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INTERNATIONAL STANDARD

Metallic communication cable test methods – Part 4-10: Electromagnetic compatibility (EMC) – Shielded screening attenuation test method for measuring the screening effectiveness of feed-throughs and electromagnetic gaskets double coaxial method

IEC 62153-4-10:2009(E)

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METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-10: Electromagnetic compatibility (EMC) – Shielded screening attenuation test method for measuring the screening effectiveness of feed-throughs and electromagnetic gaskets double coaxial method

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International Standard IEC 62153-4-10 has been prepared by IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

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

FDIS	Report on voting
46/319/FDIS	46/322/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.

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 maintenance result date *Metallic communication cable test methods* 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

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METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-10: Electromagnetic compatibility (EMC) – Shielded screening attenuation test method for measuring the screening effectiveness of feed-throughs and electromagnetic gaskets double coaxial method

1 Scope

This part of 62153-4-10 details a coaxial method suitable for determining the transfer impedance and/or screening attenuation of feed-throughs and electromagnetic gaskets.

The shielded screening attenuation test set-up according to IEC 62153-4-4 (triaxial method) has been modified to take into account the particularities of feed-throughs and gaskets.

A wide dynamic and frequency range can be applied to test even super screened feed-throughs and gaskets with normal instrumentation from low frequencies up to the limit of defined transversal waves in the coaxial circuits at approximately 4 GHz.

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/TR 62152:2004, *Background of terms and definitions of cascaded two-ports*

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 as up to and above 3 GHz*

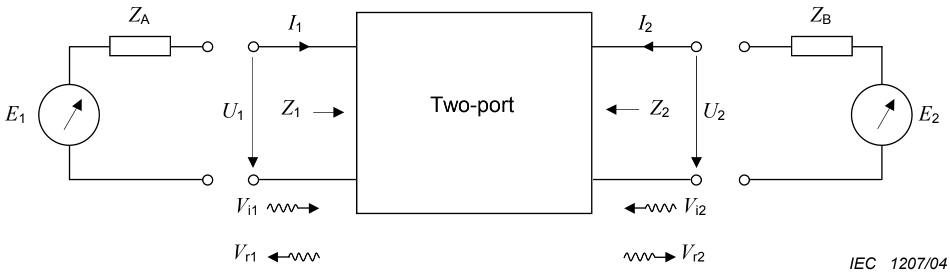
IEC 62153-4-7, *Metallic communication cable test methods – Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring the transfer impedance and the screening - or the coupling attenuation – Tube in tube method*

3 Terms and definitions

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

3.1
operational (Betriebs) transfer function in the forward direction H_{B21} or the operational (Betriebs) scattering parameter S_{21}
quotient of the reflected square root of power wave fed into the reference impedance of the output of the two-port and the unreflected square root of the power wave consumed at the input of the two-port

EXAMPLE



Key

E_1, E_2	network analyzer at input, output respectively	V_{i1}, V_{i2}	incident square root of complex power waves (see note) at input and output, respectively
Z_A, Z_B	reference impedance at input and output respectively	V_{r1}, V_{r2}	reflected square root of complex power waves (see note) at input and output, respectively
I_1, I_2	current at input and output, respectively	Z_1, Z_2	impedance at input and output, respectively
U_1, U_2	voltage at input and output, respectively		

Figure 1 – A two-port

NOTE Complex power is the product $U \cdot I$. Apparent power is the product $U \cdot I^*$, which is used in electrical power technique, where the angle between the voltage and current is of interest. I^* Is the complex conjugate of the current I.

S_{21} or H_{B21} is the operational (Betriebs) transfer function in the forward direction and they are defined as follows:

$$S_{21} = \left.\frac{V_{r2}}{V_{i1}}\right|_{V_{i2}=0} = \frac{2U_2}{E_1}\sqrt{\frac{Z_A}{Z_B}} = H_{B21}$$

See Annex C of IEC/TR 62152.

3.2
transfer impedance
equivalent circuit of the measurement of a feed-through or gasket, shunt impedance Z_T between the primary and secondary circuit

EXAMPLE

The transfer impedance of an electrically short screen is defined as the quotient of the open circuit voltage U_2 induced to the secondary circuit by the current I_1 fed into the primary circuit or vice versa. See Figure 2.

Z_T of an electrically short screen is expressed in Ω or decibels in relation to 1 Ω.

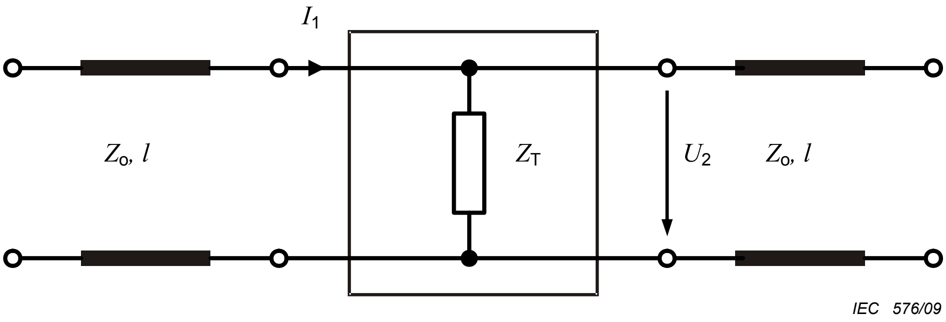


Figure 2 – Equivalent circuit of the test set-up and definition of Z_T

$$Z_T = \frac{U_2}{I_1} \qquad (1)$$

$$Z_T = +20 \times \log_{10}\left(\frac{|Z_T|}{1\Omega}\right) \qquad (2)$$

3.3
operational (Betriebs) attenuation

the quotient of the unreflected square root of power wave fed into the reference impedance of the input of the two-port and the square root of the power wave consumed by the load of the two-port expressed in dB and radians

NOTE See IEC/TR 62152.

3.4
screening attenuation

$\boldsymbol{a}_s$

logarithmic ratio of the incident (unreflected) square root of power wave fed into the nominal impedance of the primary circuit of the test set-up and the periodic maximum values of the square root of power wave $V_{r2,\,max}$ coupled into the secondary circuit of the test set-up when its characteristic impedance Z_o is normalized to 150 Ω

EXAMPLE

$$\begin{aligned} a_s &= -20 \times \log_{10}\left(\mathrm{Env}\left|\frac{V_{r2,\,max}}{V_{i1}}\right|\right) + 20 \times \log_{10}\left|\frac{\sqrt{150\ \Omega}}{\sqrt{Z_o}}\right| = \\ &= 20 \times \log_{10}\left|\frac{1}{\mathrm{Env}(S_{21,\,max})}\right| + 20 \times \log_{10}\left|\frac{\sqrt{150\ \Omega}}{\sqrt{Z_o}}\right| = \\ &= \mathrm{Min.\ Env}\ (A_{B21}) + 20 \times \log_{10}\left|\frac{\sqrt{150\ \Omega}}{\sqrt{Z_o}}\right| \end{aligned} \qquad (3)$$

where

a_s is the screening attenuation expressed in dB;

Env (A_{B21}) is the operational attenuation recorded as the envelope curve of the measured values in dB (See 7.1);

Min.Env (A_{B21}) is the operational attenuation recorded as the minimum envelope curve of the measured values in dB (See 7.1);

150 Ω is the standardized impedance of the secondary ("outer" or disturbed) circuit.

The screening attenuation, expressed in dB of an electrically short device is here:

$$a_s \approx 20 \times \log_{10} \left| \frac{50\,\Omega}{Z_T} \right| \tag{4}$$

where

a_s is the screening attenuation expressed in Ω;

150 Ω is the standardized impedance of the secondary ("outer" or disturbed) circuit.

NOTE Equation (4) may be deduced from Equations (3) and (5) as follows, assuming an electrically short device:

$a_s = 20 \times \log_{10} \left| \frac{\sqrt{Z_o \times 150\,\Omega}}{2 \times Z_T} \right|$. If we assume that $150\ \Omega \approx 3 \times Z_o$, then

$a_s = 20 \times \log_{10} \left| \frac{150\,\Omega}{2\sqrt{3} \times Z_T} \right|$ and approximate $2\sqrt{3} \approx 3$ then $a_s \approx 20 \times \log_{10} \left| \frac{50\,\Omega}{Z_T} \right|$ and Equation (4) is valid.

In the measurement, both primary and secondary circuits are low impedance. This leads to a 6 dB lower A_{B21} than in e.g. the tube in tube measurement of connectors; see IEC 62153-4-7.

3.5
device under test
DUT
connector's body or screen, intended to be mounted to a shielding or screening wall (or box), or an electromagnetic gasket

4 Principle of the test method

Figure 3 shows a typical feed-through construction where a coaxial connection is brought into a screened housing to a printed circuit board. Important are the coaxial connector body's and electromagnetic gasket's reliable connection to the screening or shielding box.

The electromagnetic tightness of a connector body's mounting or a gasket is measured as transfer impedance and/or screening attenuation.

The test set-up consists of two RF-tight coaxial systems separated by a metallic wall to which the DUT is mounted. The feed-through test set-up is shown in Figure 4. The gasket test set-up is shown in Figure 5. Here the gasket is pressed between two metallic plates.

The nominal impedances of both sides of the coaxial fixture should be the same as that of the test equipment. The generator side is called the primary circuit or inner circuit and the receiver side is called the secondary circuit or outer circuit.

The set-up is the same for measuring the transfer impedance and the screening attenuation.

Annex A gives a theoretical model of the test set-up. Useful information concerning the triaxial measurement technique is given in bibliography reference [3].

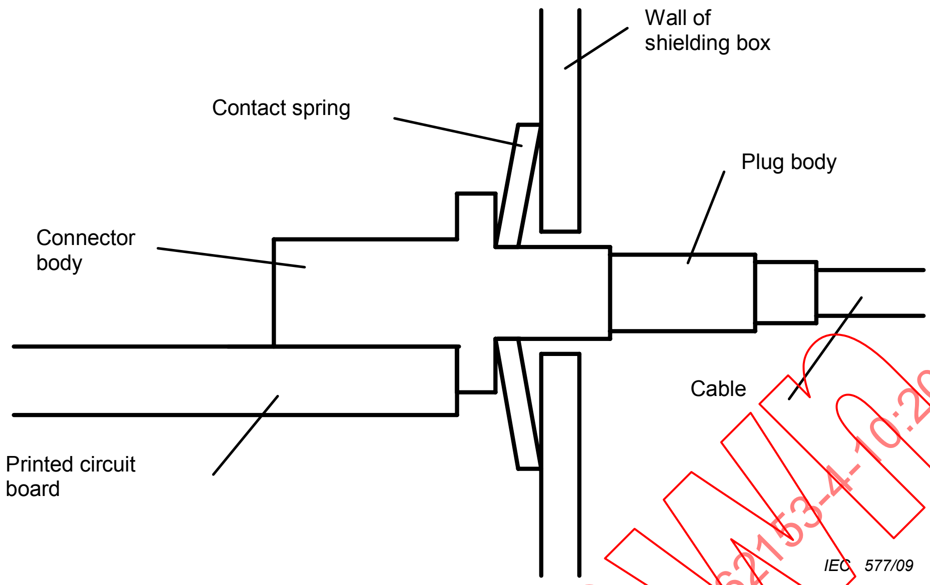
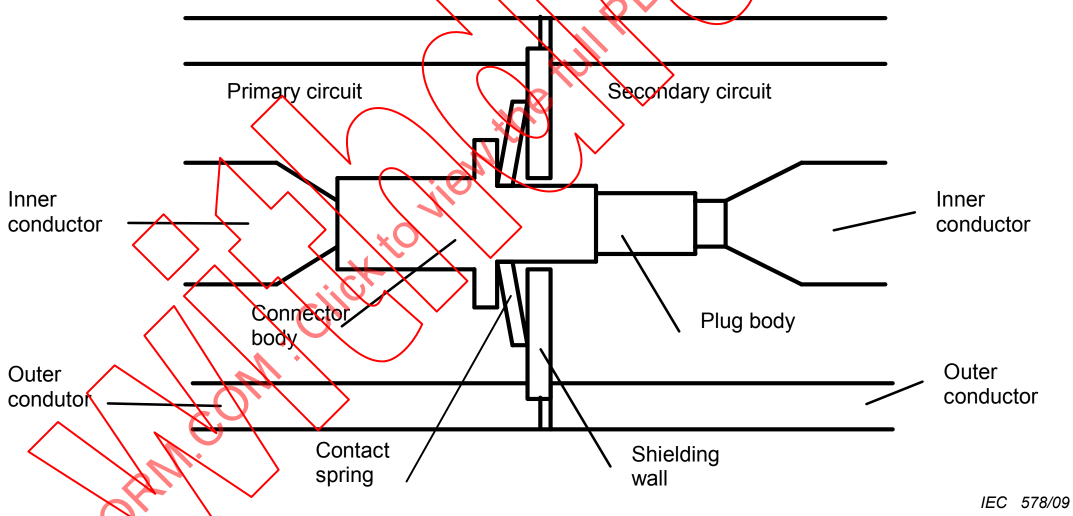
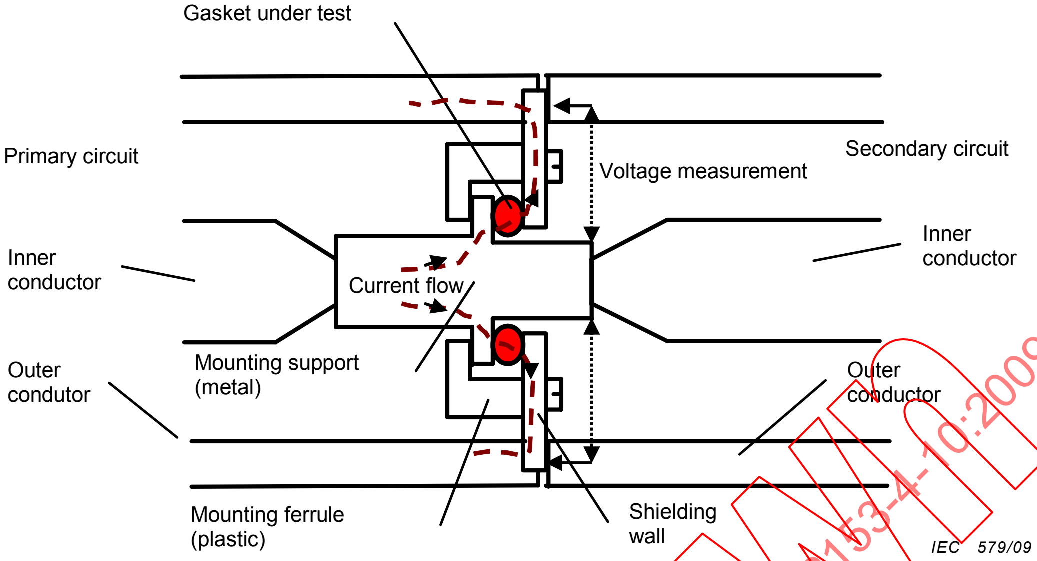


Figure 3 – Cross-section of a typical feed-through configuration



NOTE It is important that the coupled voltage is measured without any disturbing extra coupling voltage not coming from the feed-through under test (compare with Figure 5).

Figure 4 – Cross-section of the test fixture with a connector



NOTE In test rig design, care must be taken that the disturbing current in the primary circuit cannot cause unwanted transition voltages in the measuring secondary circuit. Separate voltage and current "contacts" are a must.

One should not end in a situation where transition or contact resistances of the test rig influence the test results. Special care must be taken to design the mounting of the test plate between the primary and secondary circuits or systems. In Figure 5 is shown how one can avoid to bring the transition resistance between the mounting plate and primary circuit into the disturbing voltage measurement circuit formed by the secondary circuit of the test system.

It is important that the coupled voltage is measured without any disturbing extra coupling voltage not coming from the gasket under test (compare with Figure 4).

Figure 5 – Cross-section of the test fixture with an electromagnetic gasket

5 Procedure

5.1 Equipment

The test fixture set-up is shown in Figures 3, 4 and 5 and consists of the following:

– a double coaxial test fixture where the sides are separated by metallic wall/walls for mounting of the DUT (Figure 4) (feed-through) or the gasket pressed between two plates, the first one belonging to the centre conductor and primary circuit and the second one to the outer conductor and secondary circuit, Figure 5;

– the RF-tight double coaxial, test fixture which should have preferably a diameter such that the characteristic impedance to the outer tube is 50 Ω respectively the nominal impedance of the network analyzer or generator and receiver;

– a signal generator with the same characteristic impedance as the test fixture with the mounted DUT or an impedance matching adapter, completed with a power amplifier if necessary for very high screening attenuation;

– a receiver with a calibrated step attenuator or a network analyzer (NWA).

NOTE The generator and the receiver may be included in a network analyzer.

5.2 Dynamic range

The dynamic range (noise floor) of the test setup shall be tested by replacing the DUT by a solid metallic plate.

5.3 Sample preparation

The feed-through connector or gasket shall be mounted into the fixture according to the manufacturer's instructions.

6 Measurement

6.1 General

The operational attenuation $A_{B21}(Z_T = \infty)$ of the test fixture with an open circuited DUT ($Z_T = \infty$) shall be measured and recorded vs. frequency.

The operational attenuation A'_{B21} with the feed-through connector mounted to the plate or the gasket inserted is measured and recorded vs. frequency.

The operational attenuation of the feed-through or gasket is then

$$A_{B21} = A'_{B21} - A_{B21}(Z_T = \infty)$$

6.2 Screening attenuation

See 3.4.

6.3 Transfer impedance

See 3.2.

7 Expression of results

7.1 Transfer impedance

$$Z_T = \frac{S_{21} Z_o}{2} = \frac{H_{B21} Z_o}{2}$$
$$|Z_T| = \frac{|Z_o|}{2} \times 10^{-\frac{A_{B21}}{20}} \qquad (5)$$

where

Z_o is the nominal characteristic impedance of the primary and secondary circuits, equal to the impedance of the generator and receiver.

NOTE Contrary to the measurement of the transfer impedance of cable screens, the transfer impedance of the connector is not related to length.

7.2 Screening attenuation

The screening attenuation a_s has to be normalized to the agreed standard conditions where the impedance of the "outer world" or secondary circuit is Z_S = 150 Ω:

$$a_s = \text{Min.Env}(A_{B21}) + 10 \times \log_{10}\left|\frac{Z_S = 150\,\Omega}{Z_o}\right| \quad (6)$$

where

a_s	is the screening attenuation related to a secondary or outer circuit ("radiating") impedance of 150 Ω in dB;
Min.Env(A_{B21})	is the operational attenuation recorded as the minimum envelope curve of the measured values in dB (See 7.1);
Z_o	is the characteristic impedance of the fixture in Ω.

NOTE At frequencies higher than the limit of the electrically short feed-through the measurement, results will be similar to screening attenuation measurement of a long transmission line.

7.3 Requirements

The results of the transfer impedance and/or the screening attenuation shall comply with the value indicated in a relevant specification.

Annex A
(informative)

Background for the measurement of the shielding effectiveness of feed-throughs and electromagnetic gaskets

A.1 General

A reference for the measurement of the shielding or screening effectiveness of feed-throughs and electromagnetic gaskets is given in [1][1]. The following is an excerpt of the main issues of this paper as well as additional information regarding the practical measurement, the details of DUT captivation and the obtained results.

The proper function of modern communication equipment is strongly influenced by the proper EMI shielding of electrical components. Feed-throughs can contribute significantly to the overall EMI level of communication equipment. A cross-section of the typical configuration of a feed-through is shown in Figure A.1. The connector body is soldered onto the circuit board and thus electrically connected to the ground potential of the electrical circuitry.

At higher frequencies, the potential of the circuit board's ground plane is usually not equal to that of the shielding box. A contact spring short-circuits this potential difference. If the contact spring were not present in the setup of Figure A.1, excessive radiation of electromagnetic waves along the cable's outer conductor would be the result.

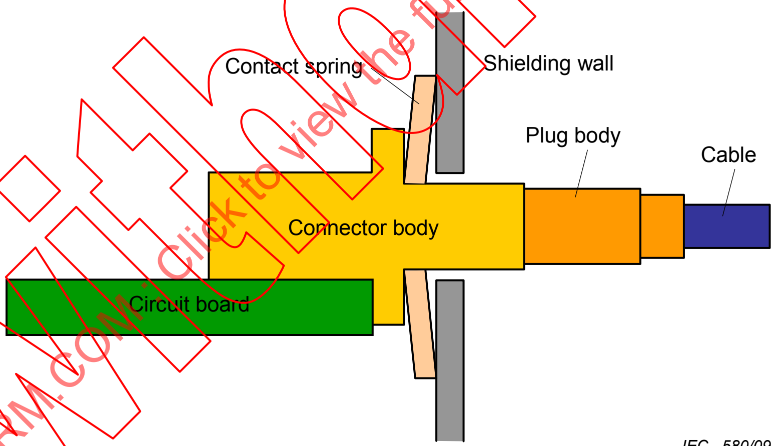


Figure A.1 – Cross-section of a typical feed-through configuration

It is usually a very time-consuming task to evaluate the shielding or screening effectiveness of a feed-through in a test configuration as is recommended in CISPR 25. The measurement setups that are described therein are generally based on some kind of free space measurement, which requires an anechoic chamber.

The introduction of well-defined electrically conducting boundaries in a test fixture would greatly simplify the measurement procedure.

This is possible by application of a coaxial test setup. A cross-section view of the test fixture is shown in Figure A.2. The section to the left of Figure A.2 represent the inner of a component. A signal is fed to the outer conductor of the connector under test by means of the coaxial line's inner conductor. The amount of RF-leakage that can be detected on the

[1] Figures in square brackets refer to the Bibliography.

opposite side of the shielding wall is picked up by the centre conductor of the coaxial line to the right. In the case of a two-port operational scattering (S_{21}) parameter or operational forward transfer function measurement, where the two ports of the network analyzer are connected to both coaxial line sections, S_{21} is a direct measure for the shielding efficiency of a feed-through or gasket tested in well defined circumstances that make repeatable and comparable tests possible.

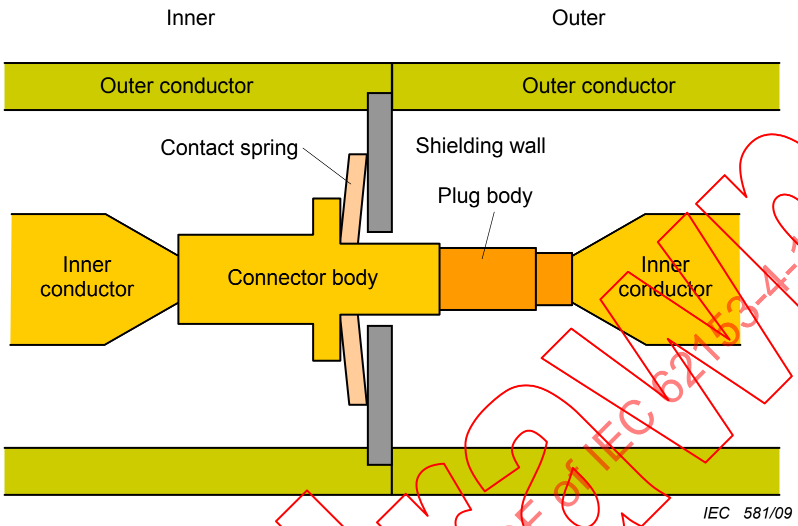


Figure A.2 – Cross-section of the test fixture with a connector

A.2 Theoretical model of the test procedure

Figure A.3 shows an equivalent circuit of the test fixture. The characteristic impedance and length on both sides of the feed-through under test are given by Z_o and l respectively. The normalized, with respect to Z_o, shunt admittance $y = 1/z$ and shunt impedance z represents a simple electrical model for the feed-through. This model is applicable, as long as the wavelength at the frequency of interest is long compared to the dimensions of the structures.

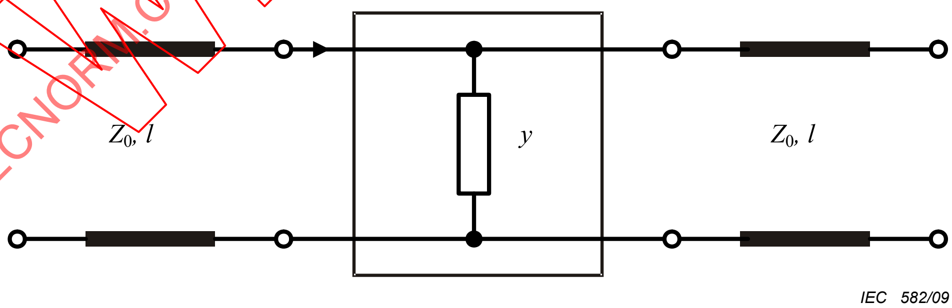


Figure A.3 – Equivalent circuit of the test setup with the shunt admittance *y* of the feed-through

Following Hoffmann [2] and/or Halme et al [1], the two-port network containing the normalized shunt admittance y or normalized shunt impedance z can be described by the operational S-parameter-matrix when placed between equal impedances which are the normalizing or reference impedances, being $Z_o = Z_L$.

$$\underline{S} = \begin{pmatrix} \dfrac{-y}{y+2} & \dfrac{2}{y+2} \\ \dfrac{2}{y+2} & \dfrac{-y}{y+2} \end{pmatrix} = \begin{pmatrix} \dfrac{-1}{1+2z} & \dfrac{2z}{1+2z} \\ \dfrac{2z}{1+2z} & \dfrac{-1}{1+2z} \end{pmatrix} \tag{A.1}$$

z and y are normalized to the reference impedance Z_o by

$$z = \frac{1}{y} = \frac{Z}{Z_o} = \frac{1}{Y \cdot Z_o} \tag{A.2}$$

For the case of an ideal open circuit and a short circuit as an equivalent circuit for the feed-through, the following S-matrices are calculated:

for $$z \to 0 : S = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$$

(A.3)

or $$z \to \infty : S = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Equation (A.1) indicates that the shunt impedance equal to Z_T of the feed-through may be estimated from the measured S-parameter S_{21} by:

$$Z_T = z \cdot Z_o = \frac{S_{21}}{2(1-S_{21})} \cdot Z_o \approx \frac{S_{21}}{2} \cdot Z_o \text{ for } |S_{21}| << 1 \tag{A.4}$$

A.3 Performing measurements

A.3.1 Characteristic impedance uniformity of the test fixture

The uniformity of the characteristic impedances within the test fixture is important. Line sections with deviations from the nominal characteristic impedance will cause impedance transformations, resulting in measurements that will generate erroneous calculations of the transfer impedance and the screening attenuation.

Cable measurements with the shielded screening effectiveness test method have shown that to obtain test results, which correspond to the theory, unintended reflection points in the test fixture must be avoided. The time domain reflectometer (TDR) measurement performed on a test fixture with a through connection shown in Figure A.4 verifies a suitable impedance smoothness of the coaxial line section within the primary and secondary circuit.

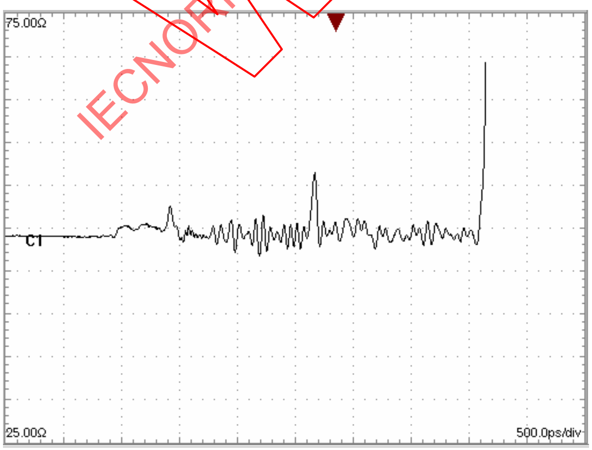


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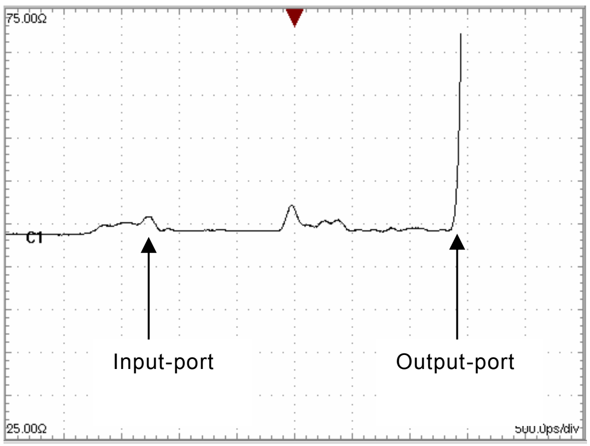
Figure A.4a – Without filter, rise time is 17 ps



IEC 585/09

Figure A.4b – With filter, rise time is 73 ps

NOTE The output-port is an open circuit. Test object “through-connection (ZT=∞)“. (0,5 ns/div or 8,5 cm/div; 5 Ω/div). The filter is lowpass (4,8 GHz).

Figure A.4 – TDR step response at input-port of test fixture

No substantial deviation from the system impedance (Z_o = 50 Ω) with potential to cause screening measurement errors can be observed.

A.3.2 Measuring EMI-gaskets by using a NWA

Screening measurements are performed with appropriate signal generators and receivers. These instruments are included in modern network analyzers (NWA) that also provide easy handling with useful internal functions and calibration procedures to ensure high measurement certainties and simple operation.

An appropriate procedure for the use of a NWA to measure the screening attenuation of a feed-through or an EMI-gasket according to the requirements in Clauses 5, 6 and 7 is given by the following step-by-step procedure.

a) Assure the capability of the test fixture, e.g. by TDR measurement of a through connection.
b) Calibrate the NWA in order to reach sufficient measurement certainty and noise floor.
c) Measure through connection ($Z_T = \infty$) with NWA and store S_{21} forward transmission log magnitude ($|S_{21}\ (Z_T = \infty)|$ [dB], equivalent to $-\ A_{B21}\ (Z_T = \infty)$).
d) Assure the needed dynamic range by replacing the through connection with a solid metallic shielding wall and recording the measured noise floor. Enabling averaging functions may help to reduce noise floor considerably.
e) Prepare a test captivation for the DUT according to applicable specification or manufacturer's instruction.
f) Replace the metallic shielding wall with the DUT mounted in the test captivation and measure S_{21} forward transmission log magnitude ($|S'_{21}|$ in [dB], equivalent to $-\ A'_{B21}$).
g) Calculate the operational screening transmission S_{21} [dB] = S'_{21} [dB] – $S_{21}\ (Z_T = \infty)$[dB] (easily done by applying NWA internal memory and calculation functions).
h) The operational attenuation of the feed-through or gasket is then $A_{B21} = -\ S_{21}$ [dB].
i) Calculate the transfer impedance or screening attenuation according to 7.1 or 7.2 respectively.

A.3.3 Pictures and measurement results

Figure A.5 shows pictures of the applied test fixture connected to a NWA. Figures A.6 and A.7 are detailed views of the test fixture and of the contact areas. Figure A.8 shows detailed pictures and depictions of the applied DUT-test captivation.

To investigate the noise level of the network analyzer, both ports were connected to shorting elements to imitate the test fixture mounted with a low transfer impedance gasket. Results are depicted in Figure A.9. The plot of Figure A.10 shows measurement results when a metal plate is mounted in the test fixture representing the dynamic range. The measured amplitude of S_{21} is comparable to the case where only the noise limit of the network analyzer was measured. This leads to the assumption that even a higher dynamic range can be achieved when a low noise amplifier, LNA, or a receiver with a lower noise floor is applied.

Figure A.11 shows a typical S_{21} measurement result of a conductive O-ring applied as an EMI-gasket. This measurement serves as a basis for the calculation of the transfer impedance Z_T (Figure A.12) or the screening attenuation a_s (Figure A.13) of the DUT according to 7.1 and 7.2, respectively.

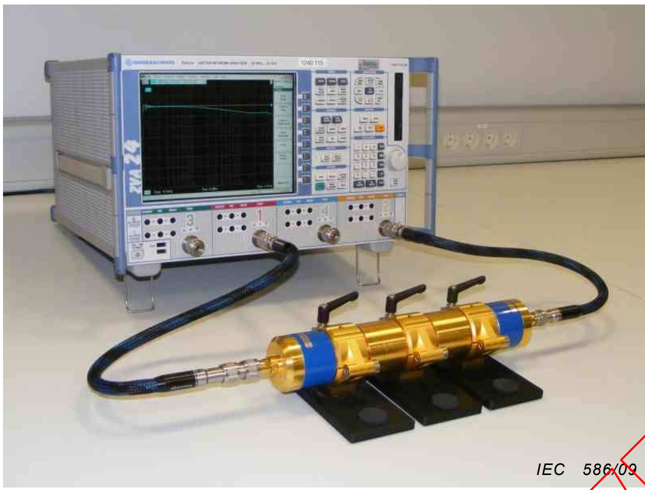


Figure A.5 – View of the test fixture connected to a network analyzer

Figure A.6a – Assembled test fixture

Figure A.6b – Open test fixture

Figure A.6 – Top view of the test fixture

Figure A.7a – De-mounted test captivation

Figure A.7b – Mounted test captivation

Figure A.7 – Detailed view of the contact area

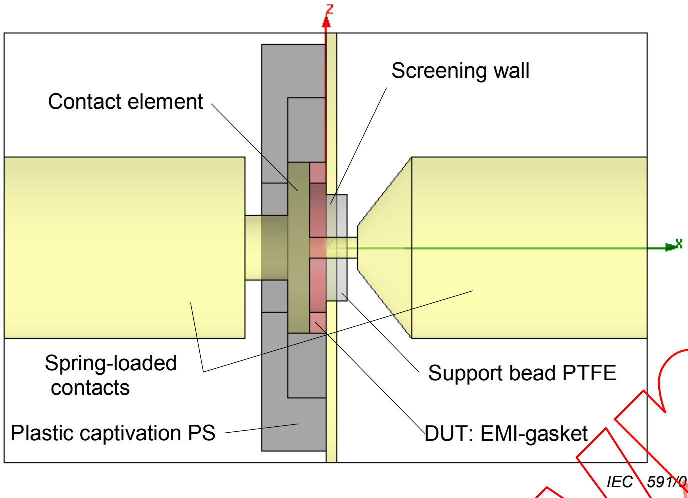


Figure A.8a – Schematic drawing of test captivation

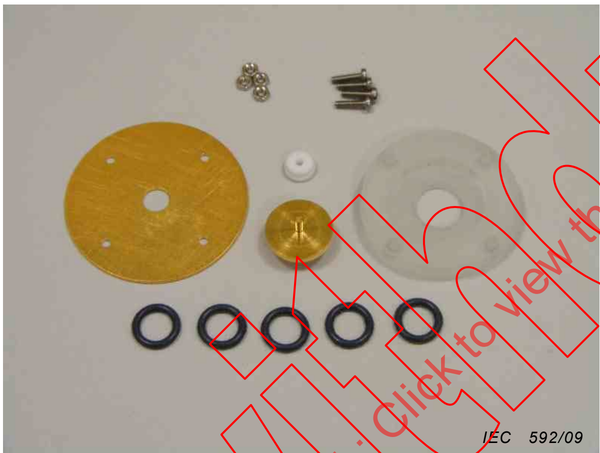


Figure A.8b – De-assembled test captivation

Figure A.8c – Pre-assembled test captivation

Figure A.8d – Front view (aiming at primary circuit)

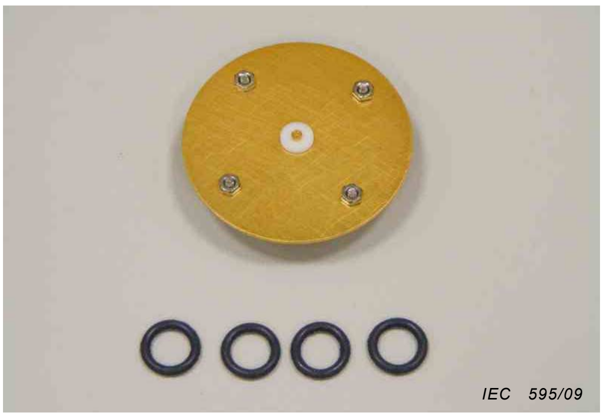


Figure A.8e – Rear view (aiming at secondary circuit)

Figure A.8 – Detailed view of the captivation for the conductive O-ring test