

ECE 3300
Electrical Circuits: Laboratory
Experiment 3 Pre-Reading
Resistors and Multimeter Measurements

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This Unit (and its associated experiment) deals with resistors and their electric properties. This material covers the use of the DC power supply to power a single resistor circuit. It also deals with the use of the multimeter to measure resistance, voltage and current.

Learning Objectives

By the end of this unit, the student should have an understanding of the properties of practical resistors, and the use of the DC power supply in powering, and the multimeter in measuring a single resistor circuit. More specifically, the student should be able to:

- Explain the meaning of tolerance and power rating of a resistor.
- Determine the required power rating for a load resistor.
- Experimentally generate a graphical representation of Ohm's law (i.e., verify the linearity of the voltage/current relation for a resistor).
- Identify the various control keys on the front panel of the Agilent E3631A DC power supply.
- Interpret the voltage and current display of the Rigol DP 800 DC power supply.
- Properly connect the Rigol DP 800 DC power supply to a resistive load.
- Adjust the Rigol DP 800 DC power supply settings to generate constant voltage.
- Adjust the Rigol DP 800 DC power supply settings to generate constant current.
- Set the current and voltage limits on the power supply according to the power rating of the load.
- Identify the various control keys on the front panel of the Rigol DM 3058E multimeter.

- Interconnect the Rigol DM 3058E multimeter to a circuit for proper current and voltage measurements.
- Use the Rigol DM 3058E multimeter to measure resistance, DC voltage and current and AC frequency .
- Explain the difference between an ideal voltmeter and a practical voltmeter.
- Explain the difference between an ideal ammeter and a practical ammeter.
- Experimentally measure the internal resistance of a voltmeter.
- Experimentally measure the internal resistance of an ammeter.

Resistors

The resistor is one of the most basic components in electric circuits. It is a two terminal component with an associated parameter R ; R is the *resistance* and it is measured in Ohms, " Ω ". The factor in the resistance which takes into account the nature of the material is the resistivity, ρ (measured in $\Omega\text{-cm}$). Although ρ is temperature dependent, it can be used at a given temperature to calculate the resistance of a wire of given geometry. The resistance is given by $R = \rho l/A$, where l is the length (in cm) and A is the cross-sectional area (in cm^2) of the resistive element. A typical material used to make resistors is carbon which has $\rho = 0.004 \Omega\text{cm}$. Copper has $\rho = 1.72 \mu\Omega\text{cm}$, iron has $\rho = 9.7 \mu\Omega\text{cm}$, and wood (an insulator) has $\rho = 300\text{M}\Omega\text{cm}$.

When connected to a circuit, a resistor develops, across its terminals, a voltage drop V_R , and a current I_R will flow through it (refer to Figure 1). A resistor's electric behavior is governed by the *linear V-I equation (Ohms law)*: $V_R = RI_R$. It should be noted that the voltage and current are algebraic quantities. A standard convention is adopted where the resistor voltage V_R is positive when the upper terminal of R (in Figure 1) has a higher voltage potential than that at the "-" marked terminal. The voltage V_R will be positive if a current ($I_R > 0$) flows into the resistor terminal marked by the "+" sign.

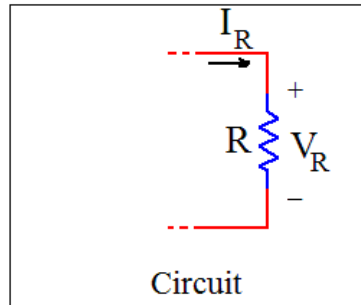


Figure 1. A resistor as a circuit component; V_R is positive if I_R is positive.

A resistor is a passive component; it dissipates energy (supplied by a power source) in the form of heat. In addition to its *nominal value* R , a practical resistor is characterized by its *power rating* and resistance *tolerance*. The power rating specifies the maximum power (P_{max} , measured in Watts) that the resistor can dissipate. Exceeding this maximum power will damage the resistor. Some typical power ratings for (common) carbon film resistors are 1/8 W, 1/4 W and 1/2 W. When resistors with higher wattage ratings are required, wire-wound resistors are generally used to dissipate the heat. In the lab, you will be using resistors rated at 1/2 W for most experiments. Generally speaking, the physical size of a resistor increases as its power rating increases. Figure 2 shows a variety of practical resistors and their power ratings. The power dissipated in a resistor is given by $P_R = V_R I_R$. Employing Ohms law, one can easily derive the following alternative expressions: $P_R = \frac{V_R^2}{R} = I_R^2 R$. The resistor can be safely operated as long as $P_R \leq P_{max}$. **In the lab, and in order to avoid accidents with high currents, we will adopt the stricter requirement:** $P_R = V_R I_R \leq \frac{P_{max}}{2}$.

Based on the above restrictions on the power dissipation in a load resistor R , the DC power supply *limit current* (I_{max}) should always be set according to $I_{max} \leq \sqrt{\frac{P_{max}}{2R}}$. For example, if a 100Ω, 1/2 W resistor is connected across one of the DC power supply outputs, the supply limit current must not exceed $\sqrt{\frac{0.5}{(2)(100)}} \cong 50\text{mA}$. Applying Ohm's law, you can determine that the voltage applied across such a resistor should not exceed 5 Volt.

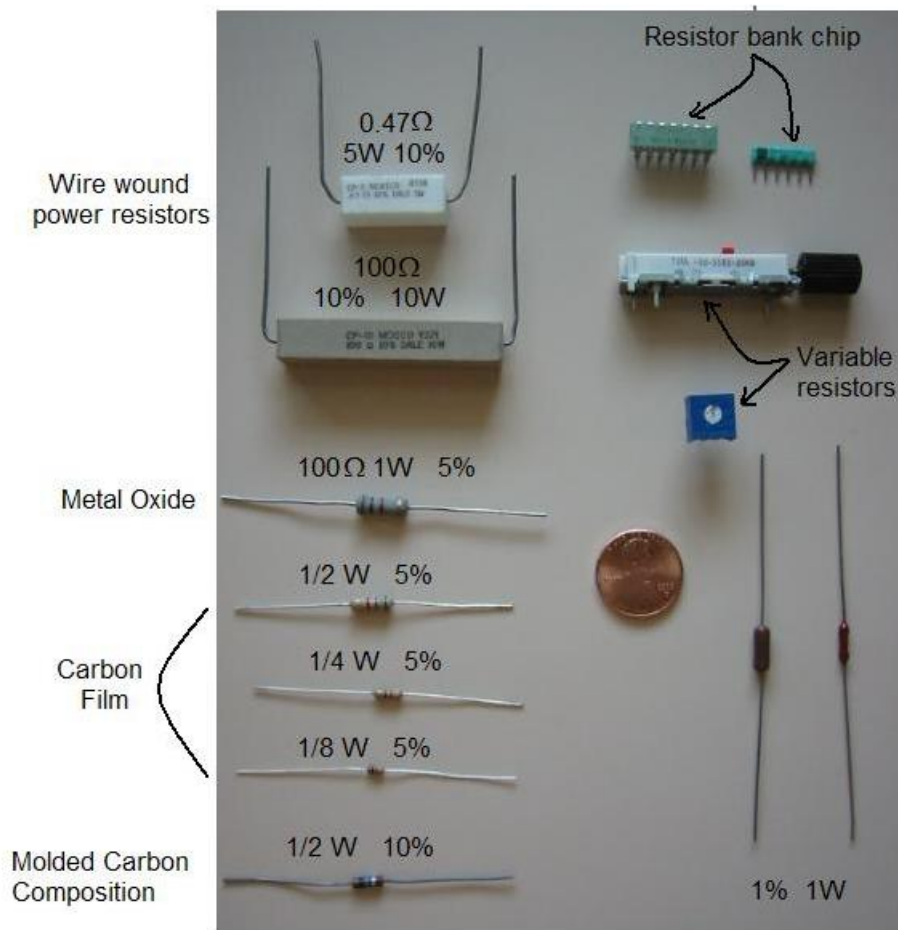


Figure 2. A variety of resistors and their tolerance and power ratings.

Tolerance is another important resistor specification. Tolerance is the *precision* of the resistor and it is given as a percentage. The tolerance specification for a resistor is typically $\pm 5\%$ or $\pm 10\%$. Resistors with $\pm 1\%$ and $\pm 2\%$ tolerance are available, but are relatively expensive. For the most part in the lab, you will be using $\pm 5\%$ resistors. For example a nominal $1\text{k}\Omega$ resistor with a $\pm 5\%$ tolerance, selected from a batch of such resistors, will have a value within $\pm 5\%$ of $1\text{k}\Omega$; i.e., the expected range for R is $1050\Omega < R < 995\Omega$.

Nominal resistor values are normally shown using colored bands. Each color represents a number, as shown in the Table 1. Most resistors have 4 bands:

- The **first band** gives the **first digit**.
- The **second band** gives the **second digit**.
- The **third band** indicates the **multiplier factor**.
- The **fourth band** is used to indicate the **tolerance** of the resistor.

Color	1st Band	2nd Band	Multiplier
Black	0	0	1
Brown	1	1	10
Red	2	2	100
Orange	3	3	1K
Yellow	4	4	10K
Green	5	5	100K
Blue	6	6	1M
Violet	7	7	10M
Grey	8	8	
White	9	9	

	Brown	+/- 1%
Tolerance:	Red	+/- 2%
	Gold	+/- 5%
	Silver	+/- 10%

Table 1. Resistor color code.

For example, consider the resistor depicted in Figure 3. The first band is yellow (= 4), the second band is violet (= 7) and the 3rd (multiplier) band is orange (= 1k). Therefore, the nominal resistor value is 47k Ω . It has a silver band for its tolerance, therefore, the resistor tolerance is $\pm 10\%$.

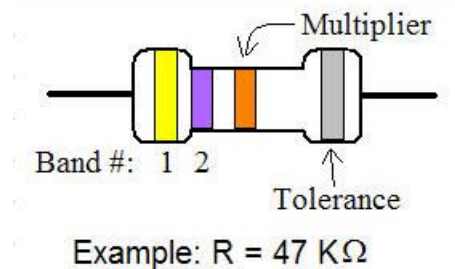


Figure 3. Computing a resistor's nominal value and tolerance from its color bands.

1.0	10	100	1.0k	10k	100k	1.0M	10M
1.1	11	110	1.1k	11k	110k	1.1M	11M
1.2	12	120	1.2k	12k	120k	1.2M	12M
1.3	13	130	1.3k	13k	130k	1.3M	13M
1.5	15	150	1.5k	15k	150k	1.5M	15M
1.6	16	160	1.6k	16k	160k	1.6M	16M
1.8	18	180	1.8k	18k	180k	1.8M	18M
2.0	20	200	2.0k	20k	200k	2.0M	20M
2.2	22	220	2.2k	22k	220k	2.2M	22M
2.4	24	240	2.4k	24k	240k	2.4M	
2.7	27	270	2.7k	27k	270k	2.7M	
3.0	30	300	3.0k	30k	300k	3.0M	
3.3	33	330	3.3k	33k	330k	3.3M	
3.6	36	360	3.6k	36k	360k	3.6M	
3.9	39	390	3.9k	39k	390k	3.9M	
4.3	43	430	4.3k	43k	430k	4.3M	
4.7	47	470	4.7k	47k	470k	4.7M	
5.1	51	510	5.1k	51k	510k	5.1M	
5.6	56	560	5.6k	56k	560k	5.6M	
6.2	62	620	6.2k	62k	620k	6.2M	
6.8	68	680	6.8k	68k	680k	6.8M	
7.5	75	750	7.5k	75k	750k	7.5M	
8.2	82	820	8.2k	82k	820k	8.2M	
9.1	91	910	9.1k	91k	910k	9.1M	

Table 2. Standard resistor values for $\pm 5\%$ and $\pm 10\%$ tolerance (shown in bold) resistors.

Table 2 lists standard resistor values for $\pm 5\%$ and $\pm 10\%$ (shown in bold) tolerance resistors. The missing resistor values in Table 2 should not be a problem, since two or more standard resistors can be connected in *series* to give the equivalent of a missing resistor. For example, the non-standard 50Ω resistor can be obtained by using the following combination of series resistors: $47\Omega + 3\Omega$, $39\Omega + 11\Omega$, $30\Omega + 20\Omega$, and so on.

Some types of resistors employ the BS 1852 (British Standard 1852) coding scheme. Here, the position of the decimal point is marked with a letter (R, K or M). The letter also serves as a multiplier: R = 1, K = 1000 and M = 1,000,000. At the end of the code is a second letter (M, K, J, G, or F) that represents tolerance, where M = $\pm 20\%$, K = $\pm 10\%$, J = $\pm 5\%$, G = $\pm 2\%$, and F = $\pm 1\%$. Here are few examples: R33J = 0.33Ω ($\pm 5\%$), 2R2K = 2.2Ω ($\pm 10\%$), 470RM = 470Ω ($\pm 20\%$), and 22K2F = $22.2k\Omega$ ($\pm 1\%$).

Consider a resistor R and its equivalent resistance consisting of two series resistors R_1 and R_2 , where $R = R_1 + R_2$. If the same voltage is applied across R and across its R_1 and R_2 equivalent, a current I_R will flow through resistor R ; similarly, a current with the same value as I_R will flow through the series resistors R_1 and R_2 . The power dissipated in R is $P_R = I_R^2 R$. The total power dissipated in the resistors R_1 and R_2 is $P_{R_1+R_2} = I_R^2 R_1 + I_R^2 R_2 = I_R^2 (R_1 + R_2) = I_R^2 R = P_R$. Therefore, the power dissipated in R is equal to that dissipated in R_1 and R_2 .

Resistors can also be connected in parallel. Figure 4 depicts two simple DC circuits. Figure 4-a shows a circuit with a single load resistor, R . In the circuit in Figure 4-b, the load is two resistors, R_1 and R_2 , connected in parallel. The two circuits are equivalent if the loads have the same resistance. Here, a power source driving the current I_s in one circuit will drive the same current in the equivalent circuit. Recall that the two loads, in Figure 4, are equal if $1/R = 1/R_1 + 1/R_2$, or $R = R_1 R_2 / (R_1 + R_2)$.

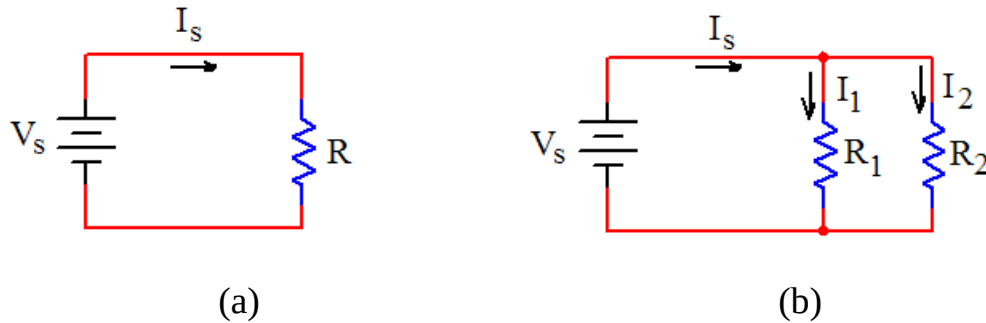


Figure 4. The circuit in (a) is equivalent to the circuit in (b) if the current I_s is the same in both circuits; this is the case when the loads have the same total resistance.

Let us inspect the formula $R = R_1 R_2 / (R_1 + R_2)$. If $R_1 = R_2$, we obtain $R = \frac{1}{2} R_1 = \frac{1}{2} R_2$; so, if two $1\text{k}\Omega$ resistors are connected in parallel, they will be equivalent to a single 500Ω resistor. Another interesting (and important) case is when one of the parallel resistors is much greater than the other resistor, say $R_1 \gg R_2$. Here, $R = R_1 R_2 / (R_1 + R_2) \cong R_1 R_2 / R_1 = R_2$; the circuit behaves (approximately) as if the (relatively) very large resistor is not present. This can be explained by noting that the portion of current I_s that flows into R_2 , current I_2 , becomes negligible as R_2 becomes very large. This phenomenon is important in the case where a voltmeter is connected across a resistor (R) to measure its voltage. The internal resistance (approx. $10\text{M}\Omega$) of the voltmeter

is placed in parallel with the resistor being tested. As long as $R \ll 10\text{M}\Omega$, the voltmeter will not load the circuit and it will give accurate reading.

Another interesting property of connecting multiple, equal-valued resistors in parallel is considered. Let us start with a network of N parallel resistors, all having the same nominal value R , *tolerance*, and *power rating*. The single resistor equivalent to this network is given by $R_{eq} = 1/(NR^{-1}) = R/N$. For example, ten parallel $10\text{k}\Omega$ resistors are equivalent to a single $1\text{k}\Omega$ resistor. Obviously, it is much more efficient (in circuit size and cost) to just use a single $1\text{k}\Omega$ resistor from the start. But, let us take a look at the resulting power rating and tolerance of the “parallel resistors” load. Since (based on symmetry considerations) the current that flows in each of the parallel-resistors load is $1/10^{\text{th}}$ of the *source current*, then one can easily show that the parallel-resistors load has an effective power rating that is 10 times that of a single resistor. Also, the tolerance of the “resulting” $1\text{k}\Omega$ resistance is enhanced (reduced). This is verified in the following example.

Consider the problem of obtaining a $1\text{k}\Omega$ resistance using three $3\text{k}\Omega$ resistors, with $\pm 5\%$ tolerance each. Assume that the measured resistances are: 3100Ω , 3025Ω and 2950Ω (the absolute errors are: 3.33% , 0.83% and 1.67% , respectively). Now, assume the resistors are connected in parallel. The resulting equivalent resistor value is $R_{eq} = 1/(1/3,100 + 1/3,025 + 1/2,925) = 1,005\Omega$. The error in R_{eq} , relative to the desired value of $1\text{k}\Omega$, is 0.5% . This error is significantly smaller than the average error for the $3\text{k}\Omega$ resistors, given by $\frac{1}{3} \sum_{i=1}^3 |\varepsilon_i| = (3.3 + 0.83 + 1.67)/3 = 1.93$.