Equivalent Meter Resistance

This installation of N.E.R.D discusses meter resistance. The equipment referenced here is found in the Undergraduate Electronics Lab at the University of Houston. Topics covered in this document are as follows.

Voltage Measurements

Equivalent Circuit

Voltage measurements are made by connecting a voltmeter in parallel with the voltage to be measured. We will suppose, to be specific, that we want to measure the voltage v_2 across resistor R_2 in the circuit in Figure 1.

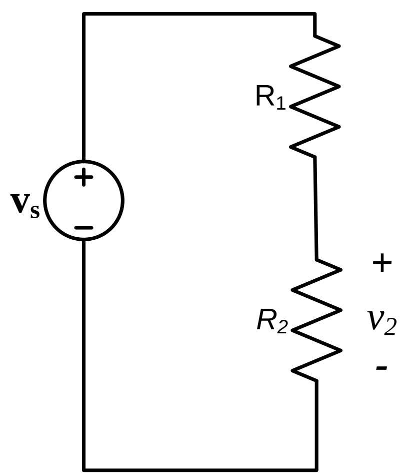

Figure 1 We wish to measure the voltage v_2 using a voltmeter.

The measurement process is illustrated in Figure 2. The figure on the left shows the voltmeter in place. The figure on the right shows the voltmeter modeled using an equivalent resistance R_{mv}.

As we will see, the presence of R_{mv} changes the value of v_2, which we know call v_{meas}. Note that v_{meas} is not the same as v_2, because of the voltmeter resistance.

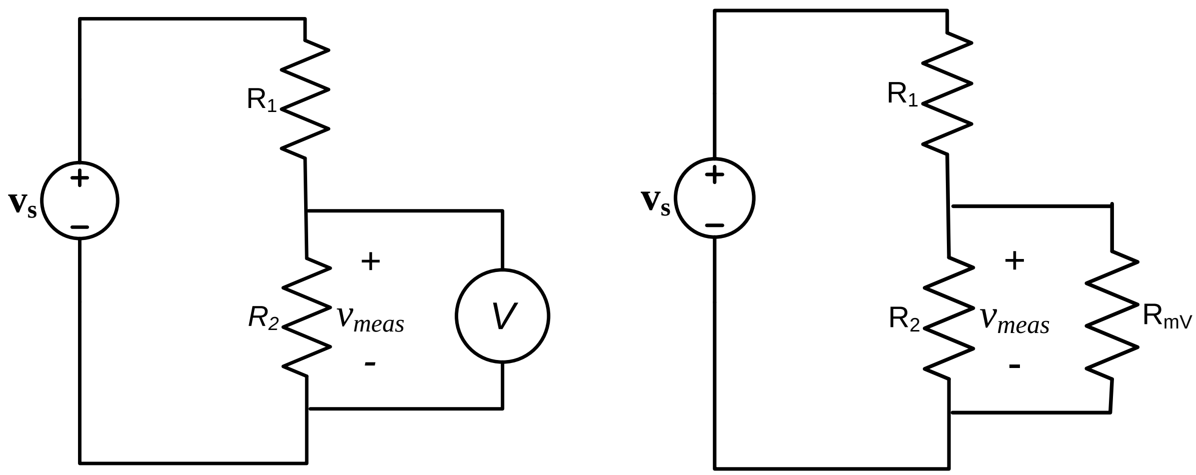

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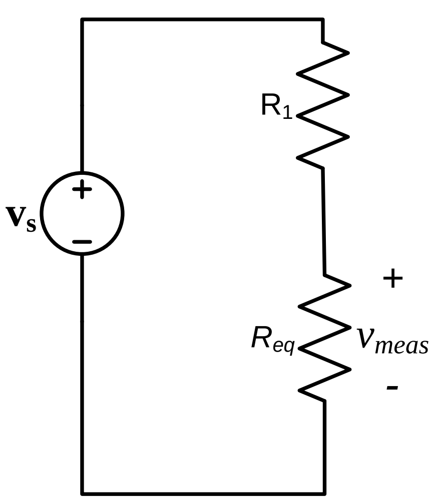
Figure 2 Left: Schematic representation of the placement of a voltmeter (V) to measure the voltage v_{meas}. **Right**: A resistor R_{mv} has been used to model the voltmeter as an equivalent resistance.

We explore the effect of the meter resistance by noting that R_2 has been replaced by the parallel combination of R_2 and R_{mv}. The circuit with the equivalent resistance is shown in Figure 3.



The equivalent resistance R_{eq} is calculated from

$$R_{eq} = R_2 // R_{mv}$$
$$= \frac{R_2 R_{mv}}{R_2 + R_{mv}}.$$

Figure 3 Circuit schematic accounting for the parallel equivalent resistance of R_2 and R_{mv}.

Effect of Voltmeter Resistance

In thinking about resistor combinations, we know that R_{eq} will be less than either R_2 or R_{mv}. From the voltage divider equation we see that the voltage v_{meas} will therefore be less v_2. This introduces an error in measuring v_2.

The error introduced by the voltmeter will be small if $R_{mv} >> R_2$. This can be seen by looking at the expression for R_{eq}. In the limit that R_{mv} is infinite (an ideal voltmeter), $R_{eq} = R_2$. Therefore a good voltmeter has a large equivalent resistance R_{mv}. Even if it does, however, there may be circumstances where we need to measure a voltage across a large resistance. In that case, we should expect an error that may be significant. But if we know the voltmeter resistance and the resistance whose voltage we are trying to measure, we can calculate, or at least estimate, the expected error.

The multimeter in the ECE Lab is an Agilent 34405A. The internal resistance of this meter when used as a voltmeter is 10[MΩ] for all full-scale measurement values.

Current Measurements

Equivalent Circuit

Current measurements are made by connecting an ammeter in series with the current to be measured. We will suppose, to be specific, that we want to measure the current i_2 through resistor R_2 in the circuit in Figure 4.

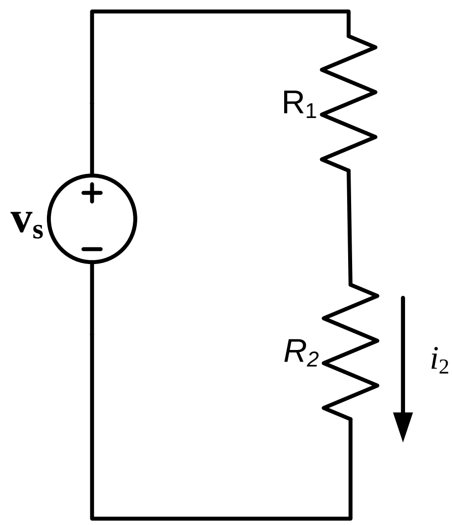
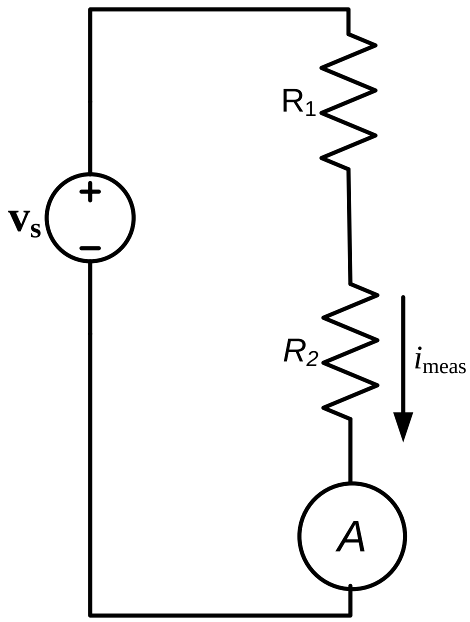


Figure 4 We wish to measure the current i_2 using an ammeter.

The measurement process is illustrated in Figure 5. The figure on the left shows the ammeter in place. The figure on the right shows the ammeter modeled using an equivalent resistance R_{ma}. As we will see, the presence of R_{ma} changes the value of i_2, which we know call i_{meas}. Note that i_{meas} is not the same as i_2, because of the ammeter resistance.



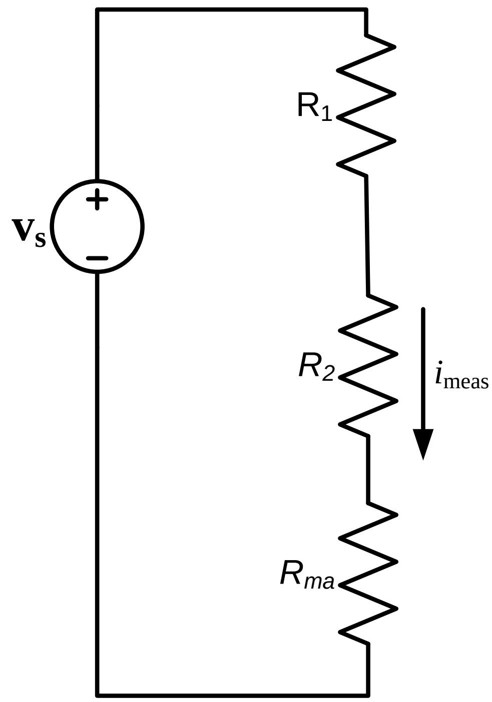
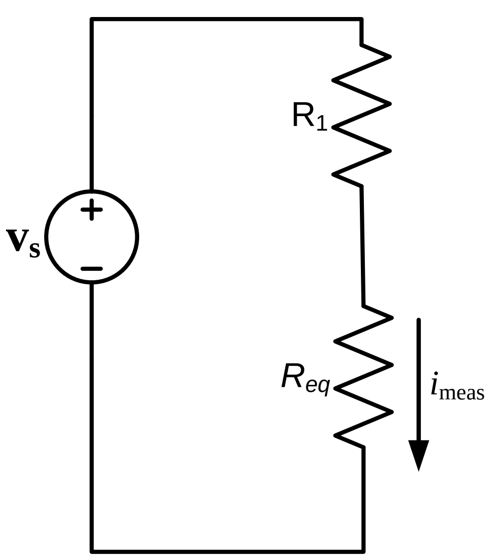


Figure 5 Left: Schematic representation of the placement of a voltmeter (V) to measure the voltage v_{meas}. **Right**: A resistor R_{mv} has been used to show that the voltmeter introduces an equivalent resistance to the circuit.

We explore the effect of the meter resistance by noting that we have introduced a series resistance R_{ma}. We can think of this as having added the meter resistance to R_2, so that now we have an equivalent resistance that is the series combination of R_2 and R_{mv}. This is illustrated in Figure 6.



The equivalent resistance R_{eq} is calculated from

$$R_{eq} = R_2 + R_{ma}$$

Figure 6 Circuit schematic accounting for the series equivalent of R_2 and R_{ma}.

Effect of Ammeter Resistance

In thinking about resistor combinations, we know that R_{mv} will be large than R_2. As a result, the current i_{meas} will be less i_2. This introduces an error in measuring i_2.

The error introduced by the ammeter will be small if $R_{ma} << R_2$. This can be seen by looking at the expression for R_{eq}. In the limit that R_{ma} is zero (an ideal ammeter), $R_{eq} = R_2$. Therefore a good ammeter has a small equivalent resistance R_{ma}. Even if it does, however, there may be circumstances where we need to measure a current through a small resistance. In that case, we should expect an error that may be significant. But if we know the ammeter resistance and the resistance whose current we are trying to measure, we can calculate, or at least estimate, the expected error.

The multimeter in the ECE Lab is an Agilent 34405A. The internal resistance of this meter when used as an ammeter is specified as less than 20[Ω] at 10[mA] scale, 2[Ω] at 100[mA] scale, and 0.5[Ω] at 1[A] scale.