

Practical Kelvin Semiconductor Test Sockets

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Abstract

A new probe technology has recently been introduced which enables Kelvin probing on semiconductor device pads with a pad pitch as tight as 0.5 mm. This technique has four important features. It allows two independent probes to contact each pad, yet spreads out the two contacts to the load board on a coarser pitch for lower cost load boards. It uses a patent pending Tungsten alloy needle tip for penetration through oxide layers on solder for long life. It has a large, vertical compliance for handler and package topology variations, and is in a conventional test socket format able to transparently interface to all handlers and load boards. This new probe technology will revolutionize Kelvin testing of leading edge semiconductor devices.

Introduction

If repeatable measurements of a low resistance to within 1 m Ω are required and the contact resistance between a single probe and a lead free pad is typically 30 m Ω and variable, what do you do?

When measuring every m Ω is important, conventional probing and fixturing techniques will not work because contact resistance may introduce unwanted artifacts. In this regime, an old technique, based on principles laid down over 100 years ago by Lord Kelvin, can come to the rescue. Using the Kelvin technique for measuring low resistance can enable 1 m Ω repeatable resistance measurements in the presence of even as much as 1 Ohm of variable contact resistance.

In virtually all power devices, such as DC to DC regulators, a pass through MOSFET is used to regulate the current flow to charge up a capacitor and keep the output supply voltage constant. The series resistance when the channel is on is typically about 100 m Ω and will always move to lower and lower values with semiconductor technology advances.

In production testing of regulators, being able to measure this on resistance, usually designated as RDSON, to a resolution of 1 m Ω can often differentiate between an acceptable part and a part destined to the scrap bin.

Testing low resistance

The way most test engineers would approach this problem is to use the conventional technique of a spring probe test socket, such as shown in Figure 1, where each pad is contacted by an individual probe. The socket provides the compliant, de-matable interface between the stationary load board, connected to the tester's pin electronics on one end, and the packaged device under test (DUT) on the other end. A high volume handler is used to feed devices into the socket so tens of thousands of packaged devices can be tested in a few hours.

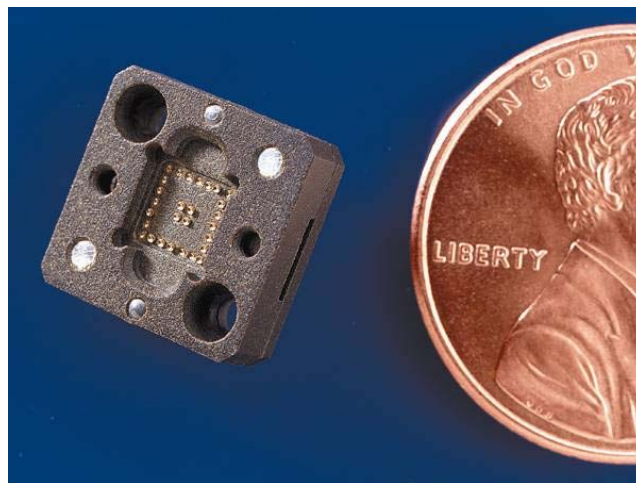


Figure 1. Example of traditional semiconductor test socket with one probe per pad, on 0.5 mm centers.

However, in all probe technologies, there is a contact resistance in series between the probe tip and the pads of the device. This is illustrated in Figure 2. Some of this resistance is due to the bulk series resistance of the spring pin connecting the pads on the load board and the leads of the package. Depending on the diameter of the pin, its length and its material composition, this resistance can be on the order of 10-20 mΩ.

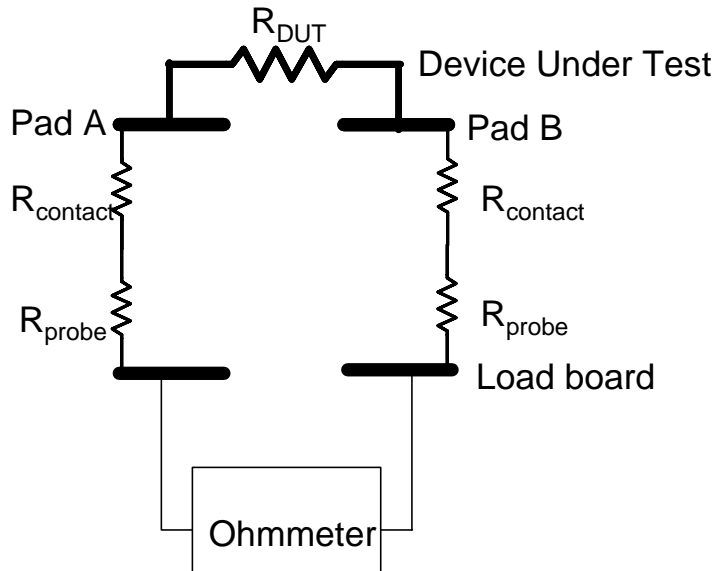


Figure 2. Equivalent resistances from the load board to the DUT

A second component of the total series resistance is the contact resistance between the probe tip and the surface of the package lead. The actual contacting surface area between the probe tip and the pad is typically less than 1 square mil in area. The necking down of the current flowing from the wide probe to the wide pad, through this narrow constricting area, creates a high resistance, which we usually call the constricting resistance. This is a dominant source of contact resistance.

In many interfaces, constriction resistance can be on the order of 2-10mΩ, depending on the materials involved. In addition, if there is an insulating oxide film, such as is always present on solder pads, the current will further be constricted to flow only through the cracks in the oxide. This can increase the contact resistance to 20 or 30mΩ, and it will vary from touchdown to touchdown.

With 30mΩ of probe contact resistance at each pad, a traditional two point resistance measurement would result in 100 mOhm + 30 mOhm + 30 mOhm or 160 mOhm. In most semiconductor test applications, even a contact resistance of 500mΩ is not a problem and would not interfere with any typical measurement.

However, in those special cases where every milliohm counts, even 30mΩ will completely swamp a real measurement and contribute to a significant measurement artifact. If the “fail threshold” were 110mΩ, a good part could be rejected due to contact resistance. Excessive contact resistance failures can significantly cut into test yield.

A common way around this problem is to measure the series resistance of the two probes against a standard, like a device with shorted pads. This resistance is subtracted off all subsequent measurements. If the contact resistance were stable and the same for each new device, this method would work fine. The problem, though, is that the contact resistance is not stable. It might change by as much as 50mΩ, as the probes encounter different oxide or contamination layers on the pads of different devices.

How do we get precision measurements with milliohm resolution in a production test environment? Enter Lord Kelvin.

The Kelvin Resistance Technique

The secret of using Lord Kelvin’s technique, usually referred to as a Kelvin measurement, or four point resistance technique, is to understand and take advantage of the origin of the different resistance contributions and how resistance is fundamentally measured.

To measure the resistance of a single conductor, a current, I , is forced through it and the voltage, V , that is generated across it is measured. By independently measuring both I and V , the resistance can be calculated as simply, $R = V/I$. This is how all conventional resistance tests are performed.

For all linear devices, such as all passive interconnects like package leads, wire bonds, probes and the channel of a MOSFET transistor when used in its linear region, the resistance is completely independent of the current through it. No matter what the current, the ratio of the voltage to the current stays the same. When measuring the resistance of the device, to first order, it doesn't matter what the current is, as long as the voltage generated is well above the noise floor of the instrument.

For example, if the current forced is 10 mA and the voltage measured is 1 mV, the resistance of the device must be $R = V/I = 1 \text{ mV}/10 \text{ mA} = 0.1 \text{ Ohm} = 100\text{m}\Omega$. The contact resistance between the test probe and the device's pads is part of the series resistance and will be included in the device's resistance.

The way around this problem is to use two independent contacts per pad, or four points all together. Figure 3 shows how these four leads would be connected to the measurement system. One lead on pad A sends current into the pad, while another lead on pad B completes the current path. This current flows through the series resistance and contact resistance of probe 1, the DUT resistance and the series resistance and contact resistance of probe 2. The current flowing through each element generates a voltage drop.

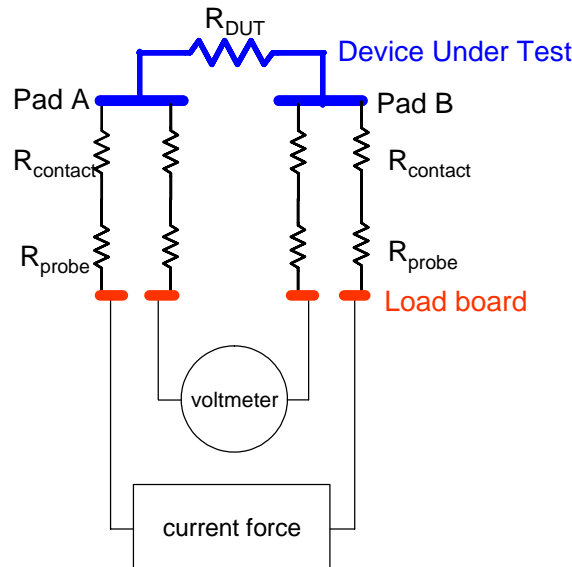


Figure 3. Diagram illustrating the Kelvin Technique

The secret of the Kelvin technique is to use two separate, independent probes to measure the voltage drop generated across the resistance of just the DUT, between the two pads. When we measure a voltage with a good volt meter, there is very little current flow, and the contact resistance of the voltage probes does not influence the voltage measurement.

The Kelvin technique, or four point technique, is based on using one pair of probes to force the current and a separate and independent pair of probes, contacting the same pads but in separate spots, to measure the voltage generated across the DUT. The resistance of the device is simply the ratio of the current forced to the voltage measured.

Practical Kelvin Test Sockets

To use the Kelvin method to measure the resistance of a device requires two probes to contact the same pad in different spots. The difficulty is that as device pads shrink, it becomes harder and harder to fit two probes on the same pad. It's hard enough fitting one probe on each pad of a peripheral device such as the MLF or QFN, with pads on 0.5 mm centers. Fitting two probes per pad is more than twice as tough.

A new approach has recently been introduced which uses eccentric offset needle probes to allow for Kelvin testing of DUTs at centers as low as 0.2 mm, while spreading out to 0.5 mm centers on the load board. The requirement of a high priced, premium load board is no longer necessary. This new probe design allows for readily available and affordable 0.5 mm pitch load boards for Kelvin applications. This is shown in Figure 4.

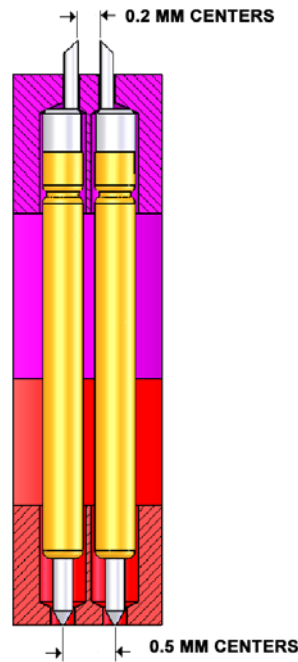


Figure 4. Eccentric Kelvin probes with 0.2 mm centers at the device side, but 0.5 mm centers on the load board side.

A second innovation is the use of Tungsten alloy needles to contact the pads. For the ultra small size the probes need to be, Tungsten offers the highest strength and highest durability for the ultra small size constraints. Figure 5 shows the surface of the Tungsten alloy tips initially, and then after 500k contacts to lead free solder pads. There is no visible wear.

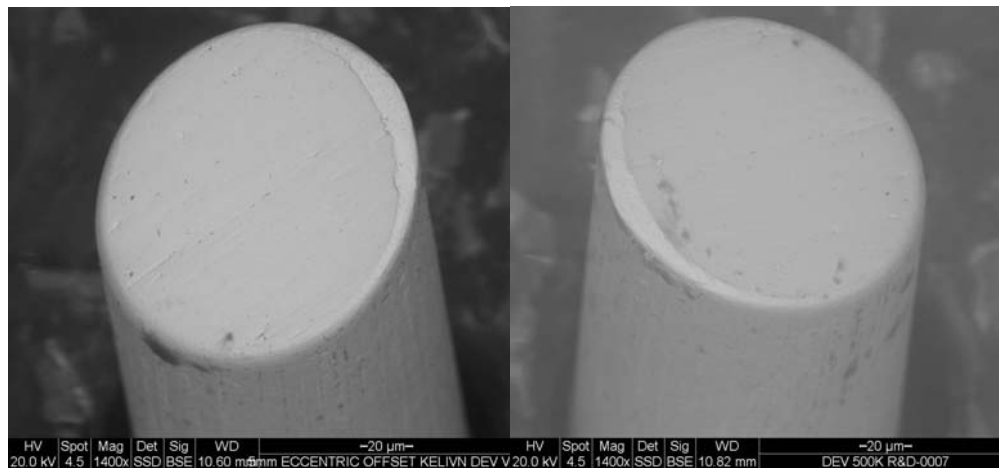


Figure 5. The same Tungsten alloy probe tip before and after 500k touch downs, with no visible wear. Left: before any contacts, right: after 500k contacts.

The use of this new eccentric offset probe technology can enable extremely stable, low device resistance measurements. Figure 6 shows an example of the resistance of a tin plated copper lead frame strip measured for 50k cycles. The resistance of the strip is about 0.5 mOhm and stable to a fraction of a milliohm, the noise floor of the measurement.

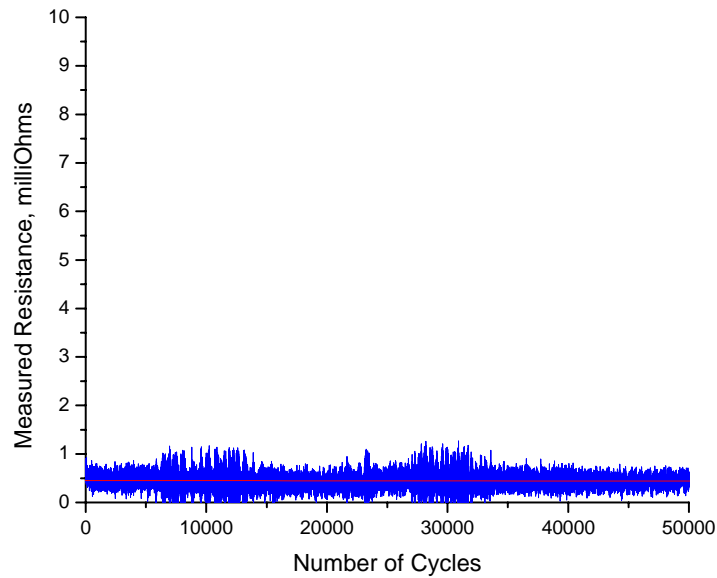


Figure 6. Measured resistance of tin plated copper lead frame sample measured for 50,000 cycles, compared with the predicted resistance of 0.5 mΩ.

The compliance of this probe is 0.020” or 0.5 mm. This is achieved by utilizing a proven spring probe base. Load board warpage and package height variations are compensated with the large, variable compression.

Conclusion

This new eccentric offset probe technology, when used for fine pitch Kelvin measurements, can measure milliohms of resistance for more than 100k cycles on device pad pitches of 0.5 mm. The combination of long life and reduced demand for fine features on the load board should dramatically reduce the cost of Kelvin testing and increase device yields for ultra miniature, fine pitch power devices.



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