Association Connecting Electronics Industries

3000 Lakeside Drive, Suite 309S
Bannockburn, IL 60015-1249

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Subject	
Power Density Rating for Embedded Resistors	
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Originating Task Group	
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IPC-TM-650
TEST METHODS MANUAL

1 Scope   The Power Density Rating (PDR) for Embedded Resistors test method covers procedures for the demonstration of the ability to operate the embedded device safely, without a permanent change in the electrical characteristic of the device. The procedure consists of monitoring a resistance change from its nominal value as a function of the dissipated power. During the test, the applied voltage or current stimulus is held until the device temperature is stable, the steady resistance reading is reached, and the dissipated power is measured. This process is repeated with higher dissipated power until the measured resistance change exceeds the specification limits. The results are presented in terms of the dissipated power density rating (PDR) factor for the embedded resistive device.

This document describes testing procedure for power density rating of embedded resistive devices, which operate in complex electrical and thermal environments, and for which existing procedures are not adequate or inapplicable.

2 Applicable Documents

IPC-4811   Specification for Embedded Passive Device Resistor Materials for Rigid and Multilayer Printed Boards

IPC-TM-650   Test Methods Manual

1.3   Ambient Conditions

3 Terminology   When current passes through a resistor, electrical energy is dissipated by the resistor in the form of heat. A resistor can be used at any combination of voltage and current as long as its dissipating power (P) does not exceed the maximum power rating (P_{max}) indicating how much power the resistor can convert into heat and absorb or/and transfer away without any damage to itself or to the surrounding circuitry.

3.1 Electrical Resistance, *R*

$$R = V / I \qquad (1)$$

R is a ratio of voltage *V* over current *I*, (Ohm's law), the unit of measure is ohm [Ω].

3.2 Dissipated Power, *P*

Direct current (DC):

$$P = V I; \quad P = V^2 / R; \quad P = I^2 R \qquad (2)$$

Alternating current (AC):

$$P = V^* I^* \cos (\varphi) \qquad (3)$$

V^* and I^* are voltage and current amplitudes, and φ is the phase angle between V^* and I^*.

3.3 Power Density Rating   The power density rating (PDR) is defined as the total dissipated power normalized by the effective surface area (heat flux cross sectional area).

$$PDR = P_{max} / S \qquad (4)$$

where, *S* is the area of the embedded resistor or device defined as one-side of the heat flux area.

3.4 Power Density Rating Comments

• The power that can be dissipated by a resistor is limited by the size of the resistor and the maximum operational temperature of the resistive material.

• The power ratings depend on thermal management of the heat generated from the resistor.

• The use of heat sinks can lower the device's operating temperature and consequently increase the power rating.

• Higher glass transition temperature laminate materials in which the resistive device is embedded can allow higher operating temperatures.

4 Test Specimen   This method recommends testing the embedded resistors in configurations that reflect the actual functional application (Figure 1).

The recommended geometrical attributes of the embedded resistors are specified in the IPC-4811.

4.1 Sampling   The sampling procedure for the tested specimen should be defined in the specification for that device. The sampling procedure should provide sufficient data to estimate the average quality and the variability of the lot being examined.

4.2 Conditioning   The test results can be influenced by temperature, moisture content and other electrically active residuals originating from the processing conditions such as
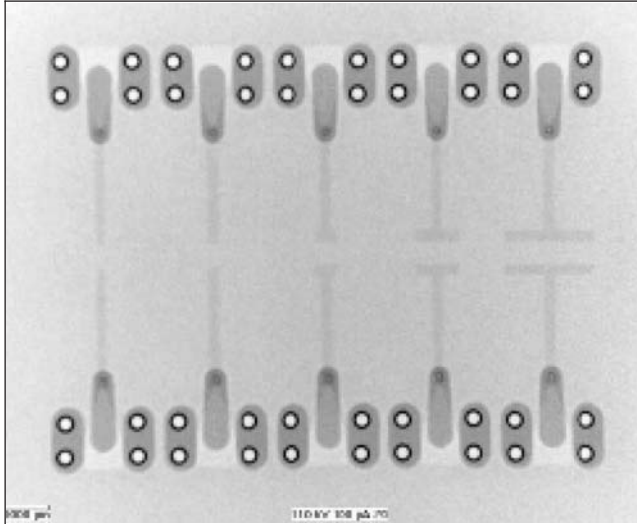
Figure 1   An X-Ray Image of Thin Film Resistors Embedded Inside a Printed Circuit Board

plating, circuit developing baths and soldering re-flows. Materials so affected should be brought to equilibrium with appropriate atmosphere and temperature control before testing. Description of the conditioning should be included in the testing report.

5 Apparatus   The method requires a power source meter and electrical resistance meter, such as Keithley[1] Source Meter or equivalent, for sourcing the applied DC power and measuring the resulting current resistance. The resolution of resistance measurements should be in the range of about 0.1 Ω or better.

5.1 Power requirements   The power capacity of the power sourcing instrumentation should be sufficient to maintain the test power until it reaches the value defined in the test failure/acceptance criteria where the specimen-maximum power will be dissipated. The voltage level should be stable to within ± 0.1% of the set value during the testing time. An output current of 1 µA to 1 A is usually sufficient for most testing conditions. The power dissipated during the test may vary depending on the specimen resistance thermal characteristics, and the failure mechanism.

5.2 Circuit controls   The apparatus should be equipped with a circuit breaking device with adjustable current/voltage

sensors, and be capable of disconnecting the power source in the case of overloading conditions. The current/voltage-sensing circuit should measure the specimen power and allow for adjustment consistent with the specimen characteristics. The sensing device should respond at the power level that is indicative of the test conditions reaching the failure criteria.

5.3 Power level controls   The power level should be adjustable with the possibility of setting discrete power level values in at least 20 steps. It is recommended that the initial power P_O is set at 1/10 of the nominal operational power of the device. A computerized experimental set-up is recommended to carry out the test.

In the case of sourcing voltage, the initial voltage, V_0 = $\sqrt{0.1 * P_{nom} * R_0}$. For example, if the initial value of R_O = 50 Ω and P_{nom} = 0.1 W then the initial voltage V_O corresponding to 0.1 of P_{nom} (i.e., P_O = 0.010 W), is $\sqrt{0.1 * 0.1 \text{ W} * 50 \text{ }\Omega}$ ≈ 0.7 V. The voltage level V_n should be increased in steps of V_s ≤ V_O, each step having duration of about 60 s. The specimen current I_n should be monitored and recorded at every power step (see 5.3.1).

In the case of sourcing current, the initial current, I_0 = $\sqrt{0.1 * P_{nom} / R_0}$. For example, if the initial value of R_O = 50 Ω and P_{nom} = 0.1 W, then the initial voltage V_O corresponding to 0.1 of P_{nom} (i.e., P_O = 0.010 W), is $\sqrt{0.1 * 0.1 \text{ W} / 50 \text{ }\Omega}$ ≈ 0.014 A. The current level I_n should be increased in steps of I_s ≤ I_O, each step having a duration of about 60 s. The specimen voltage V_n should be monitored and recorded at every power step (see 5.3.2).

5.3.1 Linear Voltage Steps   Increasing voltage in constant voltage steps will result in a quadratic increase of power. At the n_{th} voltage step the power P_n is given by (5):

$$P_n = (V_0 + nV_s)^2 / R_n \tag{5}$$

Example: R_n = R_O = 50 Ω, V_O = 0.7 V, V_s = 0.3 V. At n = 11 step V_{11} = 4 V and the corresponding applied power P_{11} = (0.7 V + 11 * 0.3V)^2 / 50 Ω = 0.32 W.

5.3.2 Linear Current Steps   Increasing current from I_O by adding a constant current step, I_s, will result in a quadratic increase of applied power. At the n_{th} current step the power P_n is given by (6):

$$P_n = (I_0 + nI_s)^2 * R_n \tag{6}$$

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1. Certain commercial equipment and materials are identified in this document in order to specify adequately the experimental procedure. In no case does such identification imply recommendations nor does it imply that the material or equipment identified is necessarily the best available for this purpose.

Example: $R_n = R_O = 50\ \Omega$, $I_O = 14$ mA, $I_s = 6$ mA. At $n = 11$ step $I_{11} = 80$ mA and the corresponding applied power $P_{11} = (0.014\ A + 11 * 0.006\ A)^2 * 50\ \Omega = 0.32$ W.

5.3.3 Linear Power Steps Setting the voltage or current stimulus for linear increase in the applied power is given by (7) and (8) respectively:

$$V_n = \sqrt{(P_0 + nP_s) * R_n} \qquad (7)$$

$$I_n = \sqrt{(P_0 + nP_s) / R_n} \qquad (8)$$

Example: $R_n = R_O = 50\ \Omega$, $P_O = 0.01$ W, $P_s = 0.01$ W. At step $n = 11$ the applied power $P_{11} = 0.01 + 11 * 0.01 = 0.12$ W. The corresponding voltage stimulus $V_{11} = \sqrt{0.12\ W * 50\ \Omega} \approx 2.5$ V. In the case of sourcing current the corresponding current stimulus $I_{11} = \sqrt{0.12\ W / 50\ \Omega} \approx 0.048$ A.

6 Procedure Testing should be performed at ambient conditions; temperature $(t_O) = 22\ °C \pm 3\ °C$ [71.6 °F ± 5.4 °F] and relative humidity $(RH_O) = 50\% \pm 10\%$ (see IPC-TM-650, Method 1.3, Ambient Conditions).

6.1 Measure the initial stable resistance, R_O at the ambient temperature (t_O) and relative humidity (RH_O).

6.2 Apply a constant power step P_n for a period of 60 s, until temperature stabilizes and a steady current reading is reached (see 5.3).

6.3 Record voltage V_n and the resulting current I_n. Calculate the actual P_n from equation (2).

6.4 Disconnect the power for a period of time sufficient for the device to return to the ambient temperature conditions t_O. Measure the device resistance R_n. Calculate the relative difference between the measured resistance and the nominal resistance:

$$(\Delta R)_r = (R_n - R_0) / R_0 \qquad (9)$$

6.5 Continue stepping up the applied power (6.2 - 6.4) for P_{max} and/or $P_{failure}$ until the relative change in resistance, $(\Delta R)_r = (R_n - R_0) / R_0$ approaches a value indicative of failure or acceptance criteria.
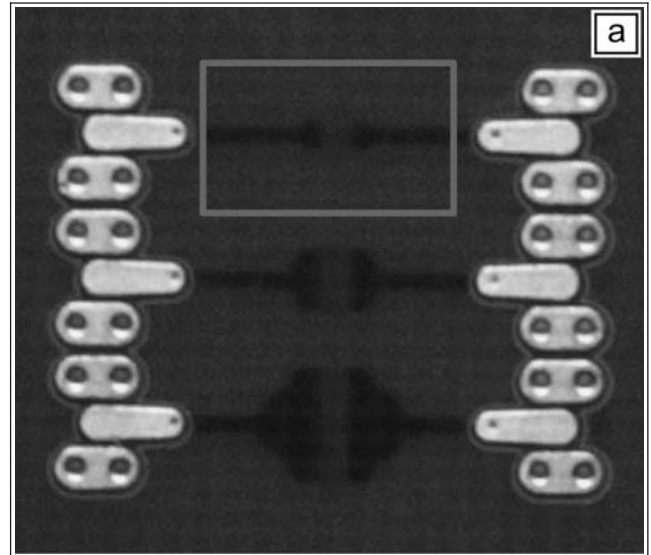
6.6 After recording P_{max}, calculate PDR using equation (4).

7 Test Example An embedded resistor $R_0 = 50\ \Omega$, $S = 0.77$ mm $*$ 0.58 mm ≈ 0.44 mm^2, shown in Figure 2a was tested under the following conditions:
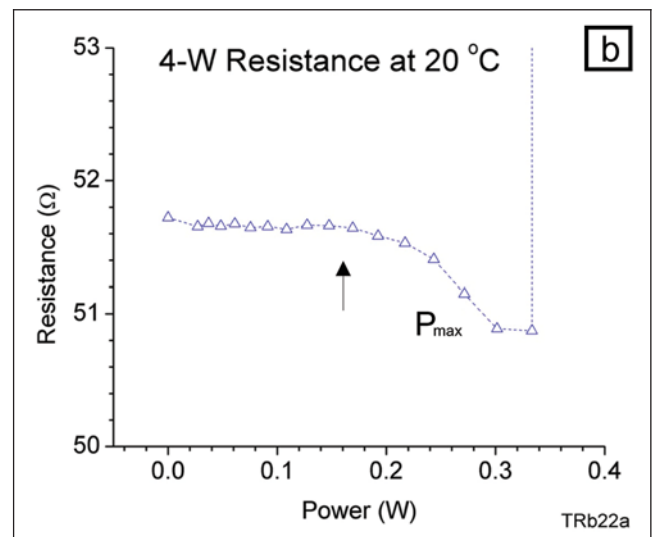
Power Stimulus: Linear voltage steps (5.3.1), $P_O = 0.01$ W, $V_O = 0.7$ V, $V_s = 0.2$ V, power step ON = 60 s.

Recording: current I_n, voltage V_n, power P_n.

Power OFF Step: 20 s (typical). Recording 4-W resistance R_n.

Figure 2 (a) Embedded resistor test vehicle. The device tested on a probe station is highlighted.

Figure 2 (b) Recorded resistance R_n as a function of applied power P_n.

Figure 2b illustrates the test results. The stable resistance value R_O is about 51.7 Ω. It remains stable until the power

level approaches 0.160 W. With increasing power above 0.160 W the resistance value gradually starts to deviate from its stable value. The resistor fails ''open'' at $P_{failure}$ of 0.360 W. The resistance plot in Figure 2b suggests that $P_{max} \approx 0.160$ W. Thus in the above illustration, the power density rating for that resistor, for which $S \approx 0.44$ mm^2, calculated from equation (4), $PDR = 0.16$ W / 0.44 mm$^2 \approx 0.36$ W / mm^2.

7.1 PDR Safety Factor In the example above, the surface temperature at the tested resistors measured (optionally) at P_n = 0.160 W was about 42 °C. Depending on the material's physical characteristics, this heating effect might lead to an accelerating aging and shortening the device operational life. Therefore it is recommended that P_{max} is reduced accordingly by a certain safety factor that can be deduced, for example, from the aging study.

8 Accuracy Considerations Several uncertainty factors such as instrumentation, dimensional uncertainty of the test specimen geometry, resistance of contacts and interconnects among others contribute to the combined uncertainty of the measurements. The complexity of modeling these factors may be considerably higher when the measurements are performed at elevated temperatures for resistors embedded in complex multilayer assemblies. Adequate analysis can be performed, however, using the partial derivative technique for equation (4) It is recommended that the combined instrumentation uncertainties should be 10 times smaller than the nominal tolerance value of the resistor. Likewise, it is recommended that uncertainty in the surface area, S, is considered very carefully since S is the primary parameter used in scaling the PDR ratings for different form-factor resistors.

Additional limitations may arise from the systematic uncertainty of the particular instrumentation, calibration standards, and the dimensional imperfections of the actually implemented test specimen. The test may require specialized instrumentation when P_n approaches the instrument maximum power compliance conditions before $P_{failure}$ is reached.

9 Notes

9.1 Resistor De-Rating In engineering practice and in typical manufacturer specifications, resistor power ratings is normally specified at +25 °C. The power rating is reduced as the resistor operational temperature increases. A de-rating chart is often employed, with de-rating typically starting at 70 °C.

Power de-rating charts are often included in manufacturers' specifications to be considered as a general guideline when projecting the power rating for application specific conditions. The safest design rules recommend using the largest geometrical size and assuming conservative (higher than actual) operating temperatures.

In the case of embedded resistive devices operating at temperature conditions above 25 °C, the heat dissipation is highly nonlinear with additional complexity resulting from a particular package design. In the presented example the tested resistor failed ''open'' at the temperature $t_{failure} \approx 52$ °C, while the stable P_{max} corresponded to temperature $t_{max} \approx 38$ °C. The operational temperature of embedded resistors may vary considerably, depending on construction, materials and manufacturing technology of the embedded package. Consequently, a reliable universal de-rating chart cannot be constructed, and therefore, it is recommended that the power rating be determined at the specific operating conditions of the device according to procedure described in this document, rather than estimated from a power de-rating chart.

9.2 Hazards During testing, a high voltage and current may be present. The experimental set-up must be properly insulated with wiring properly grounded to minimize the possibility of electrical shock. This test may cause burning of the resistive material, which in turn may produce hazardous substances resulting from material decomposition and possible subsequent chemical reactions. In all cases, the exposure limits and guidance that are set by government agencies should be observed.

The Notes section is to be used to discuss any special considerations, or detail other reference documents necessary or recommended for the test. This section should include any safety precautions, hazard information, or warning statements necessary for the safe completion of the test method. This section should also be used to show sources of obtaining specialized test apparatus or materials for the test.

10 References and Contact Information

Jan Obrzut, National Institute of Standards and Technology (NIST), jan.obrzut@nist.gov;
Jason Ferguson, Naval Surface Warfare Center (NSWC Crane), jason.ferguson@navi.mil;
Michael Azarian, Center for Advanced Life Cycle Engineering (CALCE), University of Maryland, mazarian@umd.edu.