Four-Terminal Connection Improves Measurement Accuracy

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How you attach test leads to a component can significantly affect your measurement results. There are a variety of connection methods possible. However, the four-terminal connection is the most often used method for precision measurements—especially for low R, low L, or high C measurements. Its benefits are:

- Minimized contact resistance effects.
- Minimized lead resistance effects.
- Opportunities for reduced lead impedance effects.

To take advantage of these benefits, it's best to start by understanding the simpler two-terminal connection.

The Simple Two-Terminal Connection

Figure 1 illustrates the simplest measurement connection. The measurement meter (dotted box) has two terminals for two test leads. These two leads are clipped to either side of the component under test for a two-terminal measurement.

The measurement basics are simple. There are two primary parts of the meter—a measurement or sensing circuit and a driving circuit. In the case of Figure 1, the sensing device is shown as a circled M, the drive as a circled I. Typically, the drive is a constant current signal, DC for ohmmeters and AC for impedance meters. The sense circuit should present a high impedance to prevent drive current from flowing through it; its job is to simply sense the component voltage drop caused by the drive current.

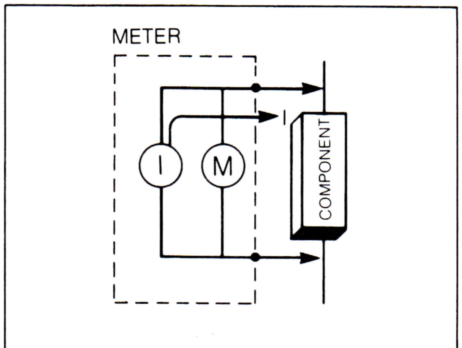


Figure 1. A simplified two-terminal measurement instrument consists of a drive circuit (I) and a sense or measurement circuit (M).

A measurement begins by first shorting the two test leads together. The meter should register zero on its display since a short is being measured (zero resistance or impedance means zero volts dropped). Some small reading may be obtained, however, due to the slight impedance of the test leads. A zeroing control is usually provided to zero out these lead effects. Some modern meters do this automatically with an autozeroing feature.

The next step is to measure the component by connecting the test leads to either side of the component. The constant current, or drive, causes a signal voltage to appear across the component. This voltage is sensed by the meter circuit and processed, using the known drive (I), to provide a reading of L, R, or C, whichever the meter is set for.

The Trouble With Two Terminals

A key point to remember with two-terminal measurements is that the meter doesn't sense just the voltage across the component being measured. It actually senses the voltage at the two terminals of the measurement circuit (points A and B in Figure 2).

The sensed voltage at A and B in Figure 2 is the sum of the voltage across the component, the voltages across the meter leads, and the voltages dropped across the resistances of the lead-to-component contacts. Since the leads and their contacts to the component have some small resistance and there is current through them, there will be some small voltage dropped across them. Unless these lead and contact voltages are removed, they will be processed into the final meter reading, resulting in measurement error.

As mentioned before, lead voltages can be compensated for by shorting the leads and zeroing the meter. For some measurements, this isn't even necessary. What is 0.1Ω of lead resistance added to a 1MΩ resistance measurement? However, for a 1Ω resistor, 0.1Ω of lead resistance is significant. If not zeroed out, it causes a 10% error in the measured value.

The sense circuit should present a high impedance to prevent drive current from flowing through it; its job is to simply sense the component voltage drop caused by the drive current.

Lead resistance, or more generally lead impedance, is also critical in measuring capacitors and inductors. This is especially true for high capacitance or low inductance. Both present low impedances to a test signal, and both can be significantly affected by the added impedance of test leads.

"Ah," you say. "But didn't we take care of all that by first shorting the leads and zeroing the meter?"

Unfortunately, often only part of the error can be taken care of by zeroing in the two-terminal system. The reason for this is the relative amounts of voltage appearing across the leads and the component impedance.

It's a problem of magnitudes. The meter range necessary to sense the voltage across the component being measured may be too high for a precision zero voltage indication when the leads are shorted. For example, a four-digit meter display might show 0.000, but the meter could actually be sensing 0.000389. You wouldn't be able to zero out the last 389 because it's not displayed.

Doing the zeroing on a lower meter range might seem to be a solution. But zeroing on a range other than the one being used for the measurement is not recommended practice and can even lead to greater errors for some types of meters.

What's more, meter zeroing cannot fully take into account contact resistance. The quality of lead-to-lead contact is not necessarily the same as the lead-to-component contact. So meter zeroing will tend to either undercompensate or overcompensate for contact resistance.

A better solution is to simply remove both the lead and contact voltages from the sense circuit. This is where the four-terminal connection comes in.

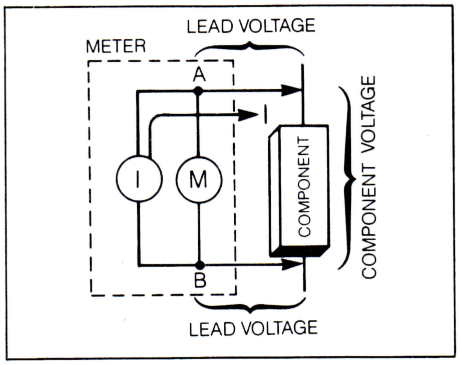


Figure 2. Simple two-terminal measurement circuit showing the sensed voltage (A to B), which is the sum of the voltages across the component and the leads.

Four-Terminal Method Solves The Problem

The lead voltages that can cause two-terminal measurement error exist because of the drive current. It's being supplied by the same leads used to sense voltage across the component.

So, why not use separate leads pairs for driving and sensing?

This is done in Figure 3 and is called the four-terminal technique.

Figure 3 shows current being driven through the component via two leads called the High Drive (HD) and Low Drive (LD) leads. The drive current still causes voltage drops across the HD and LD leads as well as the component being tested. But the sense circuit only sees the voltage across the component. This is because there is now virtually no current through the separate set of sense leads, HS and LS.

Remember, the sense circuit has a high impedance, so it draws no significant current. With no current through the sense leads, there can be no lead voltage drop to add to the component voltage. Thus, lead resistance error is eliminated from the measurement.

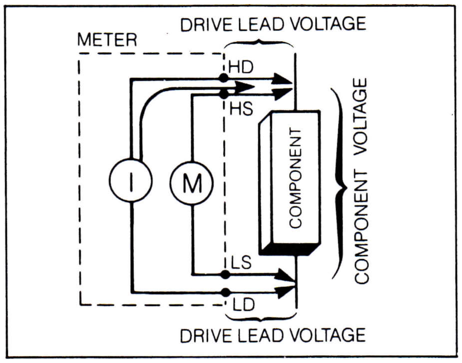


Figure 3. Four-terminal connection eliminates lead resistance from the measurement by using separate leads to directly sense the voltage across the component.

But What About Contact Resistance?

It should be pointed out that any four-terminal connection must eventually become a two-terminal connection again. There are only two terminals on a component, and all four terminals must be connected to it eventually.

Whether or not you successfully eliminate contact resistance from your measurements depends upon how you merge the four terminals into two. Figure 4 shows two approaches, one WRONG and one RIGHT.

Figure 4a represents the case where the sense and drive leads are merged before contacting the component leads. In this case, any voltage drop caused by the drive through the contact resistance is seen by the sense leads. Thus, contact resistance is included in the measurement. This error is not wanted.

With no current through the sense leads, there can be no lead voltage drop to add to the component voltage.

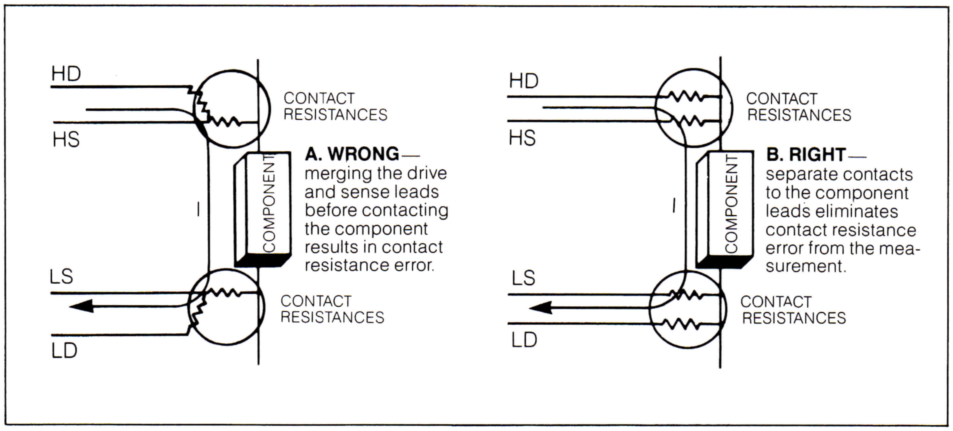


Figure 4. Eliminating contact resistance depends on proper connection of each lead to the component.

What is wanted is the case in Figure 4b. Here, the drive and sense leads make four separate contacts with the component. Now the voltages dropped across the drive contacts are not seen by the sense leads. Also, since there is no current through the sense leads, the resistance of the sense lead contacts present no voltage drop.

Again, a source of error is separated from the measurement circuit by the four-terminal technique.

More Opportunities For Accuracy

Most meters designed for high-precision component measurements have either built-in four-terminal test fixtures or individual connections for external drive and sense leads. Care must be taken in connecting leads between the meter and the component being tested. The high drive and high sense leads must be run to one side of the component and the low drive and low sense leads to the other. Mixing the leads can result in measurement error.

Also, to counteract the tendency of the drive current to induce voltages in the sense leads in an A.C. measurement of reactances, it is wise to twist the two drive leads together. The sense leads should also be twisted as a pair to reduce mutual induction.

These lead-dress details are usually taken care of in lead sets supplied by meter manufacturers. The four-terminal Kelvin Klip® set supplied by ESI is a good example. The leads are clearly labeled for proper connection to the meter (see Figure 5). Also, for convenience, the leads are brought together in special, high-quality contact clips with electrically isolated jaws. One side of the jaw makes drive contact, and the other side makes sense contact. This eliminates accidental mixing of leads when clipping to a component and maintains proper separation of drive and sense connections.

You may have also noticed a small extra clip on one of the Kelvin Klips in Figure 5. This is a shield lead intended for connection to the component case. It should not be attached to either of the component terminals or leads.

The purpose of such additional shield or guard connections is to shield against radio frequency interference on high-impedance measurements or to guard against stray capacitance effects. The latter operation, guarding, becomes important when the capacitance between test leads is comparable to the component capacitance being measured. A four-terminal connection with an additional lead for guarding is referred to as a five-terminal technique. There is also a six-terminal technique that includes another lead for driven or active guarding.

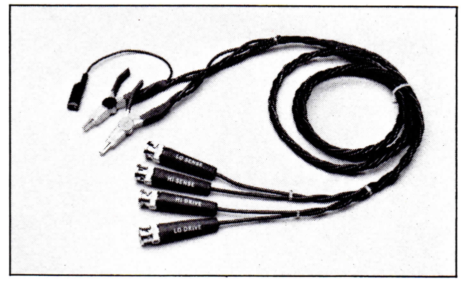
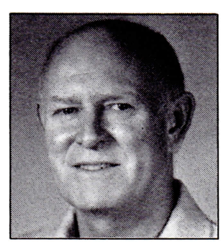


Figure 5. ESI Kelvin Klips® for use in four-terminal measurements.

As you can see, there are a variety of ways to connect test leads for greater accuracy in component measurements. To find out more about which configuration best suits your application needs, contact your local ESI sales representative or call our toll-free number, 800 547-1863. ■



The author:
Armen Grossenbacher was first introduced to electronics as a Navy Electronics Technician. After leaving the service, he attended Devry Technical Institute in Chicago, where he graduated first in his class. He received his Bachelor's and Master's degrees in applied science from Portland State University. Armen joined ESI in 1951. He has managed both assembly and production, and is currently engineering manager for the Instrument Business Unit.