BUILD ELECTRONICS BETTER
3000 Lakeside Drive, Suite 105 N
Bannockburn, Illinois 60015-1249

IPC-TM-650
TEST METHODS MANUAL

Number **2.5.4.2**	
Subject **Conductor Temperature Rise Due to Current Changes in Conductors for Printed Conductor Materials on Textiles**	
Date **11/2022**	Revision
Originating Task Group **Printed Electronics E-Textiles Electrical Test Task Group**	

1 SCOPE

This method is used to determine the effect of temperature rise in printed conductor materials on textiles and e-textiles due to resistive heating from the electrical current flow. The effects depend on material thermal coefficient of resistance (TCR), conductor cross-sectional area and the conductor deposition processes on the textile or e-textiles substrate for printing.

The temperature rise needs to be given for each conductor materials for a particular value of current, for a specified conductor cross-sectional area and substrate material. The results are reported as a plot of temperature rises versus current for each of the conductor materials, cross-sectional areas and the textile or e-textile substrate.

2 APPLICABLE DOCUMENTS

2.1 IPC IPC-TM-650 Test Methods Manual

Method 2.2.18.1 Determination of Thickness of Metallic Clad Laminates, Cross-sectional

2.2 ASTM

ASTM B193 Standard Test Method for Resistivity of Electrical Conductor Materials

3 TEST SPECIMENS

Standard test specimen, test pattern with four-wire testing pads is shown in Figure 1. Only one test pattern may be tested at one time, with current passing through only one conductor at one time. The width of the conductor traces for testing should be 0.6 mm [0.025], 1.27 mm [0.050], 1.9 mm [0.075] and 2.54 mm [0.100].

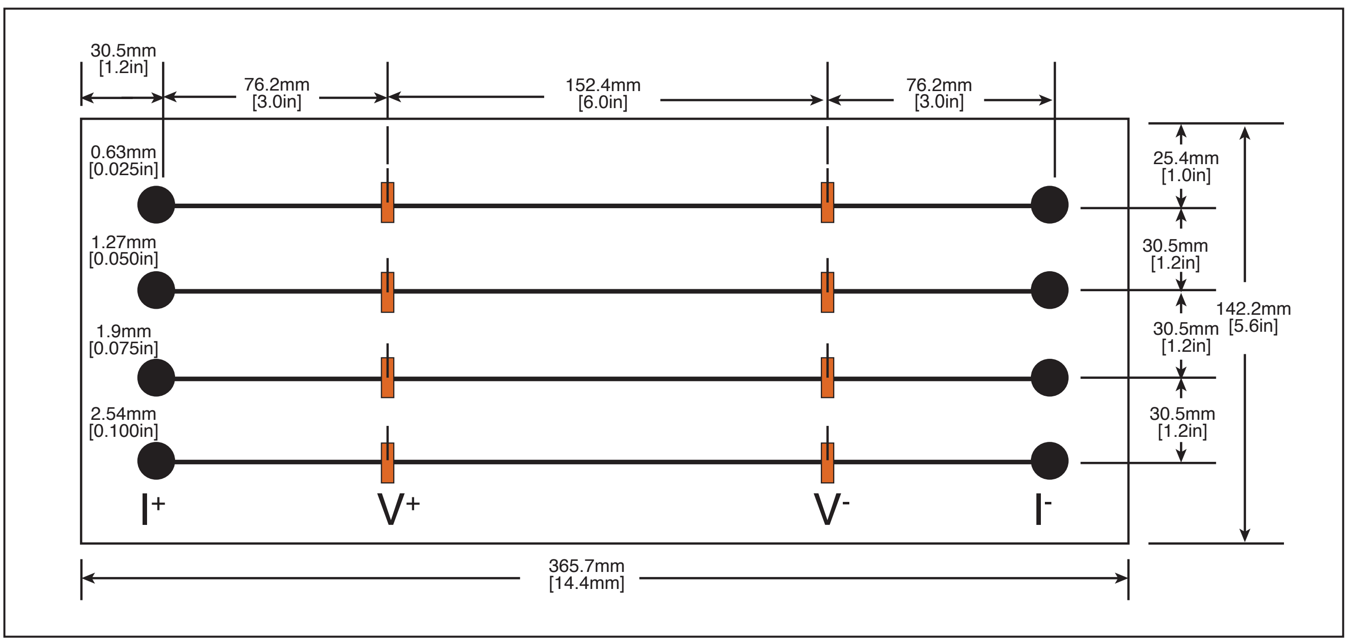

Figure 1 Test Pattern

Figure notes:
1. Terminal size for current diameter 5 mm [0.196 in]
2. Terminal size for voltage 2 mm x 4 mm [0.078 in to 0.157 in]
3. Other widths of specific interest may be used

4 APPARATUS

4.1 Multimeter – source meter with current range 0 A to 5 A, voltage range 0V to 20 V, resistance range 0.01 Ω to 2,000 Ω.

4.2 Current leads, #12 AWG stranded wire.

4.3 Potential leads, #26 AWG wire.

4.4 Soldering or bonding material to be specified along with thermal properties such as coefficient of thermal expansion (CTE), glass transition temperature (T_g).

4.5 Temperature chamber capable of maintaining required temperatures in specification (-30 °C to 80 °C [-22 °F to 176 °F]).

4.6 Thermocouple able to measure laboratory ambient temperature and substrate temperature to the nearest 0.5 °C [0.9 °F].

4.7 Apparatus for performing cross-sections per IPC-TM-650, Method 2.2.18.1.

4.8 Digital multimeter capable of taking current and voltage in specification (instead of one source meter, two separate instruments can be used: a current source and four-wire resistance meter (see 4.1).

5 TEST

5.1 Preparation

5.1.1 Condition all specimens for 72 hours at 20 °C to 25 °C [68 °F to 77 °F] and 20% to 80 % relative humidity (RH) immediately prior to exposure, or prior to temperature and humidity cycling. This is to enable the specimens to stabilize.

5.1.2 Extraneous surface coating **shall** be removed without affecting the dimensions of the conductor. The sample **shall** represent the materials and processes under investigation. To attach the potential leads, the extraneous surface material **shall** be removed from the locations specified in Figure 1 without affecting the dimensions of the conductive traces.

5.1.3 Current leads **shall** be secured by soldering or bonding to the terminal area.

5.1.4 Potential leads **shall** be attached to the test tabs by soldering or bonding with a conducting adhesive.

5.1.5 All measurements **shall** be performed in an environmental chamber capable of controlling temperature in the range of -30 °C to 80 °C [-22 °F to 176 °F]. The temperature of the specimen **shall** be measured at approximately 102 mm [4 in] perpendicularly from the center of the conductor side of the substrate by using a thermocouple. The thermocouple **shall not** move from the specified location during the test period.

5.1.6 The electrical testing configuration is shown in Figure 1.

5.2 Procedure to Determine Thermal Coefficient of Resistance (TCR)

5.2.1 The value of the temperature coefficient of resistance (TCR, α) for new printable conductors from ink materials **shall** be determined and identified according to the procedure in 5.2.2. Temperature coefficients for various electrical conductor materials are given in ASTM B193.

5.2.2 Set up the multimeter to measure four-wire resistance. Measure and record the specimen resistance (Rt) while the chamber temperature is changed from ambient to 80 °C [176 °F] then decreased to -30 °C [-22 °F] and then increased back to 80 °C [176 °F] at rate of 1 °C/minute [1.8 °F/min].

Determine reference resistance Ro at the reference temperature to = 25 °C [77 °F].

Plot the resistance difference Rt - Ro as a function of temperature (t) and fit the linear part of the plot to the following equation:

$$(Rt - Ro) / Ro = \alpha\, t$$

where α is the TCR of the conductor in units of 1/°C.

5.2.3 Evaluation of TCR TCR is the characteristic property of the material. In the case of metallic conductors, TCR is positive (i.e., the trace resistance increases with increasing temperature). In the case of semiconducting material, TCR is negative (i.e., the resistance of semiconducting materials decreases with increasing temperature, often seen in conductors made of printable ink formulations). A run-away thermal condition may be experienced when a conductor with negative TCR exceeds a certain current threshold.

5.3 Procedure to Determine Conductor Temperature Rise Due to Current Changes in Conductors

5.3.1 Set the multimeter to operate as a current source, sensing voltage wired to the test specimen as shown in Figure 2.

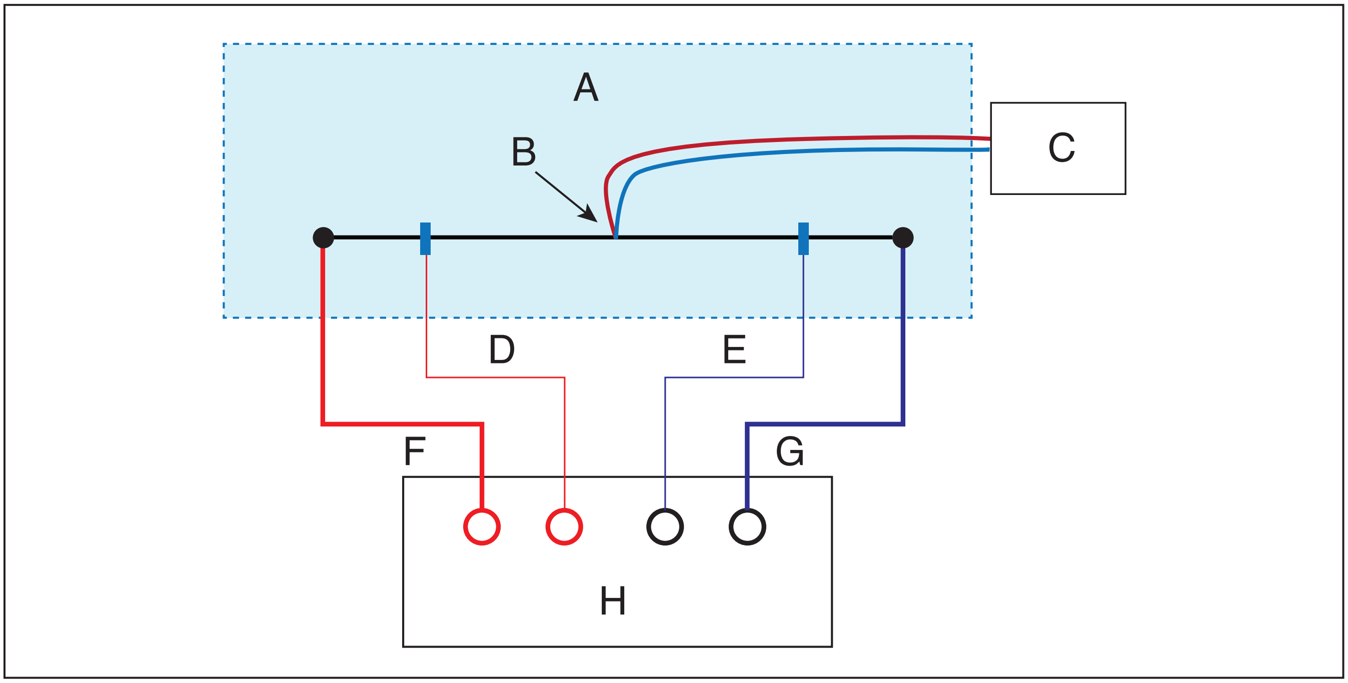

Figure 2 Electrical Connections Testing Arrangement

A – Environmental chamber
B – Thermocouple
C – Temperature meter
D – Sense high
E – Sense low
F – Input high
G – Output low
H – Four-wire source meter

5.3.2 Set the environmental chamber to constant temperature of 25 °C ± 0.5 °C [77 °F ± 0.9 °F].

5.3.3 Wait until thermocouple (TC) shown in Figure 2 indicates constant temperature of 25 °C ± 0.5 °C [77 °F ± 0.9 °F].

5.3.4 Increase current (Ic) in steps of 100 mA. At each current step wait until the thermocouple reads stable temperature. Record the temperature of the conductor (tc) and the corresponding voltage drop Vc. Calculate resistance of the conductor (Rc):

Rc = Vc/Ic (in Ω)

Calculate current density Icd:

Icd= Ic/S

Where S is the cross-sectional area of the conductor

S can be determined by using the formula

$$S = \frac{\rho_V L}{R_0}$$

Where:

ρ_v = volume resistivity in Ω-cm [circular mil/ft]

S = cross sectional area in cm^2 [circular mils]

L = gauge length, used to determine R in cm [in]

R_0 = measured resistance in Ω at reference temperature

5.3.5 Continue step 5.3.4 until the temperature of the conducting trace under test approaches the maximum operational temperature (e.g., 80 °C [176 °F]).

5.3.6 Plot R_C and I_{CD} as a function of the conductor temperature recorded by the thermocouple.

5.3.7 Repeat steps 5.3.1 through 5.3.5 for selected conductor traces shown in Figure 1.

5.3.8 Evaluation of the Conductor Temperature Rise Due to Current The temperature rise needs to be given for conductor material for a particular value of current, for a specified conductor cross sectional area and substrate material. The results are plotted of temperature rises versus current for the conductor material for a given cross-sectional area and substrate material.

6 COMMENTS

6.1 Instead of a source meter, two separate instruments may be used:

- Power supply sourcing current at terminals I^+, I^-
- Voltage meter measuring voltage drop at terminals V^+, V^- that are wired to and from the conductive trace as shown in Figure 2

The uncertainty of sourcing current and measuring voltage should be ≤ 0.1%.

7 TEST REPORT

The report **shall** include the following:

7.1 Description of the specimen.

7.1.1 Specimen identification.

7.1.2 Substrate material and color appearance before and after the test.

7.1.3 Substrate material thickness.

7.1.4 Material of the trace conductor

7.1.5 Wire-bonding material. If bonding with conducting adhesive, include its thermal properties such as usable temperature range.

7.1.6 Previous specimen treatments, test and preconditioning.

7.1.7 Technical specification of electrical instrumentation used for testing.

7. 2 Trace conductors dimensions data, including length width and thickness.

7.2.1 Average values and standard deviations of space between voltage terminals V^+ and V^- shown in Figure 1.

7.2.2 Average value and standard deviation of reference resistance R_0 measured at the reference temperature of 25 °C ± 0.5 °C [77 °F ± 0.9 °F] (see 5.2.2).

7.3 Average values and standard deviations of TCR (see 5.2.3).

7.4 Data and plots of conductor resistance (R_c) and current density (I_c) vs temperature (t_c) for each trace tested (see 5.3).

7.5 For a routine test, as deemed significant by user and supplier, the following items of the test should be reported:

7.5.1 Specimen identification.

7.5.2 Trace dimensions and trace material identification.

7.5.3 Wire bonding material. If bonding with conducting adhesive, include thermal properties such as recommended functional temperature range.

7.5.4 Conducting trace material and temperature coefficient of resistance, TCR.

7.5.5 Data and plot of conductor current density (Ic) vs temperature (tc) (see 5.3) with a given cross-sectional area, geometry and substrate material for a representative traces tested.