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5B Module: Resistor Circuits – Voltage Divider

One of the greatest challenges a new engineer faces is knowing how to use the seemingly-simple components at hand. So let's start with the humble resistor. In this module you will experiment with a common configuration of resistors called a voltage divider. It is used to reduce the voltage supplied by a constant voltage source and to interface with digital hardware.

Procedures

Voltage Divider

The voltage divider circuit is often used to step down a voltage. If a circuit needs 5V to work but more than 5V would destroy the circuitry and you only have a 9V battery – what do you do?

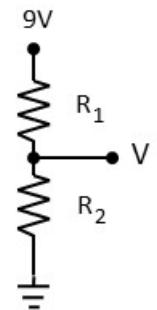
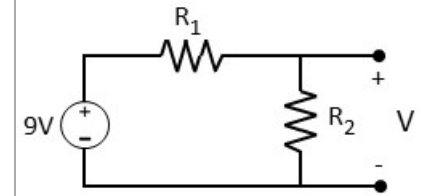
The simplest, though not the most power efficient, method is to use a voltage divider. A voltage divider, as you will learn in lecture, is a simple network of two or more resistors connected in series, powered by a source. The two figures to the right show a voltage divider circuit with a 9V source connected in series with resistors R_1 and R_2 . The two circuits are identical and are the most common configurations in schematics – the one on the right, bottom being the most widely used.

Because the same current flows through all of the components, the supply/battery, and the two resistors, the relationship between the voltages across each resistor is linear. The voltage across any resistor in series, even if there are more than two, is simply the ratio of value of the individual resistors as compared to the sum of all the resistor values. The equations below illustrate the relationship between the voltages across each resistor and the source.

$$V_{R_1} = \frac{R_1}{R_1 + R_2} V_{source} \quad V_{R_2} = V = \frac{R_2}{R_1 + R_2} V_{source} \quad V_{source} = 9V$$

Question 1: Choose the value of the two resistors R_1 and R_2 if the voltage V needs to be 3V. There are an infinite number of pairs that satisfy the condition that drives the voltage V to be $V=3V$. Pick one.

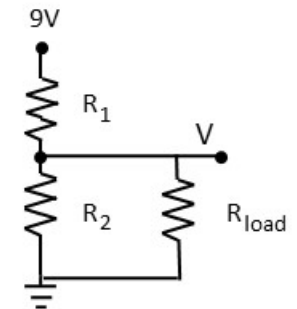
Question 2: Given that it is the ratio of the resistors, not the actual value of the resistors that determines V , discuss another constraint that might drive your choice of resistor values.



Notes:


There is a drawback when using a simple voltage divider circuit to provide a given voltage. (Devices like the power supply and smaller devices called *voltage regulators* have fairly sophisticated circuitry to bypass the problem.) Let's look at the voltage divider with voltage V connected to a device that you can model as a resistor R_{load} . By adding the load resistor you have modified the circuit so the voltage V is different.

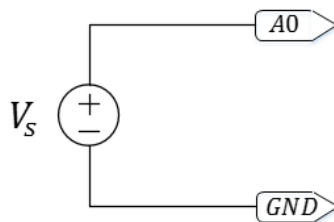
Question 3: Assume that your design constraints are such that you choose the values of R_1 and R_2 to be $R_1 = 2k\Omega$ and $R_2 = 1k\Omega$ so that $V = 3V$ with no device connected. Compute V if the resistance $R_{load} = 1k\Omega$. Why is this circuit not a good voltage regulator?



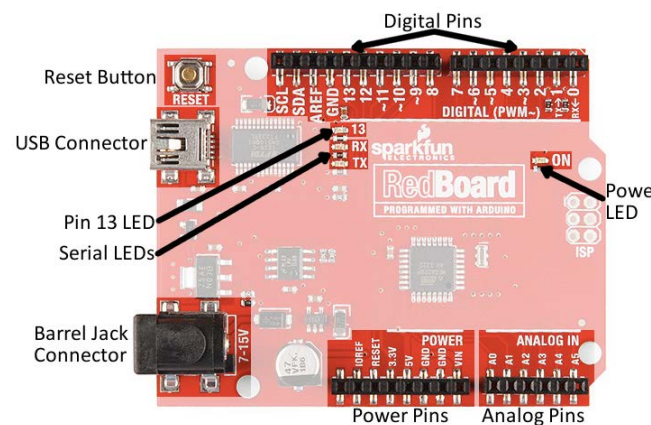
Another use for the voltage divider circuit is to interface resistive elements to digital hardware. Many of the sensors in your kit are resistive sensors. The resistance of the device changes in response to an environmental change. The temperature sensor is a resistor that is sensitive to changes in temperature, the photo resistor responds to changes in the light level, etc... So why do we need a voltage divider?

To answer that question let's build a very simple test using the Arduino/RedBoard.

- ✓ Set the power supply to 0V using the +25V mode.
- ✓ Hook-up the power supply to the analog pin labelled A0 as shown in the schematic below. The  indicate which pins on your Arduino/RedBoard to connect to the positive and negative terminals of the power supply. The pin A0 is one of the Analog Pins and GND can be found with the Power Pins.



Resistor Circuits – Voltage Divider



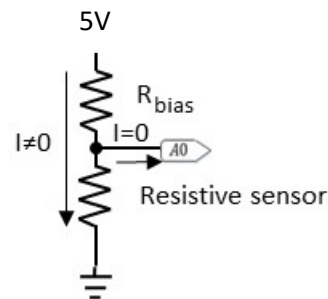
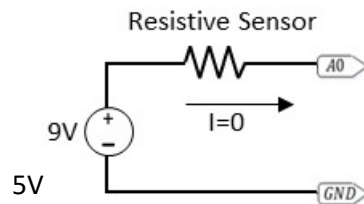
- ✓ Connect the Arduino/RedBoard your bench computer using the USB cable provided with your kit. You do not need to program the board! We are only looking at the electrical characteristics of the Analog pins on the board.

The circuitry onboard the Arduino/RedBoard works with a voltage range from 0-5V. Though the board is tolerant of higher voltages it is best not to push it too much.

Question 4: Vary the voltage from the power supply slowly between 0 and 5V and observe the current reading that is displayed on the voltage source (you will not need an ammeter). Does the current change much as the voltage is increased?

For applied voltages within the stated limits of the Arduino/RedBoard, the analog input pins behave much like the input of a voltmeter. The pins should draw almost no current from the circuit feeding them and therefore the effective resistance looking into the pins must be quite large.

So if you connected a resistive sensor to the Analog pins in what seems at first a very logical configuration, as in the schematic on the left, the Arduino would never read anything but 5V. How does a voltage divider help??



As you can see the circuit on the left will produce 5V between the Analog pin A0 and the GND pin on the microprocessor board no matter how the resistance of the sensor changes (as always, within acceptable limits). To understand why you need to realize that the board becomes part of the circuit and the resistance of that circuit is very, very large so a very, very small amount of current will ever flow through the circuit. The resistive sensor can change resistance but the voltage drop across it is too small to make a difference at the Analog pins.

The voltage divider helps with this issue. It relates the value of the resistance to a voltage through a simple linear transformation. The configuration you will use is shown in the figure to the right. Since you are using the Arduino whose usable voltage range the voltage divider is a series connection of the sensor and another resistor labeled R_{bias} across 5V.

- ✓ Build the circuit shown in the schematic to the right. Pick the resistive sensor of your choice – the flex sensor, and the photo-resistor are the easiest to use at first.

What should the value of V_{bias} be? This is a surprisingly complicated question to answer. Key pieces of data are i) the range of resistances that each device experiences when stimulated by the extremes that you expect, and, as usual, ii) power considerations.

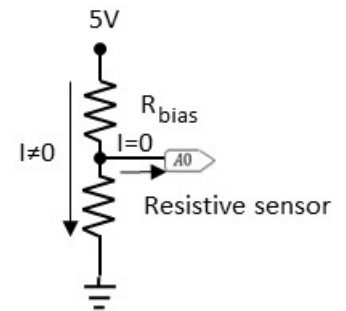
Question 5: Measure the resistance of the resistive sensor as you bend it or shine light on it or do whatever is required to change the resistance. What is the range of resistances that you have achieved?

$R_{smin} =$

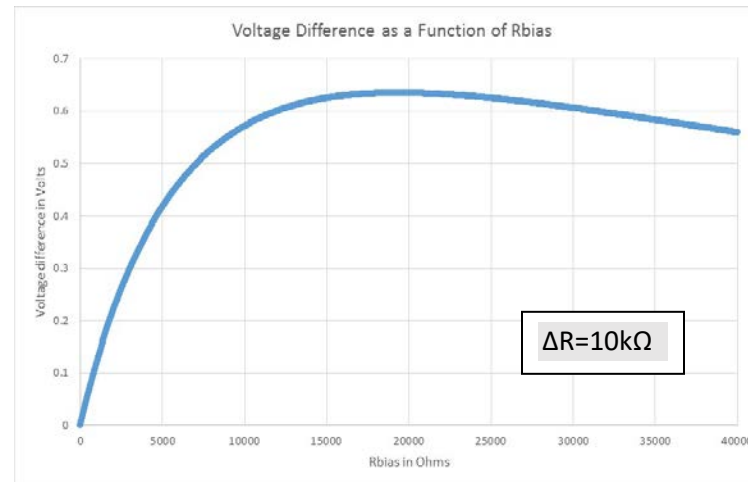
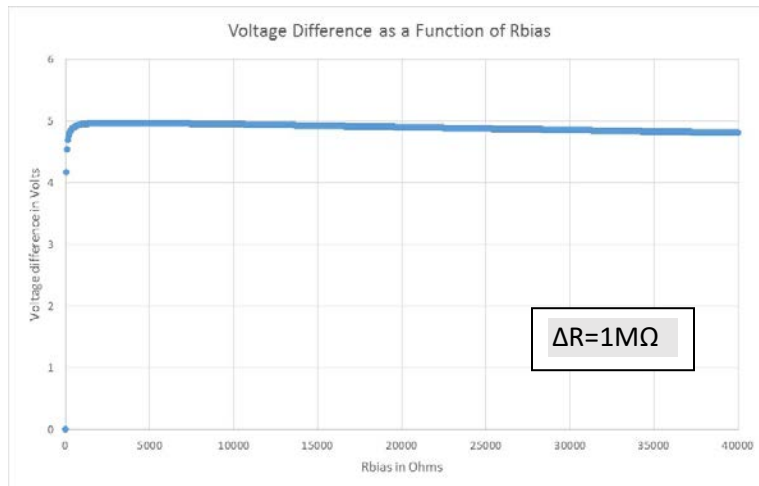
 $R_{smax} =$

The voltage across the resistive sensor at its minimum value is $V_{smin} = 5 * \frac{R_{smin}}{R_{smin} + R_{bias}}$ and the voltage across the resistive sensor when at its maximum value is $V_{smax} = 5 * \frac{R_{smax}}{R_{smax} + R_{bias}}$. The voltage different $\Delta V = V_{smax} - V_{smin}$ is usually the quantity you want to maximize. Once you have a voltage range you need then you can consider power consumption. The analog pins on the board are used to interface a continuous voltage range to a digital number. The Arduino uses a 10-bit A/D so the voltage range 0-5V are mapped onto the integers 0 – 1023. This implies that the resolution is approximately $\frac{5}{1024} \approx 5\text{mV}$.

Resistor Circuits – Voltage Divider



To choose the proper resistance let's look to Excel to help us. The two graphs below show the range of the voltage labeled V in the schematics for the case where the range of the resistances of the sensor is really large (like the photo-resistor) and the range of resistances is not as large (like the flex-sensor).



As you can see when the resistance changes over a large range the value of R_{bias} is almost irrelevant. The voltage V varies across nearly 5V for the range of resistance values in your resistor kit. In this case you have the luxury of taking into account the power consumption in the resistors. In this case you can choose a resistor with a higher value so that the current flowing through the voltage divider is minimized ensuring that not much power is wasted.

When the resistance varies over a narrower range, as in graph to the right, choosing the best value for R_{bias} is important. The graph shows that the maximum difference is approximately .63V. This difference barely registers to the Arduino. Eyeballing it – $R_{bias} \sim 17\text{k}\Omega$ maximizes the voltage difference.

Question 6: (Optional) Derive the optimal value of R_{bias} . You can find voltage difference ΔV as a function of R_{bias} , R_{smax} , and R_{smin} . Assuming that R_{smax} and R_{smin} are constants that you measured for Question 8, maximize ΔV in terms of R_{bias} .

Resistor Circuits – Voltage Divider

Question 7: Make several choices for R_{bias} based on the maximum and minimum values of the resistance that you measured in Question 8. Monitor the voltage V using the DMM as you stimulate the sensor and record the voltage range obtained. A table is provided for convenience.

R_{bias}	Voltage Range

Question 8: Using the design goals of maximizing the voltage range and minimizing power choose a value for R_{bias} . Defend your choice.

Question 9: You will notice that – for resistive sensors with a limited range of resistance – the optimal value of R_{bias} is about the value in the middle of the range. See if you can explain why.