

Low-Level Contact Resistance Characterization

Edward M. Bock, Jr.
AMP Incorporated

ABSTRACT

Contact resistance has been characterized on a number of metal finishes at low values of current/voltage. This characterization is performed with currents in the 1-nA to 100-mA range. For the cases of clean tin-, silver-, and gold-finished contacts, the contact resistance is found to be independent of either magnitude or direction of the current. A measurement of contact resistance at the 100-mA level should adequately assure performance at any lower level of current. However, for the case of stainless steel, a material known to possess a tenacious film, the contact resistance is characterized as being current invariant only when the contact voltage is below a critical value. In this case, a measurement at a specified current level may not assure performance at a lower current/voltage.

INTRODUCTION

Connectors may operate in an extremely low current environment. In some cases, this current level may be considerably less than any value applied in the product test/qualification program. As an example, a commonly used procedure allows low-level measurements under dry circuit conditions to be conducted with currents as large as 100 mA, provided the maximum voltage (open circuit voltage) is 50 mV. The question presently under discussion is whether measurements under these conditions are indicative of contact performance at currents in the low mA or μ A regions.

It is generally a very demanding process to make meaningful measurements of connector contacts when using test currents at or below a few milliamperes. Contact resistance values are usually on the order of a $m\Omega$, and contact voltages corresponding to such currents could be less than 1 μ V. For such testing, equipment requirements and test duration are burdensome. This paper deals with these and related issues, addressing specifically the needs for metrology to assure (1) acceptable contact performance at arbitrarily low values of current and voltage, and (2) that

the measurement will not modify the contact interface. Early results of these experimental studies are presented.

EXPERIMENTAL PROCEDURES AND RESULTS

Test Methodology

The emphasis is on characterization of the conduction process for electric contacts within a current range from 1 nA to a maximum of 100 mA. To express contact resistance as a function of current, the following power series is used:

$$R(I) = R_0 + \sum_{n=1}^{\infty} K_n I^n.$$

This expression is general enough to permit description of ohmic and nonohmic as well as symmetric and nonsymmetric conduction. It is desirable that the conduction process be symmetric with current, i.e., nonrectifying. In this case the series contains only even powers of I because of the requirement $R(+I) = R(-I)$. The series expression for contact resistance may then be rewritten in the following manner:

$$R(I) = R_0 + \sum_{n=1}^{\infty} K_{2n} I^{2n}.$$

In addition, if the conduction process is ohmic, that is, if $V = I \cdot R$, then the series expansion is reduced to

$$R(I) = R_0.$$

This program involves measuring contact resistance over as wide a current range as possible. The data are then examined in order to determine whether or not the conduction process is symmetric and ohmic.

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Test Equipment

The contact resistance measurements are conducted with a nanovoltmeter and a computer-controlled voltage/current source. A Keithley 182 Sensitive DVM nanovoltmeter is selected. It has 1-nV resolution and 48-nV accuracy and is the most sensitive on the market. The power source is a Keithley 238 Source-Measure Unit, covering a current range from 100 fA to 1 A with adj. V compliance and a voltage range from 100 μ V to 100 V with adj. I compliance.

Samples are in the form of Research Test Strip (RTS), with the contact configuration consisting of the 0.25-inch diameter hemisphere mated to the flat coupon section. A deadweight fixture allowing for four-terminal contact resistance measurements holds the RTS components for the measurements. Contact resistance measurements are made at normal forces of 50-, 100-, and 200-gram weights.

The materials presented here are cobalt-hardened gold, silver, and tin electroplating. The samples are not aged (environmentally exposed) and are cleaned prior to testing. To gain some insight into film-covered contact behavior, measurements were also made on 302 stainless steel RTS samples.

Experimental Results

Figures 1 through 3 summarize the contact resistance vs. current data for tin, gold, and silver. Curves are shown for the 50-, 100-, and 200-gram weight loadings and for current in both the forward (+) and reverse (-) direction. While data were collected for currents from 100 nA to 100 mA, the plots cover the range from 100 μ A to 100 mA. The reason for data truncation is that the instrumentation did not allow acceptably accurate values for currents less than 100 μ A. Specific comments concerning accuracy are made below. Examination of the plots indicates that the contact resistance does appear to be constant. Figure 4 presents data in a slightly different form. Here, contact voltage is plotted as a function of current. Results are shown for silver at 50 gm, and similar graphs could be presented for all results. This kind of data presentation clearly illustrates—in a more general form—ohmic behavior. One notices that the voltage is proportional to the current, and that it does not depend on current polarity. Such behavior is indicative of constant resistance.

Contact resistance has been characterized for tin, silver, and gold contacts in the 100- μ A to 100-mA range. However, the goals of the program will not be realized without examining the effect that contacts exert on circuits carrying even lower currents. At such minute current levels, accurate contact resistance measurements are not possible with the instrumentation employed. In such cases, a continuity verification is an option to determine whether or not the contact is adversely affecting the application. In order to verify conduction down to 1 nA, a 1-k Ω precision resistor is placed in series with the contacts and the total resistance ($R = \text{contact resistance} + 1\text{-k}\Omega$) is measured. The voltage developed across that resistance element should be sufficient to quantify with acceptable accuracy. The

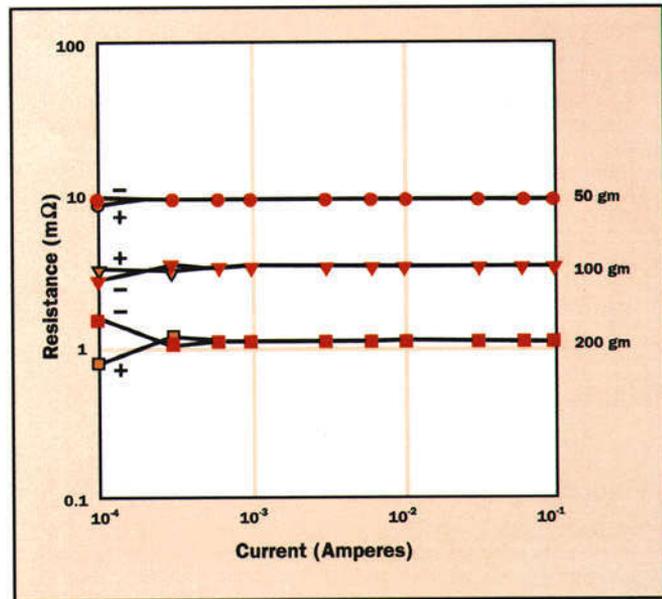


Figure 1. Contact resistance vs. current for tin-plated contacts. Data are shown for 50-, 100-, and 200-gram weight normal forces with both forward and reverse current.

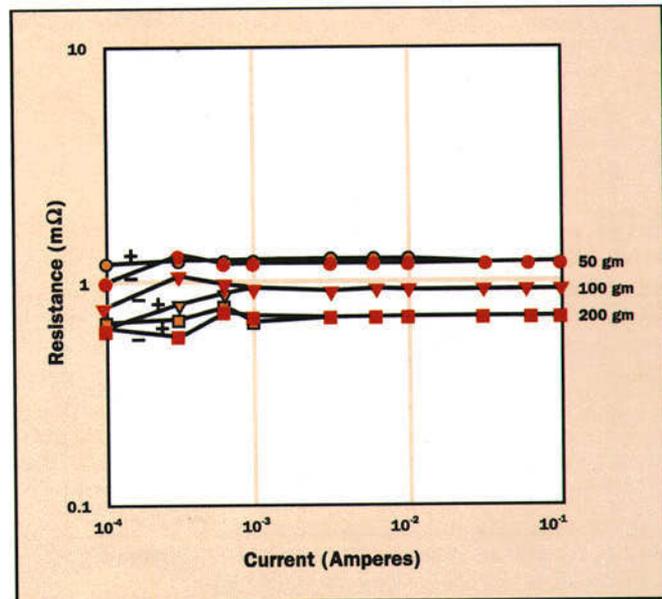


Figure 2. Contact resistance vs. current for gold-plated contacts. Data are shown for 50-, 100-, and 200-gram weight normal forces with both forward and reverse current.

functionality of the contact under such currents will be assured if it can be shown that the contact does not noticeably influence the conduction process, i.e., the resistance of the element must remain constant throughout the measurement sequence. This procedure is termed “continuity verification.”

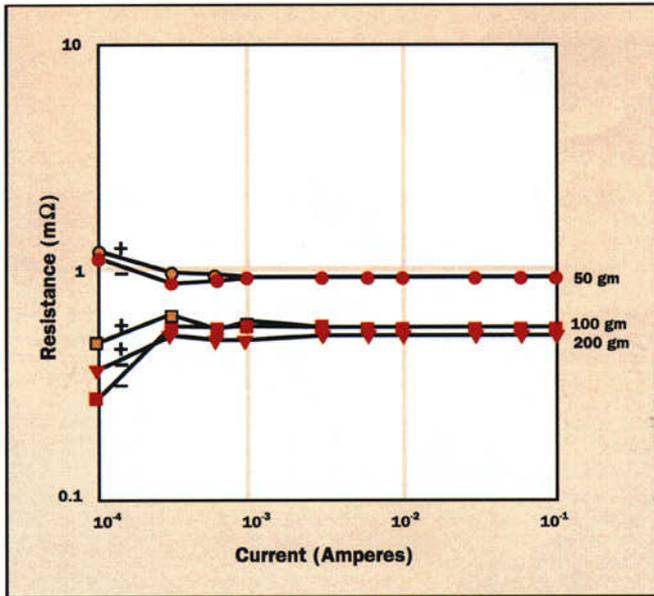


Figure 3. Contact resistance vs. current for silver-plated contacts. Data are shown at 50-, 100- and 200-gram weight normal forces with both forward and reverse current.

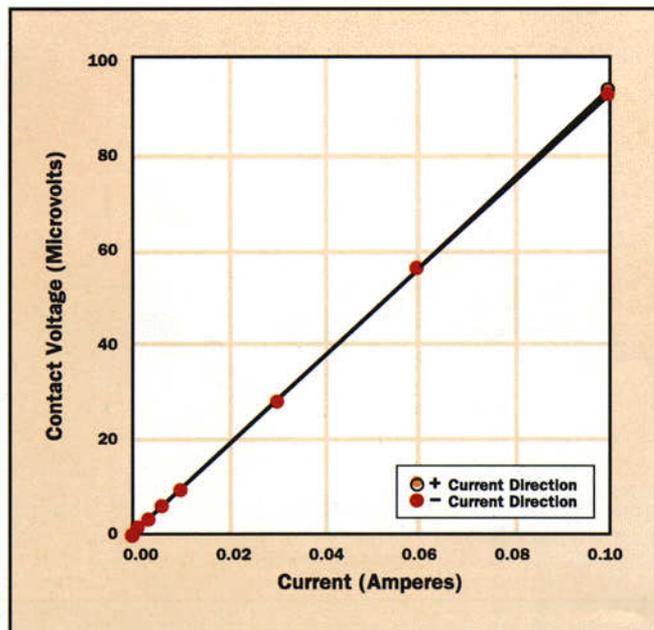


Figure 4. Contact voltage plotted vs. current for silver-plated contacts loaded to 50-gram weight. Data are shown for both forward and reverse current.

Figures 5 through 7 present results of the continuity verification for the tin-, gold-, and silver-plated contact materials. Only results for 50-gram weight loading are presented. Data are plotted from 1 nA to 100 μ A. As can be readily observed, the contact interface does not interfere

with the conduction process. The resistance of the element appears constant throughout the measurement sequence. Within the accuracy of the test equipment, conduction is verified as being completely ohmic and symmetric from 1 nA to 100 mA.

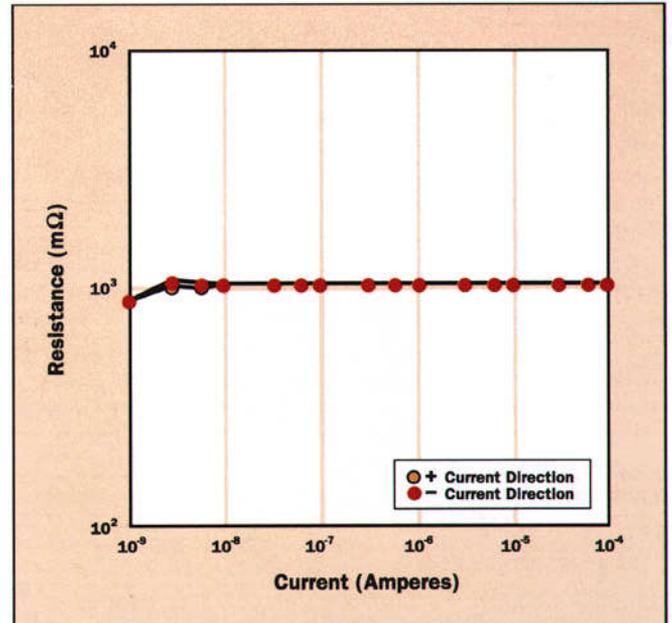


Figure 5. Results of a continuity verification for tin-plated contacts loaded to 50-gram weight. Measurements include contacts and a 1-k Ω precision resistor. Data are shown for both forward and reverse current.

Results obtained on 302 stainless steel are presented in Figures 8 and 9. Figure 8 shows an example of one R-vs.-I characterization. Here, the contact resistance is not constant throughout the measurement. For this example, resistance is constant up to the 10-mA level and then decreases with further increase of the current. In this case, a measurement at the 100-mA level would not have defined the contact resistance at any lower current value. Figure 9 summarizes the results for three runs in which the current is increased up to 100 mA and then decreased to the initial value. Contact voltage is plotted against current. The resistance is constant, denoted by a slope of 1 on the graph, only for the cases in which the contact voltage is below a “critical value” of approximately 0.3 V. The retrace indicates that the measurement process changed, or in these cases reduced, the contact resistance value. It is interesting to note that the contact modification occurs at currents as low as 2 mA. These measurements violate the prime directive for “dry circuit” contact resistance measurements. The measurement process modified the contact interface.

Discussion

The results obtained so far in this program show that the contact resistance for the tin, silver, and gold samples is,

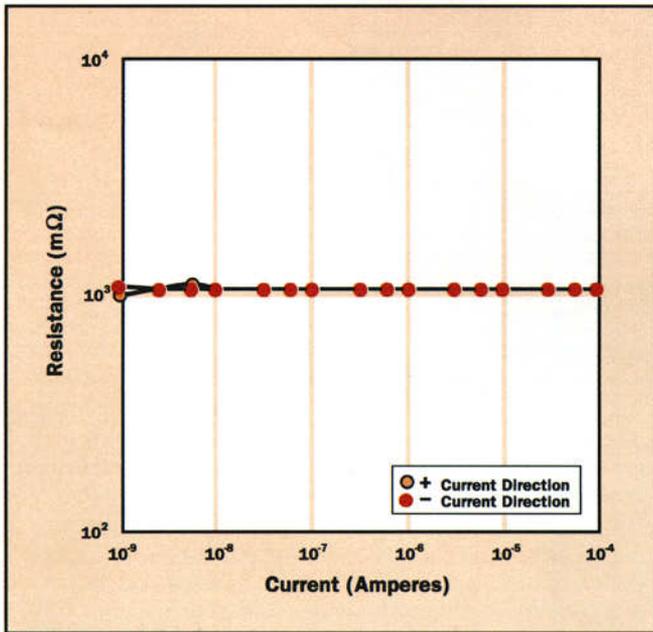


Figure 6. Results of a continuity verification for silver-plated contacts at a 50-gram weight normal load. Measurements include contacts and a 1-k Ω precision resistor. Data are for both forward and reverse current.

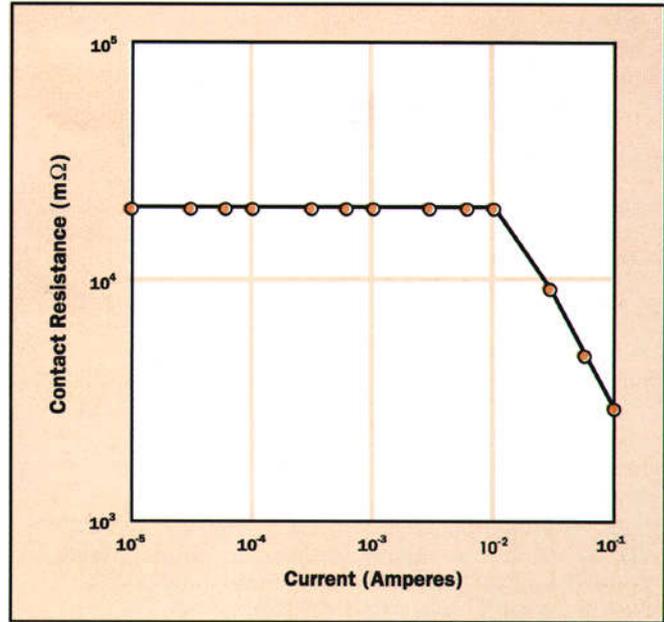


Figure 8. Contact resistance vs. current for 302 stainless steel contacts. Notice the decreasing resistance as the current is increased above 10 mA. The normal force is held at 100-gram weight.

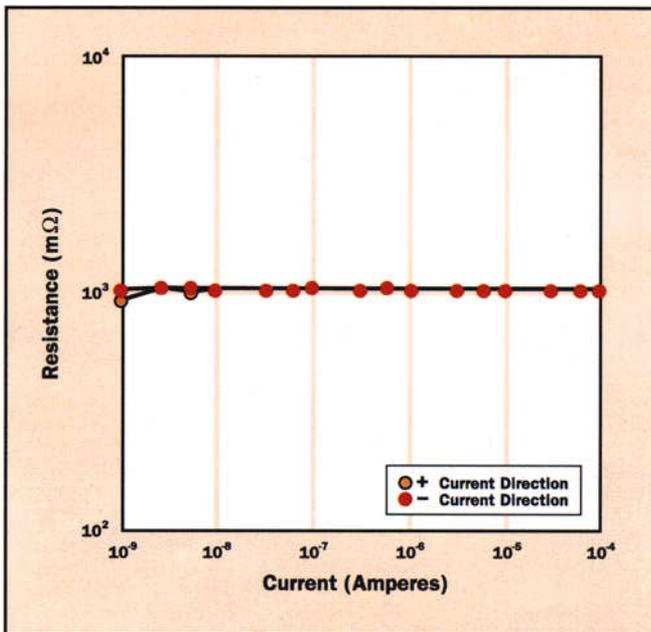


Figure 7. Results of a continuity verification test for gold-plated contacts loaded to 50-gram weight. Measurements include a 1-k Ω precision resistor in series with the contacts. Results are shown for both forward and reverse current.

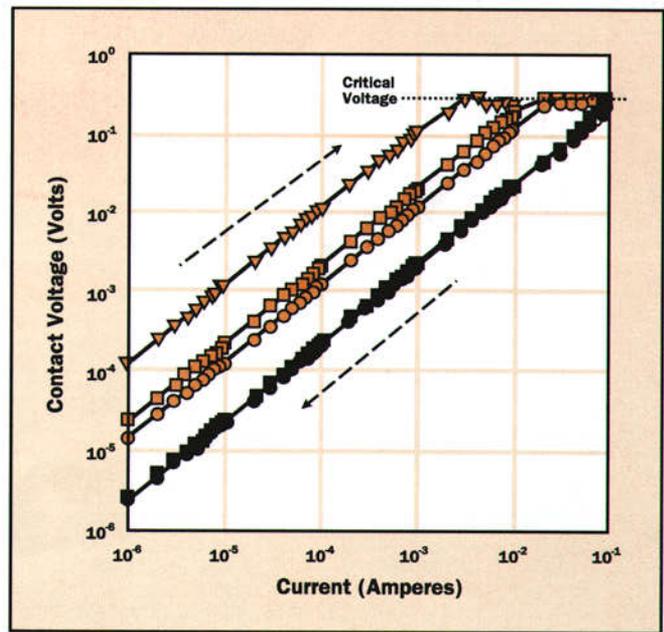


Figure 9. Contact voltage plotted against current for 302 stainless steel. In each of the three sample runs, the current is increased to 100 mA and then decreased. Resistance is constant with voltages below a critical voltage of about 0.3 V. The normal forces were maintained at 100-gram weight.

within the experimental limitations given by the instrumentation used, ohmic and symmetric in the nA to mA region and follows the relation

$$R(I) = R_0 = \text{A CONSTANT VALUE.}$$

These results were obtained on relatively clean contacts. Environmental exposure of contacts maybe expected to indicate current/voltage regions for which this equation is not true.

An example of the case in which the measurement did affect the contact interface is presented. The material was 302 stainless steel. However, and this is very important, even though interface effects are observed for currents considerably below what is allowed by the dry circuit specification, those changes are not produced because of the additional requirement concerning maximum applied voltage. The 50 mV maximum is below the "critical voltage" of approximately 0.3 V determined in this study for 302 stainless steel.

As mentioned previously, the instrument used in this study, the Keithley Model 182, is currently the most sensitive voltmeter on the market. Regardless, it is not possible to accurately measure "clean" contacts with currents in the μA , or lower, region. For the purpose of this work, a continuity verification is employed to ascertain performance at lower current values. To illustrate the magnitude of voltages developed across "good" contacts at low currents with a 1-milliohm contact resistance value, the voltage produced at $1 \mu\text{A}$ would be 1 nV, the absolute resolution limit of the instrument. This would be considerably below that necessary for acceptable accuracy, which is 48 nV.

CONCLUSIONS

The completely ohmic behavior observed for clean tin, gold, and silver contacts implies strongly that requirements for contact resistance tests at extremely low values of current are unnecessary. Measurement at the upper region of the current range (1 nA to 100 mA) completely characterizes contact resistance. Particularly, it shows that contact resistance is invariant with current.

It is desirable to verify by additional experiments the extent to which measurements conducted under present dry circuit conditions do not modify the contact interface. So far, even for the case of filmed contacts such as 302 stainless steel, no exceptions are noted. Specifically, the existence or nonexistence of critical voltages below the presently allowed maximum voltage must be established. All test data show that measurements taken with currents as high as 100 mA but below a critical voltage accurately indicate the quality of the contact, as defined by contact resistance values, at any lower value. In essence, no exceptions to present dry circuit conditions are noted.

The program continues to include these considerations as well as other metal finishes and environmentally degraded samples.

Edward M. Bock, Jr. is a member of Technical Staff in the Technology Division of AMP Incorporated in Harrisburg, Pennsylvania.

Edward holds a B.S. in mathematics from Lycoming College and a M.S. in physics from Bucknell University. He joined AMP in 1965 and has continued to work in contact physics related areas. His major areas of endeavor would include fretting corrosion and friction-wear. He has authored a number of papers dealing with electric contact behavior.