Standard Test Methods for
Measuring Resistance of Electrical Connections (Static Contacts)[1]

ε[1] NOTE—Editorial changes were made throughout in April 2003.

1. Scope

1.1 These test methods cover equipment and techniques for measuring the resistance of static electrical connections such as wire terminations or splices, friction connectors, soldered joints, and wrapped-wire connections.

1.2 Measurements under two distinct levels of electrical loading are described. These levels are: (*1*) dry circuit, (*2*) and rated current. One or both of these levels of loading may be required in specific cases.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet for this product/material as provided by the manufacturer, to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 542 Terminology Relating to Electrical Contacts and Their Use [2]

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process [3]

3. Terminology

3.1 *Definitions:* see Terminology B 542 for definitions of contact resistance, film resistance, and constriction resistance.

3.1.1 *bulk resistance*—the resistance a contact assembly would have if it were solid metal of an identical geometry so that the nominal contact area offered zero resistance. When measuring *contact resistance* one attempts to include as little *bulk resistance* as possible in the measurement, by placing measuring probes as close to the contact interface as practical.

3.1.2 *connection resistance*—the resistance from the termination point on one end of a device containing static contacts, through the contacts to the termination point on the other end of the device. The termination point is the location on a terminal of a device where a wire or printed circuit path electrically connects to the terminal. This resistance is the value of resistance displayed by the device in a circuit application.

3.1.2.1 *Discussion*—The term contact resistance is often used in commercial literature to indicate the connection resistance displayed by the device in a standard application. In the more rigorous usage of contact resistance, the connection resistance is the sum of the contact resistance plus the bulk resistance of leads within the device that go to the static contacts from the point that the leads are connected to the external circuitry. Measurement of contact resistance independent of all bulk resistance is very difficult for most commercial devices.

3.1.3 *dry circuit*—a circuit in which the *open-circuit* voltage is less than or equal to 20 mV. Current is usually low in a *dry circuit, but a low-current circuit is not necessarily a dry circuit.* When the applied voltage (*open-circuit voltage*) is too low to cause any physical changes in the contact junction, such as break-down of thin insulating films or softening of contact asperities, the circuit is said to be a *dry circuit.*

3.1.4 *open-circuit voltage*—the steady-state voltage which would appear across the contacts if they were opened.

3.1.5 *static contacts*—electric junctions designed for infrequent separation and connection, and intended to perform their function only when contacting members are stationary relative to each other. This definition includes crimped, welded, brazed, riveted, or soldered joints; friction connections such as pin and socket connectors or taper pins; twisted-wire splices; and connections made with screws, or bolts and nuts between electrical wiring and components. The definition excludes relay contacts, slip rings and commutators, and switches and circuit breakers.

3.2 *Descriptions of Terms for Levels of Electrical Loading:*

3.2.1 *dry circuit*—This method provides for measurement of contact resistance under very low levels of electrical excitation, with applied voltages and currents selected to be too low to cause breakdown of thin oxide films or other contaminates in the contact interface or to cause formation of metallic bridges across the interface where none may otherwise exist. Dry circuit testing is intended to determine whether the test contact will function properly in circuits of arbitrarily low levels of electrical excitation. Dry circuit testing procedures should be used when the possibility of films or contaminants in the contact interface exists or when the test sample is ultimately intended for use in a low-level circuit. This testing must precede other tests on the same samples at high levels of electrical loading.

3.2.2 *rated current*—The rated current for a static contact device is determined or specified by the vendor or user of the device. The rated current may be large enough to cause significant heating of the test samples. When rated current measurements of contact resistance are required, using either ac or dc test currents, the procedures outlined for temperature stabilization in 9.5.3 must be followed.

4. Summary of Test Methods

4.1 The test methods described herein are characterized as four-terminal resistance measuring techniques, wherein a measured and controlled test current is introduced into the sample using two" terminals" or connecting points, and two other points are selected on the sample across which a voltage drop is measured. This voltage drop, divided by the test current, is the effective overall resistance of the sample included between the voltage probes. The voltage-measuring points are chosen so as to measure as closely as possible the voltage drop due only to the contact resistance of the sample and to eliminate from the measurement as much as possible the resistance of the metal pieces comprising the contact and the resistance of the wires and connections used to introduce the test current into the sample.

4.2 Two different levels of test current are specified. The choice of which level to use is governed by the application and requirements of the electrical connection being tested. Electronic signal-circuit connections may require low-level (dry-circuit) testing, whereas power-handling wire connectors should be tested at rated current.

4.3 Either ac or dc test currents may be used, with appropriate instrumentation.

5. Significance and Use

5.1 As stated in Terminology B 542, contact resistance is comprised of a constriction resistance and a film resistance. When present, the latter of these is usually much greater in value and dominates the contact resistance. For a given contact spot, when the film resistance is zero or negligible the contact resistance for that spot is nearly the same as the constriction resistance and therefore, as a practical matter, has a minimum value which represents a clean metal-to-metal contact spot. As real contact surfaces exhibit varying degrees of roughness, real contacts are necessarily composed of many contact spots which are electrically parallel. In practical cases the clean metal-to-

metal contact spots will carry most of the current and the total contact resistance is primarily dependent on the size and number of metallic contact spots present (see Note 1). In addition, acceptably low values of contact resistance are often obtained with true areas of contact being significantly less than the apparent contact area. This is the result of having a large number of small contact spots spread out over a relatively large apparent contact area.

NOTE 1—The term metallic contact as used here is intended to include the so called quasi-metallic contact spots as well. The latter case was discussed in *Electric Contacts* by Holm. [4]

5.2 The practical evaluation and comparison of electrical connections depend in large part on their contact resistance characteristics. On the one hand, the absolute value of contact resistance is greatly dependent on the amount of metallic contact established and indicates initially how efficient the system is in producing areas of metallic contact. On the other hand, a comparison of the initial resistance to the resistance after aging indicates how stable the system is in maintaining the initial contact area. Both of these characteristics should be considered when evaluating contact systems. The criteria employed in evaluating contact resistance and stability are not a part of these test methods as they depend on specific applications and therefore, will not be quantitatively stated. However, an estimate of contact resistance[4] resulting from good metallic contact can be made for a given physical situation and used as a comparison to actual measurements to determine how effective the system is in establishing stable metallic contact. Resistances measured by these methods before, during and after simulated life tests are used as a means of determining the stability of contacts within a device.

6. Interferences

6.1 *Measurement of Low Resistance*:

6.1.1 Contact resistances are normally very small, ranging from microohms to a few milliohms in cases of practical interest. The measurement of resistance in this range requires special techniques to eliminate effects of thermal potentials, external interference, and resistance of connections and wires leading to the test sample.

6.1.2 The resistance-measuring procedures in these test methods are four-terminal techniques. Test current in the sample is measured and controlled, and made independent of the sample resistance. Voltage-measuring probes are attached to the sample so as to eliminate the effects of connections of the sample into the test circuit. If the purpose of the measurement is to determine the contact resistance, the voltage measuring probes are attached as close as feasible to the static contacts, so as to include as little of the bulk resistance of the sample as possible in the measurement of the contact resistance.

6.1.3 Two wire measurements of resistance are not suitable because connections to the sample will contribute part of the measured resistance, and these may be large, unknown, and variable.

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[4] Calculations and formulae for contact resistance of various types of contacts are covered very thoroughly in Holm's *Electric Contacts*, 4th Edition, Springer-Verlag, New York.

6.1.4 Because the resistance being measured is often in the microohm or milliohm range, and it is determined by measuring the potential across the static contacts, the value of the potential is often in the microvolt or millivolt range. As a result, thermal potentials may be significant in relation to the potential being measured and appropriate measures are required to cancel or eliminate their effects.

6.1.5 In the dry circuit method, high potential may change a resistance by breaking down a film. Appropriate caution is required to obtain valid dry circuit resistance measurements including limiting the open circuit voltage of the measuring apparatus that is connected to the device under test.

6.2 *ac Versus dc Measurements*:

6.2.1 Either method described herein can be used with ac or dc test currents, with appropriate changes in instrumentation to correspond with the power supply. The methods are described as using dc test currents, and the following comments apply when ac is used.

6.2.2 ac measurements should be expressed as RMS unless otherwise defined in the test report. Take appropriate measures to isolate the measurements from stray signals, especially sixty hertz power line noise. Commercial resistance measuring instruments that use ac test currents generally are suitable providing that they meet other requirements of the standard.

7. Apparatus and Test Circuits

7.1 Fig. 1 shows the basic arrangement of a four wire circuit for measuring. In the illustration, the measured resistance is the resistance between the points where the voltmeter is attached to the test specimen, that is, between the points of V1 and V2. The measured resistance includes the contact resistance at the contact between the two rounded points and the bulk resistance out to the point where the voltage probes touch the test specimen. To measure connection resistance, move the voltage probes away from the contact point to the very end of each contact member where the current leads are attached. To attempt to measure contact resistance, move the voltage probes as close as possible to the contact point. The equipment consists of the following elements:

7.1.1 *Power Supply*—A supply capable of providing the required current and, in the case of the dry circuit measurement capable of limiting the current to 100 milliamps and the open circuit voltage to 20mV. The supply may be dc or ac, but the voltage measuring device must match the type of current from the supply.

7.1.2 Voltmeters and ammeters built into power supplies may or may not meet the requirements of these methods with respect to accuracy or precision. External metering should be used when necessary.

7.1.3 Both output terminals of the dc supply must be isolated from the power line, the case of the supply, and the building ground. This prevents "ground loops" or undesired connections through ground, between the power supply and other measuring instruments (such as an electronic voltmeter) attached to the sample.

7.1.4 The maximum current required in the power supply can be estimated from Table 1, which gives rated currents for various wire-size terminations according to Military specifications.

7.1.5 The output current of the power supply should be variable and readily and accurately adjustable.

7.2 *Current Measuring Device*—a meter, ac or dc, to match the power supply current type or suitable alternate measuring circuitry is needed. The accuracy of the device must be 1 % or better of the measured current. Some power supplies include measurement capability of sufficient accuracy. An external arrangement of a calibrated fixed resistor wired in series with the test current and a voltmeter across the resistor is suitable provided that it achieves the accuracy required.

7.3 *Reversing Switch*—Since millivolt-drop readings across the sample are to be taken with both forward and reverse dc current, a double-pole-double-throw switch of suitable current-handling capacity inserted in the current leads is used to reverse the current in the test specimen. Alternatively, some power supplies are programmable to reverse the current flow direction and the current may be reversed with this feature in the supply rather than with a separate switch.

7.4 *Millivoltmeter*:

7.4.1 A voltmeter with an accuracy of 1 % or better of the measured voltage. Generally, an accuracy of 10 microvolts will be adequate to meet this requirement and is readily available in modern bench instruments.
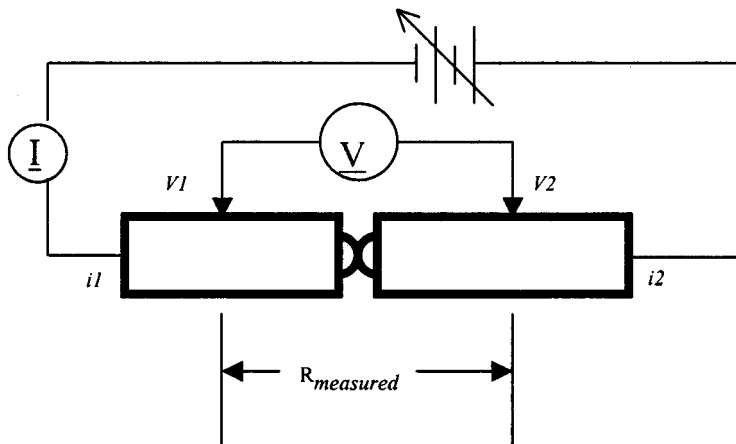
7.5 *Current and Voltage Probes*:

FIG. 1 Schematic Representation of 4 Wire Measurement Circuit

**TABLE 1 Test Current for Various Wire Sizes
(From Military Specifications MIL-T-7928 and MIL-T-7099)**

Wire Size	Amperes Copper Wire	Amperes Aluminum Wire
26	3	A
24	4.5	A
22	9	A
20	11	A
18	16	A
16	22	A
14	32	A
12	41	A
10	55	A
8	73	60
6	101	83
4	135	108
2	181	152
1/0	245	202
2/0	283	235
3/0	328	266
3/0	380	303

^{A}These values are not available.

7.5.1 Current is introduced to the device in a way to best simulate how it flows when the device is in service. For example, if the device is normally connected with soldered wires, the same arrangement would be recommended as the manner that its resistance would be measured.

7.5.2 Voltage probes must be placed or attached so as to cause minimal change in the device or the current flow pattern through it. In general, small probes are preferred. If attachment by soldering or spot welding is selected, it should be performed with caution to minimize possible heating or contamination of the contact being measured.

7.5.3 In corrosion testing of stranded wire terminations the stranded wires often become corroded under the insulation covering for some distance along the wire. Subsequent resistance measurements are then difficult to make accurately because of a loss of strand-to-strand conductivity and the inability of a probe to contact all of the strands in the wire. A procedure to eliminate this difficulty involves the inclusion of a "potential-measuring point" on the wire in the form of a current equalizer (soldered spot, welded spot, strandgathering crimped sleeve) holding all of the strands together. The current equalizer should be far enough away from the terminal (at least 2.5 cm) so that the operation of applying it cannot affect the test joint. In the final result, the fact that a resistance equivalent to the added length of wire is included in the measurement should be considered.

8. Sampling

8.1 The sampling plans described below are based on statistical procedures presented in Practice E 122.

8.2 Assuming normal statistics apply, a suitable sample size can be obtained from the following equation:

$$N = \left[\frac{3\sigma x / \bar{X}}{E / \bar{X}} \right]^2 \tag{1}$$

where:
$E / \bar{X}$ = maximum allowed sampling error, %, and

$3\sigma x / \bar{X}$ = advance estimate of sample variation, % (σx = standard deviation, $\bar{X}$ = mean).

8.2.1 For example: assume for small wire terminations (AWG 28 to AWG 20) where one inch of wire is included in the measured resistance $3\sigma x / \bar{X} = 15$ % and for $E / \bar{X} = 5$ %, the minimum value of $N = 9$ is obtained. If a sampling error of 3 % were chosen, then the sample size becomes $N = 25$. It should be noted that N is an estimate of the sample size required to statistically establish the mean response of a specimen for a prescribed sampling error and given sample variation. This test method, however, requires that the underlying statistical distributions be normal. If significant deviations from normality occur, then an analysis should be performed using more suitable statistics.

8.2.1.1 There are many mathematical techniques to test for normality but the easiest method is to plot the existing data on normal probability paper. If the data appears to fall on a straight line in such a plot, then one can assume that distribution is approximately normal and proceed accordingly. It should be noted that a good rule of thumb is to use at least eight plotted points to validate the graphical analysis. It is sometimes found that the natural log of resistance is approximately normally distributed. To test for the condition, the preceding numerical and graphical analysis would apply to replacing the resistance and standard deviation with the natural log of resistance and standard deviation of the natural log of resistance, respectively.

9. Procedure

9.1 *Preparation of Test Specimens*—In general, test specimens should be prepared as nearly as possible as they would be for normal application. Wire connectors, for example, should be applied with the manufacturer's recommended tooling on correct wire sizes. Means must be provided for connection to the test-current source, with lead lengths to the test specimens long enough to isolate the test contact from the heat generated in the power supply and its connections. Voltage-drop probing points on the test specimens must be accessible, and the test specimens must be supported so that probing will not mechanically disturb the test contact. When large numbers of similar parts are to be tested, a test fixture is recommended. On some test specimens it is possible and desirable to provide permanently attached voltage-measuring leads, but the attachment of the leads must not impose abnormal or unrealistic conditions on the test specimens. For instance, soldering voltage leads close to the contact surface of a friction connection may contaminate the contact surface or affect the temper of the spring members. Unless one is deliberately testing for the effects of contact motion on the contact resistance, it is important to avoid any mechanical motion or stress on the test specimens throughout the preparation, measurement, or conditioning steps.

9.2 Pretreatment, aging, or environmental conditioning of the test specimens is not a part of these test methods. Temperature stabilization of the test specimen, either at the ambient temperature or at rated-current operating temperature, is important, however, and should be assured as outlined in 9.5.3.

9.3 *General Procedure for dc Measurement with Current Reversal*:

9.3.1 With the current off, connect the test specimen into the test circuit.

9.3.2 Switch on the power supply, and increase the test current to the desired value (see 9.5 and 9.6).

9.3.3 When testing at rated current the temperature shall stabilize such that the increase in the temperature of the test specimen is < 2°C per hour.

9.3.4 Connect the voltmeter probes to the test specimen, and read the contact voltage drop. Check that the current through the test specimen is at the correct value.

9.3.5 Reverse the direction of the current through the test specimen.

9.3.6 Read the reverse-voltage drop.

9.3.7 Calculate the resistance as follows:

$$R = |E_f| + |E_r| / |I_f| + |I_r|$$

(2)

where:
R = resistance, Ω ,
E_f = forward voltage drop, V,
E_r = reverse voltage drop, V,
I_f = forward current, A, and
I_r = reverse current, A.

9.3.8 This procedure eliminates the effects of thermal potentials from the measurement and compensates for lack of precision in zeroing the test instruments.

9.4 *Test Method A, Standard Test Current*—Discontinued as a test method.

9.5 *Test Method B, Rated Current Testing*:

9.5.1 Table 1 is an example of currents used in rated current tests of static contacts and connectors. Rated currents are specified by vendor or user and are generally large enough to heat the test samples. Consequently, measured resistances may be different from those obtained with Test Method C.

9.5.2 Report in detail the conditions under which rated current measurements are made. The size of the parts, lead lengths, mounting provisions, ambient temperature, and ventilation of the test position will affect the temperature at which the test specimens stabilize, as well as the time required to reach a stable temperature.

9.5.3 Read the resistances when the temperature of the test specimen has stabilized with current flowing. Determine the time for stabilization by taking a series of readings of resistance or temperature as the test specimen warms. When the temperature stabilizes the readings will become constant. Record the time required, and allow this time before each measurement on similar test specimens.

9.5.4 Measure the resistance using a suitable dc or ac method. The dc method with current reversal given in 9.3 is suitable, however, current reversal may be unnecessary if the voltage drop is large compared with thermal potentials.

9.6 *Test Method C, Dry Circuit Testing:*

9.6.1 The primary requirement for dry circuit testing of contacts is that the voltage and current applied to the test specimens must never be allowed to exceed certain maximum limits. These limits are: 20 mV (0.020 V) and 100 mA (0.100 A). To assure these limits, use a power supply circuit that provides 20-mV open-circuit voltage and 100-mA short-circuit current.

9.6.2 Maintain the above maximum limits on test voltage and current. Avoid transient voltage pulses due to switching a power supply on or off, since it is known that pulses as short as 0.1 µs can cause oxide film breakdown and thereby invalidate a dry circuit test. An output resistance for the power supply of 0.2 Ω is implied by these specifications. Avoid the use of a supply with higher than 0.2 Ω to obtain a test current of 100 mA, since a momentary loss of contact in a test specimen would apply a voltage greater than 20 mV to the test specimen[5].

9.6.3 In dc dry circuit testing of contacts, thermal potentials must be eliminated as thoroughly as possible in the test specimen and its connecting leads to the power supply. The most general method of eliminating the effects of thermal potentials is to make forward-and-reverse-current readings and calculating resistance as given in 9.3. An alternate dc method uses a pulsed current where potential is measured first with an applied current and second with no current applied. The resistance is then calculated as:

$$R = \frac{(E1 - E0)}{I}$$

(3)

where:
$E1$ = potential with current I applied, and
$E0$ = potential with no current applied.

This alternate method is automatically used in some commercial instruments.

9.6.4 The use of ac in dry circuit testing eliminates problems due to thermal potentials in the test circuit and test specimen. These test methods encourage the use of ac when suitable instrumentation is available. Certain commercial LCR measurement instruments use an ac measurement current and can be programmed to meet the current and voltage requirements for dry circuit testing. Users of ac methods are cautioned that the peak to peak current and voltage must conform to the requirements of 9.6.1.

9.6.5 These test methods encourage the use of commercial test sets for dry circuit testing, provided the instrument is known to meet the voltage and current limitations of 9.6.1.

9.6.6 Dry circuit testing procedure is as given in 9.3, with precaution that dry circuit testing should precede any other electrical tests on the test specimen.

10. Report

10.1 Report the following information:

10.1.1 Test method used, B, or C,

10.1.2 DC current readings, forward, reverse, and average,

NOTE 2—For ac measurements, indicate whether readings are average, peak, or rms sine wave.

10.1.3 Calculated resistance shall be tabulated. It is recommended that medians, or means and standard deviations of

[5] R. Schubert, "Sealing Current and Regeneration of Copper Junctions," IEEE Trans. Comp., Hybrids, and Manu. Tech., Vol 14, No. 1, 214 (1991).

resistance and probability plots of resistance or resistance change be included where appropriate.

10.1.4 Description of test specimens (types, material, finish, etc.),

10.1.5 Wire and contact size, where applicable,

10.1.6 Conditions of test (temperature, humidity, etc.),

10.1.7 Sample preparation (tooling, method of application, etc.),

10.1.8 Instruments used, model, type, and accuracy,

10.1.9 Probe spacing or position, or both, of voltage-measuring probes on samples,

10.1.10 Time required for temperature stabilization, when Method B is used,

10.1.11 Readings on equivalent length of wire not including a splice or termination, or readings obtained with a standard resistance test sample, where applicable, and

10.1.12 Identification of whether reported values are contact resistance or contact resistance plus bulk resistance.

11. Precision and Bias

11.1 *Bias*—As indicated in Section 7, the ammeters and voltmeters employed in this procedure shall each have accuracies of 1 % or better. Since, in general, the accuracy associated with the voltage drop measurements is dependent on the levels of resistance being measured and the test methods in accordance with this standard, such accuracy shall be stated in the report. To determine the system accuracy, an error propagation analysis can be performed by assuming the source of error as a normal random variable. The following equation can then be used to estimate the system accuracy:

$$\epsilon_R = \sqrt{\frac{1}{2}\epsilon_v{}^2 + \frac{1}{2}\epsilon_I{}^2}$$

where:
ϵ_R = error of the resistance reading, %,
ϵ_v = error to make each voltage drop reading, %, and
ϵ_I = error to make each current reading, %.

NOTE 3—It is assumed that the instrument error for the forward and reverse current readings is the same.

11.1.1 It should be noted that in this equation the factors of one half are derived from the fact that forward and reverse measurements were used to calculate the resistance. In the case of a single measurement with alternating current, the factor should be one rather than one half. In addition, this equation does not account for errors due to thermal effects and zero drift which may occur between the forward and reverse readings, nor does it account for any bias which produce additive or scale errors. As an alternative, the system bias can be determined by making successive readings of a resistance standard which is comparable to the level of resistance the test samples exhibit. These readings can be applied using standard statistical analysis to estimate the system accuracy. A minimum of 20 readings should be used to provide sufficient statistics. A standard precision resistor with a bias of 0.1 % or better is recommended in this procedure. As an example, a 0.01 Ω resistance standard with a 0.1 % accuracy is commercially available. Resistance standards below the 0.01 Ω level are also commercially available, but these standards are generally NIST types and may not be practical to obtain. The choice of procedure used to estimate the system bias shall be described in the report.

11.2 *Precision*—Repeatability of duplicated readings by a single operator shall be within $\sqrt{2}\ \epsilon_R$ and reproducibility of mean results of unaged samples for similar specimens measured by different operators using different equipment should be within the following estimated percentage:

$$\epsilon_c = \sqrt{\epsilon^2 s_1 + \epsilon^2 s_2} \tag{4}$$

where:
ϵ_c = maximum allowable difference, %,
ϵ_{s1} = sampling errors from Laboratory 1, and
ϵ_{s2} = sampling errors from Laboratory 2.

11.2.1 It should be noted that the comparison of mean results have been based on a sample size as determined in Section 8 on sampling where an advance estimate of three times the standard deviation was used. Therefore, to make an accurate statistical statement about reproducibility which also includes a confidence limit, one must apply standard statistical techniques that utilize both the sample size and standard deviation.

12. Keywords

12.1 connection resistance; connectors; contact resistance; contacts; electrical resistance; junction resistance; low level contact resistance; separable connections