



IPC-TM-650 TEST METHODS MANUAL

1.0 Scope

1.1 Purpose This test method covers procedures for determining the electrical resistivity of copper foil. It provides for an accuracy of ± 0.30 percent of test specimens having a resistance of 0.00001 ohm (10 microhms) or more.

1.2 Definition Resistivity is the electrical resistance of a body of unit length and unit cross-sectional area or unit weight. Volume resistivity is commonly expressed in ohms for a theoretical conductor of unit length and cross-sectional area; in English units in ohm-circular mil/ft and in metric units in ohm-mm²/meter. It may be calculated by the following formula:

$$\rho = \frac{A}{L} R$$

where:

ρ = volume resistivity in ohm-circular mil/ft or ohm-mm²/meter,

A = cross-sectional area in circular mils, or sq mm,

L = gauge length, used to determine R, in ft, or m, and

R = measured resistance in ohms.

Weight resistivity is commonly expressed in ohms for a theoretical conductor of unit length and weight. The method for calculating weight resistivity, based on resistance, length, and weight measurements, of a test specimen is given in Note 2.

2.0 Applicable Documents None

3.0 Test Specimen The test specimen must have the following characteristics:

1. A resistance of at least 0.00001 ohm (10 microhms) in the test length between potential contacts,
2. A test length of at least 1 ft or 30 cm,
3. A thickness, width or other dimension suitable to the limitations of the resistance measuring instrument,
4. No surface cracks or defects visible to the unaided normal eye, and substantially free from surface oxide, dirt and grease,
5. No joints or splices.

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4.0 Apparatus

4.1 Tester

4.1.1 A Kelvin-type double bridge or a potentiometer, if the resistance of the specimen is below 1 ohm,

4.1.2 If 1 ohm or more, a Wheatstone bridge may be used.

4.1.3 Where applicable, a Hoopes conductivity bridge may be used.

4.2 Conditions When the measurement is made at any other than a reference temperature, the resistance may be corrected for moderate temperature differences to what it would be at the reference temperatures as follows:

$$R_T = \frac{R_t}{1 + \gamma T (t-T)}$$

where:

R_T = resistance at reference temperature T,

R_t = resistance as measured at temperature t,

γT = known or given temperature coefficient of resistance of the specimen being measured at reference temperature T,

T = reference temperature, and

t = temperature at which measurement is made.

NOTE: The parameter T, in the above equation, varies with conductivity and temperature. For copper of 100 percent conductivity and a reference temperature of 20°C, its value is 0.00393. Table 2 lists temperature coefficients for copper.

5.0 Procedure

5.1 Preparation

5.1.1 All determinations of the dimensions and weight of the test specimen must be accurate within 0.05%.

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5.1.2 The cross-sectional dimensions of the specimen may be determined by micrometer measurements, and a sufficient number of measurements shall be made to obtain the mean cross section to within ± 0.10 percent.

5.1.3 In case any dimension of the specimen is less than 0.100 in. and cannot be measured to the required accuracy, the cross section shall be determined from the weight, density, and length of the specimen.

5.1.4 When the density is unknown, it shall be determined by weighing a specimen first in air and then in a liquid of known density at the test temperature, which shall be at room temperature to avoid errors due to convection currents.

5.1.5 Calculate the density from the following formula:

$$\delta = \frac{W_a \times d}{W_a - W_l}$$

where:

δ = density of the specimen, grams per cu cm,

W_a = weight of the specimen in air, grams,

W_l = weight of the specimen in the liquid, grams, and

d = density of the liquid at the test temperature, grams per cu cm.

5.2 Test

5.2.1 When potential leads are used, the distance between each potential contact and the corresponding current contact shall be at least equal to 1-1/2 times the cross-sectional perimeter of the specimen.

5.2.2 The yoke resistance (between reference standard and test specimen) shall be appreciably smaller than that of either the reference standard or the test specimen unless a suitable lead compensation method is used, or it is known that the coil and lead ratios are sufficiently balanced so that variation in yoke resistance will not decrease the bridge accuracy below stated requirements.

5.2.3 Make resistance measurements to an accuracy of ± 0.15 percent.

5.2.4 In all resistance measurements, the measuring current raises the temperature of the specimen above that of the surrounding medium. Therefore, care shall be taken to keep the magnitude of the current low, and the time of its use short enough so that the change in resistance cannot be detected with the galvanometers.

5.2.5 To eliminate errors due to contact potential, two readings, one direct and one with current reversed, must be taken in direct succession.

5.2.6 Check tests are recommended whereby the specimen is turned end for end, and the test repeated.

5.2.7 Surface cleaning of the specimen at current and potential contact points may be necessary to obtain good electrical contact.

5.3 Evaluation

5.3.1 Reference Tests For reference tests, the report should include the following:

1. Identification of test specimen,
2. Kind of material,
3. Test temperature,
4. Test length of specimen,
5. Method of obtaining cross-sectional area: the average values of micrometer readings, or, if by weighing a record of length, weight, and density determinations that may be made, and calculated cross-sectional area.
6. Weight, if used,
7. Method of measuring resistance,
8. Value of resistance,
9. Reference temperature,
10. Calculated value of resistivity at the reference temperature, and
11. Previous mechanical and thermal treatments. (Since the resistivity of a material usually depends upon them, these shall be stated whenever the information is available.)

5.3.2 Routing Tests For routine tests, only such of the items in paragraph 5.3.1 as apply to the particular case, or are significant, shall be reported.

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6.0 Notes

6.1 Volume Resistivity Volume resistivity is used in place of "weight resistivity" and "percent conductivity." The value of 10.381 ohm-circular mil/ft at 20°C (68°F) is the volume resistivity equivalent to the International Annealed Copper Standard (IACS) for 100 percent conductivity. This term means that a wire 1 ft in length and 1 cir mil in cross-sectional area would have a resistance of a wire 1 m in length, and 1 sq mm in cross-sectional area.

6.2 Weight Resistivity Weight resistivity is expressed in English units in ohm-pound/mile² and in metric units in ohm-gram/meter². It may be calculated as follows:

$$\rho_w = \frac{W}{L_1 L_2} R$$

where:

ρ_w = weight resistivity in ohm-pound/mile², or ohm-gram/meter²,

W = weight of the test specimen in lb, or gm,

L₂ = length of the test specimen in miles, or m, and

L₁ = gauge length, used to determine R, in. miles or m, and

R = measured resistance in ohms.

Table 1 Equivalent Resistivity Values For Copper

Conductivity at 20°C (68°F), percent IACS.....	100.00
VOLUME RESISTIVITY	
Ohm-Circular mil/f.....	10.371000
Ohm-mm ² /meter.....	0.017241
Microhm-inch.....	0.678790
Microhm-cm.....	1.724100
WEIGHT RESISTIVITY	
Ohm-pound/mile ²	875.20
Ohm-gram/meter ²	0.15328

6.3 Conversion Resistivity and Conductivity Conversion – Conversion of the various units of volume resistivity, weight resistivity, and conductivity, may be facilitated by employing formulas and factors. Table 2 lists values of density, for the common electrical conductor materials.

6.4 Density For the purpose of resistivity and conductivity conversion, the density of copper materials may be taken as shown in Table 2, based on a temperature of 20°C (68°F).

Table 2 Density and Temperature Coefficient of Resistance for Electrical Materials

	Density at 20°C, gm per cu cm	Temperature Coefficient of Resistance at 20°C
Copper, % IACS:		
100.....	8.89	0.00393
98.40.....	8.89	0.00387
98.16.....	8.89	0.00386
97.80.....	8.89	0.00384
97.66.....	8.89	0.00384
97.40.....	8.89	0.00383
97.16.....	8.89	0.00382
96.66.....	8.89	0.00380
96.61.....	8.89	0.00380
96.16.....	8.89	0.00378
94.16.....	8.89	0.00370
93.15.....	8.89	0.00366