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TECHNICAL REPORT

colour inside

Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) screening measurements

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Metallic communication cable test methods –
Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) screening measurements

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METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) screening measurements

FOREWORD

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IEC/TR 62153-4-1, which is a technical report, has been prepared by IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This second edition cancels and replaces the first edition published in 2007. The significant change is a new clause on the background of the shielded screening attenuation test method.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
46/331/DTR	46/350/RVC

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

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

A list of all parts of the IEC 62153 series, 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 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- withdrawn,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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METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) screening measurements

1 Scope

Screening (or shielding) is one basic way of achieving electromagnetic compatibility (EMC). However, a confusingly large number of methods and concepts is available to test for the screening quality of cables and related components, and for defining their quality. This technical report gives a brief introduction to basic concepts and terms trying to reveal the common features of apparently different test methods. It should assist in correct interpretation of test data, and in the better understanding of screening (or shielding) and related specifications and standards.

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 60096-1:1986, *Radio-frequency cables – Part 1: General requirements and measuring methods*
Amendment 2 (1993)

IEC 60096-4-1, *Radio-frequency cables – Part 4: Specification for superscreened cables – Section 1: General requirements and test methods*

IEC 60169-1-3, *Radio frequency connectors – Part 1: General requirements and measuring methods – Section 3: Electrical tests and measuring procedures – Screening effectiveness*

IEC 61196-1:1995, *Radiofrequency cables – Part 1: Generic specification – General, definitions, requirements and test methods*

IEC 61726, *Cable assemblies, cables, connectors and passive microwave components – Screening attenuation measurement by the reverberation chamber method*

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 cable 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*

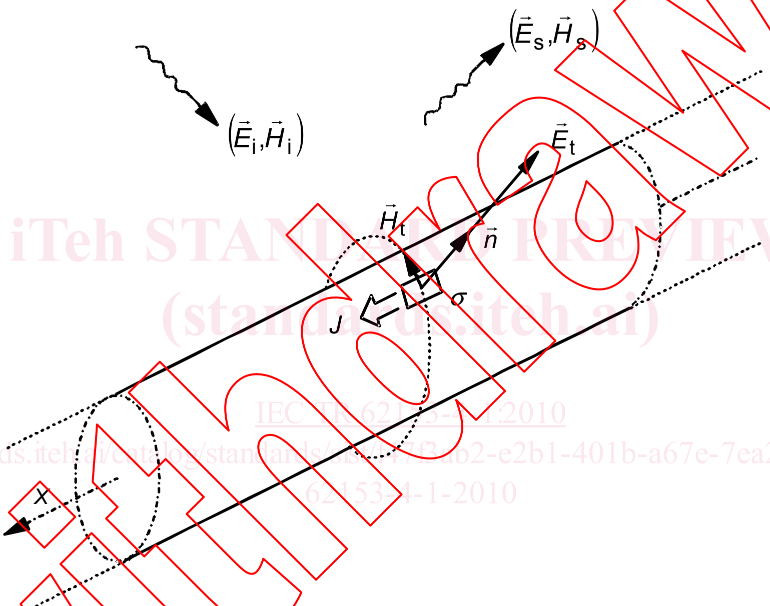
IEC 62153-4-5, *Metallic communication cable test methods – Part 4-5: Electromagnetic compatibility (EMC) – Coupling or screening attenuation – Absorbing clamp method*

EN 50289-1-6, *Communication cables – Specification for test methods – Electrical test methods – Electromagnetic performance*

3 Electromagnetic phenomena

It is assumed that if an electromagnetic field is incident on a screened cable, there is only weak coupling between the external field and that inside, and that the cable diameter is very small compared with both the cable length and the wavelength of the incident field. The superposition of the external incident field and the field scattered by the cable yields the total electromagnetic field $\left(\vec{E}_\mathrm{t},\vec{H}_\mathrm{t}\right)$ in Figure 1. The total field at the screen's surface may be considered as the source of the coupling: electric field penetrates through apertures by electric or capacitive coupling; also magnetic fields penetrate through apertures by inductive or magnetic coupling.

Additionally, the induced current in the screen results in conductive or resistive coupling.



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Key

$\left(\vec{E}_\mathrm{i},\vec{H}_\mathrm{i}\right)$	incident electromagnetic field	J	induced surface current density- (A/m)
$\left(\vec{E}_\mathrm{s},\vec{H}_\mathrm{s}\right)$	scattered electromagnetic field	σ	induced surface charge density- (C/m^2)
$\left(\vec{E}_\mathrm{t},\vec{H}_\mathrm{t}\right)$	total electromagnetic field	$\vec{n}$	unit vector normal to the surface
x	positive axial cable direction	ε_o, ε_r	permittivity, free space and relative

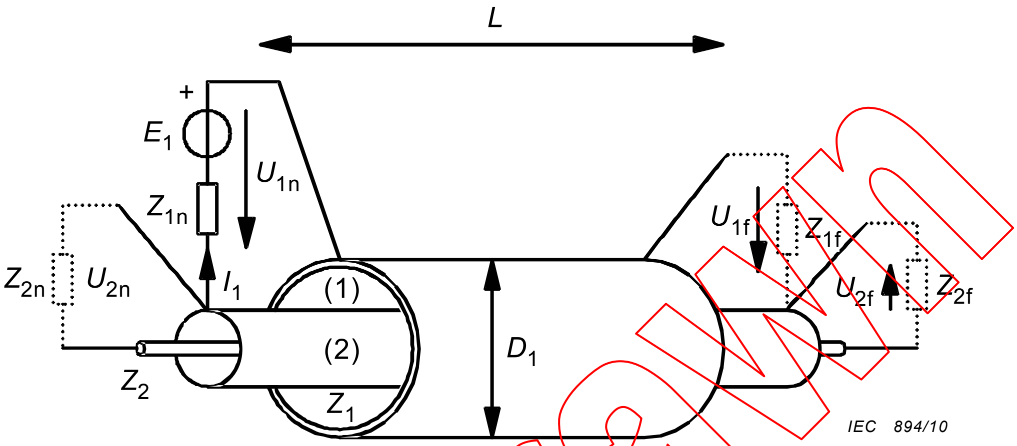
Figure 1 – Total electromagnetic field $\left(\vec{E}_\mathrm{t},\vec{H}_\mathrm{t}\right)$

$$\left(\vec{E}_\mathrm{t},\vec{H}_\mathrm{t}\right)=\left(\vec{E}_\mathrm{i},\vec{H}_\mathrm{i}\right)+\left(\vec{E}_\mathrm{s},\vec{H}_\mathrm{s}\right) \tag{1}$$

$$J=\vec{n}\cdot\vec{H}_\mathrm{t} \tag{2}$$

$$\sigma=\vec{n}\cdot\vec{E}_\mathrm{t}\varepsilon_\mathrm{o}\varepsilon_\mathrm{r} \tag{3}$$

As the field at the surface of the screen is directly related to density of surface current and surface charge, the coupling may be assigned either to the total field $\left(\vec{E}_t, \vec{H}_t\right)$ or to the surface current- and charge- densities (J and σ). Consequently, the coupling into the cable may be simulated by reproducing, through any suitable means, the surface currents and charges on the screen. Because the cable diameter is assumed to be small, the higher modes may be neglected and it is possible to use an additional coaxial conductor as the injection structure, as shown in Figure 2.



Key (for Figures 2,3,4,5)

(1), (2)	Indicates outer circuit(1), tube, respectively inner circuit(2), cable
$Z_{1,2}$	Characteristic impedance of the outer circuit(1), tube, respectively inner circuit(2), cable
$\varepsilon_{1,2}$	Dielectric permittivity of the outer circuit(1), tube, respectively inner circuit(2), cable
$\beta_{1,2}$	Phase constant of the outer circuit(1), tube, respectively inner circuit(2), cable
$\lambda_{1,2}$	Wave length of the outer circuit(1), tube, respectively inner circuit(2), cable
L	Coupling length
D_1	Diameter of injection cylinder-tube
V	Voltmeter
A	Ammeter
Z_{1n}, Z_{1f}	Load resistance at the near end, respectively far end of the outer circuit(1), tube
Z_{2n}, Z_{2f}	Load resistance at the near end, respectively far end of the inner circuit(2), cable
E_1	EMF of the generator
I_1, I_2	Current in the outer circuit(1), tube, respectively inner circuit(2), cable
U_{1n}, U_{1f}	Voltage at the near end, respectively far end of the outer circuit(1), tube
U_{2n}, U_{2f}	Voltage at the near end, respectively far end of the inner circuit(2), cable

Concept of a triaxial set-up

(1) outer circuit (1), formed by an injection cylinder-tube and the screen under test, with characteristic impedance Z_1,

(2) inner circuit (2), formed by the screen under test, and centre conductor, with characteristic impedance Z_2; screening at the ends of circuit (2) is not shown.

Observe the conditions Z_{1f}, Z_{2n}, Z_{2f} and λ in Figure 3 and Figure 4.

NOTE 1 $D_1 << L$.

NOTE 2 Both ends of circuit (2) must be well screened.

Figure 2 – Defining and measuring screening parameters – A triaxial set-up

4 The intrinsic screening parameters of short cables

4.1 General

The intrinsic parameters refer to an infinitesimal length of cable, like the inductance or capacitance per unit length of transmission lines. Assuming electrically short cables, with $L << \lambda$ which will always apply at low frequencies, the intrinsic screening parameters are defined and can be measured as indicated in the following subclauses.

4.2 Surface transfer impedance, Z_T

As shown in Figure 3, where Z_{1f} and Z_{2f} are zero, the surface transfer impedance (Z_T in Ω/m) is given:

$$Z_T = \frac{U_{2n}}{I_1 \cdot L} \tag{4}$$

The dependence of Z_T on frequency is not simple and is often shown by plotting log Z_T against log frequency. Note that the phase of Z_T may have any value, depending on braid construction and frequency range.

NOTE In circuit (2) of Figure 3, the voltmeter and short circuit can be interchanged.

4.3 Capacitive coupling admittance, Y_C

As shown in Figure 4, where Z_{1f} and Z_{2f} are open circuit, the capacitive coupling admittance (Y_C in mho/m) is given by:

$$Y_C = \mathrm{j} \cdot \omega C_T = \frac{I_2}{U_{1n} \cdot L} \tag{5}$$

where

C_T is the through capacitance;

ω is the radian frequency;

j is the imaginary operator.

The through capacitance C_T is a real capacitance and has usually a constant value up to 1 GHz and higher (with aperture $a << \lambda$).

While Z_T is independent of the characteristics of the coaxial circuits (1) and (2), C_T is dependent on those characteristics. There are two ways of overcoming this dependence:

a) The normalized through elastance K_T (with units of m/F) derived from C_T is independent of the size of the outer coaxial circuit (2), but it depends on its permittivity:

$$K_T = C_T / (C_1 \cdot C_2) \tag{6}$$

$$K_T \sim 1/(\varepsilon_{r1} + \varepsilon_{r2}) \tag{7}$$

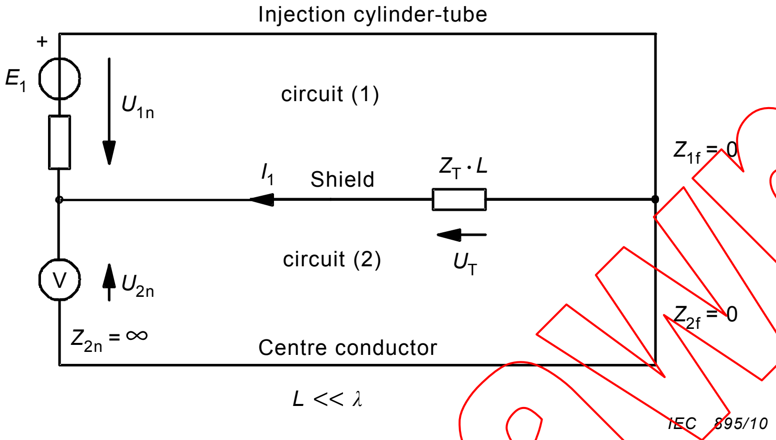
where C_1 and C_2 are the capacitance per unit length of the two coaxial circuits.

b) The capacitive coupling impedance Z_F (with units of Ω/m) again derived from C_T is also independent of the size of the outer coaxial circuit (2) and, for practical values of ε_{r1}, is only slightly dependent on its permittivity:

$$Z_F = Z_1 Z_2 Y_C = Z_1 Z_2 j\omega C_T \qquad (8)$$

$$Z_F \sim \sqrt{(\varepsilon_{r1} \cdot \varepsilon_{r2})}/(\varepsilon_{r1} + \varepsilon_{r2}) \qquad (9)$$

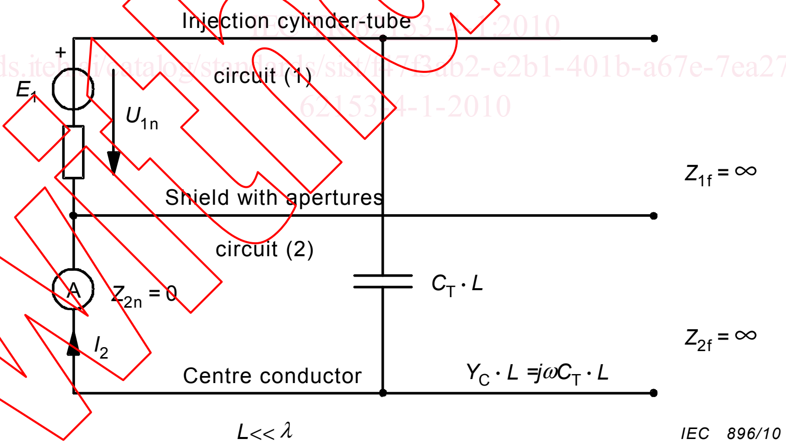
Compared with Z_T, Z_F is usually negligible, except for open weave braids. It may, however, be significant when Z_{2n} and $Z_{2f} >> Z_2$ (audio circuits).



Key

See Figure 2.

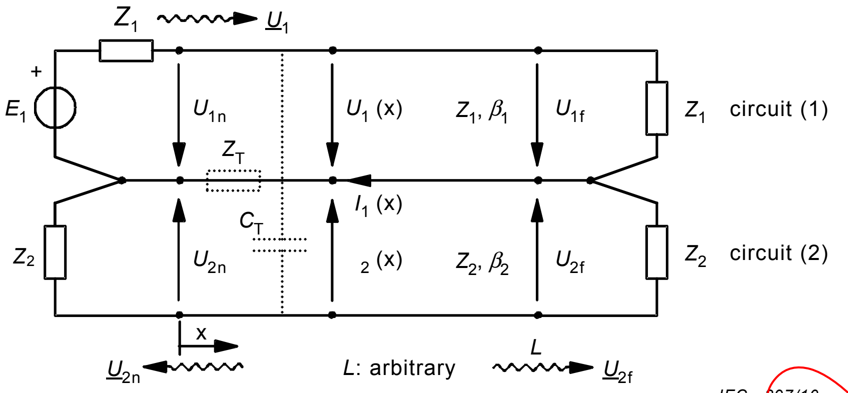
Figure 3 – Equivalent circuit for the testing of Z_T



Key

See Figure 2.

Figure 4 – Equivalent circuit for the testing of $Y_c = j\ \omega C_T$



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Key

See Figure 2.

NOTE Z_T and C_T are distributed (not correctly shown here). The loads Z_1 , Z_2 at the ends may represent matched receivers.

Figure 5 – Electrical quantities in a set-up that is matched at both ends

4.4 Injecting with arbitrary cross-sections

A coaxial outer circuit (2) has been assumed so far in this report, but it is not essential because of the invariance of Z_T and Z_F. Using a wire in place of the outer cylinder, the injection circuit (2) becomes two-wire with the return via the screen of the cable under test. Obviously the charge and current distribution become non-uniform, but the results are equivalent to coaxial injection, especially if two injection lines are used opposite to each other, and may be justified for worst-case testing. Note that the IEC line injection test uses a wire.

4.5 Reciprocity and symmetry

Assuming linear shield materials, the measured Z_T and Z_F values will not change when interchanging the injection circuit (1) and the measuring circuit (2). Each of the two conductors of the two-line circuit can be interchanged, but in practice the set-up will have to take into account possible ground loops and coupling to the environment.

4.6 Arbitrary load conditions

When the circuit ends of Figure 3 and Figure 4 are not ideally a short or open circuit, Z_T and Z_F will act simultaneously. Their superposition is noticeable in the low frequency coupling of the matched circuit (1) and circuit (2), (Figure 5 and Table 1).

5 Long cables – coupled transmission lines

The coupling over the whole length of the cable is obtained by summing up (integrating) the infinitesimal coupling contributions along the cable while observing the correct phase. The analysis utilizes the following assumptions and conventions:

- matched circuits considered with the voltage waves $\underline{U}_1$, $\underline{U}_{2n}$, $\underline{U}_{2f}$, see Figure 5,
- representation of the coupling, using the normalized wave amplitudes $U/\sqrt{Z}\left[\sqrt{Watt}\right]$, instead of voltage waves. i.e. the coupling transfer function, in the following denoted by "coupling function", will be defined as

$$T_n = \frac{\underline{U}_{2n}/\sqrt{Z_2}}{\underline{U}_1/\sqrt{Z_1}} \qquad (10)$$

$$T_{\mathrm{f}} = \frac{\underline{U}_{2\mathrm{f}} / \sqrt{Z_2}}{\underline{U}_1 / \sqrt{Z_1}} \tag{11}$$

NOTE 1 $|T|^2$ is the ratio of the power waves travelling in circuits (2) and (1). Due to reciprocity and assuming linear screen (shield) materials, T is reciprocal, i.e. invariant with respect to the interchange of injection and measuring circuits (1) and (2).

NOTE 2 The quantity $|1/T|^2$, or in logarithmic quantities

$$a_{\mathrm{s}} = -20 \times \log_{10} |T| \tag{12}$$

may be considered as the "screening attenuation" of the cable, specific to the set-up.

Performing the straight forward calculations of coupled transmission line theory, the coupling function T, given in Table 1, is obtained. The term $S\{L \cdot f\}$ is the "summing function" S, being dependent on L and f. (The wavy bracket just indicates that the product $L \cdot f$ is the argument of the function S and not a factor to S). S represents the phase effect, when summing up the infinitesimal couplings along the line, and is:

$$S_{\substack{\mathrm{n}\\ \mathrm{f}}}\{L \cdot f\} = \frac{\sin \frac{\beta L \pm}{2}}{\frac{\beta L \pm}{2}} \exp\left(-\mathrm{j} \cdot \frac{\beta L +}{2}\right) \tag{13}$$

with

$$\beta L \pm = (\beta_2 \pm \beta_1) \cdot L \tag{14}$$

$$= 2\pi L f \cdot (1/v_2 \pm 1/v_1) \tag{15}$$

$$= 2\pi L f \cdot \left(\sqrt{\varepsilon_{\mathrm{r}2}} \pm \sqrt{\varepsilon_{\mathrm{r}1}}\right)/c \tag{16}$$

subscript ± refers to near/far end respectively;
+ refers to both near/far ends.

Note that weak coupling, i.e. T << 1, has been assumed. This case, including losses, is given in [1]1).

Equation (17) and the representation in Table 1 illustrate the contributions of the different parameters to the coupling function T:

$$T_{\substack{\mathrm{n}\\ \mathrm{f}}} = (Z_{\mathrm{F}} \pm Z_{\mathrm{T}}) \cdot \frac{1}{\sqrt{Z_1 \cdot Z_2}} \cdot \frac{L}{2} \cdot S_{\substack{\mathrm{n}\\ \mathrm{f}}}\{L \cdot f, \varepsilon_{\mathrm{r}1}, \varepsilon_{\mathrm{r}2}\} \tag{17}$$

Note especially the following points.

a) There may be a directional effect ($T_{\mathrm{n}} \neq T_{\mathrm{f}}$) in the whole frequency range if Z_{F} is not negligible. (But Z_{F} is usually negligible except with loose, single braid shields.)

b) Up to a constant factor, T is the quantity directly measured in a set-up.

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1) Figures in square brackets refer to the bibliography.