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INTERNATIONAL STANDARD

colour inside

Printed electronics –
Part 202-3: Materials – Conductive ink – Measurement of sheet resistance of conductive films – Contactless method

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FOREWORD

International Standard IEC 62899-202-3 has been prepared by IEC technical committee 119: Printed Electronics.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
119/240/FDIS	119/246/RVD

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

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

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, can be found on the IEC website.

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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

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.

INTRODUCTION

Conductive films, transparent or non-transparent, are a key element for electronic products. A widespread method used for the measurement of the sheet resistance of conductive films is the 4-point probe measurement. Nevertheless, making an electrical contact with the probes is sometimes critical for the measurement. For some devices or films which are covered with an insulating layer or composed of micro-/nano-structures, establishing an electrical contact is difficult, which makes the 4-point probe method not suitable for the measurement of sheet resistance (see Table A.1 and Figures A.1 and A.2 in Annex A). The 4-point probe method is also sensitive to contact force and layer thickness. The eddy-current-based measurement method, which does not require electrical contact, is widely used for this purpose in the industry. This document specifies a standard method for measurement of sheet resistance using a contactless eddy-current method.

PRINTED ELECTRONICS –

Part 202-3: Materials – Conductive ink – Measurement of sheet resistance of conductive films – Contactless method

1 Scope

This part of IEC 62899 defines terms and specifies a standard method for the measurement of the sheet resistance of printed conductive films using a contactless eddy-current method.

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.

IEC 62899-202, *Printed electronics – Materials – Part 202: Conductive ink*

3 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
sheet resistance
R_s
electrical resistance of a thin film material measured across the opposite ends of a square area

Note 1 to entry: The unit of sheet resistance is expressed in ohms (Ω). However, for the purpose of this procedure, it represents the unit of ohms per square with the thickness of the film.

[SOURCE: IEC TS 61836:2016, 3.4.81, modified – the second sentence of the note has been added.]

3.2
eddy current
electric current induced within conductors by a time-varying magnetic field in the conductor

3.3
4-probe measurement
method to measure the resistance of a material whose measured value is independent on the probe resistance

Note 1 to entry: In this method, 4 probes contact the test sample in a linear arrangement. A voltage drop is measured between the two inner probes while a current source supplies current through the outer probes. The resistance of the sample can be calculated by Ohm's law. Furthermore, the resistivity of the sample can be obtained by consideration of the geometric factors of the sample.

[SOURCE: IEC TS 62607-2-1:2012, 2.1.6]

3.4
4-point measurement
type of 4-probe measurement defined in 3.3 in which a pointed electric tip is used as a probe

Note 1 to entry: A 4-point measurement is generally used to measure the sheet resistance of a thin film sample with relatively large width compared to the spacing between the probes.

[SOURCE: IEC TS 62607-2-1:2012, 2.1.8, modified – the reference to the term number in the definition has been changed.]

4 Background to the eddy-current method

When a conductive material is placed in an oscillating magnetic field generated by an RF generator unit as shown in Figure 1, it sets up eddy current in the material, which leads to Joule heating. Power absorbed in this process, assuming no flux leakage and negligible skin effect phenomena, is shown as follows [1, 2][1]:

$$P_\mathrm{S} = (U_\tau^2 / 8\pi n^2)\sigma t \qquad (1)$$

where

U_τ = RMS primary RF voltage

n = number of primary turns on the ferrite core

σ = conductivity of the sample

t = thickness of the sample.

The significant point is that the power absorbed is directly proportional to σt, that is, conductivity times thickness.

The system includes a feedback system to hold U_τ constant by adjusting the in-phase RF drive current I_τ. Then the power flowing into the sample can be monitored by noting the change in the RF drive current itself [2]:

$$P_\mathrm{S} = U_\tau I_\tau = (U_\tau^2 / 8\pi n^2)\sigma t \qquad (2)$$

or

$$I_\tau = (U_\tau / 8\pi n^2)\sigma t \qquad (3)$$

In general, the coupling from the RF unit to the sample is not unity, due to the existence of flux leakage arising from the finite permeability of the ferrite core. This reduces the dependence of I_τ on σt, but the relation remains linear [2]:

$$I_\tau = K(U_\tau / n^2)\sigma t \qquad (4)$$

where K is a constant involving the coupling parameters of the core. The conductivity of the sample is obtained from this linear relationship.

---

1 Numbers in square brackets refer to the Bibliography.

5 Specimen

5.1 Specimen

The specimen shall be a conductive layer with the sheet resistance of 0,01 ohms per square to 1 000 ohms per square. The thickness of the film shall be 5 nm or thicker (see Table C.1 in Annex C). The layer shall be a continuous one. There shall be no underlying conductive layer or pattern which can influence the magnetic field.

5.2 Substrate

The substrate shall be an insulated material such as polymers, paper, glass, etc. The effective sheet resistance of the substrate (bulk resistivity divided by the thickness in centimeters) shall be at least 1 000 times that of the film.

5.3 Defects

The specimen shall be visually inspected before the test. It shall not include any void, dirt, oil, scratch, and other defects.

NOTE The surface can be inspected with additional instruments such as thermography.

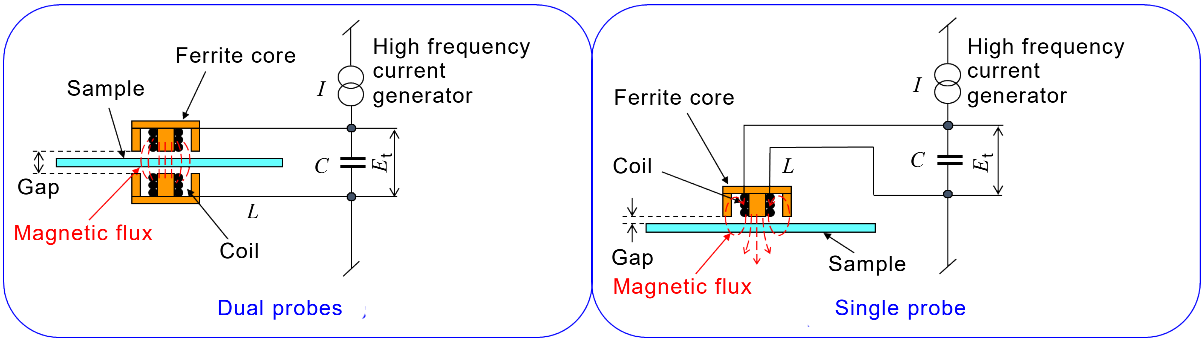
5.4 Size

The size of the specimen shall be at least twice greater than the size of the probe, considering the spread of the magnetic flux from the probe.

6 Apparatus

6.1 General

The apparatus for an eddy-current gauge consists of a high frequency current generator and probe(s) made of ferrite core and wound with coil. For reliable measurement of a wide range of resistance, it is recommended that the frequency of the RF generator cover a broad range (40 kHz to 10 MHz). There are two types of eddy-current gauges, dual and single probes, as shown in Figure 1. In a dual type apparatus, the magnetic flux flows from the top probe to the bottom one, while in the single probe type apparatus, it flows from the inner core to the outer ring. Both types may be used for measurement, since the data from both types of apparatus does not show significant difference (see Table 1).



Key

C Capacitor

I Current

L: Inductor

E_t High frequency voltage

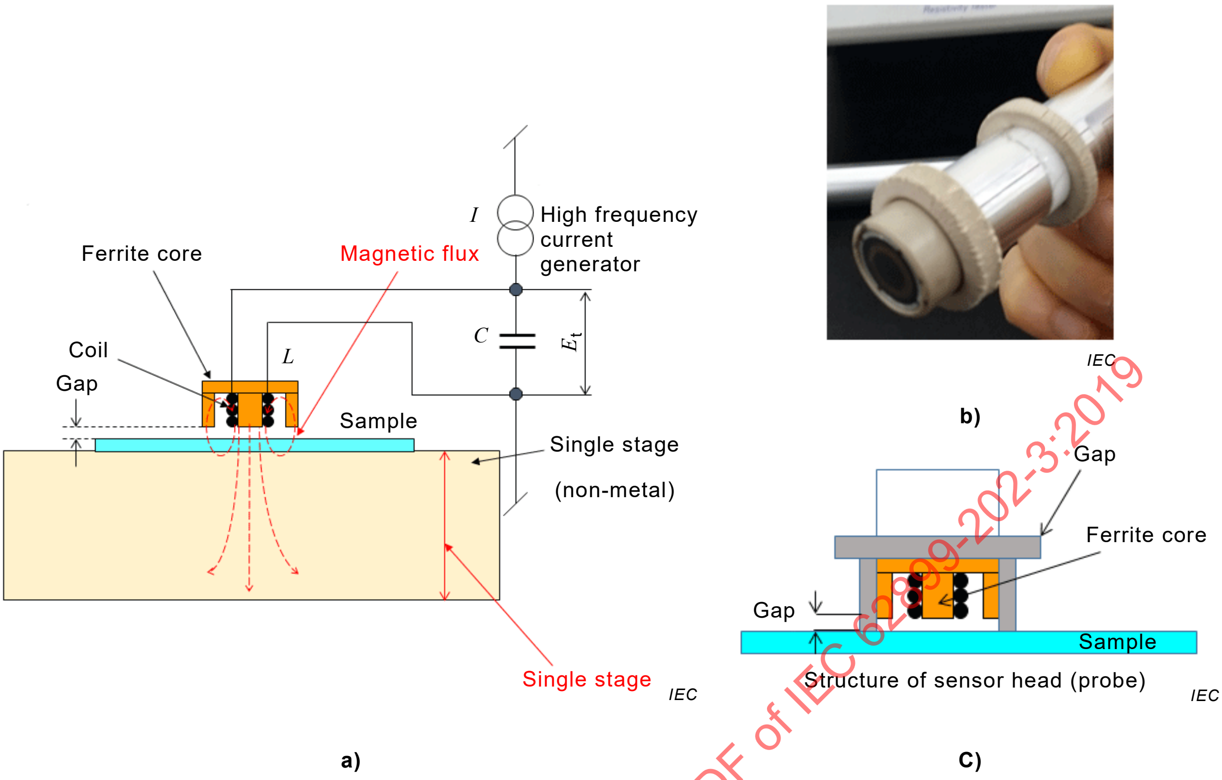
Figure 1 – Schematic diagram of eddy-current probe apparatus (left: dual, right: single)

Table 1 – Comparison between dual and single probes

	Dual probes [ohms per square]	Single probe [ohms per square]
1	75,75	74,83
2	75,79	74,75
3	76,28	75,36
4	76,32	75,20
5	76,28	74,83
6	75,87	75,08
7	76,09	75,68
8	75,94	75,43
9	76,24	75,18
10	75,97	75,84
AVG	76,05	75,22

6.2 Sample stage

For a single probe type apparatus, the specimen shall be placed on the stage of an insulating material (see Figure 2). If the stage is positioned on a stand table made of metal, the thickness of the insulating stage or separation between the sample and the metal table shall be 50 mm or greater. If less than 50 mm, eddy current could be generated in the metallic table, and would influence the result of the measurement (see Figure 2).



Key

C Capacitor

I Current

L: Inductor

E_t High frequency voltage

Figure 2 – Apparatus on a stand table (single probe type)

6.3 Gap

It should be noted that the eddy current could change depending on the distance between the ferrite core and sample. For the single probe type, when the probe is placed on the sample surface, the gap is fixed to the thickness of the cap (e.g., 0,5 mm, see Figure 2(c)). The cap shall be an insulating material. For the dual probe type, the gap is fixed on the distance between the two probes (see Figure 1). For the single probe, the measurement reliability is sensitive to some degree. The gap shall be reported together with the data.

7 Test conditions

The measurement shall be performed under the following conditions according to IEC 62899-202 unless otherwise specified:

a) Temperature

(23 ± 2) °C

b) Humidity

(50 ± 10) %

If conditioning is necessary, the same standard atmosphere specified above shall apply.

8 Measurement procedure

1) The specimen shall be placed on the stage.
2) The probe shall be positioned on the surface of the specimen facing vertically. The outer ring of the probe shall not touch the edges of the specimen (see Figure B.1 in Annex B for the effects of the edge on the resistance).

NOTE The specimen edge is defined as the line where the film ceases to exist.

3) The gap shall not be changed between the measurements.

9 Report of the results

9.1 General

The report shall include the following items.

9.2 Test environment

a) Temperature range (e.g., 23 ± 2) °C
b) Humidity

9.3 Test apparatus

a) Model of the apparatus (single or dual)
b) Material of the specimen stage and thickness

9.4 Test condition

a) Material of the substrate and thickness
b) Material of the printed layer and thickness
c) Gap

9.5 Test results

Sheet resistance (ohms per square):

The sheet resistance shall be shown by using the average of the measurement data. The averaged value, standard deviation and number of measurement points shall be reported. In the case where the sample size is such that measurement from multiple positions is not available, measurement data from a single position may be used as the result value. In such a case, the average value taken from multiple samples will be the result value.

Annex A
(informative)

Comparison between data from eddy-current probe and 4-point probe measurements

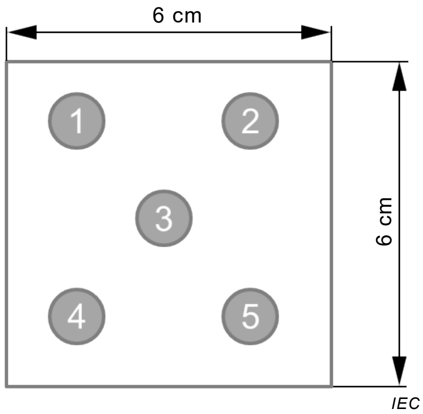
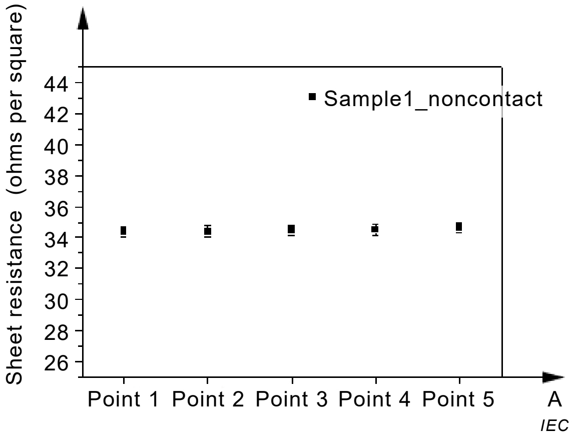


Figure A.1 – Measurement positions

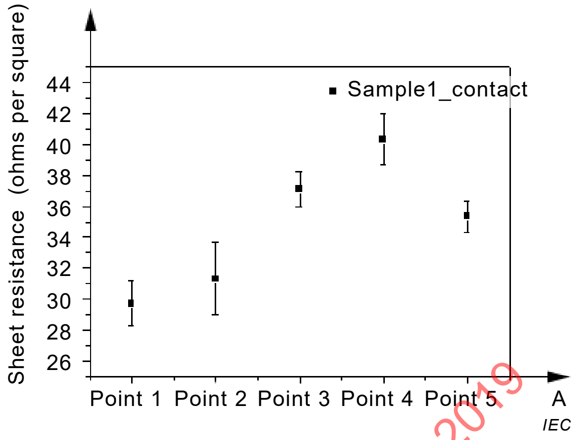
Table A.1 – Results of sheet resistance measurement

Sample No.	Solid content	Eddy-current probe		4-point probe	
		Average (ohms per square)	Standard deviation	Average (ohms per square)	Standard deviation
1	1 %	14,73	0,41	14,86	0,48
	0,7 %	34,45	0,35	34,76	1,52
	0,4 %	1 206,8	198,77	1 255,2	700,89
2	1 %	14,76	0,66	14,86	0,66
	0,7 %	34,60	0,37	33,22	1,42
	0,4 %	1 117,2	214,68	1 092	557,02
3	1 %	14,47	0,58	14,88	0,8
	0,7 %	34,68	0,38	33,21	1,42
	0,4 %	1 082,4	192,34	1 506	663,43

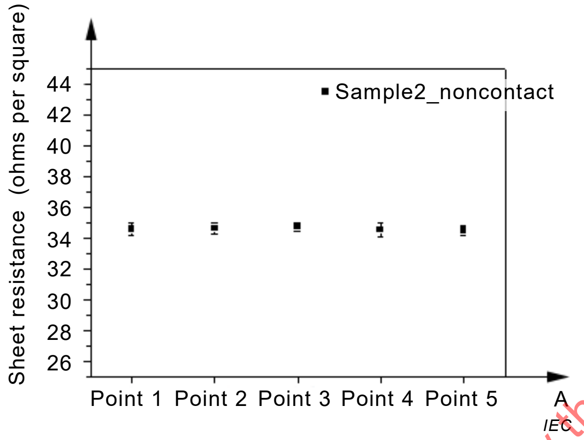
Table A.1 shows a comparison between data obtained from eddy-current probe and 4-point probe measurements for silver wire-networked transparent conductive films. The data was taken from three different solutions with different solid contents. (Note that since the wire density of the printed layer changes nearly linearly with the solid content of the solution, a lower solid content means a lower wire density on the film.) Since such films are composed of random networks of wires, establishing a reliable electrical contact with the probes in a 4-point probe measurement is not easy, which makes the measurement data scatter widely. The data from the eddy-current probe method shows much narrower deviation. This data highlights the benefits of using the eddy-current probe method, in particular, for transparent conductive printed films.



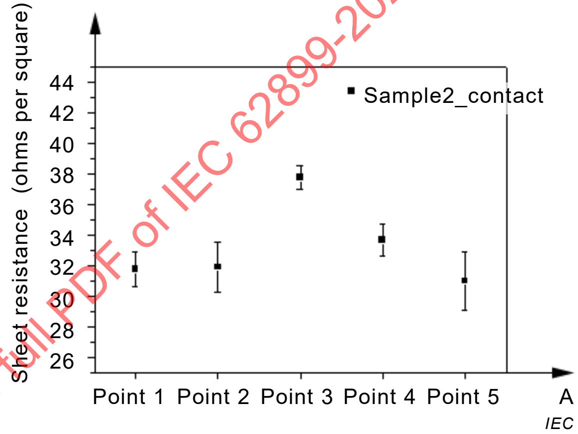
Sample 1



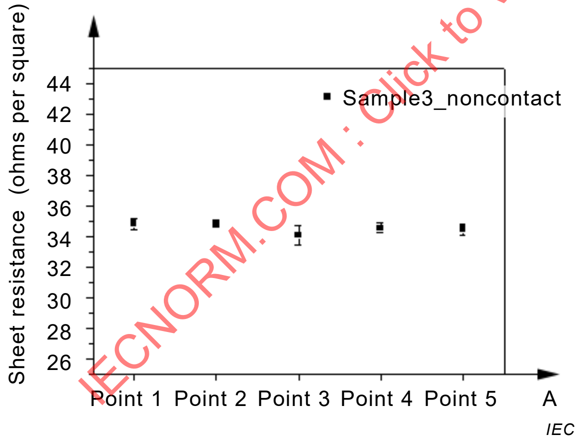
Sample 1



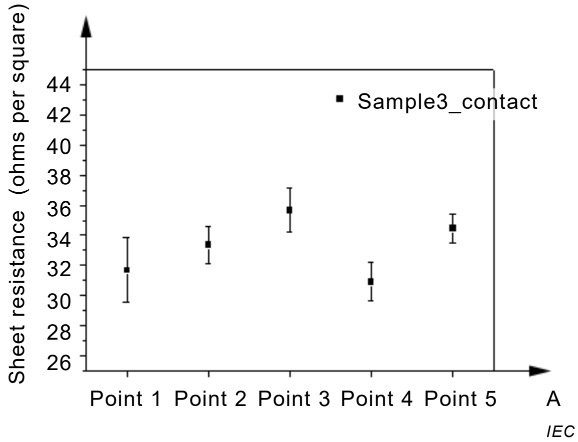
Sample 2



Sample 2



Sample 3

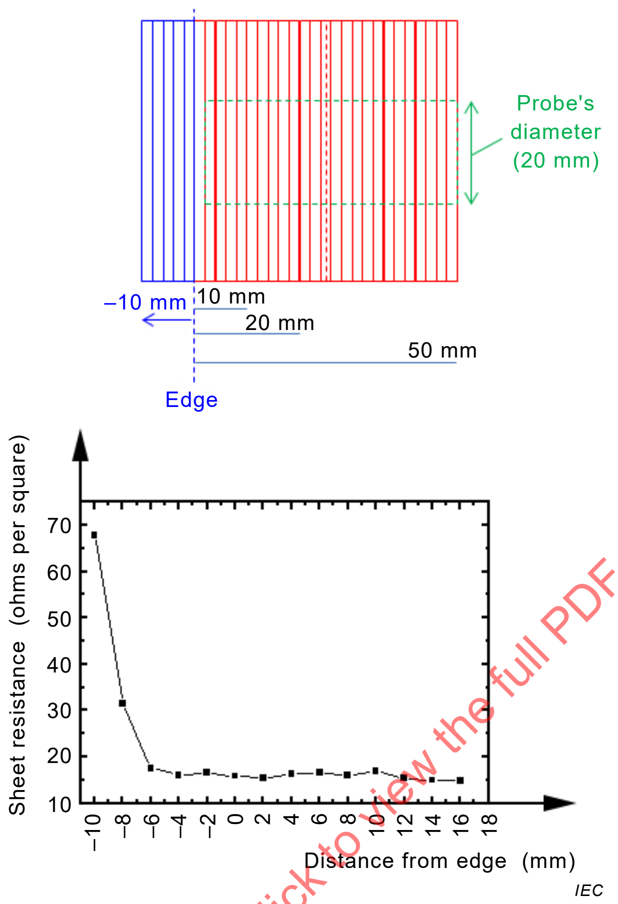


Sample 3

Figure A.2 – Comparison between contactless and 4-point methods

Annex B
(informative)

Effects of the probe position near the specimen edge



Distance from edge (mm)	Sheet resistance (Ω/sq.)
16	14,78
14	14,99
12	15,37
10	16,93
8	15,94
6	16,59
4	16,21
2	15,45
0	15,79
–2	16,51
–4	16,03
–6	17,45
–8	31,49
–10	67,83

Figure B.1 – Measurement positions

The data shown in Figure B.1 discloses the effects of the probe position on the measurement reliability. The probe diameter is 20 mm. The test was performed on positions at various distances from the edge of the specimen. The graph shows that the sheet resistance data deviates widely as the probe position is more than 6 mm from the edge.