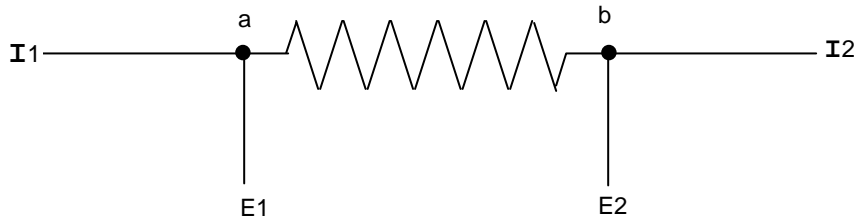# 2-TERMINAL VS. 4-TERMINAL RESISTORS

RCD APPLICATION NOTE R-31

"Kelvin" (four-terminal) connections are often required in current shunts and current sensors to achieve optimum performance and accuracy. The four-terminal method of measurement eliminates inaccuracy attributable to lead resistance, which can be quite significant in low-value resistors. Furthermore, the use of four-terminal connections avoids the TCR (temperature coefficient of resistance) contribution of the lead wires, thereby resulting in tighter thermal stability compared to conventional two-terminal shunts.

The above figure illustrates the four-terminal connection (developed by Lord Kelvin) that enables the voltage drop to be measured across the resistance element itself instead of the element and lead wires. One pair of leads is used for voltage measurement and the other for current sensing. The voltage between E1 and E2 is proportional to the current flow between I1 and I2 and the resistance between junctions "a" and "b". The voltage 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, and therefore the lead resistance is eliminated. Furthermore, the TCR of the current leads is eliminated since the voltage connections are generally affixed directly (or very close) to the resistance element. Errors/inaccuracies attributable to lead resistance, contact resistance, and temperature coefficient are therefore greatly minimized via use of "kelvin" circuits.

An alternative to 4-terminal resistors for less demading applications is to utilize 2-terminal resistors by running a pair of circuit traces to each terminal, one for current and one for voltage sense.

EXAMPLE OF 2-TERMINAL VS. 4-TERMINAL PERFORMANCE

Consider the requirement for a 10mΩ (0.01Ω) ±1% 3 watt axial lead resistor. Low-ohm resistors are generally measured at a distance of 3/8" from the body, which equates to a lead resistance of nearly 1mΩ per lead (based on .032 copper leads). The total resistance of 10mΩ is comprised of approximately 2mΩ from the leadwires and 8mΩ from the internal resistance element.

Consideration #1: Inaccuracy Attributable To Mounting Variation

Since 20% of the total resistance is attributable to the lead wires, it would be essential for the user to assemble the parts into the circuit at essentially the same spot on the leads that the manufacturer used to measure the resistance value,

in order maintain the 1% in-circuit tolerance. Considering the wide variety of mounting spans (distance between leads), mounting profiles (height off board), and

mounting configurations (horizontal vs. vertical), it is often a difficult objective to match lead lengths. Manufacturers will often customize parts to match the customers' lead spacing requirements, however variation can still result in unacceptable in-circuit resistance due to inconsistent lead formation, inconsistent positioning, etc. A variation of only 1/8" from the recommended measurement spacing of 3/8" (combined variation of 1/4") would equate to .6mΩ, or ±6% in this example. Therefore, a resistor that measured exactly 10mΩ at the manufacturer's spacing, would be approximately 6% higher with an extra 1/4" of lead wire in the circuit,

thereby falling well outside the 1% in-circuit tolerance. In order to maintain a 1% in-circuit tolerance utilizing a two-terminal axial lead resistor, the customer would have to specify a tighter tolerance (such as ±0.5% or 0.1%). With a 0.5% tolerance resistor, the user would still need to match the manufacturer's test spacing within .020" to amaintain a 1% in-circuit tolerance (since .020" would account for the remaining 0.5% allowable inaccuracy).

The recommended alternative is to utilize a 10mΩ 1% 4-terminal device (such as RCD LVF-3). This way, the lead spacing and inconsistencies associated with assembly, could be disregarded. In addition, there would be a cost savings involved in buying a ±1% 4-terminal resistor vs. a ±0.5% or 0.1% 2-terminal resistor.

Consideration #2: Resistance Shift Due To Self-Heating

In the example above, 20% of the 10mΩ resistance is contributed by the leadwires. Copper has a TCR of approximately +3800ppm/ºC (+.38%/ºC), and therefore the leadwire of a 10mΩ axial lead resistor would contribute approximately +760ppm to the TCR of the internal resistance element. Depending on the power applied, resistors often heat up 100ºC to 200ºC (or higher) above ambient. So even if the internal resistance element had a TCR of "zero", a 10mΩ 2-terminal resistor would shift roughly +5% to +10% due to TCR contribution of the leadwires alone (the amount of shift depends on the power level and how hot the leads themselves become). By utilizing a 4-terminal device, the thermal instability due to leadwire TCR is greatly minimized.

RCD manufactures the industry's widest range of 2-terminal and 4-terminal current sensors/current shunts...

□ Resistance values as low as 0.00001Ω
□ Wattage ratings 1/2W to 10,000W
□ Current ratings 1/4A to 5000A
□ TCR's as tight as 5ppm/ºC
□ Leaded and Surface Mount designs in 2- and 4-terminal designs
□ High-volume offshore production enables significant cost savings over comparable models
□ Delivery from stock on many standard values

Contact RCD Engineering for application assistance.