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# Metallic coatings for electromagnetic interference shielding — Designation and characterization method

*Revêtements métalliques pour le blindage contre les interférences électromagnétiques — Désignation et méthode de caractérisation*

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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 107, *Metallic and other inorganic coatings*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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# Introduction

This document was developed to provide the designation of characteristics and the characterization methods of metallic coatings for electromagnetic interference (EMI) shielding, in response to worldwide demand for the standardization of such products.

ISO 17334 specifies the requirements for autocatalytic copper coatings plus nickel-phosphorous alloy coatings on platable plastics or metallic materials, to provide EMI and electrostatic discharge (ESD) shielding mainly for the housing of computers, telecommunication and other devices. However, varieties of metallic coatings, which are not specified in ISO 17334, are used to provide higher EMI/ESD shielding effectiveness in a wider frequency range. In particular, metallic coatings with a larger thickness or with a higher permeability are used to provide higher EMI/ESD shielding effectiveness in automobile parts and mobile communication devices.

A number of electronic controlling units (ECUs), motors and connectors are used in a car. Their housings and covers are made from engineering plastics for mass reduction and varieties of metallic coatings are applied to these parts to provide a high EMI/ESD shielding effectiveness.

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# Metallic coatings for electromagnetic interference shielding — Designation and characterization method

## 1 Scope

This document specifies the designation and the characterization methods metallic coatings that provide electromagnetic interference (EMI) shielding for parts fabricated from plastics, ceramics, glasses and other materials.

The designation consists of the EMI shielding effectiveness in a specific frequency range and the adhesion of metallic coatings to the substrate, as well as the substrate material and the principal component, manufacturing process and thickness of the metallic coatings.

The characterization methods consist of the methods to determine the EMI shielding effectiveness of metallic coatings and those to evaluate the adhesion of metallic coatings to the substrate.

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## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 472, *Plastics — Vocabulary*

ISO 2080, *Metallic and other inorganic coatings — Surface treatment, metallic and other inorganic coatings — Vocabulary*

ISO 4525, *Metallic coatings — Electroplated coatings of nickel plus chromium on plastics materials*

ISO 16348, *Metallic and other inorganic coatings — Definitions and conventions concerning appearance*

IEC 60050, *International electrotechnical vocabulary*

ASTM B533, *Standard test method for peel strength of metal electroplated plastics*

JIS H 8630, *Electroplated coatings on plastics materials for decorative purposes*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472, ISO 2080, ISO 16348 and IEC 60050 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

**3.1**
**ABS**
**acrylonitrile-butadiene-styrene**
plastic, based on terpolymers and/or blends of polymers and copolymers, made with acrylonitrile, butadiene and styrene

[SOURCE: ISO 472:2013, 2.5]

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**3.2**
**EMI shielding effectiveness**
**electromagnetic interference effectiveness**
ratio of voltage signals transmitted by the samples with and without metallic coatings for the same incident power of electromagnetic waves

**3.3**
**LCP**
**liquid crystal plastic**
plastic material with the property of liquid crystal

**3.4**
**PBT**
**polybutylene terephthalate**
polymer made by the polycondensation of butylene glycol and terephthalic acid or dimethyl terephthalate

[SOURCE: ISO 472:2013, 2.729]

**3.5**
**PTFE**
**polytetrafluoroethylene**
polymer of tetrafluoroethylene

[SOURCE: ISO 472:2013, 2.796]

**3.6**
**TRL calibration method**
**through-reflect-line calibration method**
calibration method to fix the systematic errors with the network analyser measurements using a zero-length "through", a longer "through" (called "line") and high-reflect standards

**3.7**
**VNA**
**vector network analyser**
instrument to measure the transfer and/or impedance characteristics, that is, both magnitude and phase changes, of a linear network, device, or material through stimulus response testing over a given frequency range

## 4 Designation

### 4.1 General

A designation shall consist of the following:

a) the letters "SdM" as the elementary symbol indicating that the metallic coating has the ability for EMI shielding effectiveness (see 4.2);

b) a letter designating the frequency band classification (see 4.3.1);

c) the letter "S" and a number designating the EMI shielding effectiveness (see 4.3.2) followed by a solidus (/);

d) the letter "A" with lowercase letters designating the adhesion test method and a number designating the adhesion of the metallic coatings (see 4.4) followed by a solidus (/);

e) letters designating the substrate materials (see 4.5) followed by a solidus (/);

f) an elemental symbol of the principal component element of the coatings with lowercase letters designating the coating process (see 4.6);

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g) a number indicating the minimum local thickness in micrometres, followed by a space when the subsequent metallic coating is applied.

For multi-layered metallic coatings, designations f) and g) shall be repeated from the bottom to the top.

See 4.6 for examples of designations.

## 4.2 Shielding effectiveness of electromagnetic waves

### 4.2.1 Frequency classification

The letters shown in Table 1 shall designate the frequency bands of the electromagnetic waves under consideration.

**Table 1 — Designation of frequency bands under consideration**

| Designation | Frequency band of the electromagnetic waves under consideration[a] Hz | General identification |
|---|---|---|
| A | 50 to 60 | Ultra-low frequency wave[b] |
| B | $(3{,}0 \times 10^3)$ to $(3{,}0 \times 10^4)$ | Very low frequency wave |
| C | $(3{,}0 \times 10^4)$ to $(3{,}0 \times 10^5)$ | Low frequency wave |
| D | $(3{,}0 \times 10^5)$ to $(3{,}0 \times 10^6)$ | Medium wave |
| E | $(3{,}0 \times 10^6)$ to $(3{,}0 \times 10^7)$ | Short wave |
| F | $(3{,}0 \times 10^7)$ to $(3{,}0 \times 10^8)$ | Very high frequency wave |
| G | $(3{,}0 \times 10^8)$ to $(3{,}0 \times 10^9)$ | Ultra-high frequency wave |
| H | $(3{,}0 \times 10^9)$ to $(3{,}0 \times 10^{10})$ | Centimetre wave |
| I | $(3{,}0 \times 10^{10})$ to $(3{,}0 \times 10^{11})$ | Millimetre wave |
| J | $(3{,}0 \times 10^{11})$ to $(3{,}0 \times 10^{12})$ | Sub-millimetre wave |

[a] Lower limit exclusive, upper limit inclusive.

[b] Frequency of commercial power source.

### 4.2.2 Electromagnetic interference shielding effectiveness

The letter “S” and a number shall designate the EMI shielding effectiveness as shown in Table 2.

**Table 2 — Designation of EMI shielding effectiveness**

| Designation | Shielding effectiveness[a] dB |
|---|---|
| S- | 31 or below |
| S35 | 31 to 35 |
| S40 | 36 to 40 |
| S50 | 41 to 50 |
| S60 | 51 to 60 |
| S70 | 61 to 70 |
| S80 | 71 to 80 |
| S90 | above 80 |

[a] Lower limit exclusive, upper limit inclusive.

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## 4.3 Adhesion of metallic coatings

### 4.3.1 General

The letters shown in Table 3 and Table 4 shall designate the adhesion of metallic coatings.

**Table 3 — Designation of peel strength test**

| Designation | Peel strength[a] kN/m |
|---|---|
| $A_P1{,}0$ | 1,0 or above |
| $A_P0{,}9$ | 0,9 to 1,0 |
| $A_P0{,}8$ | 0,8 to 0,9 |
| $A_P0{,}7$ | 0,7 to 0,8 |
| $A_P0{,}6$ | 0,6 to 0,7 |
| $A_P0{,}5$ | 0,5 to 0,6 |
| $A_P0{,}4$ | 0,4 to 0,5 |
| $A_P0{,}3$ | 0,3 to 0,4 |
| $A_P$- | below 0,3 |
| [a] Lower limit inclusive, upper limit exclusive. | |

### 4.3.2 Peel strength

The letter "A" with a lowercase letter "P" and a number shall designate the adhesion of metallic coatings evaluated by a peel test (see 5.2). The number designates the peel strength as shown in Table 3.

### 4.3.3 Thermal cycle

The letter "A" with lowercase letters "TC" and a number shall designate the adhesion of metallic coatings assessed by a thermal cycle test as shown in Table 4. The number shall denote the service condition number determining the condition of thermal cycle test as specified in ISO 4525 and shall show the test condition in which the product does not constitute a failure (see 5.2).

**Table 4 — Designation of thermal cycle test**

| Designation | Service condition number[a] | Temperature limits °C | |
|---|---|---|---|
| | | High | Low |
| $A_{TC}5$ | 5 | 85 | −40 |
| $A_{TC}4$ | 4 | 80 | −40 |
| $A_{TC}3$ | 3 | 80 | −30 |
| $A_{TC}2$ | 2 | 75 | −30 |
| $A_{TC}1$ | 1 | 60 | −30 |
| [a] Service condition numbers in a thermal cycle test are defined in ISO 4525. | | | |

## 4.4 Substrate materials

The letters shown with lowercase letters as shown in Table 5 shall designate the substrate materials.

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**Table 5 — Designation of substrate materials**

| Designation | Substrate material |
|---|---|
| $PL_{XXX}$[a] | Plastics |
| GL[b] | Glasses |
| CE[b] | Ceramics |
| OM[b] | Other materials |

[a] XXX should be replaced by the relevant abbreviated term for the plastics material (see ISO 472 or Clause 3). For other materials, a conventional abbreviated term should be shown accompanied by a note explaining the abbreviated term in a separate line below the designation.

[b] The note explaining the specific material may be given in a separate line below the designation.

EXAMPLE 1 Polybutylene terephthalate is designated as $PL_{PBT}$.

EXAMPLE 2 Polyamide resin is designated as $PL_{PA}$ (where "PA" means polyamide resin).

## 4.5 Metallic coatings

An elemental symbol shall designate the principal element of the metallic coating, i.e. those of metal or alloy coatings, and the subsequent lowercase letters shall designate the coating processes as shown in Table 6. The following number shall indicate the minimum local thickness of the metallic coating in micrometres. The thickness shall be rounded off to one decimal place.

**Table 6 — Processes for metallic coatings**

| Designation | Process |
|---|---|
| VE | Vacuum evaporation |
| SP | Sputtering |
| EL | Electroless plating[a] |
| EP | Electroplating |
| OP | Other process |

[a] Electroless plating includes autocatalytic plating and immersion coating (see ISO 2080).

## 4.6 Examples of designation

An autocatalytic copper coating of 1,0 µm thickness plus autocatalytic nickel-8 % phosphorous alloy coating in thickness of 0,25 µm on an ABS substrate, which shows an electromagnetic shielding effectiveness of 80 dB at frequencies from 30 MHz to 3 GHz and a coating adhesion assessed by the thermal cycle test corresponding to service condition 2, shall have the following designation:

SdM F S80/$A_{TC}$2/$PL_{ABS}$/ $Cu_{EL}$1,0 $Ni_{EL}$0,3

SdM G S80/$A_{TC}$2/$PL_{ABS}$/ $Cu_{EL}$1,0 $Ni_{EL}$0,3

NOTE These coatings and their performance correspond to autocatalytic coating type 1 Grade 3 in ISO 17334.

A sputter deposited copper coating of 0,6 micrometre thickness plus electroplated copper coating of 3,0 micrometre thickness plus electroplated nickel coating of 20,0 micrometre thickness on a PBT substrate, which shows an electromagnetic shielding effectiveness of 72,7 dB and 101,4 dB at 1 GHz and 100 GHz, respectively, and a peel strength of 0,89 kN/m, shall have the following designation (see Annexes A and B):

SdM G S80/$A_P$0,8/$PL_{PBT}$/ $Cu_{SP}$0,6/ $Cu_{EP}$3,0 $Ni_{EP}$20,0

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SdM I S90/$A_P$0,8/$PL_{PBT}$/ $Cu_{SP}$0,6/ $Cu_{EP}$3,0 $Ni_{EP}$20,0

An electrolessly deposited copper coating of 0,6 µm thickness, an electroplated copper coating of 3,0 µm thickness and an electroplated nickel coating of 1,0 µm thickness on a LCP substrate, shows an electromagnetic shielding effectiveness of 75,3 dB and 106,3 dB at 1 GHz and 100 GHz, respectively, and a peel strength of 0,88 kN/m, shall have the following designation (see Annexes A and B):

SdM G S80/$A_P$0,8/$PL_{LCP}$/ $Cu_{EL}$0,6/ $Cu_{EP}$3,0 $Ni_{EP}$1,0

SdM I S90/$A_P$0,8/$PL_{LCP}$/ $Cu_{EL}$0,6/ $Cu_{EP}$3,0 $Ni_{EP}$1,0

# 5 Characterization methods

## 5.1 Electromagnetic interference shielding effectiveness

The EMI shielding effectiveness is expressed in dB and is defined by Formula (1) with the shielding effectiveness, $S$, in dB:

$$S = 20\log\left(\frac{V_2}{V_1}\right) \tag{1}$$

where

$S$ is the EMI shielding effectiveness;

$V_1$ is the received voltage transmitted by the sample with metallic coatings;

$V_2$ is the received voltage transmitted by the sample without metallic coatings.

The EMI shielding effectiveness for an electromagnetic wave of a frequency of ($3,0 \times 10^9$) Hz or below, corresponding to the frequency band designation of A to G shown in Table 1, should be evaluated by using the coaxial transmission line measurement configuration based on ASTM D4935-18.

The EMI shielding effectiveness for an electromagnetic wave of frequency above ($3,0 \times 10^9$) Hz, corresponding to the frequency band designation of H, I and J shown in Table 1, should be evaluated by using the free-space measurement configuration based on IEC 62431.

Examples of EMI shielding effectiveness measurements are given in Annex A.

## 5.2 Adhesion of metallic coatings

The adhesion of metallic coatings on insulating substrates shall be evaluated by a peel test or a thermal cycle test.

The peel test measures the force required to peel a metallic coating from a substrate. The procedures of the peel test should be based on JIS H 8630 or ASTM B533.

NOTE There are no International Standards specifying the procedures of a peel test. Examples of a peel test are given in Annex B.

The thermal cycle test assesses the adhesion of metallic coatings and monitors the effectiveness of processes for preparing substrates for metallic coatings. Procedures and temperature limits for specific service conditions of the thermal cycle test should be based on ISO 4525. After having been subjected to three cycles of the thermal cycle test, the metallic coatings of samples shall show no visible defects such as cracking, blistering, peeling, sink marks or distortion in accordance with ISO 4525.

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## 5.3 Sampling

The method of sampling should be selected from the procedures given in ISO 4519. When the size of the products does not fit to the device for characterization, the specially made samples of which sizes are fit to the characterization devices may be used instead of the products. Planar samples should be used in the EMI shielding effectiveness measurements. The samples for shielding effectiveness measurements shall have the same materials and the same coating configurations prepared with the same processes as the products.

The samples for the peel tests shall be planar and shall have a thick electroplated copper coating as specified in JIS H 8630 or ASTM B533. The electroplated copper coating shall be applied after the bottom coating by using the same process as the products, which enhances the adhesion, and shall replace the upper coating layers of the products.

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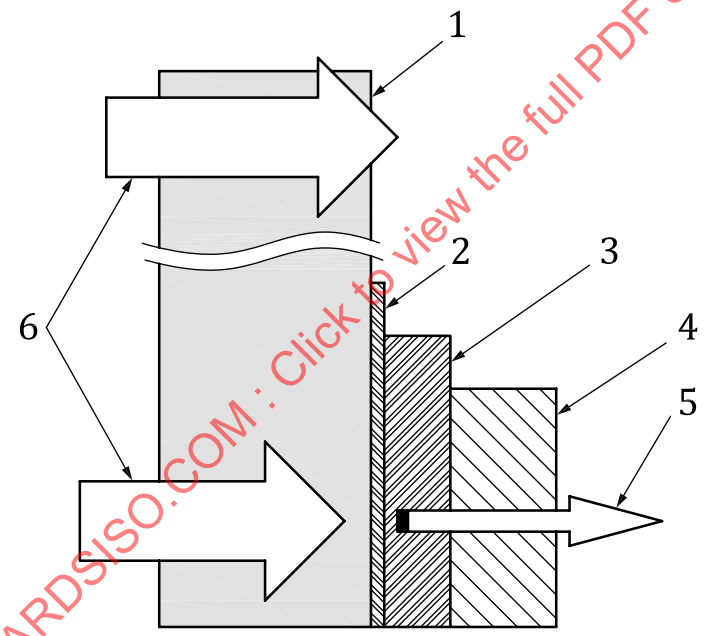
# Annex A
(informative)

# Examples of shielding effectiveness measurement of metallic coatings

## A.1 Principle

This annex gives measurement methods of the EMI shielding effectiveness of metallic coatings. The shielding effectiveness obtained from multi-layered metallic coatings on a plastics substrate for electromagnetic waves of 1 GHz and 100 GHz in normal incidence are presented. The multi-layered metallic coating consist of a copper bottom layer as the seed for subsequent processes, a second copper layer to give the conductivity and a nickel top layer as the magnetic/protective layer.

Figure A.1 shows a schematic illustration of EMI shielding effectiveness measurement.

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**Key**

1 LCP or PBT substrate
2 Cu bottom layer
3 Cu second layer
4 Ni top layer
5 received voltage transmitted by the sample with metallic coatings (see 5.1), $V_1$
6 received voltage transmitted by the sample without metallic coatings (see 5.1), $V_2$

**Figure A.1 — Schematic presentation of EMI shielding measurement and configuration of multi-layered metallic coatings**


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## A.2 Sample

Samples with copper plus nickel multi-layered metallic coatings on LCP or PBT substrates were prepared for EMI shielding effectiveness measurements (see Figure A.1).

Table A.1 shows the detailed information of configurations of multi-layered metallic coatings. The designations of substrates and metallic coatings of these samples are shown in Table A.2.

**Table A.1 — Configuration of samples**

| Sample name | Substrate | Cu bottom layer | | Cu second layer | | Ni top layer | |
|---|---|---|---|---|---|---|---|
| | | Process | Thickness µm | Process | Thickness µm | Process | Thickness µm |
| LCP-1 | LCP | EL[a] | 0,6 | EP | 3,0 | EP | 1,0 |
| LCP-2 | LCP | SP[b] | 0,6 | EP | 3,0 | EP | 1,0 |
| LCP-3 | LCP | EL[a] | 0,6 | EP | 3,0 | EP | 20,0 |
| LCP-4 | LCP | SP[b] | 0,6 | EP | 3,0 | EP | 20,0 |
| PBT-1 | PBT | EL[a] | 0,6 | EP | 3,0 | EP | 1,0 |
| PBT-2 | PBT | SP[b] | 0,6 | EP | 3,0 | EP | 1,0 |
| PBT-3 | PBT | EL[a] | 0,6 | EP | 3,0 | EP | 20,0 |
| PBT-4 | PBT | SP[b] | 0,6 | EP | 3,0 | EP | 20,0 |

[a] Conditions of electroless plating of Cu bottom layer are shown in Reference [5].

[b] Conditions of sputtering of Cu bottom layer are shown in Reference [6].

## A.3 Method

### A.3.1 Coaxial transmission line measurement

An electromagnetic signal was transmitted via coaxial adapter to measure the shielding effectiveness by a VNA as shown in Figure A.2. The measurement frequency was fixed to 1 GHz by coaxial line.

The measurement configuration is similar to the test method described in ASTM D4935-18. All measurements were performed at the Research Institute of Physical Measurement in the National Institute of Advanced Industrial Science and Technology, Japan[7].

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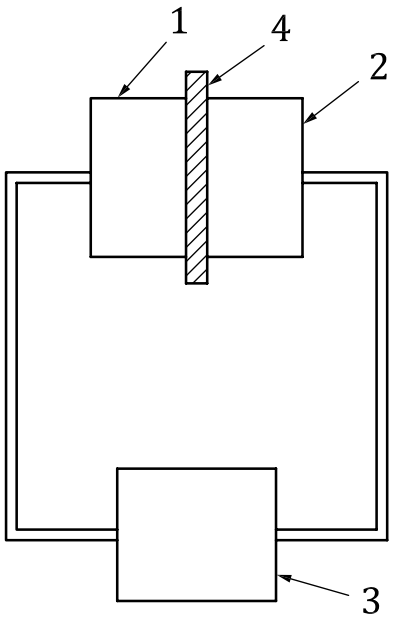


**Key**

1 coaxial adapter
2 coaxial adapter
3 VNA
4 sample

**Figure A.2 — Coaxial transmission line measurement set-up**

### A.3.2 Free-space measurement

An electromagnetic signal was focused by antennas in microwave and mm-wave frequencies in order to measure the shielding effectiveness by VNA (see Figure A.3). The antenna position was adjusted by a micrometre. The measurement frequency was fixed to 100 GHz by adjusting the position of waveguide antenna.

The measurement configuration is similar to the test method described in IEC 62431. All measurements were performed at the Research Institute of Physical Measurement in the National Institute of Advanced Industrial Science and Technology, Japan[7].

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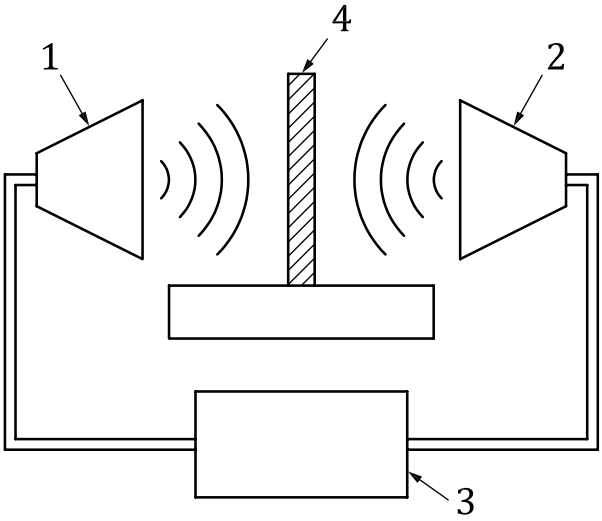


**Key**

1 transmitting antenna
2 receiving antenna
3 VNA
4 sample

**Figure A.3 — Free-space measurement set-up**

### A.3.3 Calibration

In both the coaxial transmission line and free-space systems, the TRL calibration method described in IEC 62431 was adopted to measure the shielding effectiveness. In the TRL calibration, three different types of standards (i.e. through, reflect and line) are measured in the calibration scheme.

## A.4 Results

The EMI shielding effectiveness of the samples shown in Table A.1 was measured at 1 GHz and 100 GHz. The measurement results at 1 GHz and 100 GHz are shown in Figures A.4 and A.5, respectively, and are summarized in Table A.2.

EMI shielding effectiveness at 1 GHz lies between 68 dB to 90 dB for all the samples but is slightly smaller than those at 100 GHz. Effects of substrate materials and coating thickness are not observed.

The shielding effectiveness of all the samples is significantly high at 100 GHz. Seven samples show the shielding effectiveness higher than 100 dB, while PBT-3 (i.e. the sample $Cu_{EL}$0,6 $Cu_{EP}$2,0 $Ni_{EP}$20,0 on PBT) shows the shielding effectiveness of 90,4 dB.

Sufficiently high shielding effectiveness of all the samples is successfully measured by using the methods shown in 5.1 and described in Clause A.3. These samples show high shielding effectiveness due to the metallic coatings of rather large thickness and with high adhesion to the substrate.

The designations of the EMI shielding effectiveness of these samples are summarized in Table A.2.

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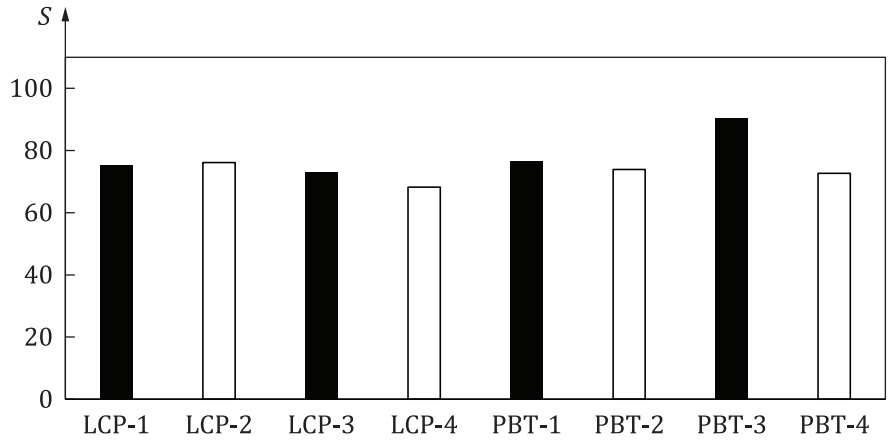
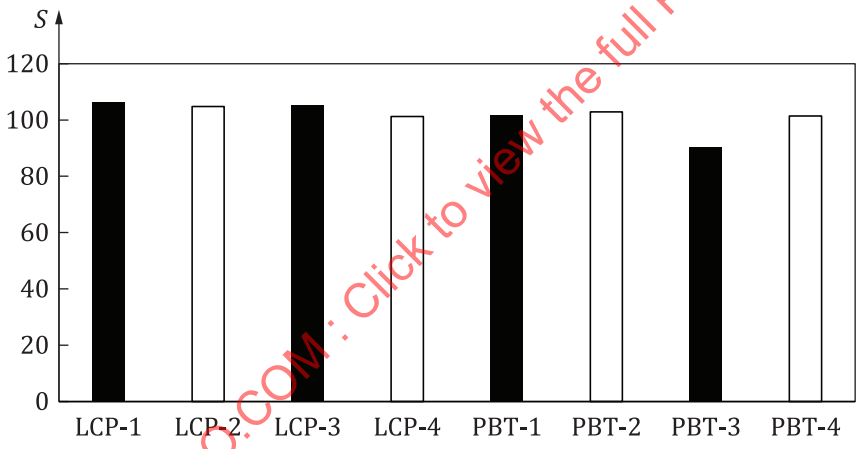



**Key**

*S* shielding effectiveness in dB

NOTE LCP-1, LCP-2, LCP-3, LCP-4, PBT-1, PBT-2, PBT-3, PBT-4 are explained in Table A.1.

**Figure A.4 — Electromagnetic shielding effectiveness at 1 GHz measured using coaxial transmission line set-up**




**Key**

*S* shielding effectiveness in dB

NOTE LCP-1, LCP-2, LCP-3, LCP-4, PBT-1, PBT-2, PBT-3, PBT-4 are explained in Table A.1.

**Figure A.5 — Electromagnetic shielding effectiveness at 100 GHz measured using free-space set-up**

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**Table A.2 — Summary of shielding effectiveness and their designations**

| Sample name | Designation of substrates and metallic coatings[a] | Shielding effectiveness | | Designation of shielding effectiveness[b] |
|---|---|---|---|---|
| | | at 1 GHz dB | at 100 GHz dB | |
| LCP-1 | $PL_{LCP}$ / $Cu_{EL}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$1,0 | 75,3 | 106,3 | G S80<br>I S90 |
| LCP-2 | $PL_{LCP}$ / $Cu_{SP}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$1,0 | 76,1 | 104,8 | G S80<br>I S90 |
| LCP-3 | $PL_{LCP}$ / $Cu_{EL}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$20,0 | 73,1 | 105,3 | G S80<br>I S90 |
| LCP-4 | $PL_{LCP}$ / $Cu_{SP}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$20,0 | 68,2 | 101,2 | G S70<br>I S90 |
| PBT-1 | $PL_{PBT}$ / $Cu_{EL}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$1,0 | 76,6 | 101,9 | G S80<br>I S90 |
| PBT-2 | $PL_{PBT}$ / $Cu_{SP}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$1,0 | 73,9 | 102,9 | G S80<br>I S90 |
| PBT-3 | $PL_{PBT}$ / $Cu_{EL}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$20,0 | 90,2 | 90,4 | G S90<br>I S90 |
| PBT-4 | $PL_{PBT}$/ $Cu_{SP}$0,6 $Cu_{EP}$3,0 $Ni_{EP}$20,0 | 72,7 | 101,4 | G S80<br>I S90 |

[a] See 4.5 and 4.6.

[b] See 4.3.

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# Annex B
(informative)

# Examples of adhesion measurement of metallic coatings — Peel strength and substrate surface roughness

## B.1 Principle

This annex gives the results of a peel test of the metallic coatings on plastics and glass substrates for EMI shielding and presents the relationship between the peel strength and surface roughness of the substrate. The multi-layered copper plus nickel coatings used in the measurements of EMI shielding effectiveness shown in Annex A were not applied. Only a thick copper coating was applied on the basis of JIS H 8630 and ASTM B533. A thick copper coating was electroplated on the copper bottom coating layer as the seed for the subsequent coating process.

To obtain the copper seed layer on a plastics or glass substrate, surface conditioning of substrate specific to the substrate materials and to the coating process was applied. The surface conditioning for electroless plating was chemical etching/catalysing and for sputtering was plasma treatments. These surface conditioning processes can cause changes in the surface roughness and/or in surface chemical states of the substrate, and can affect the adhesion of coatings. Surface roughness of the substrate with and without the surface conditioning was examined.

## B.2 Sample

### B.2.1 Substrate

As the plastics substrate, planar ABS, PBT, LCP and PTFE were used. ABS resin is known as a platable substrate as shown in Reference [8], while PBT, LCP and PTFE are relatively difficult to plate. Glass substrate is a flat alkaline-free glass called “E-glass”, which is also difficult to plate.

### B.2.2 Sample for peel strength measurements

Copper coating in a thickness of 30 µm was electroplated on the plastics or glass substrate with 0,6-µm-thick copper seed layer, on the basis of JIS H 8630 and ASTM D-4935 (see Figure B.1).

Detailed configurations of metallic coatings are listed in Table B.1.

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