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Edition 2.0 2017-08

INTERNATIONAL STANDARD

Metallic cables and other passive components test methods – Part 4-6: Electromagnetic compatibility (EMC) – Surface transfer impedance – Line injection method

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Part 4-6: Electromagnetic compatibility (EMC) – Surface transfer impedance – Line injection method

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CONTENTS

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METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-6: Electromagnetic compatibility (EMC) – Surface transfer impedance – Line injection method

FOREWORD

International Standard IEC 62153-4-6 has been prepared by subcommittee 46A: Coaxial cables, of IEC technical committee 46: Cables, wires, waveguides, RF connectors, RF and microwave passive components and accessories cables, wires, waveguides, r.f. connectors and accessories for communication and signalling.

This second edition cancels and replaces the first edition, published in 2006.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
46/650/FDIS	46/654/RVD

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

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

A list of all parts in the IEC 62153 series, published under the general title *Metallic communication cable test methods*, can be found on the IEC website.

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

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- withdrawn,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

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

METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-6: Electromagnetic compatibility (EMC) – Surface transfer impedance – Line injection method

1 Scope

This part of IEC 62153 determines the screening effectiveness of a shielded metallic communication cable by applying a well-defined current and voltage to the screen of the cable and measuring the induced voltage in order to determine the surface transfer impedance.

Measurements in the frequency range from a few kHz up to and above 1 GHz can be made with the use of normal high frequency instrumentation.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
inner circuit
circuit consisting of the conductor(s) and the screen of the CUT and is denoted by the subscript 2

3.2
outer circuit (line injection circuit)
circuit consisting of the screen surface of CUT and the injection wire and is denoted by the subscript 1

3.3
transfer impedance
Z_T
quotient of the longitudinal voltage induced in the inner circuit of the electrically short cable under test to the current in the outer circuit (line injection circuit) – or vice versa – related to unit length

4 Physical background

One important element in the determination of the screening effectiveness of cables is the transfer impedance Z_T of its screen.

Most cables have a negligible capacitive coupling. But for loose single braided cables, capacitive coupling cannot be neglected. The coupling through the holes in the screen is described in terms of the through capacitance C_T or the capacitive coupling admittance Y_C. For an electrically short uniform cable, Y_C is defined as the quotient of the current induced in the inner circuit to the voltage developed in the outer circuit – formed by the screen under test and the injection wire – or vice versa related to the unit length.

In case of a non negligible capacitive coupling, the screening effectiveness is described by the equivalent transfer impedance Z_{TE}:

$$Z_{TE} = \max\left|Z_F \pm Z_T\right| \quad (1)$$

$$Z_F = j\omega C_T Z_1 Z_2 = Y_C Z_1 Z_2 \quad (2)$$

where

ω	is the radian frequency;
$\pm$	+ refers to near end, – refers to far end measurement;
C_T	is the through capacitance;
Y_C	is the capacitive coupling admittance;
Z_1	is the characteristic impedance of the outer circuit (line injection circuit);
Z_2	is the characteristic impedance of the inner circuit (cable under test);
Z_F	is the capacitive coupling impedance;
Z_T	is the transfer impedance;
Z_{TE}	is the equivalent transfer impedance.

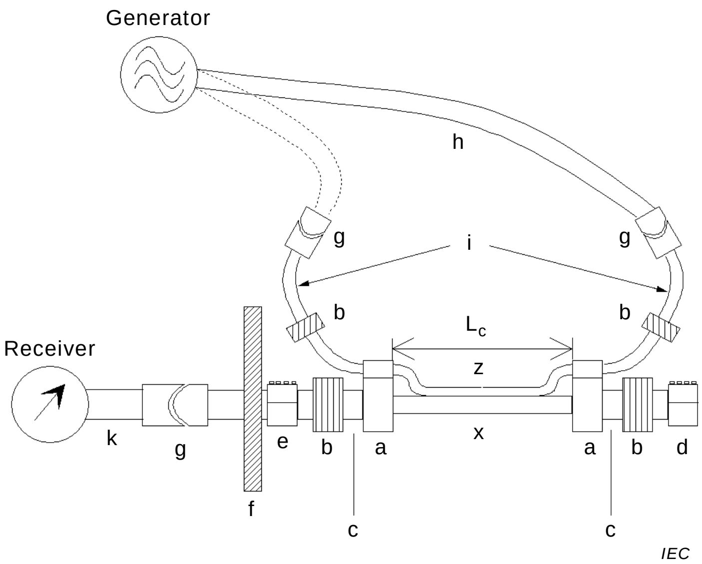
For more information, see the respective parts of IEC 62153-4-1.

5 Test set-up

5.1 General

As shown in Figure 1, the injection circuit is constructed as a transmission line using one or more parallel wires, a corrugated ribbon cable or a flat copper braid with the outer conductor of the cable under test. The injection circuit is connected to the coaxial line at each end via an injection feature. The injection wire shall be fitted tightly to the cable sample along the coupling length (e.g. with an adhesive tape). The characteristic impedance of the injection circuit shall be equal to the generator output resistance and the load resistance R_1; this is achieved by choosing an appropriate conductor size and the type of insulation of the injection wire.

The reflection coefficient of the injection feature and the injection circuit along the coupling length shall be less than 0,1 related to the generator output resistance, i.e. the return loss should be higher than 20 dB.



a	injection feature
b	ferrite
c	brass/copper tube for additional screening
d	screening box for the matching resistor of the cable under test
e	screening box for connecting the cable under test to the receiver
f	screened-room wall with screened coaxial feed-through (if needed)
g	connector (SMA, N, etc.)
h	feeding cable from the generator
i	feeding cables for injection wire
k	connecting cable to receiver
x	cable under test
z	injection line
L_c	coupling length

Figure 1 – Complete installation

5.2 Equipment

The measuring equipment consists of

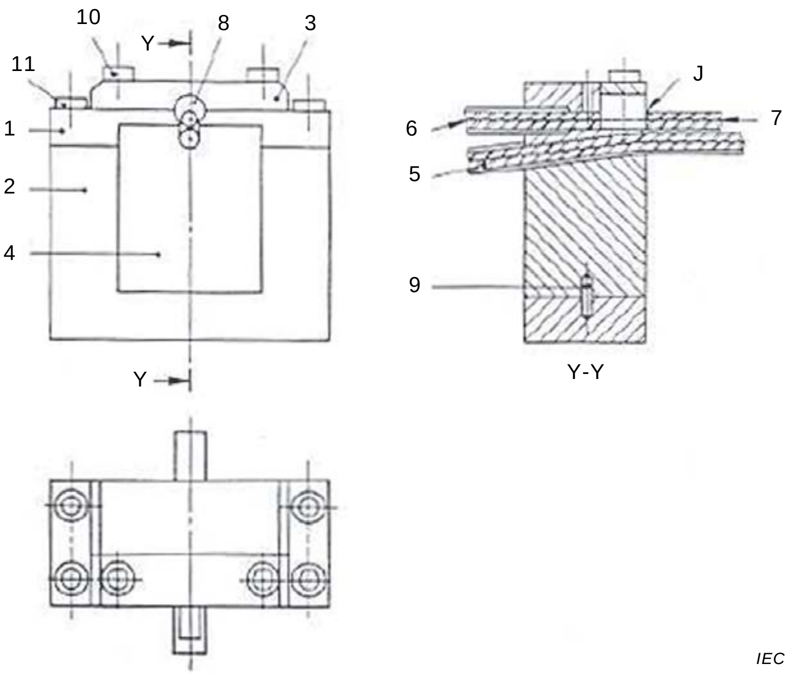
a) a vector network analyser or alternatively
   - a signal generator with the same characteristic impedance as the line injection circuit and with a power amplifier if necessary for very low transfer impedance,
   - a receiver with a calibrated step attenuator and complemented with a low noise amplifier for very low transfer impedance,

b) a time domain reflectometer (TDR) with a rise time of less than 350 ps or vector network analyser (at least 3 GHz) performing a return loss measurement transformed into the time domain.

5.3 Injection feature

The design of the injection features is adjusted to allow an optimum matching of the symmetrical TEM in the coaxial feeding and terminating cables to the asymmetrical field along the parallel line whilst maintaining good mechanical strength for repeated use. Details of a possible injection features are given in Figure 2 to Figure 6 (the figures are related for a coaxial cable connection of RG223). Fine tuning of the discontinuity can be made by varying the foam insert, item 8 of Figure 2.

Alternatively, a suitable injection features can be made with a small connector (solder spill type) strapped to the CUT, or more easily by strapping the outer conductor of a small coaxial cable of appropriate characteristic impedance to the bared sheath of the CUT. In the test section itself, the centre conductor of the coaxial cable is continued using two or four parallel wires, corrugated ribbon cable or flat copper braid. Fine tuning of an injection feature discontinuity can be achieved by strapping the joint and the injection wire more closely onto the sheath of the CUT in the test section.



Quantity	Part	Pos.	Remarks, material
4	Metric screw M3 x 10mm	11	
2	Metric screw M3 x 6mm	10	
1	Pin: dia. 2mm length 8mm	9	
1	Foam dielectric	8	εr close to 1
1	Injection wire	7	
1	50 Ω coaxial cable	6	Impedance as required
1	Cable under test (CUT)	5	
1	Insert for CUT	4	Brass
1	Impedance matching part	3	Brass
1	Lower part	2	Brass
1	Upper part	1	Brass
	Test injection feature (two required)		

Figure 2 – Assembled injection feature for the transmission type line, Injection method – Parts list

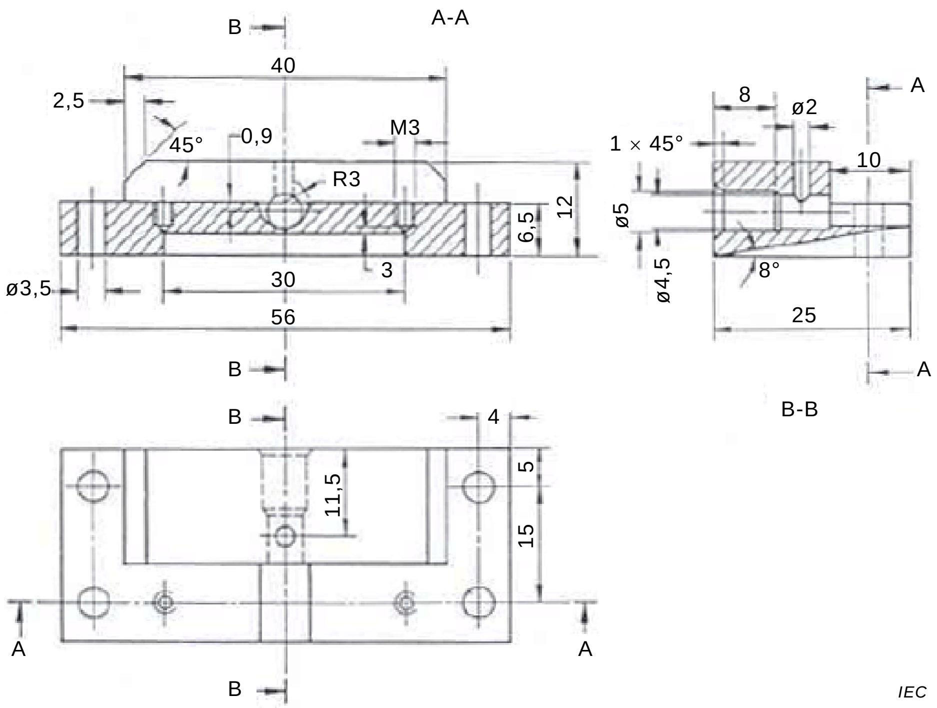


Figure 3 – Upper part of injection feature – Position 1

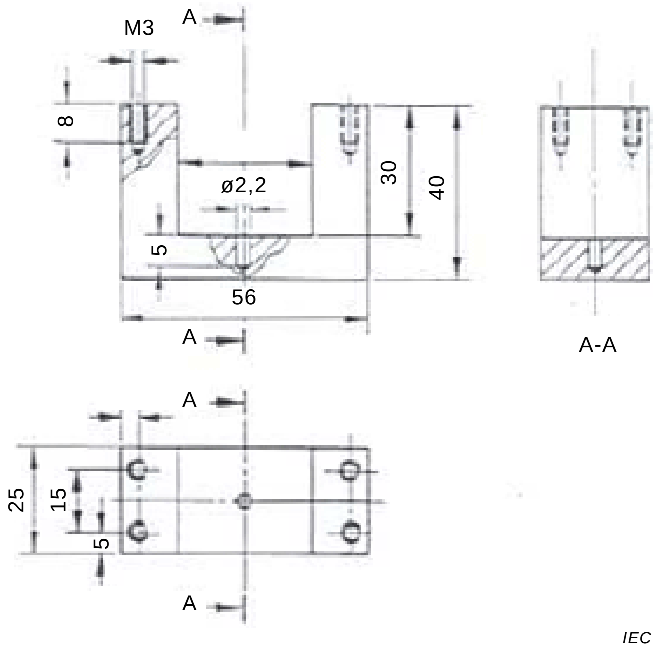


Figure 4 – Lower part of injection feature – Position 2

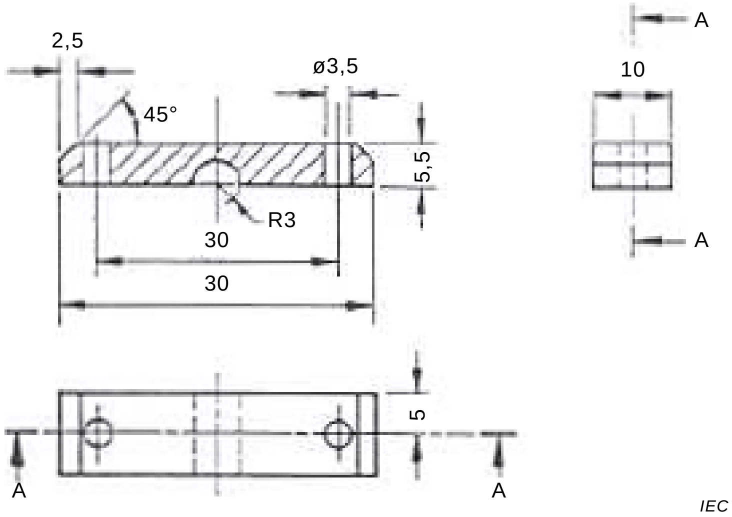


Figure 5 – Impedance matching part of injection feature – Position 3

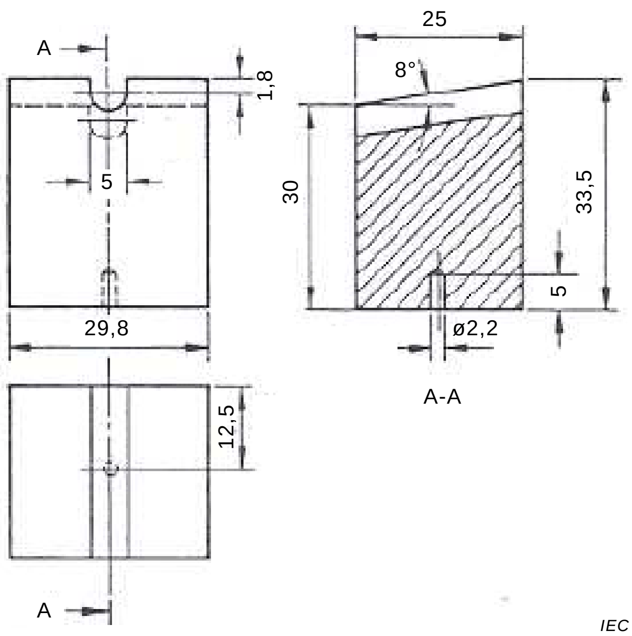


Figure 6 – Insert for adapting the different sizes of the cables under test – Position 4

5.4 Impedance of inner circuit

It is not necessary to match the impedance of the receiver with the impedance of the inner circuit (cable under test). However, the load resistance R_2 shall be equal to the characteristic impedance of the (quasi) coaxial line of the prepared cable sample (inner circuit) (see 6.2).

If the impedance Z_2 of the inner circuit (coaxial or quasi coaxial) is not known, it may be either determined with a time domain reflectometer or by using the following method:

One end of the prepared sample is connected to a network analyser, which is calibrated for impedance measurements at the connector interface reference plane. The test frequency should be at least 10 MHz and shall be the approximate frequency for which the length of the sample is 1/8 λ, where λ is the wavelength.

$$f_{\text{test}} \approx \frac{c}{8.L_{\text{sample}} \cdot \sqrt{\varepsilon_{r1}}} \tag{3}$$

where

f_{test}	is the test frequency in Hz;
c	is the velocity of light, $3 \cdot 10^8$ m/s;
L_{sample}	is the length of sample;
ε_{r1}	is the resulting relative permittivity of the line injection circuit.

The sample is short-circuited at the far end. The impedance Z_{short} is measured.

The sample is left open at the same point where it was shorted. The impedance Z_{open} is measured.

Z_2 is calculated as:

$$Z_2 = \sqrt{Z_{\text{short}} \cdot Z_{\text{open}}} \tag{4}$$

6 Preparation of the test sample

6.1 General

The recommended test length between the two injection features is 0,5 m for frequencies up to 1 GHz (see also 6.2). For an injection feature as described in 5.3, the CUT should be shielded with brass or copper tubes outside its test length (see items $h1$ and $h2$ in Figure 7). The shielding tubes shall make contact with the cable screen S at E by soldering or crimping. If soldering is used, care shall be taken not to overheat the cable dielectric. A good practice is to choose the tube diameter such that the CUT can be inserted with the outer sheath removed and fixed by a standard crimping tool. The advantage of this method is that the cable braid S is prevented from unravelling near the test length of the CUT by the close positioning of the tube. Another possibility is the use of wedges to contact non-solder able aluminium foil/braid cables.

One end of the CUT is prepared with a suitable RF connector (e.g. N (IEC 61169-16), SMA (IEC 60169-15) to make the connection to the receiver. The other end is matched with a well-screened resistor, the value of which is equal to the characteristic impedance of the CUT (coaxial or quasi coaxial system, see 6.4). For bigger cables, it is recommended to use several resistors in parallel. All connections shall be made so that the contact resistance can be neglected with respect to the results. For coaxial RF cables with standard values for the characteristic impedance (i.e. 50 Ω or 75 Ω), it is recommended to mount suitable RF connectors (N, SMA) on both ends of the CUT and to use standard highly screened coaxial terminations.

The load resistor and the connection to the receiver cable are mounted in screening boxes (Figure 8). The completed CUT and the injection circuit shall be tested with a TDR for the electrical quality of the test set-up. Bending forces shall be avoided at the joints between the tubes and the test section of the CUT to prevent mechanical damage.

To reduce the influence of unwanted coupling of electromagnetic energy into the free ends, the sum of both $l1$ and $l2$ shall not exceed the length of the test section of the CUT (Figure 7).

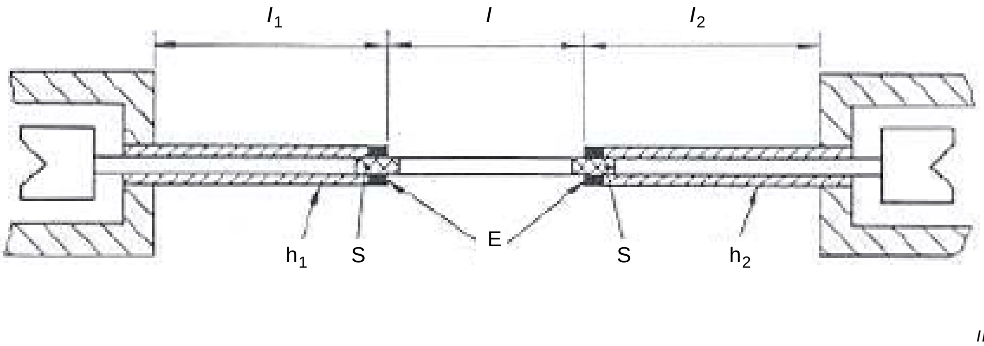


Figure 7 – Preparation of the cable under test (CUT)

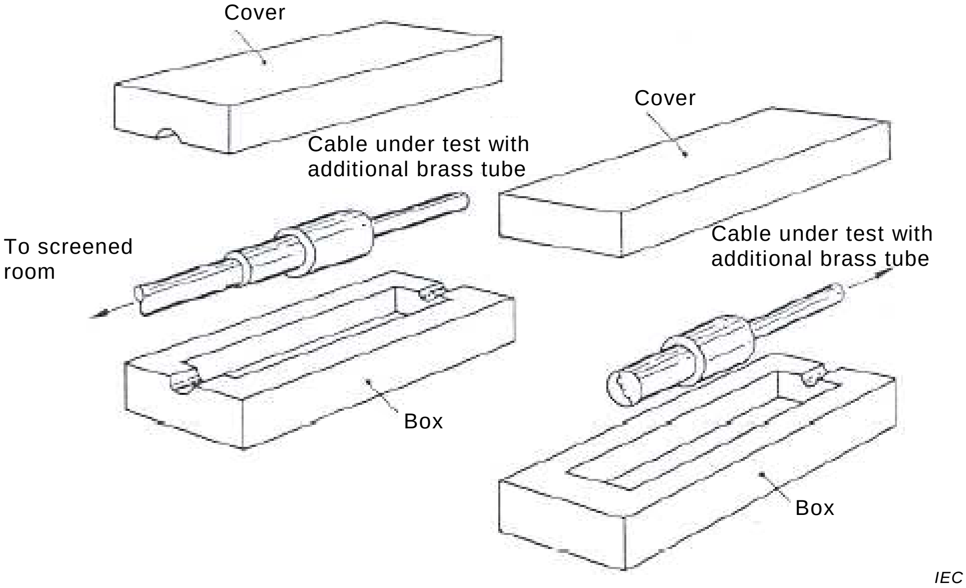


Figure 8 – Additional screening of connectors on the cable under test (CUT)

6.2 Sample length

The coupling length depends on the highest frequency to be measured. The coupling length shall be 0,5 m if not other specified, but not less than 0,3 m.

The relation between coupling length and highest test frequency is given by:

$$L_{c,\max} \leq \frac{c}{\pi \cdot f_{\max} \cdot \left|\sqrt{\varepsilon_{r2}} \pm \sqrt{\varepsilon_{r1}}\right|} \tag{5}$$

where

ε_{r1}	is the resulting relative permittivity of the line injection circuit;
ε_{r2}	is the resulting relative permittivity of the cable under test;
±	+ refers to near end , – to far end measurement;
c	is the velocity of light, $3 \cdot 10^8$ m/s;
f_{max}	is the highest frequency to be measured in Hz;
$L_{c,max}$	is the maximum coupling length in m.

The ideal conditions for the test circuits are as follows:

a) the characteristic impedance of the line injection circuit is equal to the generator output resistance and the load resistance R_1;

b) the characteristic impedance of the line injection circuit does not vary along the coupling length (reflection coefficient less than 0,1);

c) the reflection coefficient of each injection feature is less than 0,1, i.e. the return loss should be higher than 20 dB;

d) the characteristic impedance of the quasi coaxial line of the prepared cable sample is equal the load resistance R2;

e) same propagation velocity in the inner and outer circuit.

For any mismatch in the test set-up, the highest frequency to be measured with a defined coupling length will be less than calculated. In this case, the highest frequency may be derived at the 6 dB deviation of the linear progress of the curve in a diagram where the x-axis is the frequency in the logarithmic scale and the y-axis is the logarithmic voltage ratio $U_{generator}/U_{receiver}$.

6.3 Screened symmetrical cables

Screened symmetrical cables are treated as a quasi coaxial system, see Figure 9. Therefore all conductors of all pairs shall be connected together at both ends. All screens, also those of individually screened pairs or quads, shall be connected together at both ends. The screens shall be connected over the whole circumference.

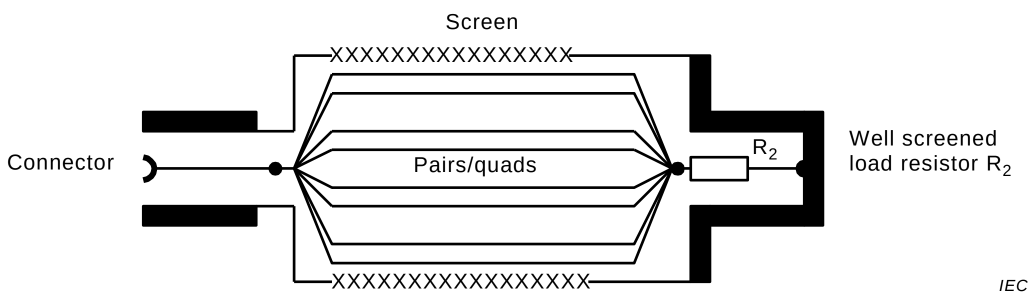


Figure 9 – Preparation of symmetrical samples

6.4 Screened multi-conductor cables

Screened multi-conductor cables are prepared as screened symmetrical cables.

7 Measurement

7.1 General

The test set-up shall be assembled in accordance with Figure 1.

7.2 Measurement precautions

7.2.1 Reduced primary current

When making far-end measurements with conventional coaxial instruments, the receiver is usually earthed. At low frequencies where resistive effects may dominate over inductive ones or due to resonance in the high kHz range, a part of the injection current may pass directly over the ground without returning along the screen of the CUT. This leads to a reduced sensitivity and even to measurement errors if the current in the screen is not directly monitored over the test section. The problem may be solved by:

a) avoiding far-end measurements at the lower frequencies (mainly in the kHz range);

b) using common mode choke (absorbers, ferrites) on the coaxial feed of the injection wire (effective in the higher kHz and beyond);

c) using an isolating transformer either for the generator or receiver mains supply (if not in the same frame) or for the coaxial feed of the injection wire. (These measures are effective from the lowest frequency ranges but care should be taken to avoid longitudinal resonances.).

7.2.2 Uncontrolled currents

Special care is required concerning low frequency earth currents not returning through the coaxial feeding circuit. Such currents pass through parts of the set-up that are not under test and especially through the frame of the receiver. Therefore the required sensitivity may not be obtained when measuring very low transfer impedance. The best method is the use of isolating transformers as discussed in 7.2.1. Another possibility is to avoid far-end measurements at the lower frequencies (mainly in the kHz range).

7.2.3 Inhomogeneities of cable screens around the circumference

The injection wire doesn’t cover the whole circumference of the cable screen. Thus for inhomogeneous cable screens (e.g. screens containing longitudinal tapes), the test results may depend on the position of the injection wire. Therefore for a sufficient coverage of the circumference, at least four measurements 90° apart shall be taken. In the case of cable diameters larger than 10 mm, more measurements may be necessary.

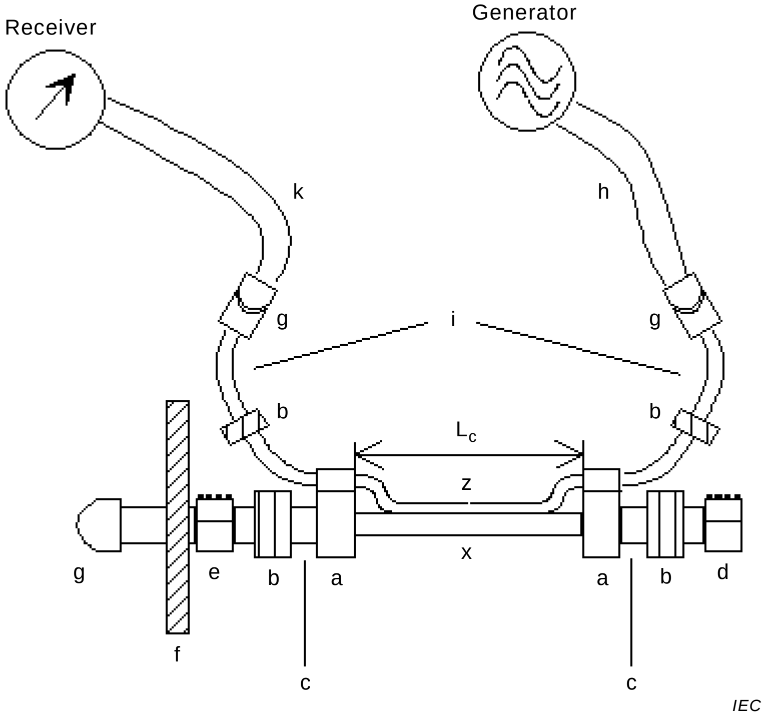
7.3 Calibration

The (Betriebs-) attenuation of the injection circuit including the connecting cables (see Figure 10) shall be measured in a logarithmic frequency sweep over the frequency range, which is specified for the transfer impedance in the relevant cable specification. The calibration data has to be saved, so that the results may be corrected.

$$a_{\text{cal}} = 10 \cdot \lg\left|\frac{P_1}{P_2}\right| = -20 \cdot \lg\left|S_{21}\right| = 20 \cdot \lg\left|\frac{U_{\text{gen, cal}}}{U_{\text{rec, cal}}}\right| \qquad (6)$$

where

P_1	is the power fed to the injection circuit during the calibration procedure;
P_2	is the power at the receiver during the calibration procedure;
S_{21}	is the scattering parameter S_{21}, forward transmission coefficient during the calibration procedure;
$U_{\text{gen, cal}}$	is the output voltage of generator during calibration procedure;
$U_{\text{rec, cal}}$	is the input voltage at the receiver during calibration procedure.



Key

a	injection feature
b	ferrite
c	brass/copper tube for additional screening
d	screening box for the matching resistor of the cable under test
e	screening box for connecting the cable under test to the receiver
f	screened-room wall with screened coaxial feed-through (if needed)
g	connector (SMA, N, etc.)
h	feeding cable from the generator
i	feeding cables for injection wire
k	connecting cable to receiver
x	cable under test
z	injection line
L_c	coupling length

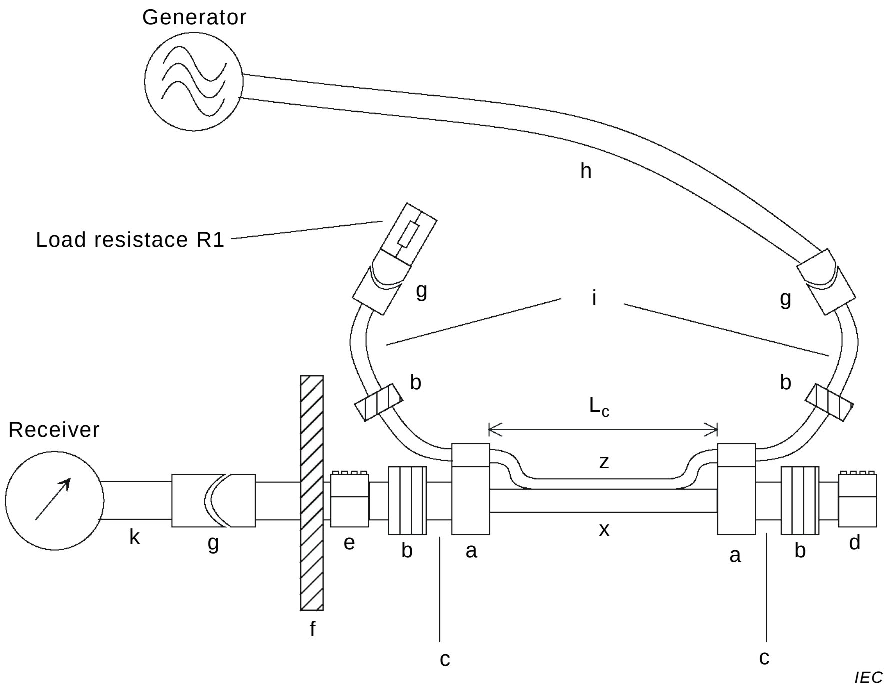
Figure 10 – Calibration set-up

7.4 Measuring procedure

In the triaxial measuring method to determine the transfer impedance (IEC 62153-4-3) the through capacitance is short-circuited by the short circuit at the near end of the outer circuit. In the line injection circuit, both the transfer impedance Z_T and the capacitive coupling impedance Z_F act on the cable at the same time, and result in the equivalent transfer impedance Z_{TE}. Thus a near and far end measurement shall be performed (see Figure 11).

The attenuation shall be measured over the whole frequency range in a logarithmic frequency sweep at the same frequency points as for the calibration procedure.

Because the cable screen cannot be considered homogeneous around the circumference, at least four measurements 90 ° apart shall be taken (see 7.2.3).



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f	screened-room wall with screened coaxial feed-through (if needed)
g	connector (SMA, N, etc.)
h	feeding cable from the generator
i	feeding cables for injection wire
k	connecting cable to receiver
x	cable under test
z	injection line
L_c	coupling length

Figure 11 – Far end measuring set-up

$$a_{\text{meas}\,\text{n}_\text{f}} = 10 \cdot \lg\left|\frac{P_{1n_f}}{P_{2n_f}}\right| = -20 \cdot \lg\left|S_{21n_f}\right| = 20 \cdot \lg\left|\frac{U_{\text{gen, meas}\,\text{n}_\text{f}}}{U_{\text{rec, meas}\,\text{n}_\text{f}}}\right| \quad (7)$$

where

$P_{1_{\mathrm{f}}^{\mathrm{n}}}$	is the power fed to the injection circuit during the measurement procedure at near end (n) respectively far end (f);
$P_{2_{\mathrm{f}}^{\mathrm{n}}}$	is the power at the receiver during the measurement procedure at near end (n) respectively far end (f);
$S_{21_{\mathrm{f}}^{\mathrm{n}}}$	scattering parameter S_{21}, forward transmission coefficient during the measurement procedure at near end (n) respectively far end (f);
$U_{\mathrm{gen,meas}_{\mathrm{f}}^{\mathrm{n}}}$	output voltage of generator during the measurement procedure at near end (n) respectively far end (f);
$U_{\mathrm{rec,meas}_{\mathrm{f}}^{\mathrm{n}}}$	input voltage at the receiver during the measurement procedure at near end (n) respectively far end (f).

7.5 Evaluation of the test results

Definition:

$$Z_{\mathrm{TE}} = \max\left(Z_{\mathrm{TEn}}; Z_{\mathrm{TEf}}\right) \tag{8}$$

$$Z_{\mathrm{TE}_{\mathrm{f}}^{\mathrm{n}}} = \frac{1}{L_{\mathrm{c}}} \frac{\left(R_1 + Z_{\mathrm{G}}\right)\left(R_2 + Z_{\mathrm{R}}\right)}{2\sqrt{Z_{\mathrm{G}} Z_{\mathrm{R}}}} 10^{-A_{\mathrm{T}_{\mathrm{f}}^{\mathrm{n}}}/20}$$

$$\text{with } Z_{\mathrm{G}} = Z_{\mathrm{R}} = R_1 = Z_0 \tag{9}$$

$$Z_{\mathrm{TE}_{\mathrm{f}}^{\mathrm{n}}} = \frac{1}{L_{\mathrm{c}}} \left(R_2 + Z_0\right) \cdot 10^{-A_{\mathrm{T}_{\mathrm{f}}^{\mathrm{n}}}/20}$$

$$A_{\mathrm{T}_{\mathrm{f}}^{\mathrm{n}}} = a_{\mathrm{meas}_{\mathrm{f}}^{\mathrm{n}}} - a_{\mathrm{cal}} \tag{10}$$

where

$Z_{\mathrm{TE}_{\mathrm{f}}^{\mathrm{n}}}$	is the equivalent transfer impedance of near end (n) or far end (f) measurement;
$a_{\mathrm{meas}_{\mathrm{f}}^{\mathrm{n}}}$	is the attenuation measured at near end (n) or far end (f) during the measuring procedure in dB;
a_{cal}	is the attenuation measured at calibration procedure in dB;
L_{c}	is the coupling length in m;
R_1	is the load resistance of the line injection circuit in Ω (50 Ω);
R_2	is the load resistance of inner circuit (coaxial or quasi coaxial circuit of the cable under test);
Z_{TE}	is the equivalent transfer impedance;
Z_{G}	is the impedance of the generator;
Z_{R}	is the impedance of the receiver;
Z_0	is the system impedance when using a system having the same impedance for the generator and receiver (e.g. vector network analyser).

8 Expression of test results

8.1 Expression

The values of the equivalent transfer impedance are expressed as Z_{TE} per unit length at the frequencies for which requirements are specified in the relevant cable specifications.

Mismatches and structural variations, resulting in poor return loss, in the primary and secondary circuit may create for the measured transfer impedance at higher frequencies deviations from or oscillations around the monotonous behaviour of the real transfer impedance. In this case, the transfer impedance measured below 100 MHz may be extrapolated by a straight line in a double logarithmic presentation of the transfer impedance. The straight line shall have the same increase as the curve in the frequency range between 10 MHz to 100 MHz. The extrapolation is valid up to the cut-off frequency of the test set-up. The cut-off frequency is obtained from:

$$f_{\mathrm{c}} = \frac{c}{\pi \cdot L_{\mathrm{c}} \cdot \left| \sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}} \right|} = \frac{1}{\pi \cdot L_{\mathrm{c}} \cdot \left| \frac{1}{v_1} - \frac{1}{v_2} \right|} = \frac{1}{\pi \cdot \left| t_1 - t_2 \right|} \tag{11}$$

where

$\varepsilon_{\mathrm{r1,2}}$	is the resulting relative permittivity of the outer (1) and inner (2) circuit respectively
c	is the velocity of light, $3 \cdot 10^8$ m/s
$v_{1,2}$	is the propagation velocity in the outer (1) and inner (2) circuit respectively
f_{c}	is the cut off frequency
L_{c}	is the coupling length in m
$t_{1,2}$	is the propagation time of the signal for the length L in the outer (1) and inner (2) circuit respectively.

NOTE The propagation time may be measured by TDR techniques. In this case – depending on the test equipment – the measured time may correspond to the round trip propagation, i.e. twice the propagation time.

8.2 Normalised screening attenuation

For homogenous screens – i.e. screens having no variations along the length – and screens having a transfer impedance increasing proportionally to frequency, the transfer impedance may be converted to a normalised screening attenuation (for details, see IEC 62153-4-0). The normalised conditions are an impedance of 150 Ω in the outer circuit and a velocity difference between the inner and outer circuit of 10 %.

$$a_{sn}(150\Omega;10\%) = 20 \cdot \lg\left(\frac{\omega\sqrt{Z_2 Z_s}}{Z_{TE} \cdot 11 \cdot v_2} \right) = 20 \times \lg\left(\frac{\omega\sqrt{Z_2 Z_s} \cdot \sqrt{\varepsilon_{r2}}}{Z_{TE} \cdot 11 \cdot c} \right) \tag{12}$$

where

a_{sn}(150 Ω;10 %)	is the normalised screening attenuation with normalised conditions of an impedance of 150 Ω in the outer circuit and a velocity difference between the inner and outer circuit of 10 %;
Z_s	is the normalised impedance of the outer circuit of 150 Ω;
Z_2	is the impedance of the inner circuit, i.e. of the impedance of the coaxial or quasi coaxial system of the cable under test;
v_2	is the propagation velocity of the signal in the inner circuit, i.e. of the coaxial or quasi coaxial system of the cable under test;
Z_{TE}	is the equivalent transfer impedance;
c_0	is the velocity of light.
ε_{r2}	is the resulting relative permittivity of the inner circuit, i.e. of the coaxial or quasi coaxial system of the cable under test.

8.3 Temperature correction

A temperature correction is not necessary.

8.4 Test report

For each frequency point, the highest value per unit length of the equivalent transfer impedance – obtained from at least four measurements either at near or far end – shall be recorded for the frequency range specified by the relevant cable specification.

9 Requirement

The results of the maximum equivalent transfer impedance shall comply with the value indicated in the relevant cable specification.

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

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)*

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