What designers need to know about low-voltage contacts

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Films that form on metal surfaces may stop current flow across a connector when the voltage drop is under 50 mV

☐ The fact that contact between mated connectors is never perfect doesn't matter in many applications. But it is critical in the growing number of designs based on integrated circuits and other low-voltage devices that need signal contacts of less than 50 millivolts. If these dry-circuit contacts, as they are called, are improperly designed, the connection will be intermittent or signal distortion will occur.

The trouble is the oxide or other contaminating film found on most metal contact surfaces. Too small a voltage drop often fails, either entirely or partially, to break through such films. One solution is to do away with the film by putting a high-quality gold plating on the dry-circuit contact, but these days this can be expensive. The other solution is to use a non-noble metal plating and break through the film mechanically, by using a high-pressure contact design.

The goal is to minimize contact resistance. To understand the mechanisms involved, it is necessary to go into the fundamentals of metal-to-metal contact.

When the two pieces of metal of a separable electrical contact are mechanically brought together, this interface creates a resistance to any current flowing through it, and a voltage drop occurs across it. Contact resistance, however, is not a function of the entire interface area but only of the actual area of contact there. And actually, the two metal surfaces touch only at relatively few peaks or asperities, normally called "a-spots" as shown in Fig. 1. The force holding the contacts together is distributed amongst these a-spots so as to generate just enough area to support the load. True contact pressure is the normal force divided by the sum of the load-bearing areas at all touching asperities.

The total load-bearing area is determined by the hardness of the contacting metals and, except for soft metals, is usually small. The balance of the apparent area of contact is filled with air. It is therefore important to realize that for clean metals, free of all oxides or tarnish, the apparent contact (total touching and nontouching surface area) is of no significance whatever.

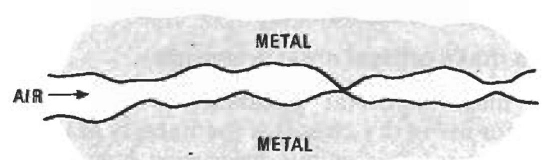
An approximate relationship for contact resistance is:

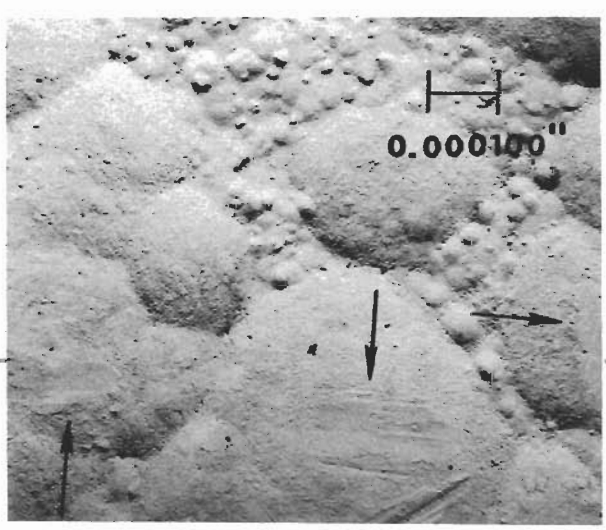
$$R = \frac{\rho_1 + \rho_2}{2}\left[\frac{H}{P}\right]^{1/2}$$

where ρ_1 and ρ_2 are the resistivities in ohm-centimeters of the two contact metals, H is the Brinell hardness of the softer metal in kilograms/centimeter^2, and P is the contact load in kilograms.

The electronmicrograph of the load-bearing areas on a single gold-plated contact surface shown in Fig. 1 reveals a ratio of real to apparent contact area that is very small. Also shown is a closeup of a single a-spot.

Even the contact areas may not be letting current through, however. Except in deep space or in a vacuum, metallic surfaces are never perfectly clean but are covered by contaminating films from a few to several 100





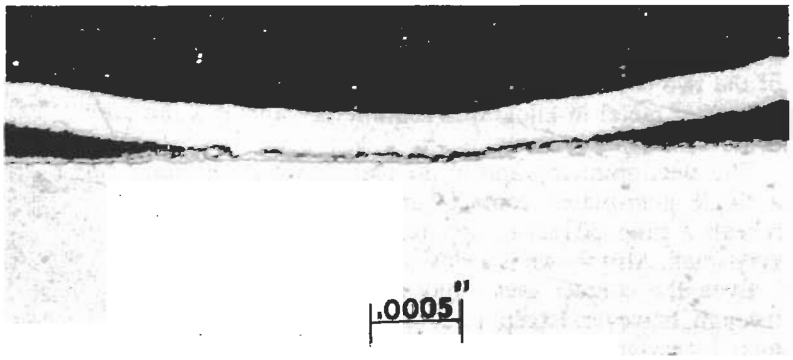
Metal-to-metal. Two magnified metallic surfaces (left) ideally clean, appear as a collection of hills and valleys. Contact is made only at a few areas, known as a-spots, pointed out by arrows at lower left. A magnified a-spot is shown below.

angstroms thick. If the metal is tarnished, for instance, current flows unhindered only through those contact areas where a break in the oxide film allows true metal-to-metal contact. Admittedly, some current can flow by semiconductor action or electron tunneling through oxide films less than 20 angstroms thick, but these films sometimes have rectifying properties and the absence of true metal-to-metal contact could distort the signal.

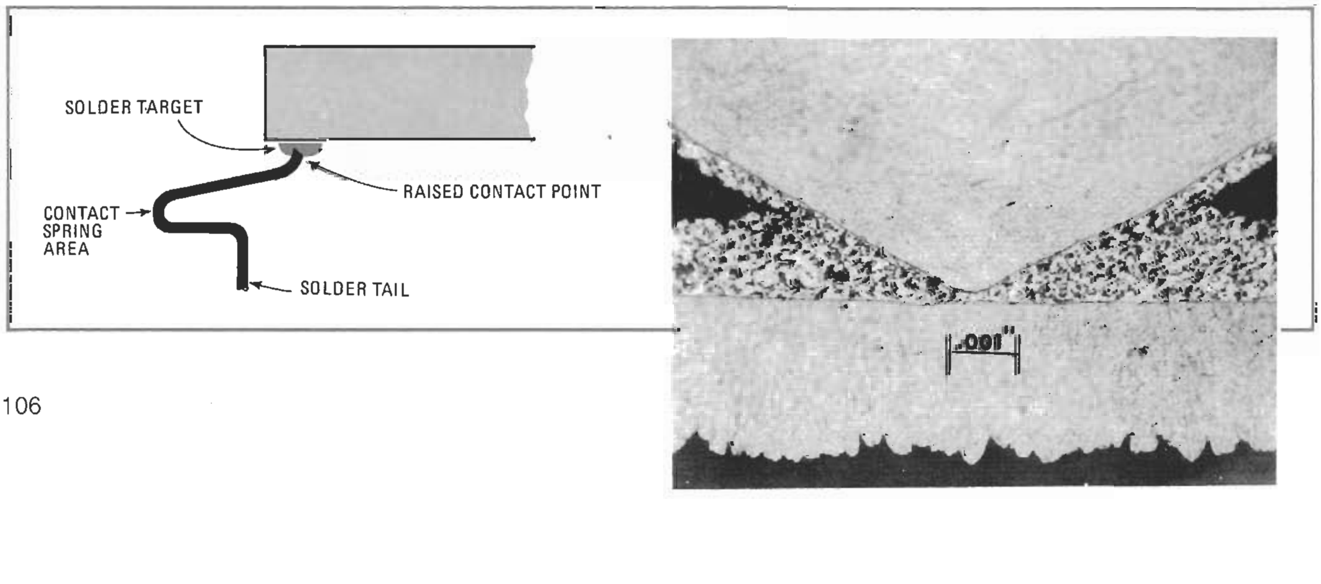
Oxide-film breakthrough occurs either mechanically, during the mating of contacts, or electrically. Whether mechanical breakup of the film will occur depends entirely on connector design, materials used, and environmental exposure prior to mating. By contrast the possibility of electrical breakdown depends on film thickness and on strength of the applied electrical field. In a given circuit, the open-circuit voltage at the unmated contact is the maximum that can occur across the film. If it fails to break through the oxide films, metallic conductivity can be established only by mechanical breakthrough.

Defining a dry circuit

A precise definition of a dry circuit, as a circuit in which this happens is called, cannot be given. The thicknesses of oxide films are too variable and unpredictable. However, it has been found that an open-circuit voltage of less than 50 mV will not penetrate most oxide films on connector contacts, so a dry circuit is conveniently defined as one with an open-circuit voltage of less than 50 mV.



2. Gold-plated contact. Even though areas of apparently close contact are revealed in this microphotograph of a gold-plated contact, much of the interface is taken up by air space.



3. Gas-tight Goldless connectors (lower left) use the sharp point of a spring contact to make metal-to-metal contact with mating surfaces. The apparent contact area of a high-pressure contact, shown right, is almost 100% actual contact area.

Connector contacts in these dry circuits will operate satisfactorily provided they either are free of oxide films or other contamination when contact is made or are properly designed, with the right contact materials, to mechanically penetrate films. Furthermore, these conditions must remain stable—the interface must not be degradable by the chemical changes, like corrosion or tarnish, or the mechanical stresses, like vibration wear, creep, and relaxation, that will occur during the lifetime of the connector.

Though hard gold platings can meet these interface requirements, current gold prices have made them uneconomic for many applications. Attempts to make them economic by reducing their thickness or alloying them with 5% or more of a base metal have not been too successful. Thin gold platings are highly porous, wear out quickly, and are subject to contamination at the surface as underlying base metals diffuse through them. Gold alloys with more than 5% of a base metal may degrade rapidly at temperatures as low as 75°C since the alloying metal is initially present at the surface in the same proportion as in the bulk of the plating.

A cross section of a conventional gold-plated contact through the contact interface is shown in Fig. 2. Some areas of close contact are seen, but much of the apparent interface is empty space, and such a contact would not be gas-tight. Its reliability depends on the quality and durability of the gold plating.

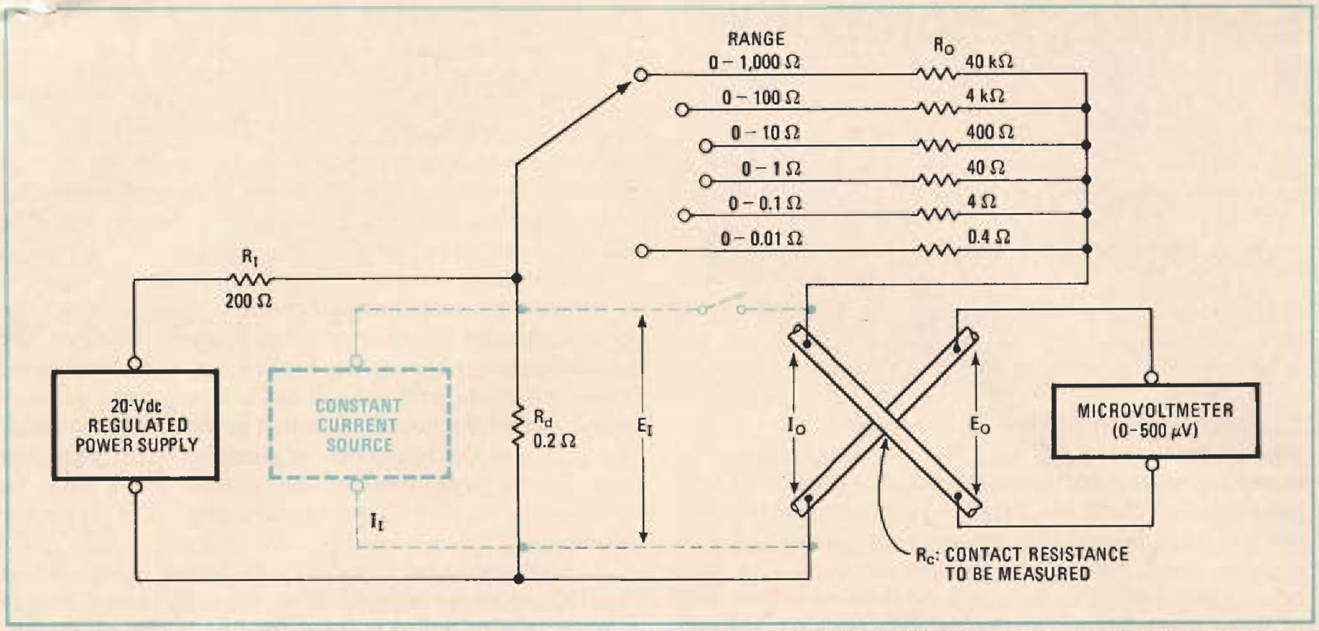
The alternative is to do away with gold altogether and to design a high-pressure contact that will penetrate any oxide film and, better yet, maintain a gas-tight interface. In one such design (Fig. 3) the contact is plated with a tin alloy and has a specially shaped spring-mounted point, to ensure oxide penetration and maintain contact pressure, and hence gas tightness.

The photo in Fig. 3 shows a section of the interface of this contact with a tin alloy plating. Virtually 100% of the apparent contact area is in actual contact.

The reliability of the system rests on the maintenance of its gas tightness by proper contact design and supporting structures. Separable connectors that use this patented Gas Tight High Pressure (GTH) concept have been designed at Burndy Corp.

How to make critical measurements

The most important parameter of connectors intended for use in dry circuits is the stability of their contact resistance. This entails measuring how the resistance changes as the contacts are subjected to the stresses associated with their expected use. The proce-



4. Contact resistance. A constant-current source (dashed lines) or a regulated voltage supply can power this contact-resistance measurement circuit. Open-circuit contact voltage must be limited to 20 mV to prevent current from puncturing (fritting) the surface films.

dure is to pass a known current through the contact and measure the voltage drop across it, but two precautions must be taken.

First, the bulk or series resistance of the contact members (conductors) must be eliminated by placing voltage probes close enough to the contact interface. Usually this problem is circumvented by including an arbitrary amount of bulk resistance in the measurement. As long as this bulk is kept constant and reproducible, any change in the measured value can be wholly attributed to a change in the true contact resistance.

Second, it must be remembered that all current sources have some open-circuit voltage associated with them. If it exceeds 50 mV, it could change the contact resistance. In fact, use of a voltage divider for limiting open-circuit voltage is mandatory for resistance measurements on contacts for dry-circuit applications.

Without a divider, consider what can happen with an electronically controlled constant-current source. When its output is fed into any resistance, this instrument will increase the voltage drop across the resistor until the programed current flows. If the contact resistance includes an oxide film, the contact voltage will increase until the film punctures and the set current can pass. After this action, the contact voltage drops to a much lower value than would have been the case had the film remained intact. A low resistance value will be measured in this case, but such a contact could fail in a dry-circuit condition.

Two methods of measuring dry-circuit contact resistance are shown in Fig. 4. One requires a regulated-voltage source, and the other uses a constant-current source. In both methods, since the voltage E_o is measured across points where no current flows, the microvoltmeter is measuring the voltage drop across the contact resistance alone, and not across any bulk resistance.

When a regulated constant voltage supply is used with voltage divider $R_i + R_d$ (solid lines of Fig. 4) having the values shown, open-circuit voltage at the contact will not exceed 20 mV. The selector switch puts a resistor R_o in series with the sample to be measured, R_c, such that R_o is larger than R_c.

An approximate value of R_c is $R_c = E_oR_o/E_i$, where E_o is the microvoltmeter reading, R_o is the value of the resistor corresponding to the range selected, and E_i is the voltage set by voltage divider action of R_i and R_d. With an unknown value of R_c, it is best to try the highest ranges first and step down the range resistor R_o in order to avoid overloading the voltmeter.

When a constant-current source is used (dotted lines in Fig. 4), the ranging switch is unnecessary, since E_i can be held below 20 mV by choosing an appropriate current across R_d. With unknown samples, the lower current values are chosen first and then stepped up until the meter reads within a convenient range.

Checking up on gas tightness

The aim of a laboratory test may be to simulate the environment with some acceleration factor or, alternatively, to measure some inherent properties of the device, to enable performance to be predicted. Gold-plated contacts may be evaluated from a knowledge of plating thickness, porosity, and wear resistance.

Tests for gas tightness, on the other hand, are particularly useful with non-noble metal contacts, to evaluate how well the mated contacts will resist the ingress of corrosive atmospheres. In these tests, the reagent must be sufficiently aggressive toward the contact materials to make the unmated surface totally nonconducting.

Burndy's method consists of exposing a mated sample connector for one hour to fumes of nitric acid followed by 15 minutes of exposure to ammonium sulfide fumes. Contact resistance is checked before and after testing. It must be emphasized that this is not an environmental test, but rather an accelerated method of testing the integrity of gas tightness. □