BS EN 55017:2011

BSI Standards Publication

Methods of measurement of the suppression characteristics of passive EMC filtering devices

National foreword

This British Standard is the UK implementation of EN 55017:2011. It is identical to CISPR 17:2011. It supersedes BS 6299:1982 which will be withdrawn on 15 July 2014.

The UK participation in its preparation was entrusted to Technical Committee GEL/210/12, EMC basic, generic and low frequency phenomena Standardization.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English version

Methods of measurement of the suppression characteristics of passive EMC filtering devices
(CISPR 17:2011)

Méthodes de mesure des caractéristiques d'antiparasitage des dispositifs de filtrage CEM passifs
(CISPR 17:2011)

Verfahren zur Messung der Entstöreigenschaften von passiven EMV-Filtern
(CISPR 17:2011)

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European Committee for Electrotechnical Standardization
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Foreword

The text of document CISPR/A/941/FDIS, future edition 2 of CISPR 17, prepared by CISPR SC A, "Radio-interference measurements and statistical methods", was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 55017 on 2011-07-15.

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The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2012-04-15
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2014-07-15

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard CISPR 17:2011 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

CISPR 12:2007	NOTE Harmonized as EN 55012:2007 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-161	-	International Electrotechnical Vocabulary (IEV) - Chapter 161: Electromagnetic compatibility	-	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

METHODS OF MEASUREMENT OF THE SUPPRESSION CHARACTERISTICS OF PASSIVE EMC FILTERING DEVICES

FOREWORD

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International Standard CISPR 17 has been prepared by CISPR subcommittee A: Radio interference measurements and statistical methods.

This second edition cancels and replaces the first edition published in 1981. It is a technical revision.

This edition includes the following significant technical change with respect to the previous edition: new measurement methods are added to characterize the more technologically sophisticated EMC filtering devices currently available.

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

FDIS	Report on voting
CISPR/A/941/FDIS	CISPR/A/951/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.

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.

IMPORTANT – The “colour inside” logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

INTRODUCTION

The suppression characteristics of EMC filters and components used for the suppression of EM disturbances, referred to in this standard as EMC filtering devices, are a function of numerous variables such as impedance of the circuits to which they connect, operating voltage and current, and ambient temperature. This standard specifies uniform test methods that will enable comparison of filtering and suppression characteristics determined by test laboratories or specified by manufacturers.

The first edition of CISPR 17 (1981) prescribed the measurement methods of insertion loss mainly for power-line filters. Today, however, many types of sophisticated EMC filters and suppression components can be found in various electronic devices. Those filters need to be characterized using standardized measurement methods. New methods for measurement of impedance and S-parameters for such EMI devices are included in this second edition.

In addition, the following insertion loss measurement methods from the first edition have been deleted because they are no longer in use in the industry:

- measurement method with a bias voltage for insertion loss measurement,
- in situ method, and
- worst-case methods.

METHODS OF MEASUREMENT OF THE SUPPRESSION CHARACTERISTICS OF PASSIVE EMC FILTERING DEVICES

1 Scope

This International standard specifies methods to measure the radio interference suppression characteristics of passive EMC filtering devices used in power and signal lines, and in other circuits.

The defined methods may also be applied to combinations of over-voltage protection devices and EMC filtering devices.

The measurement method covers the frequency range from 9 kHz to several GHz depending on the device and test circuit.

NOTE Measurement methods in this standard may be applied up to 40 GHz.

The standard describes procedures for laboratory tests (type tests) as well as factory tests. Test methods with and without bias conditions are defined.

Measurement procedures are provided for unbiased and bias conditions. Measurements under bias conditions are performed to determine potential non-linear behaviour of the EMC filtering devices such as saturation effects in inductors with magnetic cores. This testing serves to show the usability in a specific application (such as frequency converters that produce high amplitudes of common mode pulse current and thus may drive inductors into saturation). Measurement under bias conditions may be omitted if the non-linear behaviour can be determined by other methods (e.g. separate saturation measurement of the inductors used).

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 60050-161, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60050-161, apply.

3.1.1
bias current
d.c. or a.c. mains (power) frequency current flowing through the current conductor(s) of the EMC filtering device under test

3.1.2
bias voltage
d.c. or a.c. mains (power) frequency voltage applied between specified parts of the EMC filtering device under test

3.1.3
device under test
EMC filtering device subjected to measurement, calibration and test according to this standard

3.1.4
EMC filtering device
a generic term within this standard to describe any kind of suppression circuit, whether a single component or a complex circuit

3.1.5
filter
composition of single components such as inductors and capacitors that can suppress electromagnetic disturbance

3.1.6
impedance
Z
ratio of an a.c. electric current I to an a.c. voltage V (at frequency f), which may be represented by a complex number expressed as $Z = V/I$, indicating the total opposition to the passage of a.c. current; used as a parameter to represent the characteristics of two-terminal devices such as inductors, capacitors, and resistors, as well as those of four-terminal devices such as common-mode choke coils (CMCC)

NOTE Consists of ohmic resistance R and reactance X, usually represented in complex notation as $Z = R + jX$; alternatively represented in the polar coordinates as $|Z|$ exp($j\theta$) (absolute value $|Z|$ and phase angle θ); may imply the performance of an EMC filtering device; Z is expressed in Ω.

3.1.7
insertion loss
for a filter connected into a given transmission system, the ratio of voltages appearing across the line immediately beyond the point of insertion, before and after insertion of the EMC filtering device under test

NOTE Insertion loss is expressed in dB.

3.1.8
impedances of the test circuit
impedance across the terminals of the test circuit without the filter connected

NOTE For insertion loss measurement shown in Figure 4, impedances are designated Z_0, Z_{11}, Z_{12} and Z_2 referenced to 50 Ω; in special cases the impedances may be changed to other values that reflect the environmental conditions of certain applications.

3.1.9
receiver
selective or non-selective instrument, such as a broadband voltmeter, a tunable voltmeter, a spectrum analyzer or the receiving part of a network analyzer

NOTE See 5.2.2 for details.

3.1.10
reference impedance
impedance of a line or port at the point where the insertion loss or S-parameters are measured or evaluated, specified when results are reported

NOTE The reference impedance is usually 50 Ω.

3.1.11
reference potential
reference for voltage measurement to which the ground connections of the test equipment and the filter are connected, normally provided by a metallic plane of sufficient size

3.1.12
single component
basic component used for EMC purposes such as capacitors or inductors

3.1.13
***S*-parameter**
scattering parameter
S_{ij}
an element of the S-matrix expressing the transmission and reflection coefficients of a device

NOTE 1 As most commonly used, each S-parameter relates the complex electric field strength (or voltage) of a reflected or transmitted wave to that of an incident wave; the subscripts of a typical S-parameter S_{ij} refer to the output and input ports related by the S-parameter, which may vary with frequency and apply at a specified set of input and output reference planes; may imply the performance of an EMC filtering device.

EXAMPLE The S-parameters for a two-port circuit are defined as follows:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

where

S_{11} and S_{22}	are the reflection coefficients at port 1 or 2 of a circuit component, respectively, where the opposite port is terminated with a port reference impedance (for example 50 Ω); and
S_{21} and S_{12}	are the transmission coefficients representing the ratio of the signal transmitted to port 2 to that incident from port 1, and vice versa, respectively. The value of S_{21} is a good indicator of the noise suppression for a signal passing through this component.

NOTE 2 It is important to evaluate the degradation of a signal waveform caused by variation in the S-parameters with the frequency.

3.1.14
test circuits

3.1.14.1
asymmetrical (common mode) test circuit
test circuit in which all input lines of a filter under test are connected to a signal generator with all output lines being connected to a receiver

NOTE The test circuit used to measure the asymmetrical (common mode) insertion loss of a filter is shown in Figure 5.

3.1.14.2
symmetrical (differential mode) test circuit
test circuit in which the signal is fed across a pair of input lines of a filter under test, and the corresponding pair of output lines is connected to a receiver; the other lines are not terminated

NOTE An example of the test circuit used to measure the symmetrical (differential mode) insertion loss of a filter is shown in Figure 6; all combinations of each two lines of the filter are measured; ground or PE (protective earth) terminals are not considered.

3.1.14.3
unsymmetrical test circuit
test circuit in which the signal is fed to an input line of a filter under test, and the corresponding output line is connected to a receiver; the other input and output lines are terminated in specified impedances

NOTE An example of the test circuit used to measure the unsymmetrical insertion loss of a filter is shown in Figure 7; each line of the filter is measured with all unused lines terminated to reference potential with Z_{11} or Z_{12}.

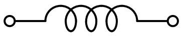
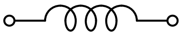
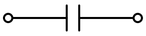
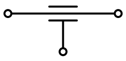
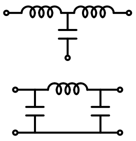
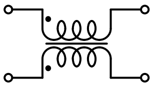
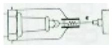
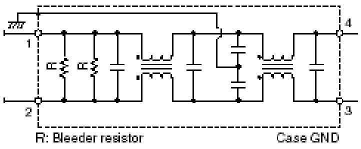
3.2 Abbreviations

CMCC	Common-mode choke coils
DUT	Device under test
EM	Electromagnetic
EMC	Electromagnetic compatibility
e.m.f.	Electromotive force
GND	Ground
HPF	High-pass filter
L	Line
N	Neutral
PE	Protective earth
RF	Radio frequency
SMD	Surface mount device
TRL	Thru/Reflect/Line
VNA	Vector network analyzer
VSWR	Voltage-standing wave ratio

4 Classification of EMC filtering devices

Examples of EMC filtering devices and their applicable measurement methods are shown in Table 1.

Table 1 – Examples of EMC filtering devices

Filter type	Examples	Symbol or circuit diagram	Parameters to be measured and measurement method		
	Outer view		Insertion loss	Impedance	*S*-parameter
Ferrite cores and absorbing clamps			Clause 5	Clause 6	Clause 7
Chokes, inductors and beads	 		Clause 5	Clause 6	Clause 7
Non-feedthrough capacitors	 		Clause 5	Clause 6	Clause 7
Feedthrough capacitors	 		Clause 5	–	Clause 7
Three-terminal capacitors	 		Clause 5	–	Clause 7
Common mode choke coils	 		Clause 7	Clause 6	Clause 7
Resistors			Annex E of CISPR 12:2007	–	–
Filter (multiple lines[a] with GND)			Clause 5	–	–

[a] one line without neutral, multiple lines with or without neutral.

4.1 Insertion loss

4.1.1 Insertion loss calculation

The standard test method uses a calibrated 50-Ω signal source and a 50-Ω receiver. The insertion loss is determined by the following formula:

$$a_e = 20\log\frac{V_o}{2V_2} \qquad (1)$$

where

a_e is the insertion loss (dB),

V_o is the open circuit output voltage of a 50-Ω signal generator, and

V_2 is the voltage at the output of the filter circuit.

Theory and background information on insertion loss measurement are presented in Annex E.

4.1.2 Asymmetrical (common) mode

Because all input and output lines are connected in parallel, only one set of values for the asymmetrical insertion loss is measured (see 5.2.3).

4.1.3 Symmetrical (differential) mode

Each pair of input lines shall be measured against the corresponding output lines; one set of insertion loss values or curves is measured for each of the line pairs. Ground or PE (protective earth) terminals are not considered (see 5.2.4).

For example, for a three-line filter with neutral line (line terminals L1, L2, L3, neutral terminal N and PE) the following measurements shall be performed: L1 to L2, L1 to L3, L2 to L3, L1 to N, L2 to N, L3 to N (six measurements in total).

Symmetrical mode measurements cannot be applied to single-line filters or components.

4.1.4 Unsymmetrical mode

Each input line shall be measured against the corresponding output line with all unused lines being terminated by specified impedance (normally 50 Ω) to reference potential (see 5.2.5).

For example, for a three-line filter with neutral line (line terminals L1, L2, L3, neutral terminal N and PE) the following measurements shall be performed: L1 with L2, L3 and N terminated, L2 with L1, L3 and N terminated, L3 with L1, L2 and N terminated and N with L1, L2 and L3 terminated.

Unsymmetrical mode measurements cannot be applied to one-line filters or components.

4.2 Impedance

An EMC filtering device of certain impedance is often inserted into a circuit to reduce the unwanted current. The suppression characteristics may be determined by the impedance characteristics of both the inserted device and the original circuit.

The impedance of the device, and therefore the suppression characteristics, vary with frequency, bias condition, etc. Consequently, the impedance should be measured at various frequencies. This frequency dependence is used to design an EMC filtering device. The impedance measurements may be applied in the frequency range from 9 kHz to 3 GHz.

4.3 S-parameters

4.3.1 General

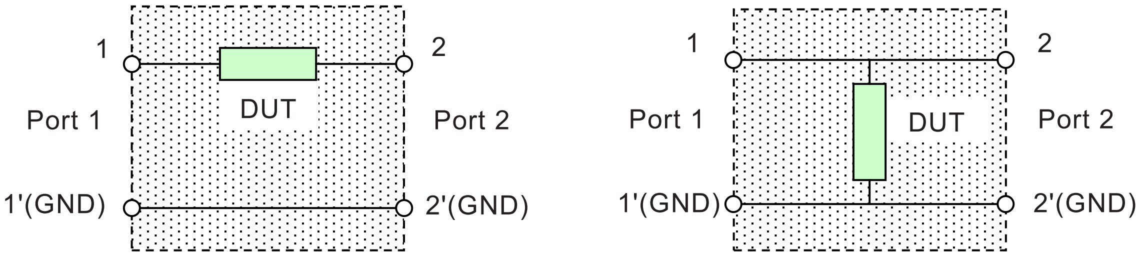
The EMC characteristics of a device are determined by the S-parameters of both the inserted device and the original circuit.

The S-parameters of the device, and therefore the suppression characteristics, vary with frequency, bias condition, etc. Consequently, S-parameters should be measured at various frequencies. This frequency dependence is used to design an EMC filtering device. The S-parameter measurements may be applied in the frequency range from around 100 MHz to 6 GHz.

4.3.2 Two-port S-parameters

The characteristics of two-terminal components (inductors, capacitors, etc.) can be evaluated in terms of the two-port S-parameters using a test fixture as shown in Figure 1. Three-terminal filters (feedthrough capacitors, other three-terminal filters) are also evaluated using a test fixture as shown in Figure 2.

Two configurations for connecting the two-terminal devices and fixture are possible: one using a series connection and one using a shunt connection. One of these configurations should be chosen according to the application of the device. The series connection is normally selected for inductors, and the shunt connection is chosen for capacitors. However, when capacitors are used as high-pass filters (HPF), the series connection should be selected.



a) Series connection, for high impedance DUT compared to 50 Ω

b) Shunt connection, for low impedance DUT compared to 50 Ω

Figure 1 – Measurement arrangement for S-parameters of a two-terminal device

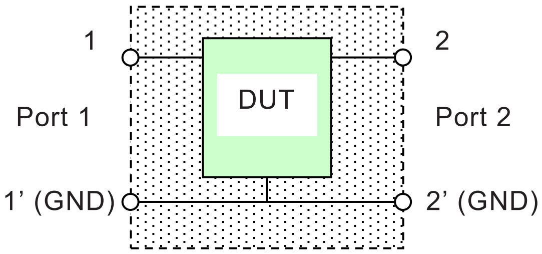


Figure 2 – Measurement arrangement for S-parameters of a three-terminal device

The characteristic impedance of the S-parameter test fixture should be matched to the port impedance of a network analyzer (50 Ω).

When the test fixture is matched to 50 Ω, the insertion loss (a_e) in dB can be given by

$$a_\mathrm{e} = -20\log|S_{ij}| \tag{2}$$

The return loss (a_r) in dB is defined as

$$a_\mathrm{r} = -20\log|S_{ii}| \tag{3}$$

4.3.3 Four-port S-parameters

The characteristics of a four-port device (illustrated in Figure 3), such as common-mode choke coils (CMCC) may be evaluated using the four port S-parameters (see Annex G).

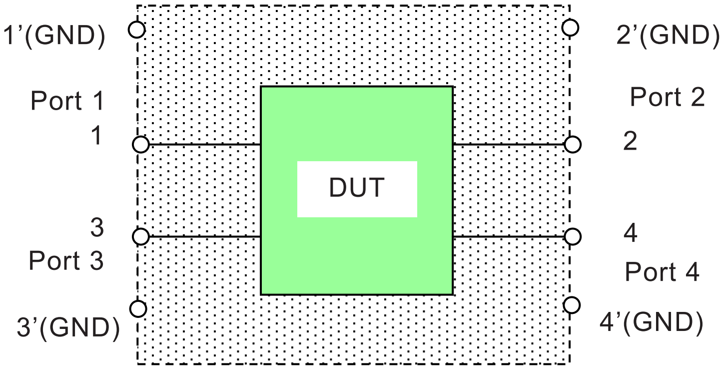


Figure 3 – Measurement arrangement for four-port S-parameters

Measurements using a vector network analyzer (VNA) yield S-parameters S_{ij} for the four ports. However, the common/differential-mode S-parameters derived from the measured S-parameters are more useful for characterizing the device (hereafter referred to as the mixed-mode S-parameters) [5][1]. These are defined by the following formula:

$$S' = \begin{bmatrix} S_\mathrm{cc} & S_\mathrm{cd} \\ S_\mathrm{dc} & S_\mathrm{dd} \end{bmatrix} = \left[\begin{array}{cc|cc} S_\mathrm{cc11} & S_\mathrm{cc12} & S_\mathrm{cd11} & S_\mathrm{cd12} \\ S_\mathrm{cc21} & S_\mathrm{cc22} & S_\mathrm{cd21} & S_\mathrm{cd22} \\ \hline S_\mathrm{dc11} & S_\mathrm{dc12} & S_\mathrm{dd11} & S_\mathrm{dd12} \\ S_\mathrm{dc21} & S_\mathrm{dc22} & S_\mathrm{dd21} & S_\mathrm{dd22} \end{array}\right]$$

$$= \frac{1}{2}\left[\begin{array}{cc|cc} S_{11}+S_{31}+S_{13}+S_{33} & S_{12}+S_{32}+S_{14}+S_{34} & S_{11}+S_{31}-S_{13}-S_{33} & S_{12}+S_{32}-S_{14}-S_{34} \\ S_{21}+S_{41}+S_{23}+S_{43} & S_{22}+S_{42}+S_{24}+S_{44} & S_{21}+S_{41}-S_{23}-S_{43} & S_{22}+S_{42}-S_{24}-S_{44} \\ \hline S_{11}-S_{31}+S_{13}-S_{33} & S_{12}-S_{32}+S_{14}-S_{34} & S_{11}-S_{31}-S_{13}+S_{33} & S_{12}-S_{32}-S_{14}+S_{34} \\ S_{21}-S_{41}+S_{23}-S_{43} & S_{22}-S_{42}+S_{24}-S_{44} & S_{21}-S_{41}-S_{23}+S_{43} & S_{22}-S_{42}-S_{24}+S_{44} \end{array}\right] \tag{4}$$

The sub-matrices in the above formula express conversion characteristics between the modes, where

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

S_{cc} is the matrix for conversion from common mode to common mode,

S_{cd} is the matrix for conversion from differential mode to common mode,

S_{dc} is the matrix for conversion from common mode to differential mode, and

S_{dd} is the matrix for conversion from differential mode to differential mode.

Each sub-matrix has four elements. For example, for sub-matrix S_{cc}:

S_{cc11} is the reflection coefficient at the input,

S_{cc12} is the transmission coefficient from the output to input,

S_{cc21} is the transmission coefficient from the input to output, and

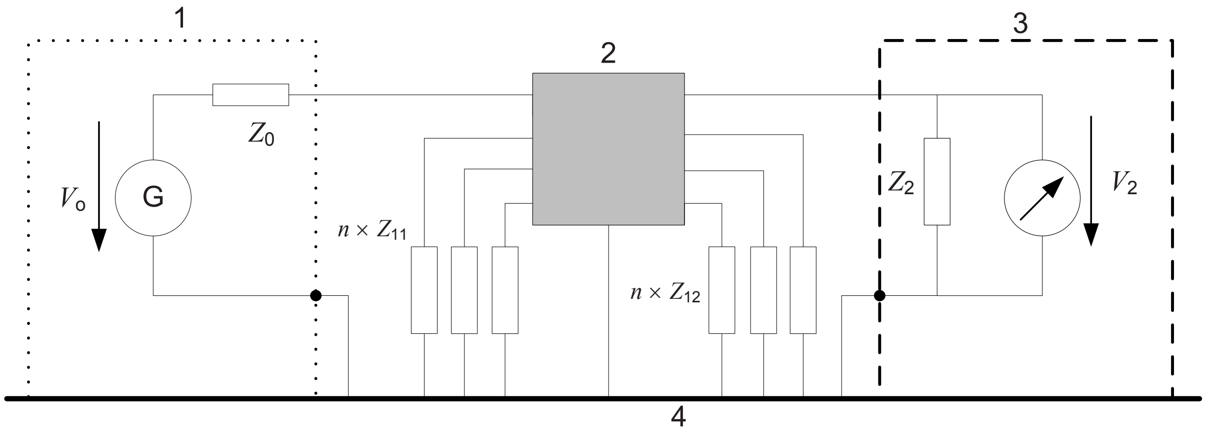
S_{cc22} is the reflection coefficient at the output.

The reference impedances of the common mode and differential mode are half of and double the actual port reference impedance, respectively. For example, when the original S-parameters are measured with a 50-Ω instrument, then the common- and differential-mode port reference impedances become 25 Ω and 100 Ω, respectively.

5 Insertion loss measurement

5.1 General

This clause describes the methods for performing insertion loss measurement of a DUT. In addition, the two-port S-parameters measurement described in 4.3.2 may be used. An example measurement set-up is shown in Figure 4.



Key

1	signal generator
2	EMC filtering (device under test)
3	measuring receiver
4	reference potential (metallic ground plane)
V_o	open circuit generator voltage
V_2	output voltage
Z_0	generator impedance
Z_{11}	termination impedance (of adjacent lines) at filter input
Z_{12}	termination impedance (of adjacent lines) at filter output
Z_2	receiver impedance

Figure 4 – Test circuit for insertion loss measurement (example: 4-line-filter)

5.2 Measurement set-up

5.2.1 General

The insertion loss of an EMC filtering device shall be tested without and with bias current.

5.2.2 Test equipment

NOTE Substantial simplification of the measurement procedure can be achieved by using a suitable sweep generator and receiver tuned synchronously or a network analyzer. The insertion loss characteristic may then be observed on a display, or automatically recorded.

5.2.2.1 Signal generator

A sinusoidal signal generator is recommended. Generators of other signals (for example noise or impulse), which have a uniform output spectrum in the frequency range of interest, may also be used, but in such cases the receiver shall have good selectivity and spurious rejection. The impedance of the signal generator shall be 50 Ω.

5.2.2.2 Receiver

A selective receiver (having at least one resonant circuit before the first amplifying stage) is recommended. The use of a non-selective receiver is acceptable if harmonic and other undesirable frequencies in the output of the generator are small enough but are taken into account in the measurement uncertainty. The impedance of the receiver shall be 50 Ω.

5.2.2.3 Bias current source

The source providing biasing current shall be floating and have both terminals (E and F in Figure 9) isolated from earth with the possibility of earthing any of them when it is appropriate.

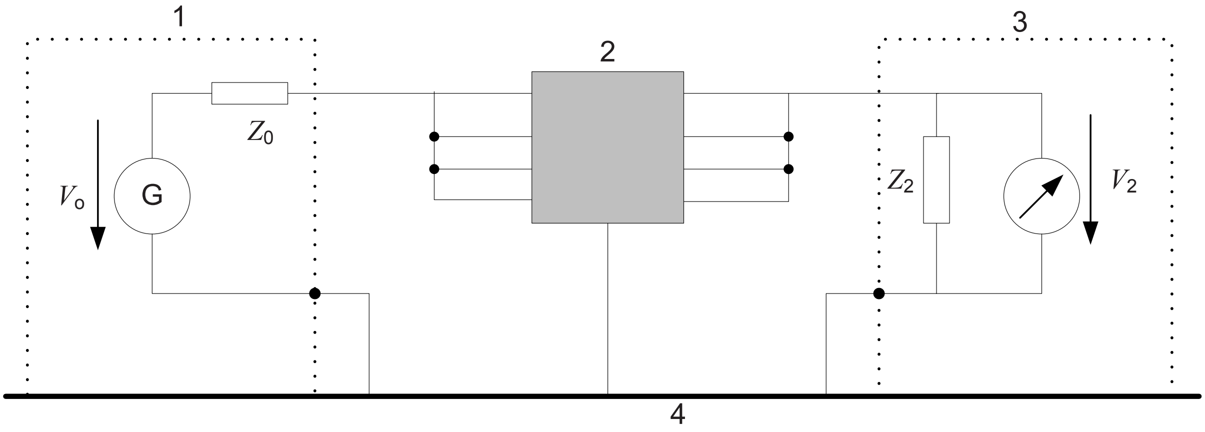
Care should be taken that RF disturbances produced by the bias current source (e.g. if a switch-mode power supply is chosen as a bias source) do not influence the measurement results.

5.2.2.4 Test box

The filter shall be mounted in a shielded metal box and the filter ground shall be properly connected to the metal box bottom in order to ensure a low inductive grounding. The size of the box shall be chosen so as to ensure an appropriate distance between the filter under test and the metal walls and cover of the box but to allow short connecting wires from the coaxial sockets to the filter terminals. For general-purpose filters, an average distance of 5 cm is recommended. A typical test box designed for the test of a general-purpose filter and a feedthrough filter is shown in Annex B.

5.2.3 Asymmetrical (common mode) test circuit

The filter shall be connected between the signal generator and the receiver with all input and output lines connected each other in parallel as shown in Figure 5.



Key

1	signal generator
2	EMC filtering (device under test)
3	measuring receiver
4	reference potential (metallic ground plane)
V_o	open circuit generator voltage
V_2	output voltage
Z_0	generator impedance
Z_2	receiver impedance

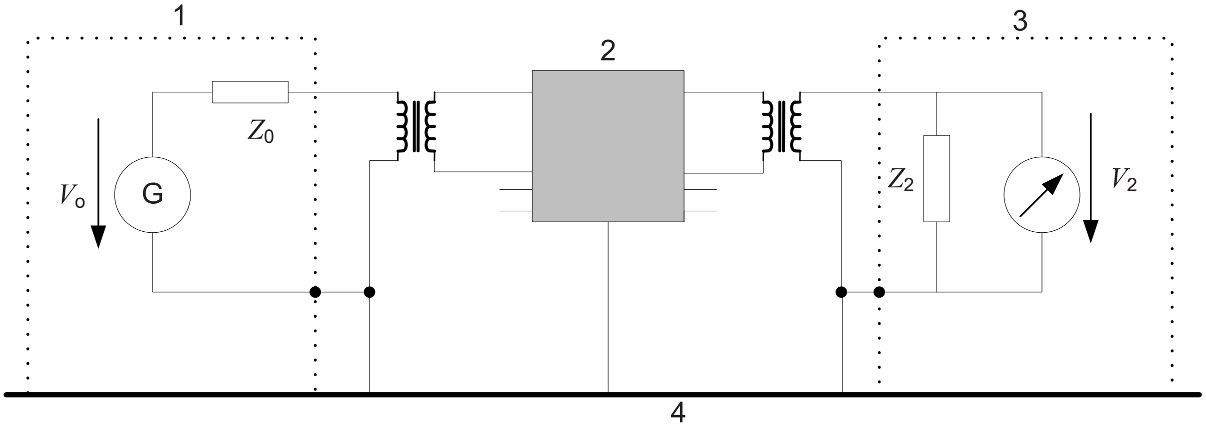
Figure 5 – Test circuit for asymmetrical insertion loss measurement (example: 4-line-filter)

5.2.4 Symmetrical (differential mode) test circuit

Each two input lines and the corresponding output lines shall be measured through isolating transformers as shown in Figure 6. All unused lines shall not be terminated.

The turns ratio of the transformer should be specified to be 1:1. If other turns ratios are selected, they shall be described in the test report.

NOTE The undesired influence of transformer characteristics may be avoided by the use of a four-port VNA instead of a transformer.



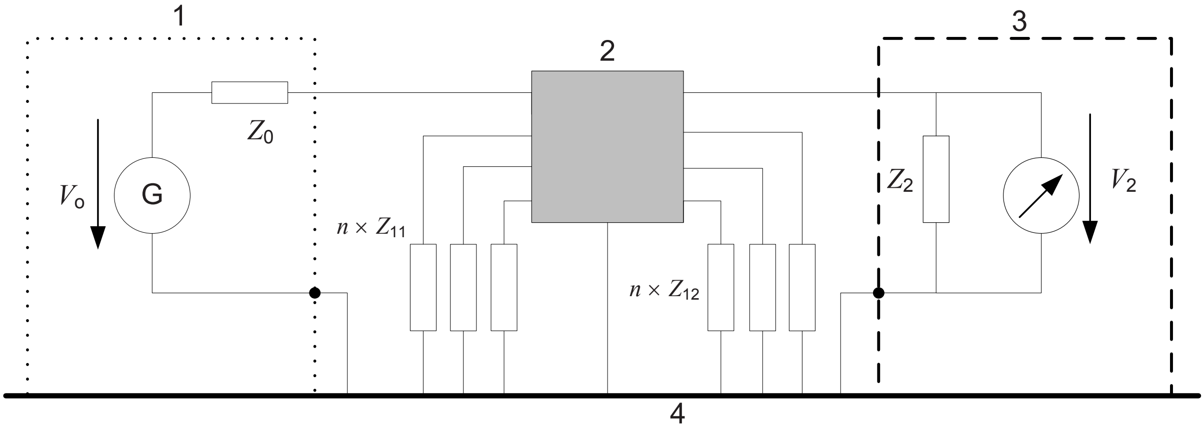
Key

1	signal generator
2	EMC filtering (device under test)
3	measuring receiver
4	reference potential (metallic ground plane)
V_o	open circuit generator voltage
V_2	output voltage
Z_0	generator impedance
Z_2	receiver impedance

Figure 6 – Test circuit for symmetrical insertion loss measurement (example: 4-line-filter)

5.2.5 Unsymmetrical test circuit

Each input line and the corresponding output line of the filter shall be measured with all unused lines terminated to the reference potential with a specified impedance (normally 50 Ω, see 3.1.8), as shown in Figure 7.



Key

1	signal generator
2	EMC filtering (device under test)
3	measuring receiver
4	reference potential (metallic ground plane)
V_o	open circuit generator voltage
V_2	output voltage
Z_0	generator impedance
Z_{11}	termination impedance (of adjacent lines) at filter input
Z_{12}	termination impedance (of adjacent lines) at filter output
Z_2	receiver impedance

Figure 7 – Test circuit for unsymmetrical insertion loss measurement (example: 4-line filter)

5.3 Measurement methods (procedure)

5.3.1 General

Two methods are in use:

a) filter without bias;

b) filter under full d.c. or a.c. bias current.

Those two methods shall be used for investigation of filters as follows:

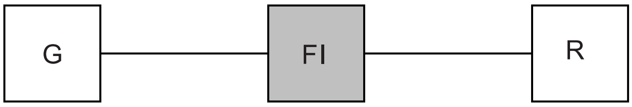
- without bias, and applicable frequency range 10 kHz to 10 GHz, or
- under bias current up to 100 A, and applicable frequency range 10 kHz to 100 MHz.

The only test method specified in this standard shall be the 50-Ω/50-Ω test method. This means that all impedances of the test circuit Z_0, Z_{11}, Z_{12} and Z_2 shall be 50 Ω (see 3.1.10).

Test methods using different and possibly non-symmetrical impedances may be used if necessary. One example is described in Annex C. Normally, test methods using impedance values other than 50 Ω are application-dependent and shall be described in the respective equipment standard.

5.3.2 Measurement without bias

The characteristics obtained from measurement without bias may differ from those observed in practice, because the terminating impedances during the measurement differ from those existing during use in a real apparatus or system. See Figure 8.



Key

G	signal generator
FI	EMC filtering (device under test)
R	measuring receiver

Figure 8 – Test circuit for insertion loss measurement without bias

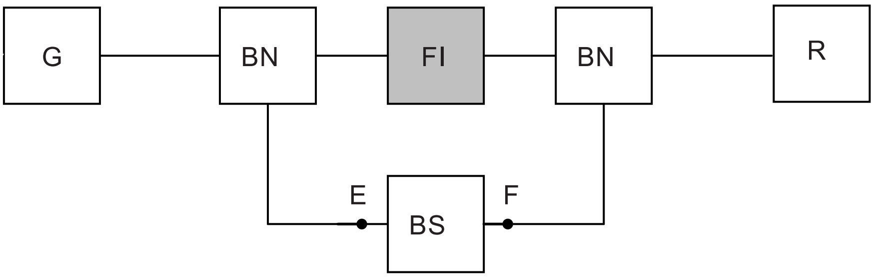
5.3.3 Measurement with bias

The test method is the same as described in 5.3.2 with buffer networks for the bias current sources added. See Figure 9.

The bias current applied to the filter under test shall be the rated current of the filter. For filters that are regularly used in applications with high pulse currents (e.g. frequency converters) it may be necessary to select the bias current accordingly.

The source for the bias current is connected to the measurement circuit via two buffer networks that shall give sufficient decoupling between the current source and the measurement circuit in the frequency range to be measured. The requirements for the buffer network in Annex D shall be observed.

The bias source shall be isolated against the measurement circuit.



Key

G	signal generator
FI	EMC filtering device under test
R	measuring receiver
BN	buffer network
BS	bias source (current source) – isolated form reference potential

Figure 9 – Test circuit for insertion loss measurement with bias

5.4 Calibration and verification

5.4.1 General

All test equipment (signal generator, receiver, cables, attenuators etc.) shall be calibrated and traceable to a national standards organization.

The complete test set-up shall be evaluated to prove that it meets all requirements. This includes also the shielded box used to contain the filter and the buffer networks for bias tests and manual switches or relay boxes used for automated measurement.

Because filters do not have an impedance of 50 Ω, some verification steps are needed to also show the correct function of the test set-up for the mismatched test object.

5.4.2 Validation of test set-up without bias

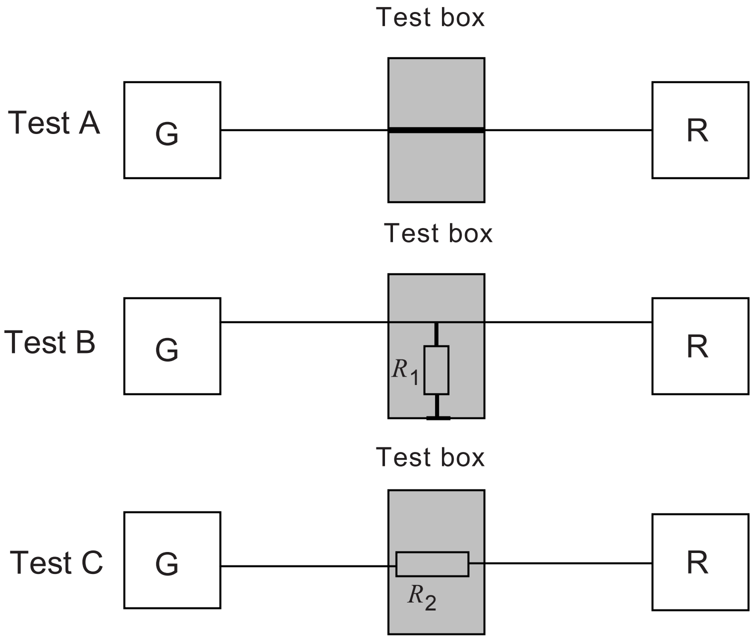
The test set-up shall be verified by a series of measurements with defined ohmic test circuits as shown in Figure 10.

Test A shows the correct value of the RF signal generator output voltage that is half the open circuit voltage when terminated with 50 Ω (by the impedance of the test receiver).

Test B shows the capability of the RF signal generator to provide sufficient output current into low impedance test objects (such as filters with high capacitive values).

Test C shows that the dynamic range of the test receiver is sufficient.

For each of Test A to C, measurements shall be made within the tolerance specified in Table 2.



Key

G signal generator

R measuring receiver

Figure 10 – Test circuit for verification of measurement circuit without bias

Table 2 – Conditions and target values for validation of test set-up without bias

Test	R	V_2	V_2/V_o
A	THRU	0,5 × V_o	-6 dB ± 0,5 dB
B	R_1 = 0,1 Ω	0,002 × V_o	-54 dB ± 1 dB
C	R_2 = 100 kΩ	0,000 5 × V_o	-66 dB ± 1 dB
Tolerance for R_1 and R_2: ± 1 %.			

The test set-ups shall be used in the frequency range where the validation results meet Table 2, where V_o is the e.m.f. (V) of the signal generator, G, and V_2 is the voltage (V) across the terminals of the measuring receiver. The values of R_1 and R_2 may be different depending on the frequency and device under test (DUT).

5.4.3 Validation of test set-up with bias

The test set-up shall be verified by a series of measurements with defined ohmic test circuits as shown in Figure 11.

Test A shows the correct value of the RF signal generator output voltage that is half the open circuit voltage when terminated with 50 Ω (by the impedance of the test receiver).

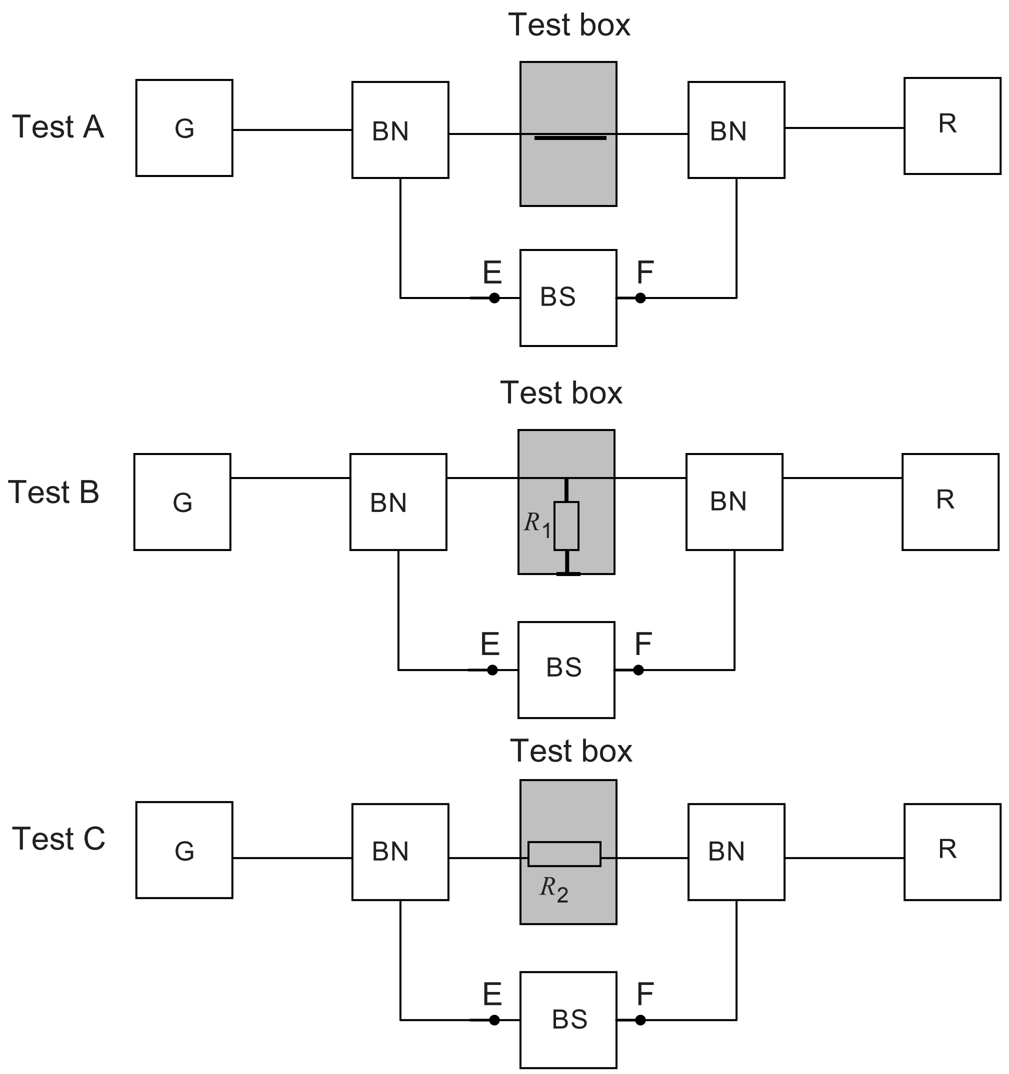
Test B shows the capability of the RF signal generator to provide sufficient output current into low impedance test objects (like filters with high capacitive values).

Test C shows that the dynamic range of the test receiver is sufficient.

Each of Test A to C shall be performed for these conditions:

- terminals E and F are not connected (open circuit),
- terminals E and F are connected by a short circuit.

For each of Test A to C, the measurements shall be made within the tolerance specified in Table 3.



Key

G	signal generator
FI	EMC filtering device under test
R	measuring receiver
BN	buffer network
BS	bias source (current source) – isolated form reference potential

Figure 11 – Test circuit for verification of measurement circuit with bias

Table 3 – Conditions and target values for validation of test set-up with bias

Test		***R***	V_2	V_2/V_o
A	open	THRU	0,5 × V_o	-6 dB ± 0,5 dB
	short		0,5 × V_o	-6 dB ± 0,5 dB
B	open	R_1 = 0,1 Ω	0,002 × V_o	-54 dB ± 1 dB
	short		0,002 × V_o	-54 dB ± 1 dB
C	open	R_2 = 100 kΩ	0,000 5 × V_o	-66 dB ± 1 dB
	short		0,000 5 × V_o	-66 dB ± 1 dB
Tolerance for R_1 and R_2: ± 1 %.				

The test set-ups shall be used in the frequency range where the validation results meet Table 3 where V_0 is the e.m.f. (V) of the signal generator, G, and V_2 is the voltage (V) across the terminals of the measuring receiver. The values of $R_1$and R_2 may be different depending on the frequency and DUT.

5.5 Uncertainty

The following factors shall be considered in assessing the uncertainties associated with the insertion loss measurements:

- uncertainty contribution due to the measuring equipment (refer to manufacturer’s specification);
- uncertainty contribution due to the test fixture including the buffer networks (refer to manufacturer’s specification, if available);
- uncertainty contribution due to variation in measurement conditions (evaluated through repeated measurements).

Details are provided in Annex A.

6 Impedance measurement

6.1 General

Impedance measurement of a DUT is carried out by one of two methods: the direct method, in which impedance is measured directly using an impedance-measuring equipment, or the indirect method, in which impedance is calculated from the S-parameters measured by a VNA. Modern VNAs typically include a function for calculating the impedances.

NOTE The indirect method is commonly used for measurements at frequencies above 1 GHz.

6.2 Direct method

6.2.1 Measurement set-up and procedure

The impedance of a DUT is measured using impedance-measuring equipment and a test fixture.

Impedance shall be measured by inserting the DUT into the test fixture and by sweeping the measurement frequency with the impedance-measuring equipment. The relationship between the impedance and the frequency shall be recorded within the required frequency range.

An appropriate combination of the measuring equipment and test fixture shall be selected according to the DUT configuration and the test frequency. Examples of impedance measurement are shown in Annex F (for a leaded device, SMD, four-terminal CMCC, etc.).

When applying a bias voltage or current to the DUT, it shall be applied via a buffer circuit to avoid affecting the measurement circuit. If the impedance-measuring equipment does not have a built-in buffer circuit, then a buffer circuit may be used in the test set-up. In the latter case, calibration shall be performed with the buffer circuit inserted.

The impedance-measuring equipment and the test fixture shall be set up in an environment free from significant temperature variations and external electromagnetic fields. The test system shall be calibrated including the test fixture. Environmental conditions and analyzer settings used in measurement shall be recorded, such as temperature, frequency range, input RF power, bias current or voltage, etc. The following shall be considered:

- the test system shall have a sufficient signal-to-noise ratio (≥ 30 dB);
- unless otherwise specified, the test shall be made under the rated conditions of the DUT;

- when applying bias voltage or current, care shall be taken not to overbias the DUT (especially in the case of ferrite devices);
- an appropriate calibration method shall be selected for the test fixture used (open/short calibration, open/short/load calibration, etc.).

6.2.2 Calibrations of the test set-up

The measurement system shall be traceable to a national standards organization.

The following factors may affect measurement results on a DUT, so that the measurement system shall be calibrated to reduce the measurement uncertainty from effects of unknown impedance associated with the measuring instruments, test fixtures and cables.

An example of the calibration procedure is the OSL calibration, which uses a calibration kit consisting of OPEN, SHORT and LOAD standard terminations. In some cases, if a higher measurement accuracy is not required, it may not be necessary to use all three terminations in the calibration kit. Details of the procedures may be found in the instruction manuals for the measuring instruments.

If available, standard DUTs can be used to improve measurement accuracy.

6.2.3 Measurement uncertainty

The following factors shall be considered in assessing the uncertainties associated with measurements using impedance-measuring equipment:

- uncertainty components related to the impedance-measuring equipment (refer to manufacturer’s specifications);
- uncertainty components related to the test fixture (refer to manufacturer’s specification, if available);
- uncertainty components related to variation in measurement conditions (evaluated through repeated measurements).

Details are provided in Annex A.

6.3 Indirect method

6.3.1 Measurement set-up and procedure

6.3.1.1 General

The impedance of a DUT may be evaluated from its S-parameters. In this case, the S-parameters are measured using a network analyzer. See 7.1 for a description of the S-parameter measurement set-up.

The impedance of a DUT can be calculated from either of the one-port, two-port, or four-port S-parameters. Note that the measured values for the S-parameters should be those of the DUT only, and free of any effects of the test fixture.

6.3.1.2 Evaluation from the one-port S-parameter

The following formula is used to calculate impedance Z_x from S_{11}, where Z_0 is the port reference impedance. See Figure 12.

$$Z_x = Z_0 \frac{1+S_{11}}{1-S_{11}} \tag{5}$$

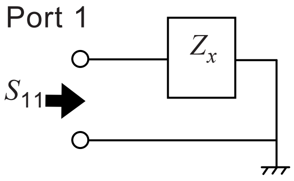
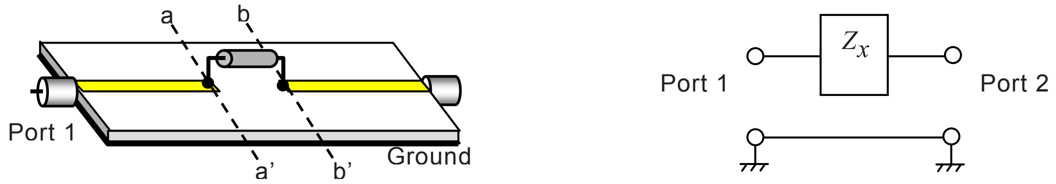


Figure 12 – One-port measurement of a two-terminal device

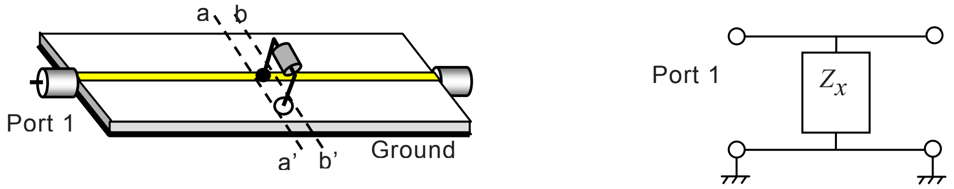
6.3.1.3 Evaluation from the two-port S-parameters

The impedance of a DUT can be evaluated from S-parameter measurements with a VNA using an appropriate test fixture as illustrated in Figures 13 and 14.



a) Example of a measurement set-up b) Equivalent circuit

Figure 13 – S-parameter measurements for evaluating the impedance of a device in a series connection



a) Example of a measurement set-up b) Equivalent circuit

Figure 14 – S-parameter measurements for evaluating the impedance of a device in a shunt connection

The S-parameters shall be evaluated between two reference planes (a-a’) and (b-b’) either with the TRL calibration or with correcting S-parameters measured between ports 1 and 2 for the electrical lengths of the lines.

Assuming symmetrical properties of the DUT, the mean reflection and transmission coefficients are given by:

$$R = \frac{S_{11} + S_{22}}{2} \quad \text{and} \quad T = \frac{S_{12} + S_{21}}{2} \tag{6}$$

If the condition $\left|2T\right| >> \left|(1-T)^2 - R^2\right|$ is satisfied, then the impedance of the device, Z_x is calculated from Equations (7) and (8):

For series connection,

$$Z_X = Z_0 \frac{(1+R)^2 - T^2}{2T} \quad , \tag{7}$$

and for shunt connection,

$$Z_X = Z_0 \frac{2T}{(1-R)^2 - T^2} \quad , \tag{8}$$

where Z_0 is the characteristic impedance of the test fixture.

If the above condition is not fulfilled, the test fixture may affect the measurements, and Equations (7) and (8) may yield erroneous results.

Impedances given by the two-port S-parameters described in this subclause may be different to some extent at high frequencies from those described in 6.3.1.2, because the one-port S-parameter may depend on the structure of the test fixture used.

6.3.1.4 Evaluation from the four-port S-parameters

The common-mode and differential-mode impedances, Z_c and Z_d, of a DUT can be evaluated in terms of the mixed-mode S-parameters S_cc and S_dd using the following equations, if the DUT has good symmetry. The definitions of the mixed-mode S-parameters are given in 4.3.3. Impedances Z_c and Z_d are derived from Equations (9) and (10) with actual S-parameter measurements. Note that Z_c0 and Z_d0 are the reference impedances of common- and differential-mode, respectively.

$$\begin{aligned} Z_\mathrm{c} &= Z_\mathrm{c0} \frac{(1+R_\mathrm{c})^2 - {T_\mathrm{c}}^2}{2T_\mathrm{c}} \\ R_\mathrm{c} &= \frac{S_\mathrm{cc11} + S_\mathrm{cc22}}{2} \\ T_\mathrm{c} &= \frac{S_\mathrm{cc12} + S_\mathrm{cc21}}{2} \end{aligned} \tag{9}$$

$$\begin{aligned} Z_\mathrm{d} &= Z_\mathrm{d0} \frac{(1+R_\mathrm{d})^2 - {T_\mathrm{d}}^2}{2T} \\ R_\mathrm{d} &= \frac{S_\mathrm{dd11} + S_\mathrm{dd22}}{2} \\ T_\mathrm{d} &= \frac{S_\mathrm{dd12} + S_\mathrm{dd21}}{2} \end{aligned} \tag{10}$$

6.3.2 Calibration of the test set-up

See 7.2.

6.3.3 Measurement uncertainty

The uncertainty of the impedance obtained from S-parameters is calculated from the uncertainties associated with the S-parameter measurements. See 7.3.

7 *S*-parameter measurement

7.1 Measurement set-up and procedure

7.1.1 General

A network analyzer (50 Ω system) is used for measuring the *S*-parameters of a DUT. A VNA is an instrument with a function for determining *S*-parameters directly from measurement of the amplitude and phase differences of the incident, reflected, and transmitted waves. Figure 15 illustrates the set-up for a two-port measurement.

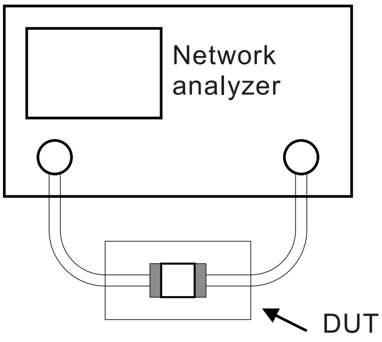


Figure 15 – Two-port *S*-parameter measurement set-up

S-parameters shall be measured by inserting the DUT into the test fixture and by sweeping the measurement frequency with the network analyzer. The relationship between the *S*-parameters and the frequency should be recorded within the required frequency range.

A bias voltage or current at the DUT shall be applied via a buffer circuit to avoid affecting the measurement circuit. If the network analyzer does not have a built-in buffer circuit, then a commercially available bias-tee may be used in the test set-up. In the latter case, calibration shall be performed with the buffer circuit inserted.

When only the insertion loss $|S_{21}|$ is required, measurements may be made using a combination of a tracking generator and a measuring receiver instead of the network analyzer described above.

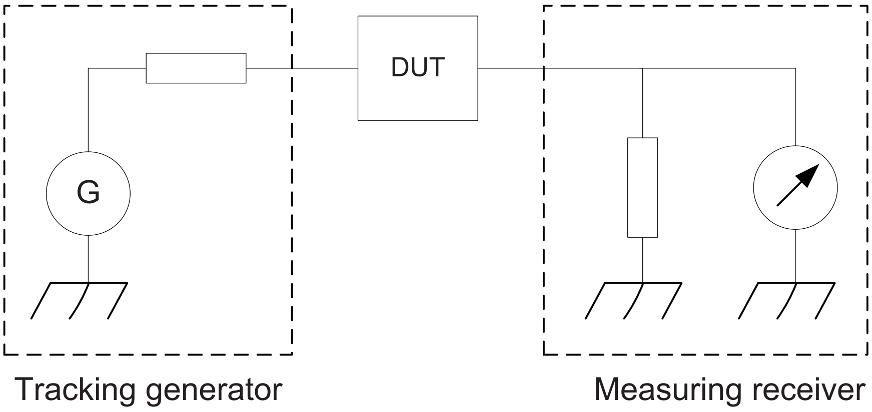


Figure 16 – An alternative measurement system specifically for the insertion loss of a DUT (using a combination of tracking generator and measuring receiver)

The network analyzer and test fixture shall be set up in an environment free from significant temperature variations and external electromagnetic fields. The test system should be calibrated including the test fixture. Environmental conditions and analyzer settings used in measurement shall be recorded, such as temperature, frequency range, input RF power, bias current or voltage, etc.

The following are examples of the required characteristics of the S-parameter measurement system:

- the dynamic range shall be sufficient for measuring the attenuation of the DUT;
- appropriate cables, connectors, adapters, etc. shall be selected for the measurement frequency range. The connectors shall be fastened with the specified torque;
- unless otherwise specified, the test shall be made under the rated conditions of the DUT;
- when applying bias voltage or current, care should be taken not to overload the DUT, especially in the case of ferrite devices.

7.1.2 Test fixture

7.1.2.1 General

In general, a DUT is connected to the network analyzer via cables. Some categories of devices, such as SMD and leaded devices, may not be appropriate for direct connection, where they shall be measured using a test fixture. The following figures show examples of the fixtures using printed circuit boards (PCB), which use planar transmission lines, such as micro-strip and coplanar ones, with a characteristic impedance of 50 Ω. Connectors are attached to the ends of the PCB. Symbols are defined in Figure 17.

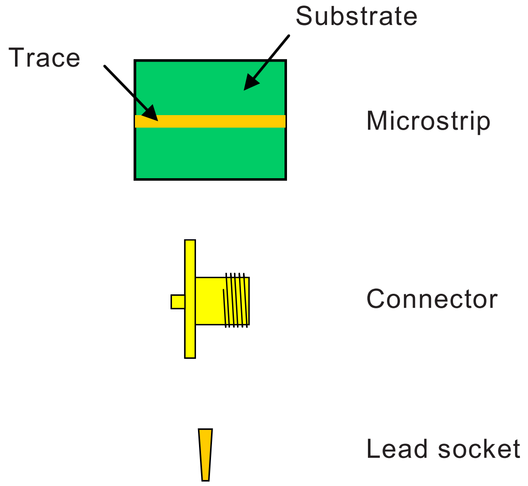
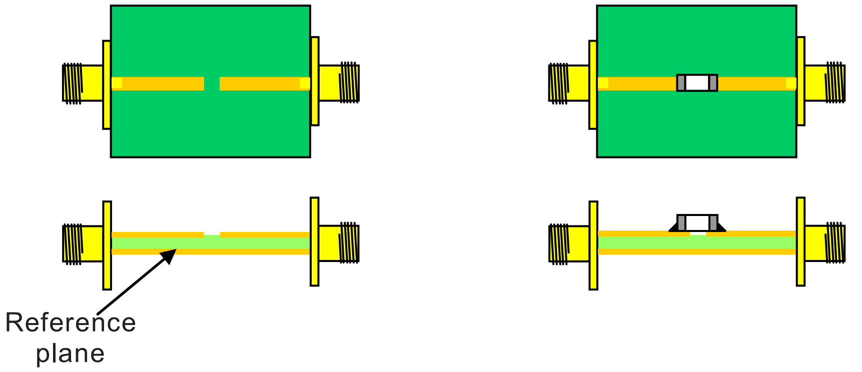


Figure 17 – Symbolic expressions

7.1.2.2 Test fixtures for SMD

7.1.2.2.1 Two-terminal device – series connection

Figure 18 shows a test fixture for measuring the S-parameters of a two-terminal device in a series connection. Maximum applicable frequency is around 6 GHz.



Fixture only Two-terminal device mounted

Figure 18 – Test fixture for a two-terminal device (series connection)

7.1.2.2.2 Two-terminal device – shunt connection

Figure 19 shows a test fixture for measuring the S-parameters of a two-terminal device in a shunt connection. Maximum applicable frequency is around 6 GHz.

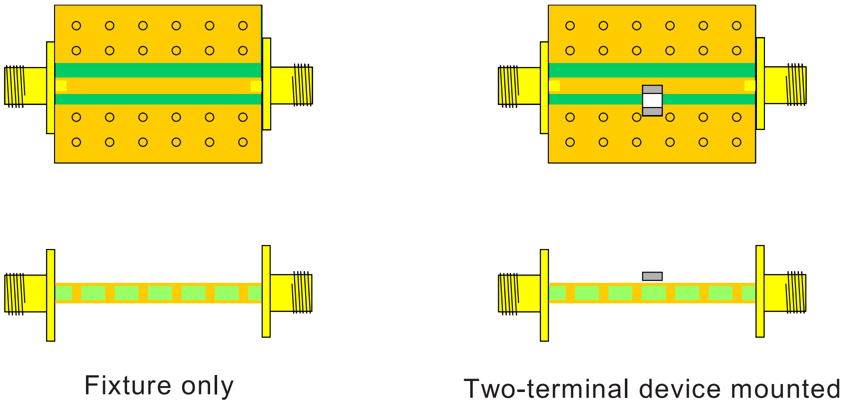


Figure 19 – Test fixture for a two-terminal device (shunt connection)

7.1.2.2.3 Three-terminal filter

Figure 20 shows a test fixture for measuring the S-parameters of a three-terminal filter. Maximum applicable frequency is around 6 GHz.

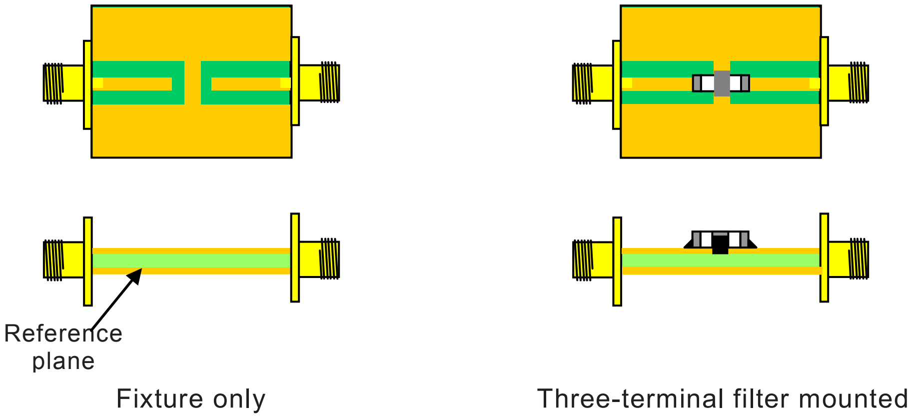
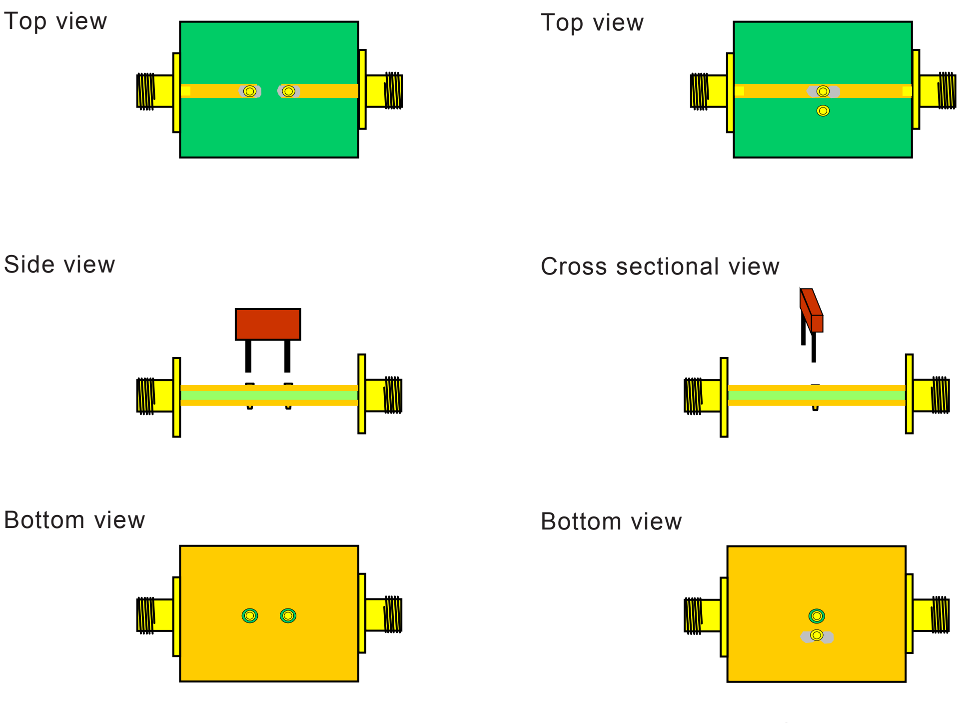


Figure 20 – Test fixture for a three-terminal filter

7.1.2.3 Test fixtures for leaded devices

7.1.2.3.1 Two-terminal device with leads

Figure 21 shows a test fixture for measuring the S-parameters of a two-terminal device with leads in series or shunt connections. Maximum applicable frequency is around 1 GHz.



Series connection

Shunt connection

Figure 21 – Test fixture for a two-terminal device with leads

7.1.2.3.2 Three-terminal filter

Figure 22 shows a test fixture for measuring the S-parameters of a three-terminal filter with leads. Maximum applicable frequency is around 1 GHz.

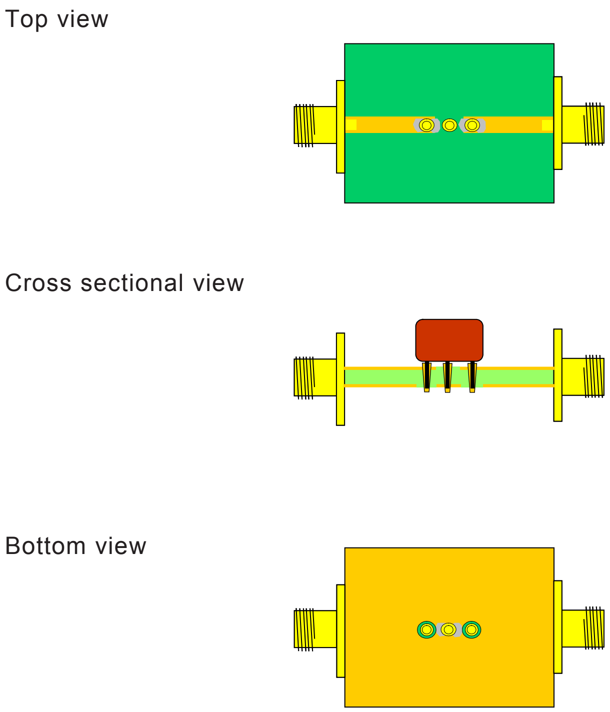


Figure 22 – Test fixture for a three-terminal filter with leads

7.1.2.4 Test fixtures for a core device

A DUT such as ferrite cores or ferrite beads are measured with a test fixture where a conducting wire is inserted into the hole of the DUT as shown in Figure 23. See also Annex H.

Care should be taken to centre the wire in the hole using a spacer. The wire in the hole should be placed in parallel with the ground plane.

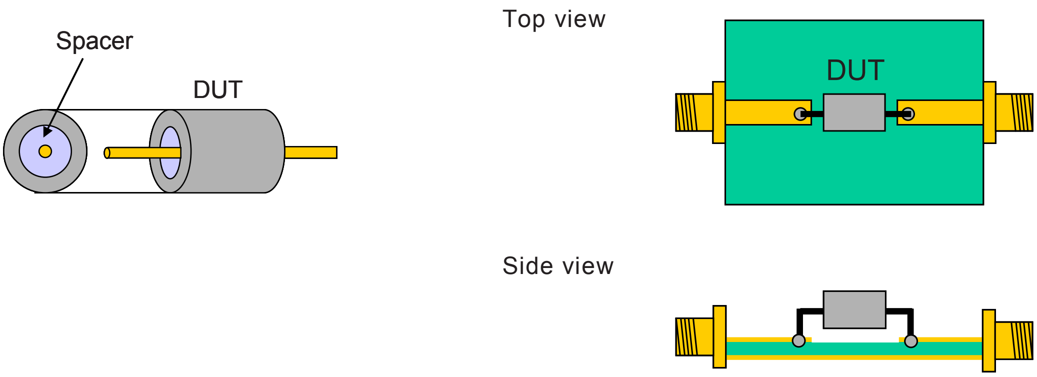


Figure 23 – Test fixture for a core device

7.2 Calibration of test set-up

Cables and a test fixture attached to the network analyzer affect the measurement results. Calibration shall be made to eliminate these effects.

One of the following full n-port calibration methods shall be used:

a) SOLT calibration: four types of calibration standards (Short/Open/Load/Thru) are used.

b) TRL calibration: three types of calibration standards (Thru/Reflect/Line [6]) are used.

Refer to the instruction manual of the analyzer for details of the calibration procedure.

NOTE When only the insertion loss, $1/|S_{21}|$, is required, it is sufficient to perform a calibration using a Thru standard (i.e. Thru calibration). However, two-port calibration is a higher-accuracy alternative.

Examples of a calibration standard (micro-strip line) for the TRL calibration are shown below.

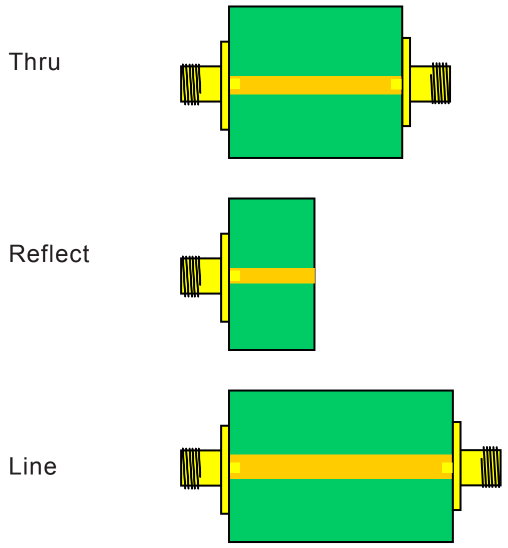


Figure 24 – Example of the standards for TRL calibration

7.3 Measurement uncertainties

The following factors shall be considered in assessing the uncertainties associated with measurements using a VNA.

- uncertainty components related to the network analyzer (refer to catalogue values);
- uncertainty components related to the test fixture (refer to the manufacturer's specifications, if available);
- uncertainty components related to variation in measurement conditions (evaluated through repeated measurements).

Details are provided in Annex A.

8 Presentation of results

8.1 General

The report of measurements shall contain at least the following specific data:

a) test set-up (measuring instrument and test fixture);

b) measurement conditions: RF output (current, voltage), bias voltage or current, etc. ;

c) environmental conditions: temperature, humidity, etc.;

d) calibration/validation method;

e) measurement point;

f) results of measurements (for example, in the form of a table or diagram showing the insertion loss in decibels as a function of frequency in orthogonal semi-logarithmic coordinates);

g) measurement uncertainty;

h) description (photo or sketch) of connection and mounting of the device in the test circuit, giving the shape and dimensions of the test container/fixture and connecting leads (if required);

i) exact description of the device under test (e.g. order number, serial number, technical data, circuit diagram);

j) date and time of measurement;

k) name and function of the person that performed the measurement;

l) referenced standards and specifications; and

m) insertion loss, impedance, and S-parameters depending on the parameter to be measured, in accordance with 8.2 through 8.4.

8.2 Insertion loss

The report of measurements shall contain the following specific data:

– test circuit impedance,

– maximum measurable insertion loss of the test circuit.

8.3 Impedance

The report of measurements shall contain the port reference impedance when the indirect method is used. The impedance is not reported for the direct method.

8.4 S-parameters

The report of measurements shall contain port assignments and port reference impedance.

Annex A
(normative)

Uncertainty estimation for the measurement of the suppression characteristics of EMC filtering devices

A.1 Estimation procedure

A.1.1 General

First of all, consider the relationship between the measurand Y (insertion loss, impedance or S-parameters) and the input quantities X_i on which Y depends. The relationship should contain every quantity, including all corrections and correction factors, that can contribute a significant component of uncertainty to the result of the measurement.

Next, determine x_i, the estimated value of input quantity X_i, either on the basis of the statistical analysis of the series of observations or by other means.

A.1.2 Standard uncertainty: $u(x_i)$

A.1.2.1 General

In order to list each influence quantity that contributes to the overall measurement uncertainty, identify influence quantity x_i as to its type, either evaluated statistically (Type A) or by another method (Type B). Type B method shall be used in case that manufacturers data or calibration data are available, Type A method shall be restricted to equipment for which such data cannot be made available (e.g. special test adapters or test fixtures).

A.1.2.2 Type A (statistical method)

The Type A evaluation method may be based on any valid statistical method for treating data.

The descriptive statistics of the readings (i.e. the mean value μ and standard deviation σ of the readings) are found by a statistical method. The standard uncertainty $u(x_i)$ is the standard deviation of the mean of n measurements and expressed by

$$u(x_i) = \frac{\sigma}{\sqrt{n}} \tag{A.1}$$

where n is the number of readings.

A.1.2.3 Type B (other methods)

This approach requires the identification of all relevant uncertainty components and an estimate of their magnitude. Furthermore, a suitable probability distribution function is to be selected in order to “normalize” each contributing factor to a standard deviation.

The Type B method is based on all relevant information available, such as the following:

a) previous measurement data;
b) manufacturer’s specifications;
c) data provided on calibration or other reports;
d) estimates based on experience;
e) other data.

A.1.3 Combined standard uncertainty: $u_c(y)$

The standard deviations of all normalized uncertainty components, i.e. standard uncertainties $u(x_i)$, are then combined to determine the combined standard uncertainty $u_c(y)$ as follows (with square root):

$$u_c(y) = \sqrt{\sum_i \left[c_i u(x_i)\right]^2} \tag{A.2}$$

where c_i is called sensitivity coefficient and describes how the estimate y varies with changes in the values of the input estimate x_i.

A.1.4 Expanded uncertainty: U

A coverage factor k is applied to expand the combined standard uncertainty to show the interval having a confidence level (for example, k = 2 for a level of confidence of approximately 95 %).

Expanded uncertainty is obtained by the next equation.

$$U = k\,u_c(y) \tag{A.3}$$

A.2 Reporting of the uncertainty

The proper way to report measurement uncertainty in a test report is the inclusion of a statement of the expanded uncertainty and the k-factor, along with the level of confidence. For example:

> Measurement result = ($y \pm U$) dB or Ω, k = 2 (level of confidence 95 %)

Note that any measurement uncertainty analysis is based on a set of assumptions. These shall be defined and documented. If the actual measurement scenario deviates from these assumptions, the uncertainty estimate will not be valid and shall be recalculated to address the deviation.

A.3 Measurement uncertainty calculation example – insertion loss

The uncertainty analysis in Table A.1 demonstrates the application of the ISO/IEC Guide 98-3 [4] approach to a measurement method of insertion loss defined in 5.3. It is assumed that a Type B analysis is to be performed, which requires the identification of all relevant influence factors and an estimate of their magnitude. In case of measuring a significant number of filters, as may be the case in a production environment, the measurement uncertainty analysis could also be based on a Type A method. In either case, the determination of the magnitude of the measurement repeatability is based on a Type A analysis, where the measurand (i.e. the insertion loss of the filter) is determined repeatedly in a series of measurements.

Table A.1 – Measurement uncertainty of insertion loss (example)

Source of uncertainty	Value dB	Probability distribution	Divisor	Sensitivity coefficient	Standard uncertainty dB
Signal generator (G) [a]	0,2	Rectangular	1,732	1	0,12
Receiver [a]	0,2	Rectangular	1,732	1	0,12
Validation of test set-up [b]	0,5	Rectangular	1,732	1	0,29
Repeatability	0,1	Normal	1	1	0,1
Combined standard uncertainty (u_c)	-	-	-	-	0,35
Expanded uncertainty (U) for k=2	-	-	-	-	0,70

[a] If a network analyzer is used, there may be only one value for the complete measuring equipment (signal generator + receiver), the uncertainty value is mainly determined by the stability of the measurement equipment.

[b] The measurement uncertainty from the test set-up (cables, test box, etc.) is the result of the verification procedure as of 5.4.2 or 5.4.3

Under the assumptions documented below, the expanded uncertainty for the filter insertion loss measurement, common-mode, unbiased case, is ± 0,70 dB.

a) The frequency range of interest for this measurement is assumed to be 10 kHz to 1 GHz.

b) The measurement set-up is implemented in accordance with Figure 8.

c) The measurement procedure outlined in 5.3 is followed closely.

d) A validation of the suitability of the test set-up, in accordance with 5.4.2 is performed before the actual insertion loss measurement has commenced. This verification measurement will demonstrate that the test set-up is suitable to measure a constant value of insertion loss within ±0,5 dB over the required frequency range, when the standard attenuator is measured.

In addition, uncertainty analysis for insertion loss measurement shall take into account the following precautions:

1) The test system (i.e. signal generator and receiver) may be included in one test instrument.
2) Because radiated disturbances in the environment can influence the test results significantly, measures shall be taken to minimize the error caused by such external disturbances to an acceptable value. It may be necessary to use a shielded test box or to shield the test set-up completely. The residual value caused by the disturbances shall be at least 6 dB lower than the measured signal.
3) The use of isolation attenuators (inserted in the set-up at the output of the signal generator and the input of the measurement receiver) is recommended to decrease the influence of VSWR and resonances on the test result. Isolation attenuators are not required if two-port calibration is applied with a VNA.
4) The uncertainty evaluation shall be done with the circuits shown in Figures 8 and 9, respectively (depending if a unbiased or bias test is performed).
5) The influence by mismatching of the connectors, cables and the test box are covered by the verification measurement as of 5.4.2 and 5.4.3.

A.4 Measurement uncertainty calculation example – impedance

The uncertainty analysis in Table A.2 demonstrates the uncertainty estimation approach to a measurement method of impedance defined in 6.2.

Table A.2 – Measurement uncertainty of impedance (example)

Source of uncertainty	Value %	Probability distribution	Divisor	Sensitivity coefficient	Standard uncertainty %
Impedance-measuring equipment	0,66	Rectangular	1,732	1	0,12
Test fixture	0,5	Rectangular	1,732	1	0,29
Repeatability	0,29	Normal	1	1	0,29
Combined standard uncertainty (u_c)	-	-	-	-	0,48
Expanded uncertainty (U) for k=2	-	-	-	-	0,96

Under the assumptions documented below, the expanded uncertainty for the impedance measurement at 100 MHz, unbiased case, is ± 0,96 %.

a) Measurement is conducted in accordance with 6.2 and Annex F.

b) DUT is an SMD-type inductor and its typical parameter $|Z|$ = 1 kΩ at 100 MHz.

c) Impedance-measuring equipment is calibrated by OPEN/SHORT/LOAD calibration.

d) Test set-up (test fixture) is verified by OPEN (test port is not connected to GND) and SHORT (short chip which is the same dimension as DUT used) connection.

A.5 Measurement uncertainty calculation example – S-parameters

The uncertainty analysis in Table A.3 demonstrates the uncertainty estimation approach to a measurement method of S_{21} and S_{12} at 100 MHz, unbiased case, while Table A.4 describes an example of uncertainties for the S_{11} and S_{22} measurements.

Table A.3 – Measurement uncertainties of $|S_{21}|$ and $|S_{12}|$ (example)

Source of uncertainty	Value dB	Probability distribution	Divisor	Sensitivity coefficient	Standard uncertainty dB
Network analyzer	0,026	Rectangular	1,732	1	0,015
Test set-up (calibration)	0,498	Rectangular	1,732	1	0,288
Repeatability	0,078	Normal	1	1	0,078
Combined standard uncertainty (u_c)	-	-	-	-	0,30
Expanded uncertainty (U) for k=2	-	-	-	-	0,60

Table A.4 – Measurement uncertainties of $|S_{11}|$ and $|S_{22}|$ (example)

Source of uncertainty	Value dB	Probability distribution	Divisor	Sensitivity coefficient	Standard uncertainty dB
Network analyzer	0,014	Rectangular	1,732	1	0,008
Test set-up (calibration)	0,027	Rectangular	1,732	1	0,016
Repeatability	0,010	Normal	1	1	0,010
Combined standard uncertainty (u_c)	-	-	-	-	0,021
Expanded uncertainty (U) for k=2	-	-	-	-	0,04

Under the assumptions documented below, the expanded uncertainties for the measurement of magnitude of S_{21} and S_{12}, and S_{11} and S_{22} are 0,60 dB and 0,04 dB, respectively.

NOTE For high insertion loss devices, the uncertainty of transmission coefficients S_{21} and S_{12} could increase significantly due to the cross-talk error of network analyzer.

a) Measurement is conducted in accordance with 7.1 of this standard.

b) DUT is an SMD-type inductor and its typical parameters are 20log $|S_{21}|$ = -20 dB and 20log $|S_{11}|$ = -0,94 dB at 100 MHz.

c) The network analyzer is calibrated by TRL calibration. The source level is 0 dBm and IF bandwidth is 100 Hz.

d) The test fixture is implemented in accordance with Figure 18.

Annex B
(informative)

Examples of test boxes for insertion loss measurement

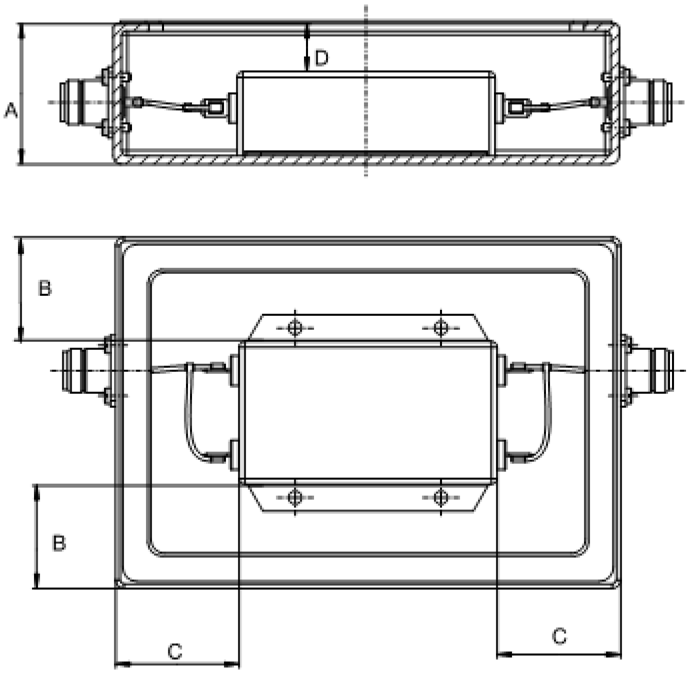
B.1 Facility and apparatus filters

B.1.1 General

An EMC filtering device under test should be mounted in an appropriate test box. Unless the specific test arrangement is otherwise specified for a specific application, by the user, manufacturer or test authority as appropriate, the test container is as described in the following manner.

B.1.2 Construction of the test box

Refer to Figures B.1 and B.2. The interference suppression elements and filters, which have no screens and coaxial plugs of their own at the input and output, are placed for measurements in a test box the dimensions of which depend on those of the device under test (e.g. on its length l, height h, and width w). A container is a box that is supplied with a metal cover and is made of non-magnetic metal. A box which is intended for measurement of feedthrough capacitors and filters with flange mounting should have an internal partition with a hole for the mounting of capacitors and filters. Reliable electrical contact should exist between separate parts of the container. Separate parts of the housing are joined by soldering or continuous-seam welding; the lid and the housing are joined together by a spring-contact device or by a screw joint, and particular care should be taken to ensure the lid makes good contact with the flange along its full length when measuring coaxial feedthrough capacitors and filters. Coaxial jacks are mounted on two walls of the box.



NOTE 'A' is the overall height of the test box. See B.1.3 for recommended values of dimensions B, C, and D.

Figure B.1 – Design of typical test box for general-purpose filters

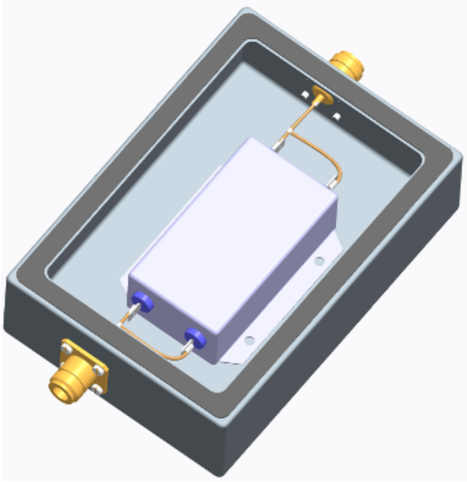


Figure B.2 – 3D view of typical test box for general purpose filters

B.1.3 Mounting of the EMC filtering devices in the test boxes

The filters under test are mounted in the test box as intended for their normal use, e.g. fixed by screwing to the bottom of the box or mounted RF tightly into the inner shielding wall of the box in case of a feedthrough filter. The connecting wires are as short as possible to avoid any error by coupling and parasitic inductances and capacitances.

The box is chosen to be only slightly bigger than the filter under test; recommended values are B = 5 cm, C = 5 cm, D = 5 cm.

B.2 Feedthrough components

Feedthrough capacitors and feedthrough filters with flange mounting are mounted as shown in Figures B.3 and B.4.

If the ground connection is made through a wire, this wire is used in the length specified by the manufacturer and arranged in a straight line. Other kinds of terminals are connected to the metalwork by a wire as short as possible for use in practice.

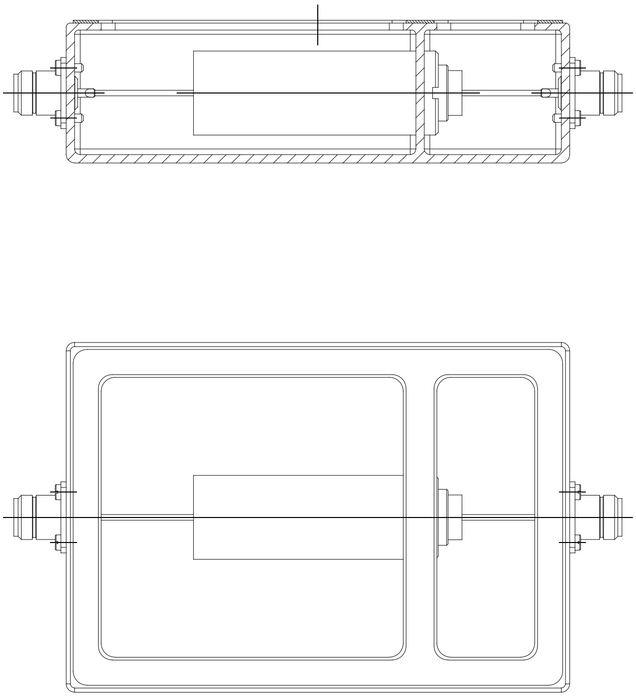


Figure B.3 – Design of typical test box for feedthrough components

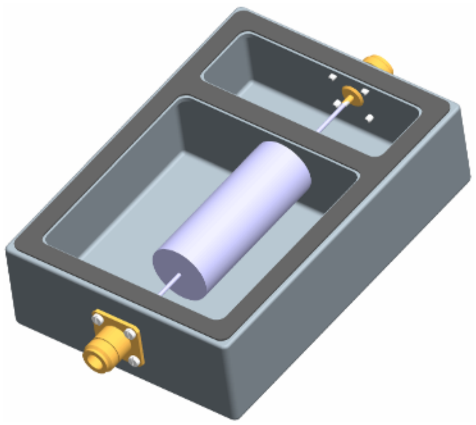


Figure B.4 – 3D view of typical test box for feedthrough components

B.3 Single components

B.3.1 Capacitors

Capacitors with two wires are mounted as intended by the manufacturer (e.g. on a PCB). If components have wire connections, care should be taken that, unless otherwise specified the length of each wire is 6 mm for bare wires or 50 mm for insulated wires.

B.3.2 Inductors

The mounting and connections of inductors are similar to filters as described in B.1. Care should be taken to have sufficient distance between the metal parts of the test box and the inductor to avoid magnetic coupling. The inductors are connected to the terminals of the test box as intended by the manufacturer (e.g. by mounting on a PCB). The connecting wires are straight and as short as possible.

B.3.3 Interference-suppression resistors, cables and other devices used for suppression of interference from ignition systems of vehicles

The mounting, connecting and making of measurements should comply with the requirements of CISPR 12 [1].

Annex C
(informative)

Insertion loss test methods with non-50 Ω systems

C.1 0,1 Ω / 100 Ω system

C.1.1 General

These systems are used for power line filters.

With this method, instead of measuring the insertion loss in a 50 Ω/50 Ω system (75 Ω/75 Ω), the filter is measured in a 0,1 Ω/100 Ω (and its reverse) system. In the frequency range of 1 kHz to 300 kHz, two wideband transformers are required (1,4:1 and 22:1 for a 50 Ω system). See Figure C.1.

NOTE For some filters, e.g. high-permeability ferrites, a 0,1 Ω/1,0 MΩ system provides the worst-case insertion loss.

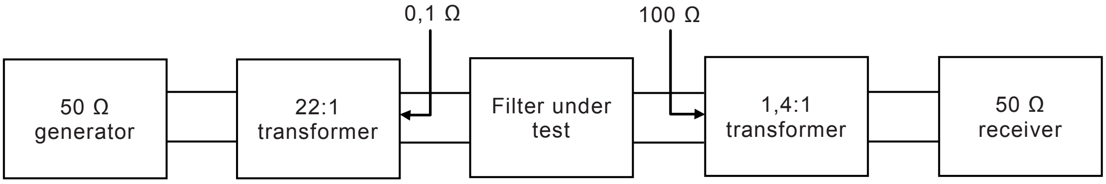


Figure C.1 – Test circuit

C.1.2 Theory of the method

With this method of measurement, the objective is to determine that in actual operation, with uncertain interface impedances, the filter:

a) in the specified stop band has a good and reasonably predictable insertion loss characteristic, and
b) in the pass band, does not exhibit unacceptable ringing.

The method takes into account boundary conditions representing actual circuits in terms of impedances established empirically from statistical data (sources and loads).

From theoretical analysis of mismatched filters, three distinct problem areas can be delineated:

1) Ringing in the pass band and transition band caused by two different mechanisms of different significance:
   i) interfacial resonances (the filter resonates with the generator and/or load impedances corresponding to image parameter terminations). Fortunately, in actual circuits, such resonances are highly damped because of the low Q of the equivalent circuit. (An exception occurs in the common mode, but this can easily be overcome.)
   ii) pronounced ringing that can be attributed to the eigen-resonances of the filter. Critical eigen-resonances can occur if, and only if, one interface impedance is much higher and the other much lower than the characteristic impedance of the filter. Then, the high Q of the filter itself is dominant. This mechanism can lead to insertion gain (negative insertion loss) of up to 30 dB. This phenomenon shows up in a 0,1 Ω/100 Ω (and reverse) measuring system. It can be eliminated by proper filter design.

   NOTE Eigen-resonances occur for any combination of effectively 0 Ω or ∞ Ω terminations.

2) Poor performance in the lower part of the stop band. Generally, for low-pass filters such as power line filters, the effects of impedance mismatch are most severe at frequencies in the lowest part of the stop band. Here the 0,1 Ω/100 Ω (and reverse) method will identify any filter that deviates strongly from the performance expected from the results of measurements in a 50-Ω system. In this context it should be mentioned that multiple section filters (”partitioned” filters) are not only much better under strong mismatch than simple filters, but also much smaller and economical (for details, see [7]).
3) Method of measurement. Tests are made with the circuit shown in Figure C.1.

In addition, tests are made with the transformers interchanged and reversed. The transformers are wide-band (ferrite) and cover the frequency range of 1 kHz to 300 kHz. For 75 Ω systems, the transformer ratios are 27:1 and 1,15:1.

It should be noted that where equipment with adequate sensitivity is available, it may be possible to use test circuits providing the required resistance terminations without using transformers.

For a satisfactory filter, over the frequency range of 1 kHz to 100 kHz, the maximum insertion gain at any frequency should be less than 10 dB. Over the frequency range of the stop band, the insertion loss should not deviate more than 10 dB from the specified value.

Annex D
(informative)

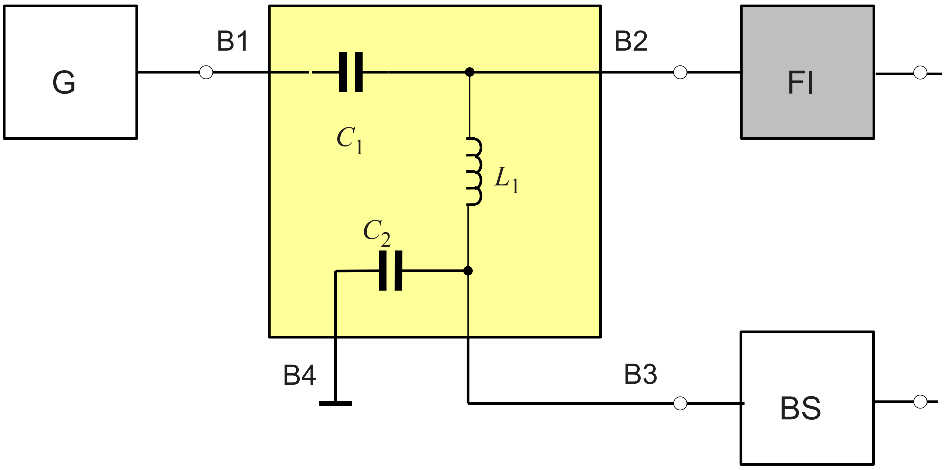
Realization of the buffer-network for insertion loss measurement

D.1 General

The buffer-network is needed for measurements under bias conditions to decouple the bias current source from the test set-up (generator, receiver and device under test).

D.2 Layout for a typical buffer-network

The layout for a typical buffer-network is shown in Figure D.1.



Key

G	signal generator
FI	EMC filtering device (DUT)
BS	bias current source
L_1	decoupling inductor
C_1	coupling capacitor for RF signal
C_2	decoupling capacitor for bias current
B1	terminal for connection of signal generator/receiver
B2	terminal for connection of the DUT
B3	terminal for connection of the bias current source
B4	terminal for connection to reference potential

Figure D.1 – Example of connecting buffer-networks for test with bias

The capacitor C_1 should couple the RF signal into the measurement circuit and decouple the RF signal generator from the bias circuit. It should have low impedance over the regarded frequency range compared to the impedance of the RF signal source and the impedance of the device under test, seen from the terminal B2, where the lower value has to be considered.

The inductor L_1 should decouple the bias current source from the RF measurement circuit. It should have high impedance over the regarded frequency range compared to the impedance of the RF signal source and the impedance of the device under test seen from the terminal B2, where the higher value has to be considered. The inductor should not go into saturation by the maximum bias current to be applied to the device under test.

The capacitor C_2 together with L_1 should protect the bias current source from the RF signal. It should have low impedance over the regarded frequency range compared to the RF impedance of the bias current source. If possible, a feedthrough type should be utilized.

The components C_1, C_2 and L_1 should have their self-resonance frequency outside the regarded frequency range and should be connected regarding the principles of RF compliant layout.

Before testing the attenuation of the biased device under test, it should be ascertained by a preliminary test made without current (unbiased device under test) that the tests in the frequency range considered are not influenced by the presence of the buffer-networks and of the bias current source.

D.3 Example for a buffer-network (0,1 MHz to 30 MHz)

Table D.1 contains recommendations for a buffer-network for use in the frequency range from 0,1 MHz to 30 MHz.

Table D.1 – Specifications of the elements of buffer-networks

Buffer-network for the range from 0,1 MHz to 30 MHz		
Element	**Type**	**Value**
C_1	Low-inductivity capacitor	100 nF
C_2	Feedthrough capacitor or low-inductivity capacitor	1 μF
L	I-core choke	10 mH

These L and C values are considered only a guideline. It may be necessary to adapt them for the measurement of a certain device under test, e.g. in case of a filter with a very high insertion loss to prevent any influence to the measurement result.

Annex E
(informative)

Insertion loss measurement – General discussion

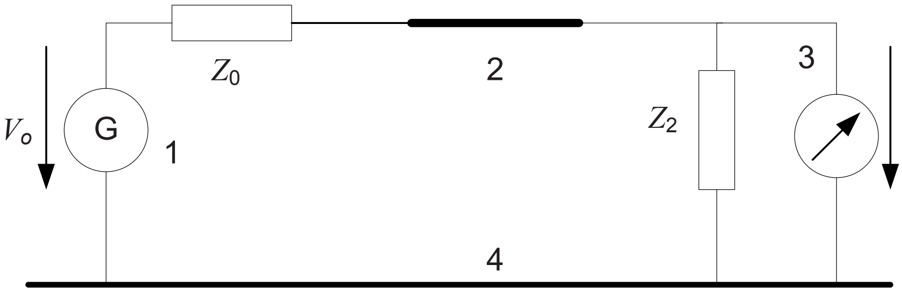
E.1 Theory of insertion loss measurement

E.1.1 General

Insertion loss measurement is a standardized method to determine the suppression of RF disturbances by a filter or any suppression circuit.

First a reference measurement is performed with a short connection between signal generator and receiver and the voltage V_{20} is measured across the termination Z_2. See Figure E.1.

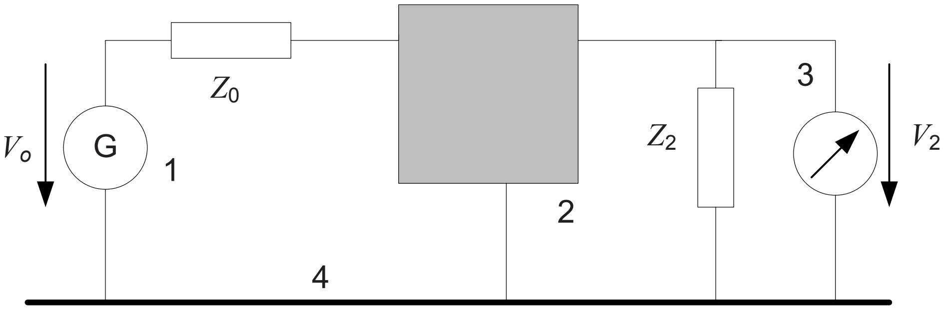
Then the filter is inserted into the test circuit (see Figure E.2) and a second measurement is performed to measure the voltage V_2 across the termination Z_2.



Key

1	signal generator
2	short circuit
3	measuring receiver
4	reference potential (metallic ground plane)
V_o	open circuit generator voltage
V_2	output voltage
Z_0	generator impedance
Z_2	receiver impedance

Figure E.1 – Test circuit for insertion loss measurement, reference measurement (filter replaced by a short circuit)



Key

1	signal generator
2	EMC filtering device under test
3	measuring receiver
4	reference potential (metallic ground plane)
V_o	open circuit generator voltage
V_2	output voltage
Z_0	generator impedance
Z_2	receiver impedance

Figure E.2 – Test circuit for insertion loss measurement, measurement of filter under test

E.1.2 Definition

The insertion loss is defined in dB by the following formula:

$$a_e = 20\log\frac{V_{20}}{V_2} = 20\log\frac{V_o}{2V_2} , \qquad \text{(E.1)}$$

where

$$Z_0 = Z_2 = 50\ \Omega\text{, and thus } V_2 = \frac{V_o}{2} .$$

E.2 Insertion loss measurement

E.2.1 Original test method

As defined in former standards, the insertion loss measurement is performed by taking a measurement using the test circuit shown in Figure E.1 to get the reference voltage and then a measurement after insertion of the filter shown in Figure E.2, either a complete scan or even for each test frequency separately. The results of both measurements are transformed into insertion loss values by the above formula.

E.2.2 Simplified test method

With modern signal generators and receivers usually only one measurement is performed of the voltage V_2 across the termination Z_2 with the filter inserted. The reference measurement may be omitted if evaluation determines that the signal generator delivers constant voltage V_o even when a filter under test with a low impedance is connected (e.g. caused by high capacitor values in the filter).

If the signal generator is stable enough, the “reference voltage” always is the half value of V_o and thus also a constant value that is put into the above formula. This allows faster and less costly measurements that may also be fully automated, which is a precondition for factory tests.

Annex F
(informative)

Set-up for impedance measurement

F.1 General

This Annex describes an example of impedance measurement using impedance-measuring equipment.

F.2 Example of the set-up

F.2.1 Two-terminal devices with leads

A four-terminal impedance measuring equipment is used in measurement. Figures F.1 and F.2 show the measurement set-up and the four-terminal test fixture for the leaded device, respectively. This configuration enables measurement up to a maximum frequency of about 100 MHz.

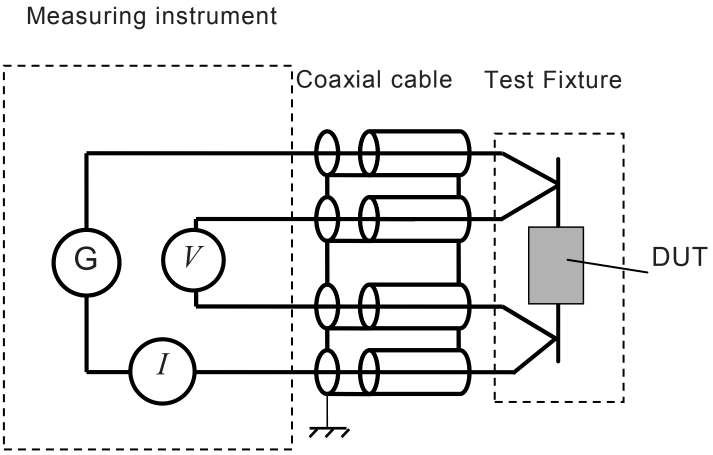
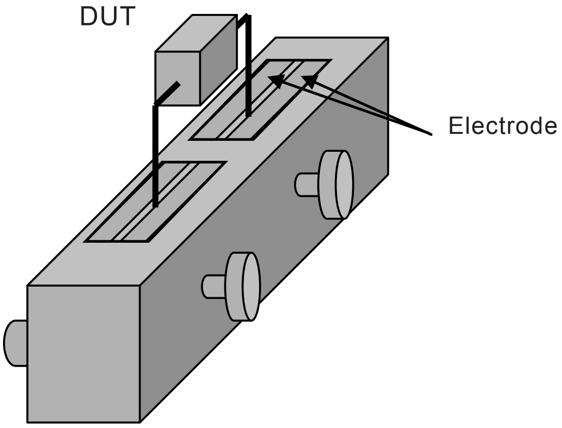


Figure F.1 – Measurement set-up for a leaded device (DUT)



NOTE A large DUT with leads is measured in the frequency range up to around 100 MHz. The DUT is fixed in place using electrode plates by turning the screws. The electrodes are wired to the connectors on the rear side.

Figure F.2 – Four-terminal test fixture for a leaded device (DUT)

F.2.2 Surface-mount device (SMD)

F.2.2.1 Measurement set-up

An impedance-measuring instrument is used for measurement as shown in Figure F.3.

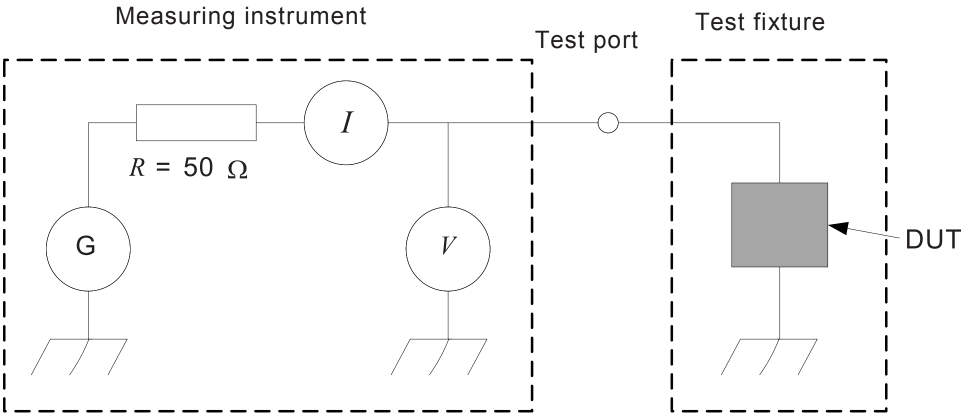


Figure F.3 – Measurement set-up for an SMD

F.2.2.2 Clamp-type measurement configuration

Figure F.4 shows the clamp-type test fixture of the two-terminal device. This configuration enables measurement up to a maximum frequency of about 2 GHz.

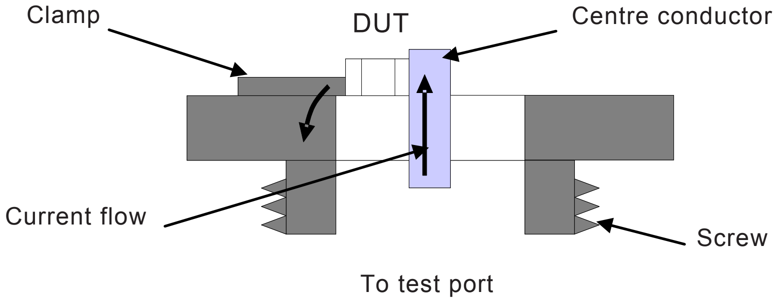


Figure F.4 – Clamp-type test fixture

F.2.2.3 Measurement using a coaxial test fixture

Impedance measuring equipment is used for measurement. Figure F.5 shows a coaxial test fixture for the two-terminal device. This configuration enables measurement up to a maximum frequency of about 3 GHz.

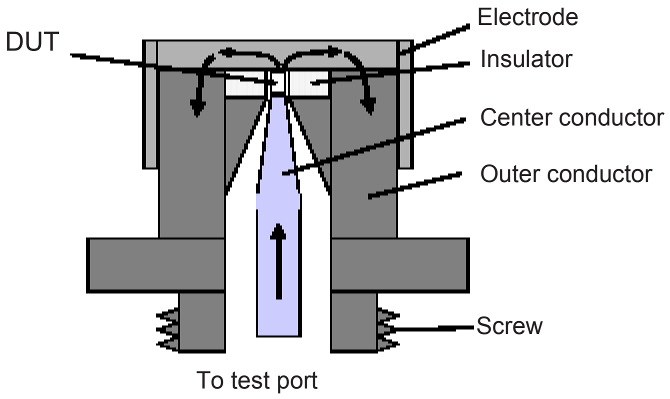


Figure F.5 – Coaxial test fixture for an SMD

F.2.2.4 Measurement using a press-type test fixture

Impedance measuring equipment is used for measurement. Figure F.6 shows a press-type test fixture for the two-terminal device. This configuration enables measurement up to a maximum frequency of about 3 GHz.

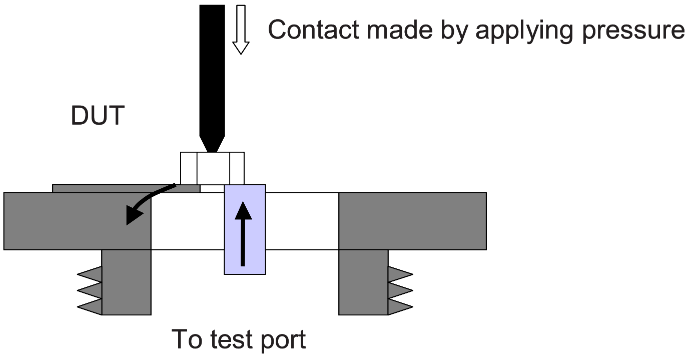
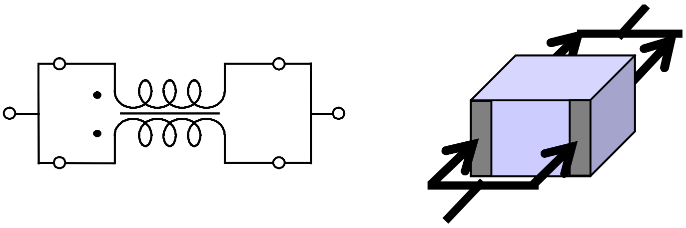


Figure F.6 – Press-type test fixture for an SMD

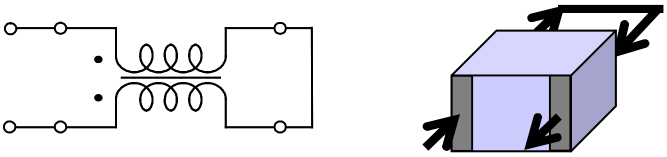
F.2.3 Common-mode choke coil (CMCC)

F.2.3.1 Definition

For a four-terminal CMCC, impedances measured with connections shown in Figure F.7 a) and b) are called the common-mode impedance (Z_c), and the differential-mode impedance (Z_d), respectively.



a) Common-mode impedance, Z_c



b) Differential-mode impedance, Z_d

Figure F.7 – Connection for CMCC measurement

F.2.3.2 Measuring instrument and test fixture

Impedance measuring equipment is used to measure the impedance between the two connected terminals for each mode. Figure F.8 shows the measurement set-up in which an SMD is tested. This configuration enables measurement up to a maximum frequency of around 3 GHz.

When a leaded DUT is tested, the test fixture used may be similar to that shown in Figure F.2.

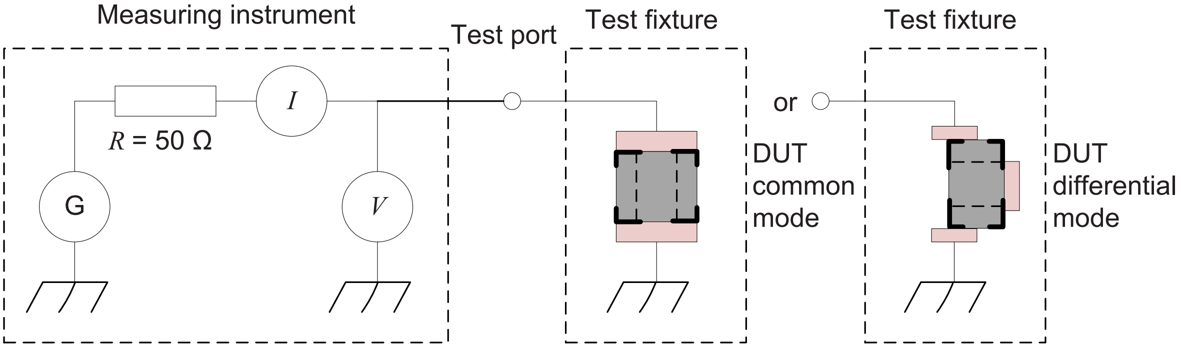


Figure F.8 – Test fixture and measurement set-up for an SMD common-mode choke coil

Annex G
(informative)

S-parameter measurement of common-mode choke coils

G.1 General

Figure G.1 shows a schematic circuit of the common-mode choke coil (CMCC). The characteristics in common and differential modes can be measured by either direct measurement (see G.2 and G.3) or indirect measurement using four-port S-parameters (see G.4).

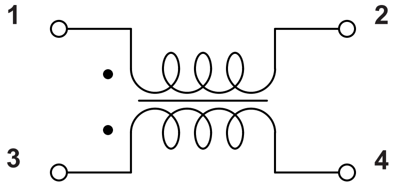


Figure G.1 – Common-mode choke coil

G.2 Set-up for measurements of common-mode characteristics

G.2.1 General

The input/output terminals of a CMCC are connected as shown in Figure G.2 to form a two-port device.

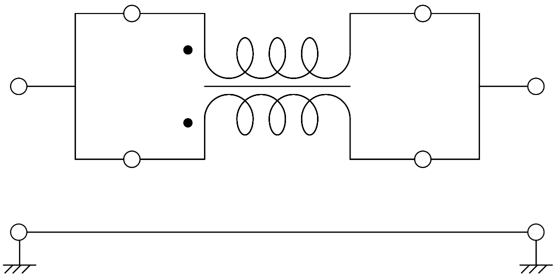
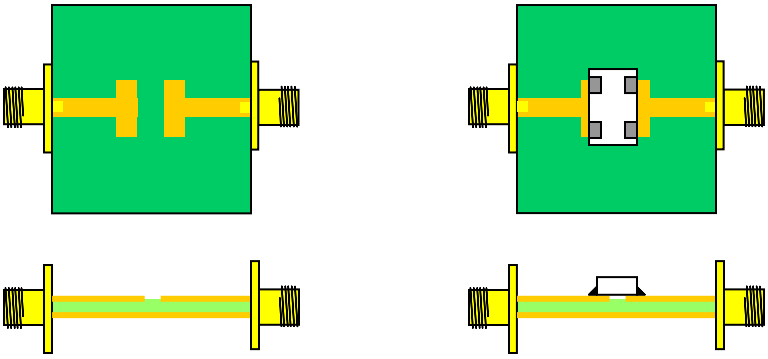


Figure G.2 – Set-up for measurements of common-mode characteristics

G.2.2 Test fixture for SMD

An example of a test fixture is shown in Figure G.3.



(a) Test fixture only

(b) With a CMCC mounted

Figure G.3 – Test fixture for an SMD

G.2.3 Test fixture for a leaded device

An example of a test fixture is shown in Figure G.4.

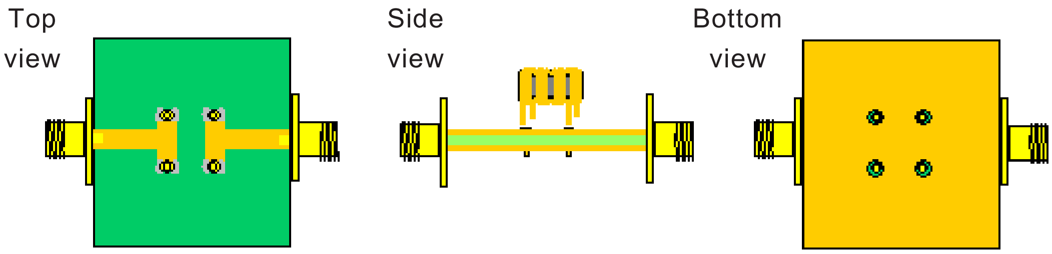


Figure G.4 – Test fixture for a leaded device

G.3 Set-up for measurements of differential-mode characteristics

G.3.1 General

One of the input/output terminals of a CMCC is grounded as shown in Figure G.5 to form a two-port device.

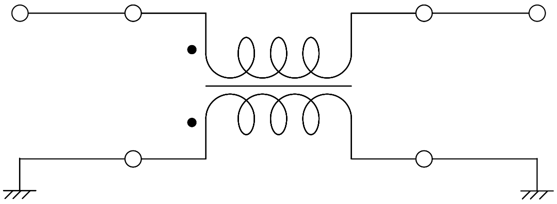
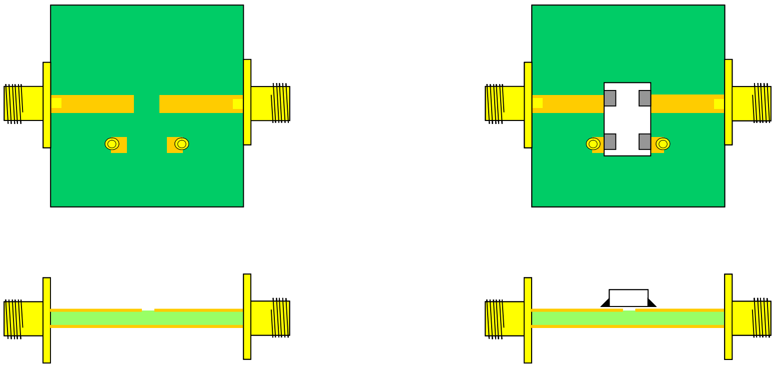


Figure G.5 – Set-up for measurements of differential-mode characteristics

G.3.2 Test fixture for SMD

An example of a test fixture is shown in Figure G.6.



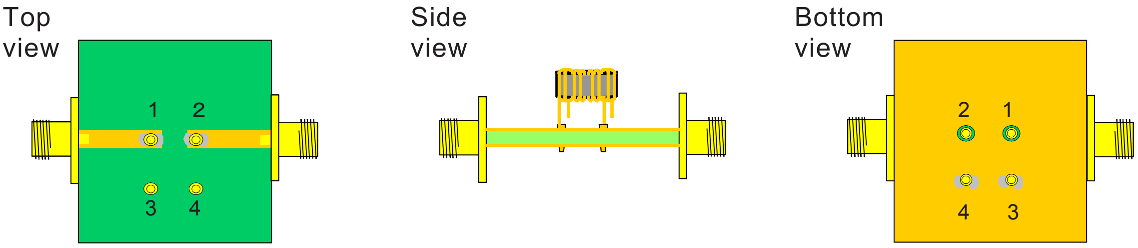
(a) Test fixture only

(b) With a CMCC mounted

Figure G.6 – Test fixture for an SMD

G.3.3 Test fixture for a leaded device

An example of a test fixture is shown in Figure G.7.



1 and 2: lead socket connected to trace
3 and 4: lead socket connected to ground

Figure G.7 – Test fixture for a leaded device

G.4 Measurement in terms of four-port S-parameters

G.4.1 General

Since there are four terminals in a CMCC, the characteristics can be evaluated by using the four-port S-parameters as shown in Figure G.8.

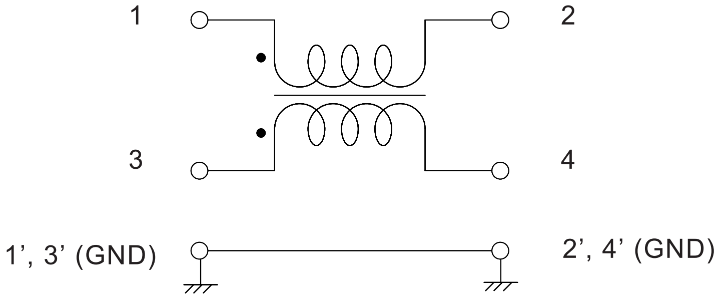
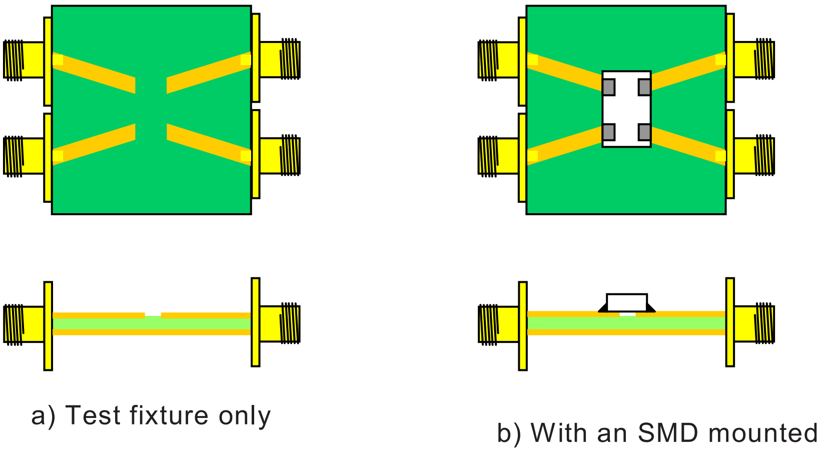


Figure G.8 – Set-up for measurement of four-port S-parameters

G.4.2 Test fixture for SMD

An example of a test fixture is shown in Figure G.9.

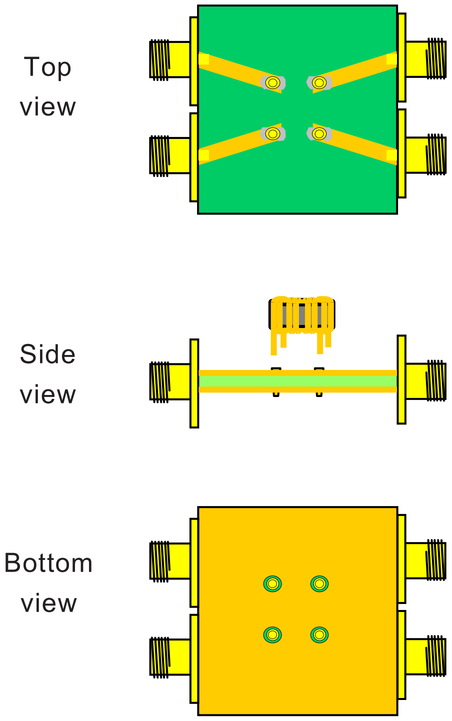

a) Test fixture only

b) With an SMD mounted

Figure G.9 – Test fixture for the four-port S-parameters of an SMD

G.4.3 Test fixture for a leaded device

An example of a test fixture is shown in Figure G.10.



Top view

Side view

Bottom view

Figure G.10 – Test fixture for the four-port *S*-parameters of a leaded device

Annex H
(informative)

Measurement set-up for S-parameters of a DUT without wire leads

H.1 General

Measurement method described in this annex can be applied for DUT without wire leads. For example, ferrite core and ferrite beads to suppress common-mode current on cables.

H.2 Measurement method

S-parameters of a DUT without leads, such as ferrite cores or ferrite beads, are measured by using a VNA with a test fixture as shown in Figure H.1. A conducting wire above a ground plane is inserted into the hole of the DUT using a spacer. The spacer should be of a material having a low permittivity, e.g. foamed polystyrene. Care should be taken for centring the wire in the hole. The wire in the hole should be placed in parallel with the ground plane.

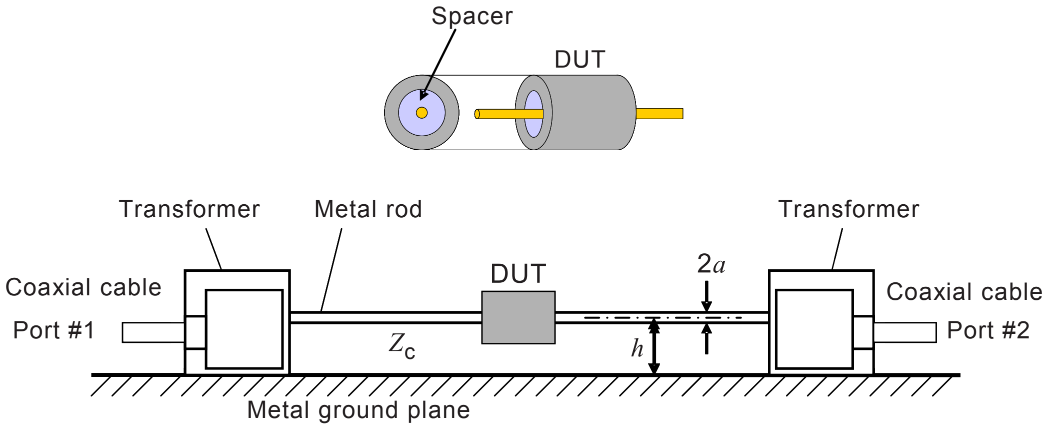


Figure H.1 – S-parameters measurement of a DUT without leads

The characteristic impedance, Z_{c}, of the transmission line is defined by

$$Z_{\mathrm{c}} = 60\cosh^{-1}\left(\frac{h}{a}\right) \tag{H.1}$$

in Ω , where h and a denote height and radius of the metal rod. Z_{c} = 270 Ω is preferred. See [8] and 4.9.2.1 of CISPR 16-3:2010 [2].

H.3 Calibration

To remove the effects of the transformer, a calibration should be performed. The TRL calibration method [6] should be used in this fixture. As shown in Figure H.2, two metal rods with different lengths are required for Thru and Line measurements in the TRL calibration procedure.

NOTE To check the limitation of measurable insertion loss of the test fixture, the S_{21} between transformers should be measured with the Reflect position as shown in Figure H.2.

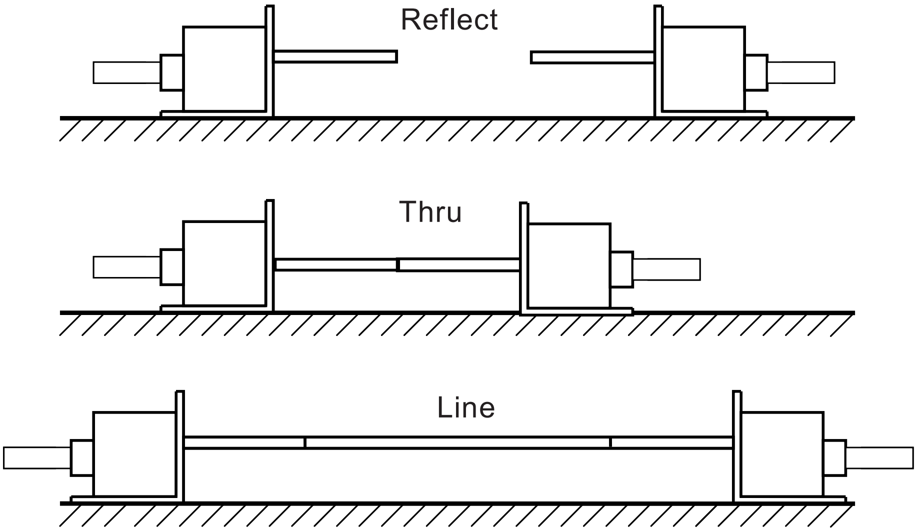


Figure H.2 – Procedure for TRL calibration

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