application.

The individual strands of the conductor may be plain or metal-coated.

Joints in individual strands are permitted provided that the tensile strength of a joint is not less than 85 % of the breaking strength of the unjointed individual strand. Joints in the complete stranded conductor are not permitted unless allowed and specified in the relevant detail specification.

The conductor of the work area and equipment cables may consist of one or more elements of thin copper or copper alloy tape which shall be applied spirally over a fibrous thread. Joints in the complete element are not permitted.

5.2.2 Insulation

The conductor insulation is composed of one or more suitable dielectric materials. The insulation may be solid, cellular or composite (for example, foam skin).

The insulation shall be continuous, having a uniform thickness.

The insulation shall be applied to fit closely to the conductor.

The insulated conductors may be identified by colours and/or additional ring markings and/or symbols achieved by the use of coloured insulation or by a coloured surface using extrusion, printing or painting. Colours shall be clearly identifiable and shall correspond reasonably with the standard colours shown in IEC 60304.

5.2.2.1 Colour code

The colour code for insulation is given in the relevant detail specification.

5.2.3 Cable element

5.2.3.1 General

The cable element is

- a pair consisting of two insulated conductors twisted together and designated wire "a" and wire "b", or
- a quad consisting of four insulated conductors twisted together and designated wire "a", wire "c", wire "b" and wire "d" in order of rotation.

The choice of the maximum average length of lay in the finished cable shall be made with respect to the specified crosstalk requirements, handling performance and the pair or quad integrity.

NOTE Forming the element with a variable lay can lead to the infrequent but acceptable occurrence of the maximum lay being longer than the specified length of lay.

5.2.3.2 Screening of the cable element

When a screen is required over the pair or quad, it may consist of the following:

- a) an aluminium tape laminated to a plastic tape;
- b) an aluminium tape laminated to a plastic tape and a metal-coated or plain copper drain wire whereby the metal tape is in contact with the drain wire;
- c) metallic braid;
- d) an aluminium tape laminated to a plastic tape and a metallic braid.

Care should be taken when putting dissimilar metals in contact with each other. Coatings or other methods of protection may be necessary to prevent galvanic interaction.

A protective wrapping may be applied under and/or over the screen.

5.2.4 Cable make-up

The cable elements may be laid up in concentric layers or in unit construction. The cable core may be protected by wrappings of a non-hygroscopic, non-wicking tape.

NOTE 1 Fillers may be used to maintain a circular formation.

NOTE 2 Forming the element with a variable lay can lead to the infrequent but acceptable occurrence of the maximum lay being longer than the specified length of lay.

5.2.5 Screening of the cable core

The cable core may be screened by

- a) an aluminium tape laminated to a plastic tape which may be bonded to the sheath;
- b) an aluminium tape laminated to a plastic tape and a metal-coated or plain copper drain wire whereby the metal tape is in contact with the drain wire;
- c) metallic braid;
- d) an aluminium tape laminated to a plastic tape and a metallic braid;
- e) plain copper or aluminium tape.

Care should be taken when putting dissimilar metals in contact with each other. Coatings or other methods of protection may be necessary to prevent galvanic interaction.

A protective wrapping may be applied under and/or over the screen.

5.2.6 Sheath

The sheath shall be a polymeric material.

The sheath shall be continuous, having a uniform thickness.

The sheath shall be applied to fit closely to the core of the cable. In the case of screened cables, the sheath shall not adhere to the screen except when it is intentionally bonded to it.

The colour of the sheath may be specified in the relevant detail specification.

5.2.7 Identification

5.2.7.1 Cable marking

Each length of cable shall bear the name of the supplier and the cable type and, when provided, the year of manufacture, using one of the following methods:

- a) coloured threads or tapes;
- b) printed tape;
- c) printing on the core wrappings;
- d) marking on the sheath.

Additional markings may be provided on the sheath as indicated in the relevant detail specification.

5.2.7.2 Labelling

The following information shall be provided either on a label attached to each length of finished cable or on the outside of the product package:

- a) type of cable;
- b) supplier's name or logo;
- c) year of manufacture;
- d) length of cable in metres.

5.2.8 Finished cable

The finished cable shall have adequate protection for storage and shipment.

6 Characteristics and requirements

6.1 General remarks – Test configurations

Typical test configurations for the test specimen are

- a) laid out on a non-metallic surface at least 25 mm from a conductive surface;
- b) supported in aerial spans in such a way that there is a minimum separation of 25 mm between convolutions;
- c) wound as a single open helix on a drum with at least 25 mm between turns.

The configurations a), b) and c) are not necessary for screened cables.

The parameters of mutual capacitance, crosstalk, characteristic impedance and attenuation sometimes show measured values up to 10 % higher when the cable is measured in its packaging. This difference arises due to the tight packaging density and interwinding effects. Also, box packaging may negatively affect the cable return loss, crosstalk and characteristic impedance with full or partial recovery of cable performance after installation.

In case of doubt, the measurements of mutual capacitance, impedance, attenuation and crosstalk shall be performed on a cable sample removed from its packaging.

Measurement procedures for alien (exogenous) crosstalk specify options for the mounting of the cables into special test configurations.

The common-mode termination resistors shall be

- 0 Ω for individually screened pair cables;
- 25 Ω for overall screened cables;
- 45 Ω to 50 Ω for unscreened cables.

6.2 Electrical characteristics and tests

6.2.1 Conductor resistance

The measurement of the conductor resistance shall be in accordance with 6.1 of IEC 60189-1.

6.2.2 Resistance unbalance

The measurement of the resistance unbalance and the accuracy of the measurement equipment shall be in accordance with IEC 60708.

6.2.2.1 Resistance unbalance within a pair

The resistance unbalance between conductors of a pair or in the same side of a quad is given by

$$\Delta R = \frac{(R_{\max} - R_{\min})}{(R_{\max} + R_{\min})} \times 100 \quad (1)$$

where

ΔR is the conductor resistance unbalance (%);

$R_{\max}$ is the resistance for the conductor with the higher resistance value (Ω);

$R_{\min}$ is the resistance for the conductor with the lower resistance value (Ω).

6.2.2.2 Resistance unbalance between pairs

The resistance unbalance between pairs or sides of quads is given by

$$\Delta RP_{i,k} = 100 \frac{\left| R_{\max i} \cdot R_{\min i} (R_{\max k} + R_{\min k}) - R_{\max k} \cdot R_{\min k} (R_{\max i} + R_{\min i}) \right|}{R_{\max i} \cdot R_{\min i} (R_{\max k} + R_{\min k}) + R_{\max k} \cdot R_{\min k} (R_{\max i} + R_{\min i})} \quad (2)$$

where

$\Delta RP_{i,k}$ is the resistance unbalance between pair i and pair k (%);

$R_{\max}$ is the resistance of the wire with the higher resistance of a pair (Ω);

$R_{\min}$ is the resistance of the wire with the lower resistance of a pair (Ω);

i, k $i \neq k$ where $i = 1$ to n and $k = 1$ to n for $n =$ number of pairs.

6.2.3 Dielectric strength

The measurement of dielectric strength shall be in accordance with IEC 61196-1-105 for conductor/conductor, conductor/screen and screen/screen.

6.2.4 Insulation resistance

The measurement of the insulation resistance between conductor/conductor, conductor/screen and screen/screen shall be in accordance with 6.3 of IEC 60189-1. The test voltage shall be between 100 V and 500 V d.c. unless otherwise specified in the detail specification.

6.2.5 Mutual capacitance

The measurement of the mutual capacitance of pairs in a multipair or quad cable shall be in accordance with 6.4 of IEC 60189-1.

6.2.6 Capacitance unbalance to earth

The measurement of the capacitance unbalance in a multipair or quad cable shall be in accordance with 6.5 of IEC 60189-1.

The capacitance unbalance to earth of a pair or one side of a quad is given by

$$\Delta C_e = C_1 - C_2 \quad (3)$$

where

ΔC_e is the pair-to-earth capacitance unbalance (pF/m);

C_1 is the capacitance between conductor "a" and conductor "b" with conductor "b" connected to all other conductors, to the screen (if present) and to earth (pF/m);

C_2 is the capacitance between conductor "b" and conductor "a" with conductor "a" connected to all other conductors, to the screen (if present) and to earth (pF/m).

If the cable under test has a length, L , other than 500 m, the measured value shall be corrected:

– for pair-to-pair and side-to-side by

$$C_{\text{corr}} = \frac{C_{\text{meas}}}{0,5 \times (L/500 + \sqrt{L/500})} \quad (4)$$

– for pair-to-earth and side-to-earth by

$$C_{\text{corr}} = \frac{C_{\text{meas}}}{L/500} \quad (5)$$

where

C_{corr} is the corrected capacitance (pF/m);

C_{meas} is the measured capacitance (pF/m);

L is the length of cable under test (m).

6.2.7 Transfer impedance

The measurement of the transfer impedance shall be in accordance with IEC 62153-4-3. All of the screens shall be connected together at the ends of the test specimen. The transfer impedance shall be measured over the frequency range indicated in the relevant sectional specification.

6.2.8 Coupling attenuation

The measurement of the coupling attenuation shall be in accordance with IEC 62153-4-5. All of the screens shall be connected together at the ends of the test specimen. The coupling attenuation shall be measured over the frequency range indicated in the relevant sectional specification.

6.2.9 Current-carrying capacity

Under consideration.

6.3 Transmission characteristics

Transmission measurements are in the balanced mode with measuring equipment (network analyser or signal generator/receiver) and baluns to connect the cable to the equipment. The baluns shall be selected to match the test equipment to the cable nominal impedance and shall have the relevant performance characteristics given in Table 1. The residual mismatch of the baluns is compensated by calibrating the system with the baluns connected to a short length (≤ 1 m) of the cable to be tested.

6.3.1 Velocity of propagation (phase velocity)

The velocity of propagation shall be determined over the frequency range indicated in the relevant sectional specification.

The test equipment schematic is given in Figure 1. For this measurement, the common-mode balun ports are optional.

The measurement determines the frequency interval, Δf for which the phase of the output signal makes a 2π radians rotation in comparison with the input signal.

The velocity of propagation is determined from

$$v_p = L \cdot \Delta f \quad (6)$$

where

v_p is the phase velocity (m/s);

L is the length of the cable under test (m);

Δf is the frequency interval (Hz).

In order to evaluate Δf with sufficient accuracy, the frequency difference Δf for n rotations of 2π radians may be measured as

$$\Delta f = \Delta f' / n \quad (7)$$

where

$\Delta f'$ is the frequency difference for n rotations;

n is the number of rotations ≤ 10 .

6.3.2 Phase delay and differential delay (delay skew)

The phase delay is determined from the phase velocity:

$$\tau_p = \frac{L}{v_p} \quad (8)$$

where

τ_p is the phase delay (s);

v_p is the phase velocity (m/s);

L is the cable length under test (m).

The differential phase delay (delay skew) is determined from

$$\Delta \tau_p = \left| L \cdot \left(\frac{1}{v_{p,1}} - \frac{1}{v_{p,2}} \right) \right| \quad (9)$$

where

$\Delta\tau_p$ is the differential phase delay (delay skew) (s);

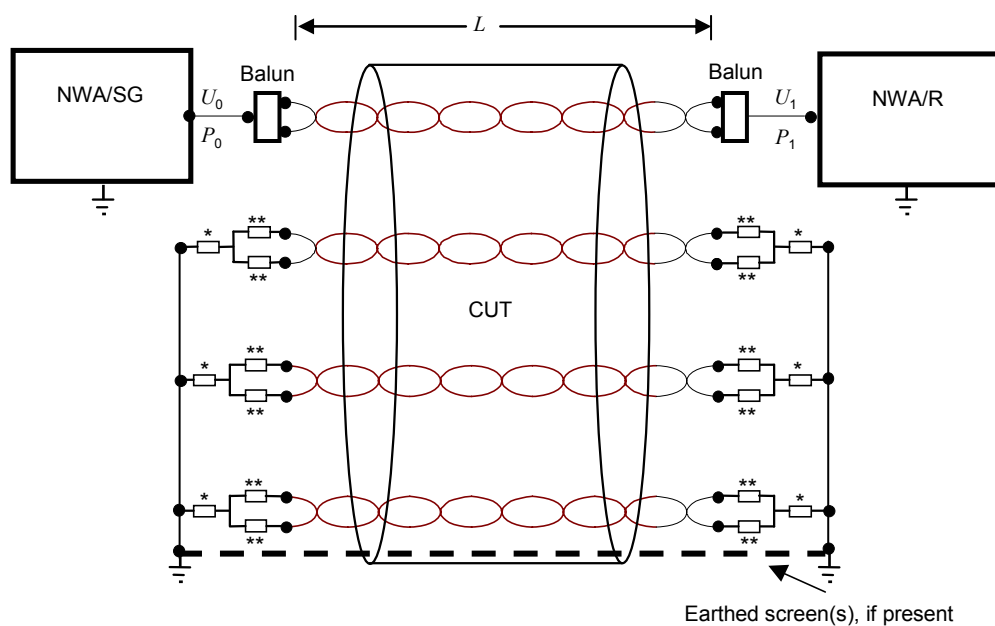
$v_{p,1}$ is the phase velocity of one pair (m/s);

$v_{p,2}$ is the phase velocity of another pair (m/s).

6.3.3 Attenuation

6.3.3.1 Attenuation at ambient temperature

The measurement shall be over the frequency range indicated in the relevant sectional specification. The test schematic is given in Figure 1. For this measurement, the common-mode balun ports are optional.



IEC 653/07

Key

CUT	cable under test
NWA/SG	network analyser port or signal generator
NWA/R	network analyser port or receiver
*	common-mode termination resistor (see 6.1)
**	differential-mode termination resistor (matched in pairs)
L	length of cable under test (m)
U_0	voltage at network analyser port or signal generator (V)
U_1	voltage at network analyser port or receiver (V)
P_0	power at network analyser port or signal generator (W)
P_1	power at network analyser port or receiver (W)

Figure 1 – Test set-up for the measurement of attenuation, velocity of propagation and phase delay

The measurements are made at ambient temperature and attenuation on a 100 m cable length is given by equation (10).

$$\begin{aligned}\alpha &= 10 \times \log_{10} \left(\frac{P_0}{P_1} \right) \\ &= 20 \times \log_{10} \left(\frac{U_0}{U_1} \right)\end{aligned}\quad (10)$$

where

α is the measured attenuation (dB/100 m) and is corrected to 20 °C as follows.

$$\alpha_{20} = \frac{\alpha}{1 + \delta_{\text{cable}} \cdot (T - 20)} \quad (11)$$

where

α_{20} is the attenuation corrected to 20 °C (dB/100 m);

δ_{cable} is the attenuation temperature coefficient (%/°C);

T is the ambient temperature (°C).

Attenuation temperature coefficient values are given in the relevant sectional specification.

6.3.3.2 Attenuation at elevated temperatures

6.3.3.2.1 Test chamber

The test chamber shall be either an air-circulating oven or an environmental chamber. The test chamber shall be capable of maintaining the required test temperature, ± 2 °C, for the duration of the test. The chamber dimensions shall be adequate to contain the sample and fixtures as required to support the sample. The chamber shall be provided with access ports for connecting the sample to test equipment. The maximum length of the cable ends extending out of the test chamber shall be 1 m.

6.3.3.2.2 Sample preparation and test configuration

The sample may be loosely coiled with a minimum diameter of 18 cm and placed in the chamber. In this configuration the wraps of the coil may be in close proximity and inter-winding coupling may appear in the test results for unscreened cable.

Alternately, the sample may be wound on a non-metallic drum with adjacent wraps separated by a minimum of 2,5 cm which will eliminate inter-winding coupling for unscreened cable.

6.3.3.2.3 Test procedure

The attenuation of the sample shall be measured at ambient temperature according to 6.3.3.1 after conditioning in the chamber for at least 4 h.

The temperature in the chamber shall be maintained at the required temperature, and the attenuation of the sample shall be measured again after a time duration between 4 h and 24 h.

A mathematical smoothing algorithm that may be applied to the measured attenuation data to correct for inter-winding coupling is given by the following:

$$\alpha_{\text{sm}} = a + b \times \sqrt{f} + c \times f + d / \sqrt{f} \quad (12)$$

where

α_{sm} is the smoothed attenuation data (dB/100 m);
 a, b, c, d are the regression coefficients;
 f is the frequency (Hz).

6.3.3.3 Attenuation temperature coefficient

The attenuation temperature coefficient is given by equation (13).

$$\delta_{\text{cable}} = \frac{\alpha_{T2} - \alpha_{T1}}{\alpha_{T1} \cdot (T_2 - T_1)} \times 100 \quad (13)$$

where

δ_{cable} is the attenuation temperature coefficient (%/°C);
 α_{T1} is the attenuation at temperature T_1 (dB/100 m);
 α_{T2} is the attenuation at temperature T_2 (dB/100 m);
 T_1 is the reference or ambient temperature (°C);
 T_2 is the elevated temperature (°C).

NOTE The calculation according to equation (13) is applicable to both the measured and the smoothed attenuation data.

6.3.4 Unbalance attenuation

6.3.4.1 Equipment

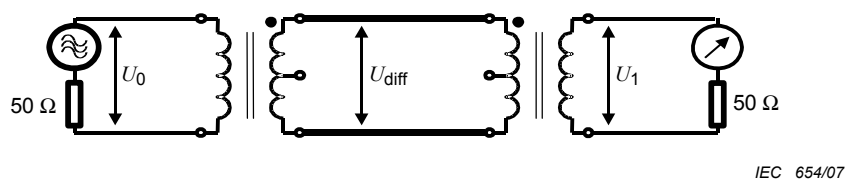
- a) It is mandatory to create a defined return (common-mode) path. This is normally achieved by earthing all other pairs and screen(s) if present in common to the balun earth. The pairs shall be terminated with differential-mode and common-mode terminations and earthed at near and far ends. However, the cable under test may be wound onto an earthed metal drum. The drum surface may have a suitable groove, wide enough to contain the cable and shall be adequate to hold 100 m of cable in one layer.
- b) A network analyser or generator/receiver combination suitable for the required frequency and dynamic range.
- c) The baluns shall have a common-mode port and the characteristics given in Table 1.
- d) Time domain reflectometer (optional).

Table 1 – Test balun performance characteristics

Parameter	Class A-250 value	Class A-600 value	Class B value
Impedance, primary ^a	50 Ω unbalanced	50 Ω unbalanced	50 Ω unbalanced
Impedance, secondary	Matched balanced	Matched balanced	Matched balanced
Insertion loss	3 dB max.	3 dB max.	10 dB max.
Return loss, secondary	20 dB min.	12 dB min., 5-15 MHz 20 dB min., 15-550 MHz 17,5 dB min., 550-600 MHz	6 dB min.
Return loss, common mode ^b	10 dB min.	15 dB min., 5-15 MHz 20 dB min., 15-400 MHz 15 dB min., 400-600 MHz	10 dB min.
Power rating	0,1 W min.	0,1 W min.	0,1 W min.
Longitudinal balance ^c	60 dB min.	60 dB min., 15-350 MHz 50 dB min., 350-600 MHz	35 dB min.
Output signal balance ^c	50 dB min.	60 dB min., 15-350 MHz 50 dB min., 350-600 MHz	35 dB min.
Common-mode rejection ^c	50 dB min.	60 dB min., 15-350 MHz 50 dB min., 350-600 MHz	35 dB min.
^a Primary impedance may differ, if necessary, to accommodate analyser outputs other than 50 Ω . ^b Measured by connecting the balanced output terminals together and measuring the return loss. The unbalanced balun input terminal shall be terminated by a 50 Ω load. ^c Measured according to ITU-T Recommendation G.117 and ITU-T Recommendation O.9. ^d For 120 Ω cables, 120 Ω baluns will be used only in cases where it is requested by the user. Usually 100 Ω baluns will be used.			
Special guidelines for the use of baluns 1) For best accuracy, the baluns should be supplied with connectors (for example, with IEC 60169-22 connectors). 2) For tests up to 250 MHz, class A-250 baluns should be used. 3) For tests up to 600 MHz, class A-600 baluns should be used. 4) For class B baluns, there is a trade-off between insertion loss and return loss. Return loss can be improved by using an attenuator, which then increases insertion loss. If return loss is less than 10 dB, insertion loss shall be less than 5 dB. If Insertion loss is higher than 5 dB, return loss shall be higher than 10 dB.			

6.3.4.2 Balun calibration

- The reference line calibration (0 dB-line) shall be determined by connecting coaxial cables between the analyser input and output. The same coaxial cables shall also be used for the balun loss measurements. The calibration shall be established over the whole frequency range specified in the relevant cable specification. This calibration method is valid for closely matched baluns that satisfy the characteristics of Table 1.
- Figure 2 gives the schematic for the measurement of the differential-mode loss of the baluns. Two baluns are connected back to back 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.

**Key**

U_0 voltage at network analyser port or signal generator

U_1 voltage at network analyser port or receiver

U_{diff} voltage at symmetrical port of baluns

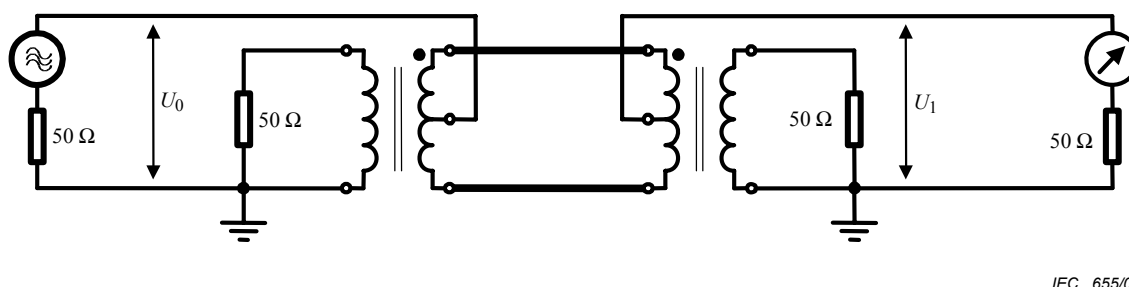
Figure 2 – Test set-up for the measurement of the differential-mode loss of the baluns

The differential-mode loss of the baluns is given by

$$\alpha_{\text{diff}} = 0,5 \times \left(20 \times \log_{10} \left| \frac{U_1}{U_0} \right| \right) \quad (14)$$

where α_{diff} is the differential-mode loss of the baluns (dB).

- c) Figure 3 gives the schematic for the measurement of the common-mode loss of the baluns. The baluns used in b) are connected together; the unbalanced balun ports are terminated with the nominal test equipment impedance, the test equipment is connected to the common-mode port (centre tap) of the baluns.

**Key**

U_0 voltage at network analyser port or signal generator

U_1 voltage at network analyser port or receiver

Figure 3 – Test set-up for the measurement of the common-mode loss of the baluns

The common-mode loss of the baluns is given by

$$\alpha_{\text{com}} = 0,5 \times \left(20 \times \log_{10} \left| \frac{U_1}{U_0} \right| \right) \quad (15)$$

where α_{com} is the common-mode loss of the balun (dB).

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

$$\alpha_{\text{balun}} = \alpha_{\text{diff}} + \alpha_{\text{com}} \quad (16)$$

where α_{balun} is the operational attenuation or intrinsic loss of the balun (dB).

NOTE 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 assumption of identical baluns is not required.

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

$$\begin{aligned} 20 \times \log_{10} \left| \frac{U_{\text{diff}}}{U_0} \right| &= 10 \times \log_{10} \left| \frac{Z_{\text{diff}}}{Z_0} \right| - \alpha_{\text{balun}} \\ 20 \times \log_{10} \left| \frac{U_{\text{diff}}}{U_1} \right| &= 10 \times \log_{10} \left| \frac{Z_{\text{diff}}}{Z_1} \right| - \alpha_{\text{balun}} \end{aligned} \quad (17)$$

where

U_{diff} is the differential-mode voltage at the input of the cable under test (V);

U_0 is the voltage at the network analyser port or signal generator (V);

Z_{diff} is the characteristic impedance of the differential-mode circuit (Ω);

Z_0 is the output impedance of the network analyser or signal generator (Ω);

U_1 is the voltage at the input of the load (V);

Z_1 is the input impedance of the load (Ω).

6.3.4.3 Measurements

All pairs/quads of the cable shall be measured at both ends of the cable under test (CUT). 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 Ω , the value of Z_{com} is 75 Ω for up to 25 pair-count unscreened pair cables, 50 Ω for common screened pair cables and more than 25 pair-count unscreened pair cables, and 25 Ω for individually screened pair cables. The impedance of the common-mode circuit Z_{com} can be measured more precisely either with a time domain reflectometer (TDR) or a network analyser. The two conductors of the pair are connected together at both ends and the impedance is measured between these conductors and the return path.

6.3.4.3.1 Cable under test (CUT)

The ends of the CUT shall be prepared so that the twisting of the pairs/quads is maintained up to the terminals of the test equipment. The CUT shall have a length of 100 m $\pm$ 1 m. All pairs not under test shall be connected to earth through appropriate common-mode (see 6.1) and differential-mode terminations at the near and far end. The screens, if any, shall be connected to earth at both ends of the cable.

6.3.4.3.2 Test set-up for unbalance measurements

Figure 4 gives a schematic of the measurement for unbalance attenuation at the near end.

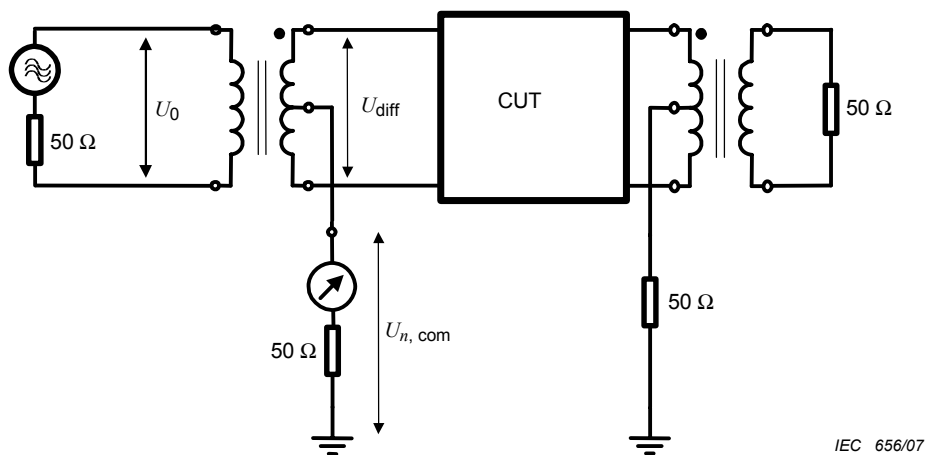


Figure 4 – Test set-up for unbalance attenuation at near end (*TCL*)

$$\alpha_{\text{meas}} = 20 \times \log_{10} \left| \frac{U_{n, \text{com}}}{U_0} \right| \quad (18)$$

where

α_{meas} is the measured attenuation (dB);

$U_{n, \text{com}}$ voltage in the common-mode circuit (V);

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

Figure 5 gives a schematic of the measurement for unbalance attenuation at far end.

NOTE In theory, the 50 Ω common mode termination in Figures 4 and 5 should be Z_{com} , but the error in using 50 Ω is small.

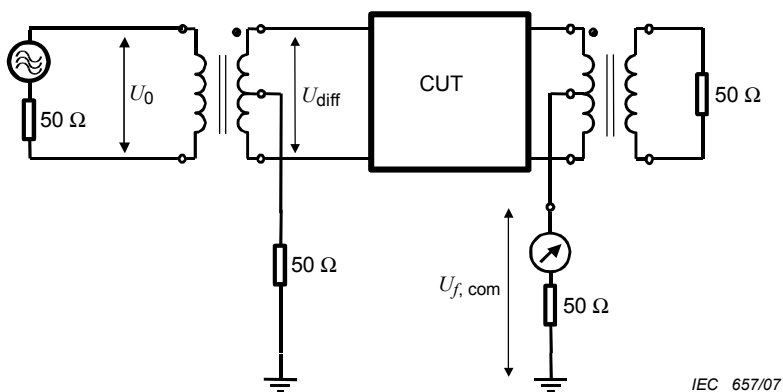


Figure 5 – Test set-up for unbalance attenuation at far end (*TCTL*)

$$\alpha_{\text{meas}} = 20 \times \log_{10} \left| \frac{U_{f, \text{com}}}{U_0} \right| \quad (19)$$

6.3.4.3.3 Expression of test result

The unbalance attenuation is defined as the logarithmic ratio of the common-mode power to the differential-mode power.

$$\alpha_{u,n} = 20 \times \log_{10} \left| \frac{\sqrt{P_{n,com}}}{\sqrt{P_{diff}}} \right| = 20 \times \log_{10} \left| \frac{U_{n,com}}{U_{diff}} \right| + 10 \times \log_{10} \left| \frac{Z_{diff}}{Z_{com}} \right| \quad (20)$$

where

α_u is the unbalance attenuation (dB);

P_{com} is the matched common-mode power (W);

P_{diff} is the matched differential-mode power (W).

When measuring with S-parameter test-sets, the output voltage of the generator is measured instead of the differential-mode voltage in the cable under test. Taking the operational attenuation of the balun into account, the equation for the unbalance attenuation near or far end is:

$$\begin{aligned} \alpha_{u,n} &= 10 \times \log_{10} \left| \frac{P_{n,com}}{P_{diff}} \right| = 10 \times \log_{10} \left| \frac{P_{n,com}}{P_0} \right| - \alpha_{balun} \\ &= 20 \times \log_{10} \left| \frac{U_{n,com}}{U_0} \right| + 10 \times \log_{10} \left| \frac{Z_0}{Z_{com}} \right| - \alpha_{balun} \end{aligned} \quad (21)$$

$$\alpha_{u,n} = \alpha_{meas} + 10 \times \log_{10} \left| \frac{Z_0}{Z_{com}} \right| - \alpha_{balun} \quad (22)$$

The equal level unbalance attenuation at the far end is then

$$EL \alpha_{u,f} = \alpha_{meas} + 10 \times \log_{10} \left| \frac{Z_0}{Z_{com}} \right| - \alpha_{balun} - \alpha_{cable} \quad (23)$$

where

$EL \alpha_{u,f}$ is the equal level unbalance attenuation at far end ($EL TCTL$) (dB);

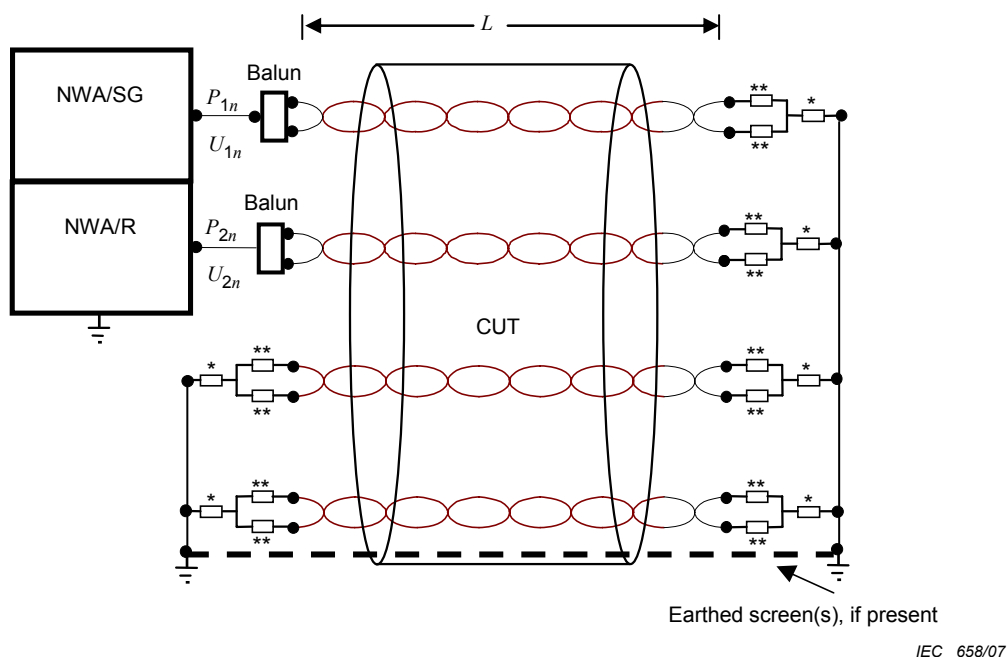
α_{cable} is the attenuation of the cable (dB).

6.3.5 Near-end crosstalk

Figure 6 gives the schematic for the measurement of near-end crosstalk. The near-end crosstalk loss shall be measured using a network analyser or equivalent measuring equipment over the frequency range indicated in the relevant sectional specification.

The test schematic is given in Figure 6. The pairs under test shall be connected to earth at the far end through appropriate common-mode (see 6.1) and differential-mode terminations. The baluns shall comply with the relevant requirements of Table 1 and shall be selected to match the test equipment to the cable nominal impedance.

All pairs not under test shall be connected to earth through appropriate common-mode (see 6.1) and differential-mode terminations at the near and far end. The screens, if any, shall be connected to earth at both ends of the cable. Precautions shall be taken to minimize end effect couplings. When the cable sheath is removed, the pairs shall maintain their twist and shall be well separated.



Key

CUT	cable under test
NWA/SG	network analyser port or signal generator
NWA/R	network analyser port or receiver
*	common-mode termination resistor (see 6.1)
**	differential-mode termination resistor (matched in pairs)
<i>L</i>	length of cable under test (m)

Figure 6 – Test set-up for near-end crosstalk

Near-end crosstalk loss *NEXT* is given by

$$\begin{aligned}
 NEXT &= 10 \times \log_{10} \left| \frac{P_{1n}}{P_{2n}} \right| \\
 &= 20 \times \log_{10} \left| \frac{U_{1n}}{U_{2n}} \right| + 10 \times \log_{10} \left| \frac{Z_1}{Z_2} \right|
 \end{aligned}
 \tag{24}$$

where

<i>NEXT</i>	is the near-end crosstalk (dB);
P_{1n}	is the input power of the disturbing pair at the near end (W);
P_{2n}	is the output power of the disturbed pair at the near end (W);
U_{1n}	is the input voltage of the disturbing pair at the near end (V);
U_{2n}	is the output voltage of the disturbed pair at the near end (V);

Z_1 is the characteristic impedance of the disturbing pair (Ω);
 Z_2 is the characteristic impedance of the disturbed pair (Ω).

Measurements shall be on a length of at least 100 m. For a length greater than 100 m, the measured value may be corrected to 100 m using the following correction formula:

$$NEXT_{100} = NEXT + 10 \times \log_{10} \left[\left(1 - 10^{-\frac{\alpha \cdot L}{5}} \right) / \left(1 - 10^{-\frac{\alpha}{5}} \right) \right] \quad (25)$$

where

$NEXT_{100}$ is the near-end crosstalk corrected to a length of 100 m (dB);
 $NEXT$ is the near-end crosstalk on the measured cable length (dB);
 α is the attenuation of the measured cable length (dB).

The power sum near-end crosstalk $PS\ NEXT$ is calculated from

$$PS\ NEXT_j = -10 \times \log_{10} \sum_{\substack{i=1 \\ i \neq j}}^m \left(10^{\frac{NEXT_{i,j}}{10}} \right) \quad (26)$$

where

$PS\ NEXT_j$ is the power sum of the pair j (dB);
 $NEXT_{i,j}$ is the crosstalk coupled from the pairs i into the pair j (dB);
 m is the number of pairs contained within the cable.

6.3.6 Far-end crosstalk

Figure 7 gives the schematic for the measurement of far-end crosstalk. The far-end crosstalk loss shall be measured using a network analyser or equivalent measuring equipment over the frequency range indicated in the relevant sectional specification.

The pairs under test shall be connected to baluns which comply with the relevant requirements of Table 1. The baluns shall be selected to match the test equipment to the cable nominal impedance.

All pairs not under test shall be connected to earth through appropriate common-mode (see 6.1) and differential-mode terminations at the near and far end. The screens, if any, shall be connected to earth at both ends of the cable. Precautions shall be taken to minimize end effect couplings. When the cable sheath is removed, the pairs shall maintain their twist and shall be well separated.