

# TECHNICAL REPORT



Measurement methods of the complex relative permeability and permittivity of  
noise suppression sheet  
**(standards.iteh.ai)**

IEC TR 63307:2020

<https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020>



**THIS PUBLICATION IS COPYRIGHT PROTECTED**  
**Copyright © 2020 IEC, Geneva, Switzerland**

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office  
3, rue de Varembe  
CH-1211 Geneva 20  
Switzerland

Tel.: +41 22 919 02 11  
[info@iec.ch](mailto:info@iec.ch)  
[www.iec.ch](http://www.iec.ch)

#### **About the IEC**

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

#### **About IEC publications**

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

#### **IEC publications search - [webstore.iec.ch/advsearchform](http://webstore.iec.ch/advsearchform)**

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

#### **IEC Just Published - [webstore.iec.ch/justpublished](http://webstore.iec.ch/justpublished)**

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

#### **IEC Customer Service Centre - [webstore.iec.ch/csc](http://webstore.iec.ch/csc)**

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: [sales@iec.ch](mailto:sales@iec.ch).

#### **Electropedia - [www.electropedia.org](http://www.electropedia.org)**

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

#### **IEC Glossary - [std.iec.ch/glossary](http://std.iec.ch/glossary)**

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

[IEC TR 63307:2020](#)

<https://standards.iec.ch/catalog/standards/sis/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020>

# TECHNICAL REPORT



**Measurement methods of the complex relative permeability and permittivity of noise suppression sheet** (standards.iteh.ai)

IEC TR 63307:2020

<https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020>

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

ICS 29.100.10

ISBN 978-2-8322-9085-9

**Warning! Make sure that you obtained this publication from an authorized distributor.**

## CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	9
2 Normative references .....	9
3 Terms, definitions and symbols.....	9
3.1 Terms and definitions.....	9
3.2 Symbols.....	9
4 General .....	10
5 Measurement methods .....	11
5.1 Inductance method .....	11
5.1.1 Measurement parameters .....	11
5.1.2 Measurement frequency and accuracy.....	11
5.1.3 Measurement principle.....	12
5.1.4 Test sample.....	14
5.1.5 Test fixture .....	14
5.1.6 Measurement environment.....	14
5.1.7 Measurement uncertainty.....	14
5.1.8 Measurement system.....	16
5.1.9 Measurement procedure .....	16
5.1.10 Example of measurement results .....	16
5.1.11 Remarks .....	17
5.2 Nicolson Ross Weir method IEC TR 63307:2020 .....	18
5.2.1 Principle.....	18
5.2.2 Measurement frequency and accuracy.....	20
5.2.3 Measurement parameters .....	20
5.2.4 Test sample.....	20
5.2.5 Measurement environment.....	21
5.2.6 Measurement uncertainty.....	21
5.2.7 Measurement system.....	22
5.2.8 Test fixture .....	22
5.2.9 Measurement procedure .....	22
5.2.10 Example of measurement results .....	23
5.2.11 Remarks .....	23
5.3 Short-circuited microstrip line method .....	24
5.3.1 Principle .....	24
5.3.2 Measurement frequency and accuracy.....	25
5.3.3 Measurement parameters .....	25
5.3.4 Test sample.....	25
5.3.5 Measurement environment.....	26
5.3.6 Measurement system.....	26
5.3.7 Test fixture (MSL jig) .....	26
5.3.8 Measurement procedure .....	27
5.3.9 Results (example).....	27
5.3.10 Remarks .....	28
5.4 Short-circuited coaxial line method .....	28
5.4.1 Principle .....	28

ITEH STANDARD PREVIEW  
 (standards.iteh.ai)

<https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020>

5.4.2	Measurement frequency and accuracy .....	29
5.4.3	Measurement parameters .....	30
5.4.4	Test sample .....	30
5.4.5	Measurement environments .....	30
5.4.6	Measurement system .....	30
5.4.7	Test fixture (coax jig) .....	31
5.4.8	Measurement procedure .....	31
5.4.9	Results (example) .....	32
5.4.10	Remarks .....	33
5.5	Shielded loop coil method .....	33
5.5.1	Measurement principle .....	33
5.5.2	Measurement frequency and accuracy .....	38
5.5.3	Measurement parameters .....	39
5.5.4	NSS sample dimension and recommendation .....	39
5.5.5	Measurement environment .....	40
5.5.6	Measurement system .....	40
5.5.7	Measurement procedure .....	40
5.5.8	Measurement results .....	41
5.5.9	Summary .....	44
5.6	Harmonic resonance cavity perturbation method .....	45
5.6.1	Theory .....	45
5.6.2	Permeability evaluation .....	46
5.6.3	Permittivity evaluation .....	53
Annex A (informative)	Derivation of the complex relative permeability of the inductance method .....	59
Annex B (informative)	Short-circuited microstrip line method .....	61
B.1	Fundamental calculation .....	61
B.2	Determination of $C_S$ and $G_S$ .....	62
B.3	Determination of demagnetization factor $N$ and coupling coefficient $\eta$ .....	64
B.4	Analysis with the software to determine the $\mu_r$ .....	64
Annex C (informative)	Short-circuited coaxial line method .....	66
C.1	Fundamental calculation to determine $\mu_r$ .....	66
C.2	Open-circuited coaxial line .....	67
C.2.1	Measurement of effective permittivity $\varepsilon_r (\varepsilon'_r - j\varepsilon''_r)$ .....	67
C.2.2	Example of the complex permittivity .....	70
C.3	Remarks on lumped element approximation .....	71
Bibliography	.....	73
Figure 1	– In-plane and perpendicular measurement direction of NSS sample .....	11
Figure 2	– Toroidal-shaped sample cut from the NSS .....	12
Figure 3	– Test fixture with a toroidal-shaped NSS sample .....	13
Figure 4	– Equivalent circuit model of the test fixture .....	13
Figure 5	– Schematic diagram of measurement system .....	16
Figure 6	– Measurement results of NSS samples .....	17
Figure 7	– Schematic diagram of a test fixture with a sample and signal flow graph .....	18
Figure 8	– Cross section of coaxial line with NSS .....	20
Figure 9	– Dimensions of test sample .....	21

Figure 10 – Schematic diagram of equipment system for measurement .....	22
Figure 11 – Specification for test fixture of a 7 mm coaxial transmission line .....	22
Figure 12 – Measurement results of noise suppression sheet .....	23
Figure 13 – Equivalent circuits for the MSL .....	25
Figure 14 – Rectangular shape of NSS sample .....	26
Figure 15 – Measurement system .....	26
Figure 16 – Short-circuited microstrip line test fixture (MSL jig).....	27
Figure 17 – Complex relative permeability of a NSS sample C with 0,236 mm thickness, as measured at $N = 0$ (and $\eta = 0,135 2$ ) and corrected by demagnetization factor $N = 0,037$ (and $\eta = 0,135 2$ ) .....	28
Figure 18 – Equivalent circuits for the coax jig .....	29
Figure 19 – Toroidal shape of NSS sample .....	30
Figure 20 – Measurement system .....	31
Figure 21 – Short-circuited coaxial line test fixture (coax jig).....	31
Figure 22 – Complex relative permeability of a NSS sample A with 0,29 mm thickness, as measured and corrected by the permittivity .....	32
Figure 23 – Complex relative permeability of a NSS sample B with 0,25 mm thickness, as measured and corrected by the effective permittivity .....	33
Figure 24 – Structure of shielded loop coil .....	34
Figure 25 – Shielded loop coil and NSS sample arrangement .....	34
Figure 26 – Whole structure of the measuring unit of the equipment .....	35
Figure 27 – DC magnetization curve .....	38
Figure 28 – Estimation of absolute value correction coefficient $M'_s$ .....	38
Figure 29 – Recommended shape of NSS sample .....	39
Figure 30 – Block diagram of measurement system .....	40
Figure 31 – Measured complex relative permeability as a function of the size of a NSS sheet (Sample A-01) .....	42
Figure 32 – Measured complex relative permeability as a function of the size of a NSS sheet (Sample B-01) .....	43
Figure 33 – Measured complex relative permeability of a NSS sheet as a function of DC bias field intensity (Sample A-02).....	43
Figure 34 – Measured complex relative permeability after absolute value calibration (Sample A-01) .....	44
Figure 35 – Measured complex relative permeability after absolute value calibration (Sample B-01) .....	44
Figure 36 – Electromagnetic flux to evaluate permeability in the harmonic resonance cavity resonator .....	47
Figure 37 – Example of the resonance characteristics change .....	47
Figure 38 – Cavity resonator for 3,6 GHz to 7,2 GHz .....	48
Figure 39 – Cavity resonator for 0,25 GHz to 2 GHz .....	48
Figure 40 – Examples of resonance frequencies .....	49
Figure 41 – Example of the resonance curves of a harmonic resonance cavity .....	49
Figure 42 – Examples of samples .....	50
Figure 43 – Measuring system .....	50
Figure 44 – Sample installation in the cavity for the permeability measurement .....	51
Figure 45 – Measured results of the permeability for Sample A and B and a copper rod .....	53

Figure 46 – Electromagnetic flux to evaluate permittivity in the harmonic resonance cavity resonator .....	53
Figure 47 – Sample installation in the cavity for the permittivity measurement .....	55
Figure 48 – Adjustment procedure and adjusted results .....	56
Figure 49 – Measured results of the permittivity for the two samples, A and B .....	58
Figure B.1 – Complex relative permeabilities of Sample C with 0,236 mm thickness for toroidal shape and rectangular shape corrected by $N = 0,037$ and $\eta = 0,135\ 2$ .....	64
Figure B.2 – Complex relative permeabilities of Sample C with 0,236 mm thickness for rectangular shape corrected by $N = 0, 0,018\ 5$ and $0,037$ with $\eta = 0,135\ 2$ .....	65
Figure B.3 – Complex relative permeabilities of Sample C with 0,236 mm thickness for rectangular shape corrected by $\eta = 0,225\ 3, 0,169$ and $0,135\ 2$ with $N = 0,037$ .....	65
Figure C.1 – Open-circuited coaxial line jig .....	68
Figure C.2 – Equivalent circuits for the open-circuited coaxial line .....	68
Figure C.3 – Complex relative permittivity of NSS Sample A with 0,29 mm thickness, as measured and corrected by the permeability .....	71
Figure C.4 – Complex relative permittivity of NSS Sample B with 0,25 mm thickness, as measured and corrected by the permeability .....	71
Figure C.5 – Dependence of phase shift $\beta l$ on frequency .....	72
Table 1 – Measurement method and frequency .....	10
Table 2 – Measurement sample table .....	42

Iteh STANDARD PREVIEW  
(standards.iteh.ai)

[IEC TR 63307:2020](https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020)

<https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020>

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## MEASUREMENT METHODS OF THE COMPLEX RELATIVE PERMEABILITY AND PERMITTIVITY OF NOISE SUPPRESSION SHEET

### FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63307, which is a technical report, has been prepared by IEC technical committee 51: Magnetic components, ferrite and magnetic powder materials.

The text of this Technical Specification is based on the following documents:

Draft TR	Report on voting
51/1349/DTR	51/1356/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at [www.iec.ch/members\\_experts/refdocs](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/standardsdev/publications](http://www.iec.ch/standardsdev/publications).

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

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

**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 document using a colour printer.**

## **iTeh STANDARD PREVIEW** **(standards.iteh.ai)**

[IEC TR 63307:2020](#)

<https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020>

## INTRODUCTION

Noise suppression sheet (NSS) is used near the source of high frequency electromagnetic noise, path of noise propagation and source of emission. It is used like a patch and is different from an electromagnetic wave absorber in free space. IEC 62333-2 specifies five measurement methods in order to estimate the effect of NSS. To evaluate the effect by computer simulation, it is indispensable to know the frequency characteristics of both permeability and permittivity. And to make a rough estimate of the noise suppression effect of NSS, it is useful to understand effective permeability and effective permittivity, which are the permeability and permittivity of an actually used shape.

As most NSSs are flexible, and both complex relative permeability and complex relative permittivity have anisotropy, careful study and understanding of the principles are indispensable for the measurement of the frequency characteristics of permeability and permittivity.

There are various methods to measure permeability and permittivity under the frequency range where NSS is used. This document is intended to be used for the proper selection of the measurement method and the preparation of the test sample to achieve the above purpose when measuring permeability and permittivity, the two parameters which largely influence the noise suppression effect of the NSS.

## **iTeh STANDARD PREVIEW** **(standards.iteh.ai)**

[IEC TR 63307:2020](#)

<https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-5b171b8fca3b/iec-tr-63307-2020>

# MEASUREMENT METHODS OF THE COMPLEX RELATIVE PERMEABILITY AND PERMITTIVITY OF NOISE SUPPRESSION SHEET

## 1 Scope

This document provides guidelines on the methods for measuring the frequency characteristics of permeability and permittivity in the frequency range of 1 MHz to 6 GHz for a noise suppression sheet for each electromagnetic noise countermeasure.

## 2 Normative references

There are no normative references in this document.

## 3 Terms, definitions and symbols

### 3.1 Terms and definitions

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

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

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

#### 3.1.1

##### noise suppression

suppression which consists of signal decoupling, radiation suppression and attenuation of the transmission power of noise by an electronic product

Note 1 to entry: Each function above is achieved by absorption and/or shielding.

#### 3.1.2

##### noise suppression sheet

NSS

sheet which enables noise suppression and is composed of magnetic, dielectric or conductive material with electromagnetic losses

EXAMPLE Sheet made of soft magnetic metal powder and resin or rubber.

#### 3.1.3

##### suppression ratio

ratio of the noise level with and without suppression sheets

Note 1 to entry: The suppression ratio is classified into intra-decoupling ratio, inter-decoupling ratio, transmission attenuation power ratio and radiation suppression ratio. It is expressed in dB.

## 3.2 Symbols

$\mu_r$	complex relative permeability
$\mu_r'$	real part of complex relative permeability
$\mu_r''$	imaginary part of complex relative permeability
$\varepsilon_r$	complex relative permittivity

- $\epsilon'_r$  real part of complex relative permittivity
- $\epsilon''_r$  imaginary part of complex relative permittivity
- $Z$  impedance ( $\Omega$ )
- $\omega = 2\pi f$  angular frequency (rad/s)
- $I$  current (A)
- $B = \mu_0\mu_r H$  magnetic flux density (T)
- $H$  magnetic field strength (A/m)
- $\mu_0$  permeability of vacuum ( $4\pi \times 10^{-7}$  H/m)
- $f$  frequency

#### 4 General

Composite materials made by embedding magnetic metal flakes in a plastic sheet are widely used in PCs or mobile phone handsets. This sheet is well known as a noise suppression sheet (NSS) and is used to reduce unwanted signals in transmission lines or unwanted couplings between circuit elements in the devices described above.

Electromagnetic compatibility (EMC) designers recently have been using simulations for the design of the circuit boards for PCs and mobile phone handsets. In these simulations, it is important to know the complex relative permeability  $\mu_r$  and the complex relative permittivity  $\epsilon_r$  of NSS. This document shows the six measurement methods of  $\mu_r$  and  $\epsilon_r$  of NSS. The measurement frequency range is from 1 MHz to 6 GHz, as shown in Table 1. Figure 1 illustrates the in-plane and perpendicular measurement direction of Table 1.

<https://standards.iteh.ai/catalog/standards/sist/b6b1f532-c66b-4d77-bea5-14231e962b1c/iec-63307-2020>

**Table 1 – Measurement method and frequency**

Method Name	$\mu_r$ and $\epsilon_r$				Frequency				
	In-plane		Perpendicular		1 MHz to 10 MHz	100 MHz	1 GHz	10 GHz	100 GHz
	$\mu_r$	$\epsilon_r$	$\mu_r$	$\epsilon_r$					
5.1 Inductance	○				1 MHz to 1 GHz				
5.2 Nicolson Ross Weir	○	○					500 MHz to		
5.3 Short-circuited micro strip line	○				10 MHz to 10 GHz				
5.4 Short-circuited coaxial line	○	○			1 MHz to 18 GHz				
5.5 Shielded loop coil	○				1 MHz to 10 GHz				
5.6 Harmonic resonance cavity perturbation	○		○				250 MHz to 18 GHz		
		○		○				1,8 MHz	

Range of frequency (1 MHz to 6 GHz)

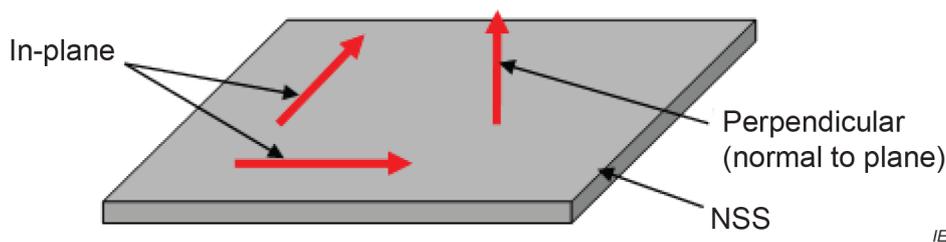


Figure 1 – In-plane and perpendicular measurement direction of NSS sample

## 5 Measurement methods

### 5.1 Inductance method

#### 5.1.1 Measurement parameters

The measurement parameters of a magnetic material are defined as follows:

$$\mu_r = \mu_r' - j\mu_r'' \quad (1)$$

where

$\mu_r'$  and  $\mu_r''$  are the real part and the imaginary part of the complex relative permeability, respectively.

#### 5.1.2 Measurement frequency and accuracy

The objective of this method is to evaluate the in-plane permeability of toroidal-shaped thin NSS samples shown in Figure 2 and is applicable for the measurements under the following conditions:

frequency	:	$1 \text{ MHz} \leq f \leq 1 \text{ GHz}$
relative permeability	:	$1 \leq \mu_r' \leq 1\,000$ $0 \leq \mu_r'' \leq 1\,000$
accuracy	:	value error $\pm 20\%$ for $\mu_r'$ value error $\pm 20\%$ for $\mu_r''$

The measurement frequency range is affected by the dimensions and the permeability values of the NSS sample. The higher the permittivity, the lower the upper limit of the frequency range will be.

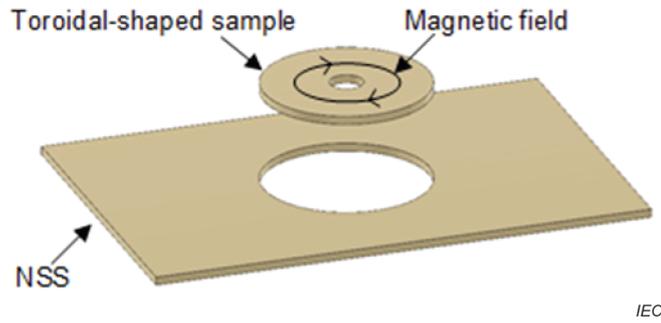


Figure 2 – Toroidal-shaped sample cut from the NSS

5.1.3 Measurement principle

The test fixture shown in Figure 3 forms the ideal one-turn inductor. The self-inductance is given by

$$\frac{Z}{j\omega} = \frac{1}{I} \int_S B ds \tag{2}$$

where

$Z$  is the impedance ( $\Omega$ );

$\omega = 2\pi f$  is the angular frequency (rad/s);

$I$  is the current (A);

$B = \mu_0 \mu_r H$  is the magnetic flux density (T);

$H$  is the Magnetic field strength (A/m);

$\mu_0$  is the permeability of vacuum ( $4\pi \times 10^{-7}$  H/m);

$S$  is the surface shown in Figure 3.

Therefore, the complex relative permeability is

$$\mu_r = \frac{2\pi Z_m - Z_{sm}}{\mu_0 j\omega F} + 1 = \frac{2\pi Z_{NSS}}{\mu_0 j\omega F} + 1 \tag{3}$$

or

$$\mu_r' = \frac{2\pi x_m - x_{sm}}{\mu_0 \omega F} + 1 = \frac{2\pi x_{NSS}}{\mu_0 \omega F} + 1 \tag{4}$$

$$\mu_r'' = \frac{2\pi r_m - r_{sm}}{\mu_0 \omega F} = \frac{2\pi r_{NSS}}{\mu_0 \omega F} \tag{5}$$

where

$Z_m = r_m + jx_m$  is the measured impedance with a sample;

$Z_{sm} = r_{sm} + jx_{sm}$  is the measured impedance without a sample (in short state);

$Z_{NSS} = r_{NSS} + jx_{NSS}$  is the impedance of a NSS sample;

$F = t \ln\left(\frac{b}{a}\right)$  is the shape factor of a sample, inner diameter  $a$ , outer diameter  $b$ , and thickness  $t$ .

$Z_{sm}$  is used to minimize errors due to residual impedance by compensation. The equivalent circuit model of the test fixture is shown in Figure 4.  $g_p + jb_p$  is the admittance of the test fixture and its effect can be neglected in a simplified case. Therefore, the impedance  $Z_{NSS}$  of a NSS sample is  $Z_m - Z_{sm}$ .

The derivation procedure is shown in detail in Annex A.

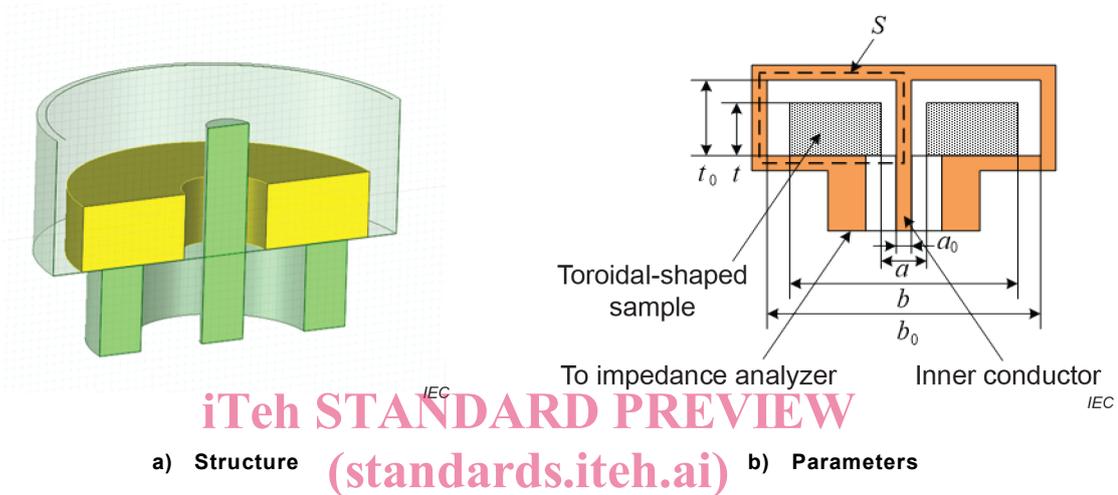


Figure 3 – Test fixture with a toroidal-shaped NSS sample

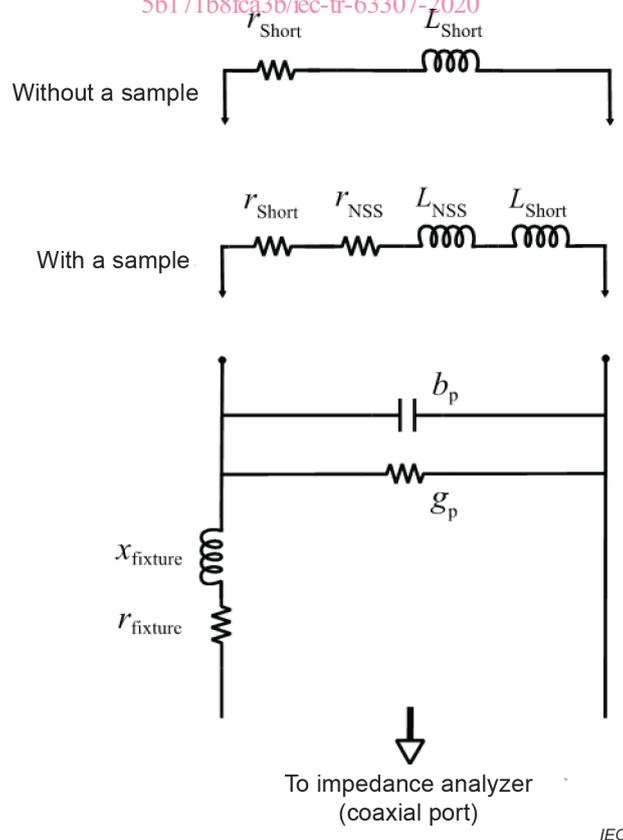


Figure 4 – Equivalent circuit model of the test fixture