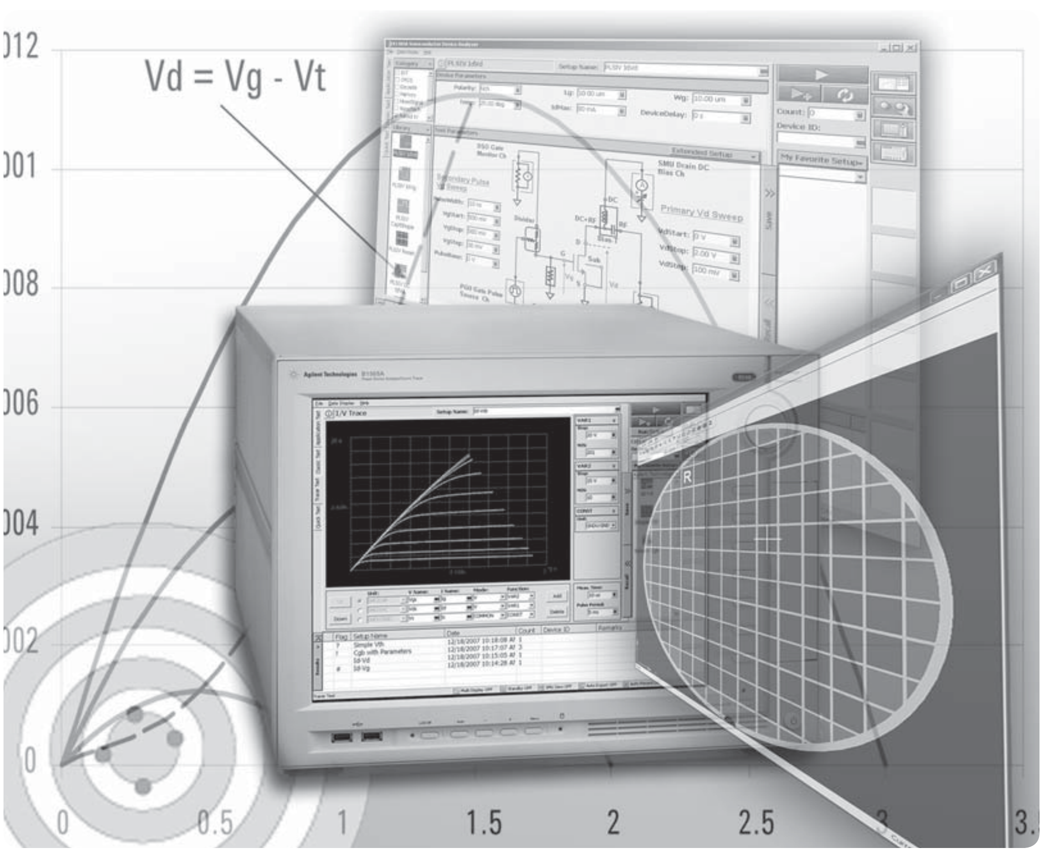
Excerpt Edition

This PDF is an excerpt from Chapter 6 of the Parametric Measurement Handbook.

The Parametric Measurement Handbook

Third Edition
March 2012



Agilent Technologies

Chapter 6: Making Accurate Resistance Measurements

"It requires a very unusual mind to undertake the analysis of the obvious."
— Alfred North Whitehead

Resistance measurement basics

Upon first thought it might seem strange to devote a chapter to resistance measurement. After all, resistance is governed by the simplest of all rules (Ohm's law) that every electrical engineering student learns in their first week of class:

$$V = I \times R \qquad \textit{(Equation 6.1)}$$

However, despite the simplicity of this equation it turns out that measuring resistance accurately is actually one of the more challenging areas of parametric test. The reason for this is that the above equation is overly simplistic, and ignores the fact that resistance generates heat, which in-turn affects the value of the resistance itself. Therefore, it would be more accurate to re-write the above equation as:

$$V = I \times R(T) \qquad \textit{(Equation 6.2)}$$

In this equation the resistance (R) is a function of temperature (T). This phenomenon, whereby the actual value of the resistance being measured changes due to heat generated by the current flow, is commonly referred to as the Joule self-heating effect.

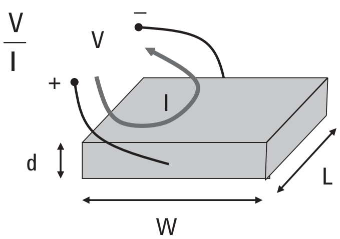
Another factor requiring consideration is the resistance of the cables used to make a resistance measurement. When attempting to measure very small resistance values, Kelvin measurement techniques must be employed. The basics of Kelvin measurements have been explained in earlier chapters, and it is straightforward to apply these techniques to resistor measurements. However, it is worthwhile to point out that the combination of Joule self-heating effects and cable resistance make resistor measurements especially challenging. To reduce Joule self-heating you need to reduce the current (power) flowing into the resistor being measured. However, small currents flowing through the cable resistance require measurement equipment with very accurate voltage measurement capabilities in order to distinguish the cable voltage drop from the voltage drop across the actual resistor. Therefore, for these reasons resistor measurements can easily require a voltage measurement resolution capability of less than 1 millivolt.

The final factor to consider when making resistance measurements is electromotive force (EMF). EMF is the technical name for the burst of electrical noise that is generated when a mechanical relay opens or closes. All SMUs have mechanical (reed) relays in their output paths that generate EMF when the SMU is activated. EMF can have significant impact upon measurement accuracy for all types of measurements, but it can especially impact low-level resistance measurements because they require extremely sensitive voltage measurement resolution.

Resistivity

Resistivity is a basic material property. If we measure the current flowing through a bar of homogeneous material with a uniform cross section when a voltage is applied to it, we can determine its resistance from the equation R = V/I. The related material property of resistivity can be calculated from the resistance measurement if the cross-sectional area (width × depth) and length of the sample are known as shown below.

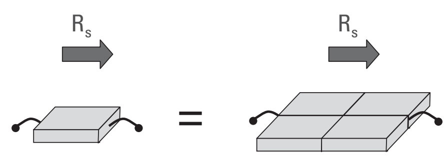
$$R = \frac{V}{I}$$



$$\rho = R\,\frac{A}{L} = R\,\frac{Wd}{L}$$

Figure 6.1. Calculating resistivity from a resistance measurement.

Sheet resistivity is typically measured for all of the implantation layers as well as the metal interconnect layers. It is common to see resistivity expressed in “Ohms per square”, in recognition of the fact that the resistance from one side of a square of homogeneous material of uniform depth to the other side is always the same regardless of the size of the square. A little reflection on the effect of combining squares of material of uniform thickness together into larger squares should convince the reader of this fact.



$$R_S = (R_S \parallel R_S) + (R_S \parallel R_S)$$

Figure 6.2. The Ohms per square of a homogenous material of uniform thickness is always the same regardless of the size of the square.

Van der Pauw test structures

The resistances measured when making resistivity measurements can be extremely small (on the order of milliohms), which mandates the use of Kelvin measurement techniques. Therefore, it is extremely convenient to be able to combine the Kelvin measurement technique with a simple geometry in order to determine the sheet resistance of a given material. The configuration universally used to achieve this is known as a Van der Pauw structure, named after L.J. Van der Pauw who first proposed this measurement technique in 1958. The Van der Pauw structure consists of a square sample with an electrical contact at each of the corners as shown below.

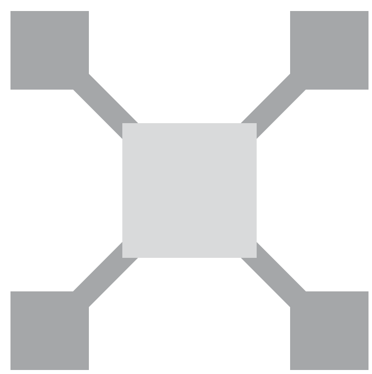


Figure 6.3. The Van der Pauw test structure for determining resistivity.

Van der Pauw showed in his original paper that the following relationship holds:

$$\exp\frac{-\pi d R_{AB,CD}}{\rho} + \exp\frac{-\pi d R_{BC,DA}}{\rho} = 1$$

Here d is the thickness of the sample, ρ is the sheet resistance of the sample, and the resistance measurements are defined as shown below.

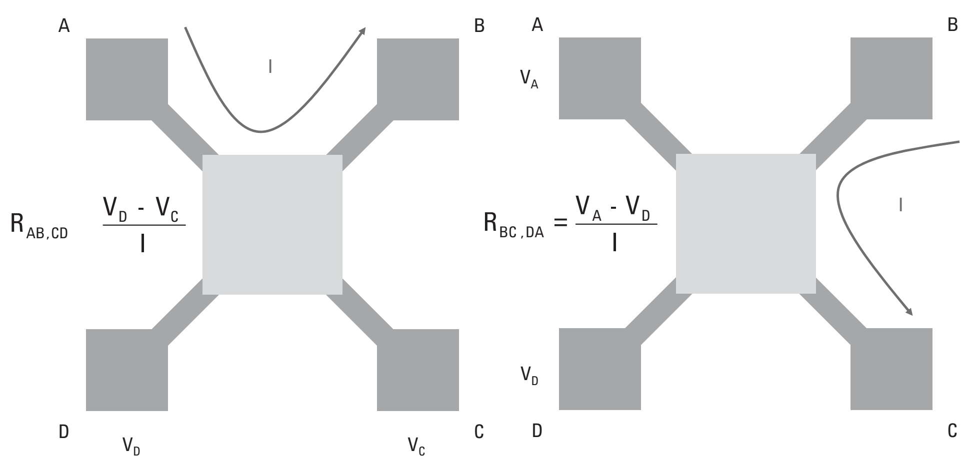


Figure 6.4. Calculating sheet resistance from a Van der Pauw test structure.

The calculation of the resistivity from this equation and these measurements is straightforward.

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