ELECTRICAL ENGINEERING DEPARTMENT

EE143 California Polytechnic State University Lab #5

Voltage Division & Loading Effects

VIDEOS:

Experiment #4 Playlist at
https://www.youtube.com/playlist?list=PLkooZoxYRwMjJQtUZn2KSK5ejgw0bKGSz

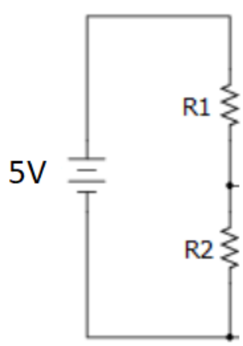
5% Standard Values (EIA E24) Decade multiples are available from 10 Ω through 22 MΩ											
10	11	12	13	15	16	18	20	22	24	27	30
33	36	39	43	47	51	56	62	68	75	82	91

5% Standard Values (EIA E24) Decade multiples are available from 10 Ω through 22 MΩ											
10	11	12	13	15	16	18	20	22	24	27	30
33	36	39	43	47	51	56	62	68	75	82	91

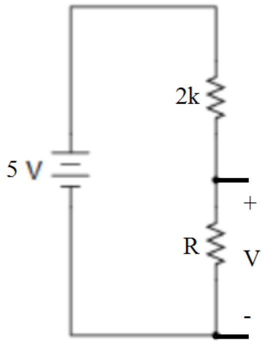
For example; 56Ω, 560Ω, 5.6KΩ, 56KΩ, 560KΩ and 5.6MΩ are standard values.

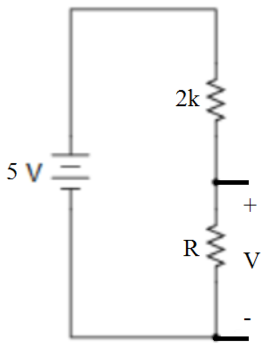
PRELAB:

1. Suppose you have a 5V source, but need 1V to operate a device. Design a Voltage Divider that provides 1V across R2 with 5mA through R2 without exceeding a power rating of ¼ W. Use only standard ohm resistors from the Digi-Key parts. Simulate your design in LTSpice and include a picture of your schematic and simulation (showing the voltage across and current through R2).



2. Using Voltage Division, write an equation for R in terms of V for the following circuit:





3. Assuming you are using a 10-bit Analog to Digital converter with a 5V reference voltage, write an expression for the analog voltage (V) in terms of the digital value (X).

4. Locate the datasheet for the KTY81-210 temperature sensor online. This sensor changes its resistance in response to changes in temperature. Locate the table that relates typical (TYP) resistance to degrees F for the KTY81-210. Come up with a linear equation that allows you to plug in a value for resistance and it will give you a value for degrees F. (Enter the table into Excel and find a linear trend-line). Write your equation here.

Voltage Division & Loading Effects

PURPOSE:

- To become familiar with the engineering design process (design, simulate, build, test)
- To become familiar with software used to design and simulate circuits.
- To become familiar with some of the instruments used in this and subsequent labs.
- To develop proper laboratory procedures relative to collecting, recording, and analyzing data.
- To study different applications of voltage division
- To understand loading effects

This experiment relates to the following **course learning objectives** of the course:

1. Ability to interconnect equipment and devices such as multi-meters and power supplies, to achieve required results.
2. Acquire practice in recording data and results.
3. Ability to relate laboratory results with lecture theory.
4. Ability to analyze and evaluate data.

STUDENT PROVIDED EQUIPMENT:

1 Arduino
1 Digital Multi-meter (and its User's Guide)
1 Breadboard
1 Jumper Wire Set
1 820Ω ¼ Watt Resistor
2 100Ω ¼ Watt Resistor 1
1 DC Buzzer
1 DC motor
1 KTY81-210 temperature sensor

EXPERIMENTAL SECTIONS:

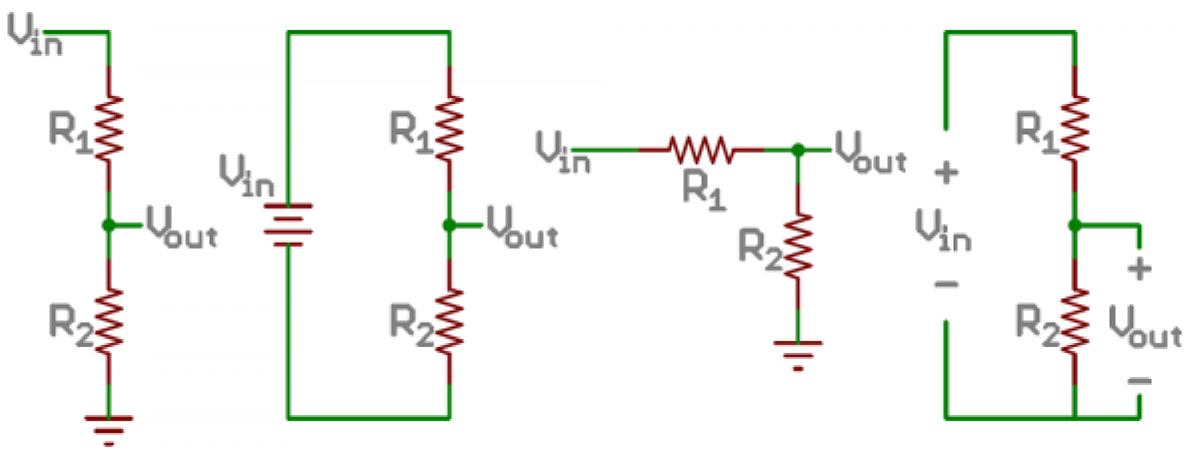
1) Voltage Division: Level Shifting
2) Voltage-Follower & FET as a Switch
3) Voltage Division: Reading Resistive Sensors

BACKGROUND:

Voltage Division

The image below shows four different ways of drawing a simple voltage divider circuit. Assuming you know the values of Vin, R2, and R1, you can solve for Vout using the following equation:

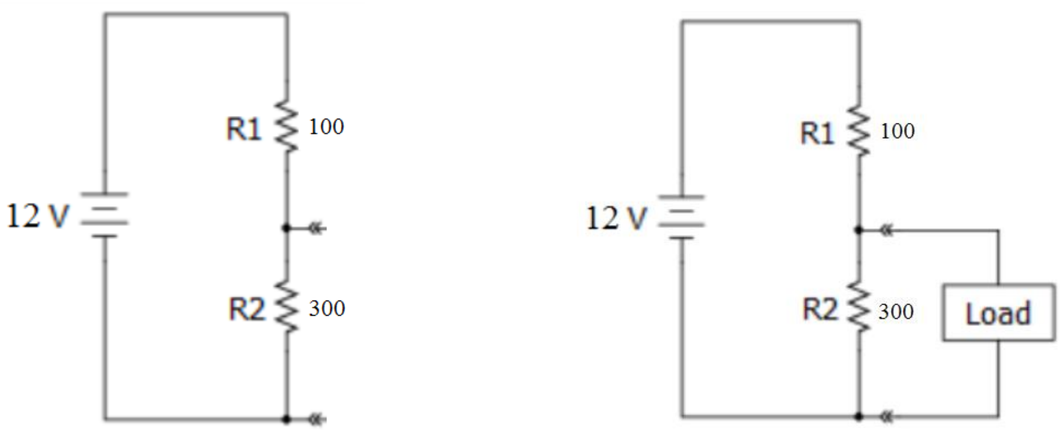
$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

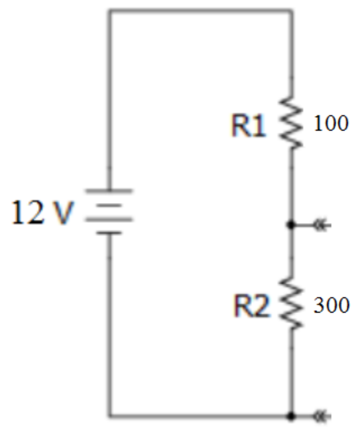


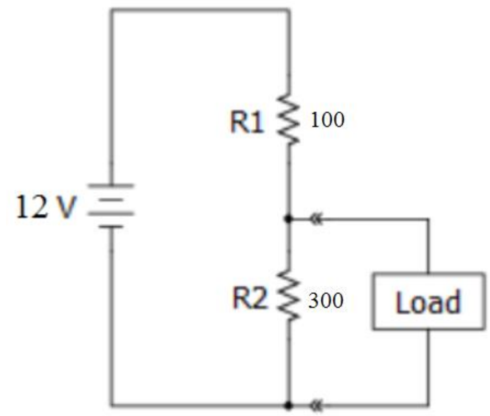
In this lab you will explore two applications of voltage divider circuits: Level Shifting and Reading Resistive Sensors. Level Shifting involves reducing a source voltage to a smaller voltage to power lower voltage elements of your circuit (for example, you may be using 5V to power your circuit, but some circuitry requires a 3.3V source). Reading resistive sensors assumes you are able to able to measure Vin, R1, and Vout and can use those to determine the unknown value of the resistance R2.

Loading Effects

When you design voltage dividers to act as a level shifter, you have to be aware of loading effects. For example, suppose you designed the following level shifting circuit (see circuit on the left at the top of the next page) that starts off with a 12V source and outputs 9V (the voltage across R2). The voltage across R2 is 9V and the current through it is 12/(400) = 30mA.







Now suppose you attach the circuit element (the load) that requires the 9V source to your circuit (see circuit on the right). Are 9V and 30 mA really delivered to your load?

No! Suppose your load has a resistance of 100 ohms. Now R2 and your load are in parallel and the parallel combination of their resistances is 75 ohms. This will produce a voltage of (75/(75+100)*12) = 5.14 V across your load, which is not the intended 9V you had in mind. This reduction in voltage is known as a '**loading effect**' and must be taken into consideration when designing level shifters and other circuits. Also, the current delivered to the load will not be 30mA. Using Ohm's law, it will be V/R = 5.14/100 = 51.4mA.

Voltage Follower

A voltage follower, also known as a unity gain amplifier, a buffer amplifier, or an isolation amplifier, is an op-amp circuit that has a voltage gain of 1. This means that the op amp does not provide any amplification to the signal, which may at first seem pretty useless. However, one great application of the voltage follower is to reduce loading effects in a voltage divider level shifting circuit. See the link below to read more about how this works:

http://www.learningaboutelectronics.com/Articles/Voltage-follower

FET as a Switch

A FET can be used as a voltage-controlled switch. A sufficient voltage on the gate of a FET will ideally cause the drain to source to act like a short (i.e., acts like an on switch). If the voltage on the gate of a FET is not sufficient, the drain to source will ideally act like an open (i.e., acts like an off switch). In addition, a FET has very high gate resistance (really impedance but impedance is a circuits 2 topic) meaning the FET will draw very little gate current. This characteristic of an FET can be useful in reducing loading effects, especially for "heavy" loads, loads that require large currents (100mA or more); DC motors for example. See the link below to read more:

http://www.learningaboutelectronics.com/Articles/What-is-an-enhancement-type-MOSFET

Analog to Digital Converters

Voltage is an analog signal, meaning that it can take on an infinite number of possible values. When we measure a voltage, we often might want a computer to read that voltage and perform some computations on it. However, computers represent numbers digitally – meaning numbers can only take on a finite (or discrete) number of possible values. The number of possible values a computer can represent depends on the number of bits it uses to represent numbers. For example, if a computer uses 2 bits it can represent unsigned decimal numbers 0->3.

Binary (2 bits)	Decimal
00	0
01	1
10	2
11	3

If a computer uses 8 bits to represent numbers, it can represent unsigned decimal numbers 0->255.

Binary (8 bits)	Decimal
00000000	0
00000001	1
00000010	2
00000011	3
00000100	4
…..	
11111101	253
11111110	254
11111111	255

So when we want a computer to read an analog voltage (such as when we design a voltage divider to read a resistive sensor), we need to perform an analog to digital conversion using an ADC (analog to digital converter). The governing equation that relates the analog (voltage) value to digital value is:

Analog_Value = Digital_Value * (Vref / (2^n-1))

Where Vref is the maximum value of the voltage signal you are measuring and n is the number of bits used in conversion.

So for example, let's say you wanted to measure a voltage signal that varies between 0 and 5V using an 8 bit ADC. You measure a voltage of 4V. The ADC will represent this voltage as:

Digital_Value = (4) / (5 / 255) = 204 (note the digital value must be rounded to the nearest integer).

ADCs that use more bits will more accurately represent the voltage signal measured.

PROCEDURE:

Section1) Voltage Division: Level Shifting

a) Suppose you wish to operate a buzzer (or DC motor) at 1V, but all you have is a 5V source (rather than an adjustable power supply). Using your breadboard, standard value resistors and your Arduino 5V supply, build the voltage divider circuit from your pre-lab to level shift 5V to 1V. Using your multi-meter **in parallel** with R2, record the voltage across R2. Then place the multi-meter **in series** with R2 to measure the current through R2. Compare these results with your (modified) LTSpice simulation, they should be similar.

	Voltage across R2 (V):	Current through R2 (mA):
Simulation Values		
Measured Values		

Table for part a

b) Now connect your buzzer (your load) in parallel with R2.

Note: Connect black lead of buzzer to ground (ground of power source).

Use your multi-meter to measure the voltage across your load (**meter is in parallel**) and current through your load (**meter is in series**). Comment on buzzer sound, buzzing loud, soft or silent?

Voltage across load:	Current through load:	Buzz:

Is the buzzer getting the intended voltage and current?

Is the buzzer making a sound? What happened?

c) Disconnect the buzzer and replace it with the DC motor. Use your multi-meter to measure the voltage across your load (**meter is in parallel**) and current through your load (**meter is in series**). Also, comment on the motor spin rate; fast, slow, medium or not spinning.

Voltage across load:	Current through load:	Motor:

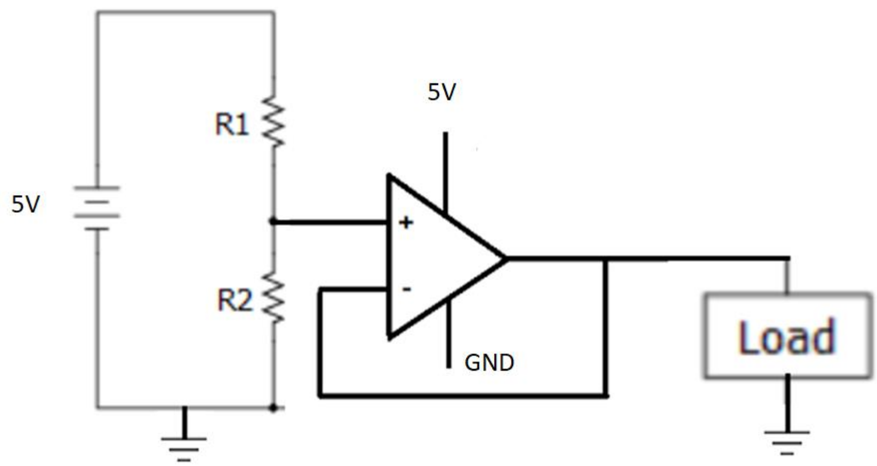
Is the motor getting the intended voltage and current?

What happened?

Section 2) Voltage-Follower & FET as a Switch

d) Build a voltage-follower circuit (same as discussed in lecture) using the LM358 op-amp (first using the buzzer as the load). To do this:

   a. Place your op-amp across a gap on your breadboard and connect wires for 5V and ground from Arduino board to breadboard. To determine which pins to connect to, Google “LM358 op-amp datasheet” to find the LM358 pin diagram.
   b. Wire the rest of the circuit, see below. **Be sure to connect all grounds (ground of Arduino, ground of LM358, voltage divider circuit ground and black lead of buzzer) to the same node.**



e) Measure and record the voltage across and current through the buzzer.

Voltage (V)	Current (mA)	Buzz? Loudness Comment

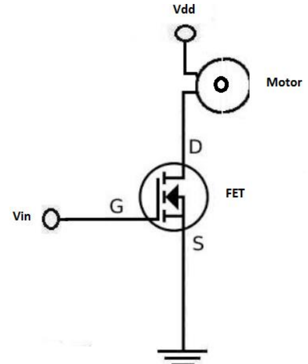
You should observe, as you did in the simulation, that the new circuit is able to supply sufficient voltage and current to the buzzer to turn it on.

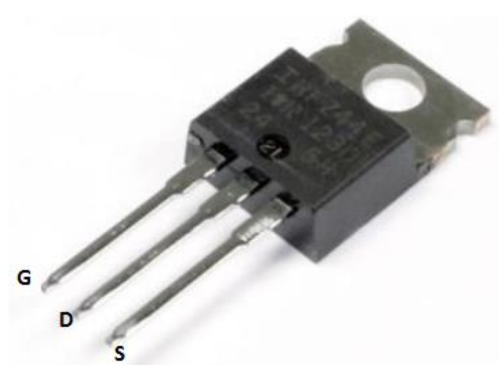
f) Replace the buzzer with the motor. Measure and record the voltage across and current through the motor.

Voltage (V)	Current (mA)	Motor Comment

You should observe there still is not a sufficient amount of voltage and current supplied to the load to turn the motor on.

g) In order to get the motor to run, we can use an FET instead of a voltage follower as the FET can source enough current for the motor. However, for the FET to turn on, we need to provide a 4V gate voltage. So first, reverse ground and 5V for the voltage divider and use the voltage across the 820Ω resistor as the gate voltage. Connect the drain of the FET (D) to one end of the motor and the other end of the motor to Vdd = 5V (use Arduino 5V supply). Connect the source (S) of the FET to ground.





The motor should now operate, thus, an FET switch can be used to solve loading effects that a voltage-follower cannot solve.

Section 3) Voltage Division: Reading Resistive Sensors

a) Use the USB cable to connect the Arduino to the computer and open up the Arduino IDE.

b) Select the appropriate 'Board' and 'Port' from the Tools menu.

c) Connect 3.3V to the Arduino A0 port.

d) Under the File tab, open up the Example -> Basics -> AnalogReadSerial example and upload it to your Arduino. Open the Serial Monitor (Tools menu). You should see 683, 684 scrolling on the left side of the serial monitor window.

e) Connect 5V to A0, what change occurs in the serial monitor window? Connect GND to A0.

DO NOT exceed 5V, could damage Arduino) and make sure you see the digital numbers (in decimal) on your Serial Monitor vary from 0 to 683, 684 to 1023 as A0 voltage vary from GND (0V) to 3.3V to 5V.

The digital numbers vary from 0 to 1023 because the Arduino has a 10-bit ADC (Analog to Digital Converter).

Binary (10 bits)	Decimal
0000000000	0
0000000001	1
0000000010	2
…..	
1111111101	1021
1111111110	1022
1111111111	1023

0V should read 0, 2.5 V should read about 512 (half the 10-bit range) and 5V should read 1023 (full 10-bit range).

f) Disconnect A0 and close the Serial Monitor.

g) Build the voltage divider circuit from your pre-lab question 2. Use the Arduino's 5V port as your source and the KTY81-210 as your R. Connect the node between the 2k resistor and the KTY81-210 to port A0 on the Arduino. Also, be sure to connect the GND of the Arduino to the temperature sensor.

h) Modify the AnalogReadSerial program to print the temperature in Fahrenheit once every 5 seconds

Program Hints:

- Read the digital value from the ADC and convert it to an analog voltage using the formula from pre-lab question 3 (remember to use a float type and floating-point division)
- Convert the voltage to a resistance using the formula from your pre-lab question 2
- Convert the resistance to degrees Fahrenheit using the formula from your pre-lab question 4
- Use delay (5000) to create a 5 second delay

i) Test your program by observing the temperature read by the sensor on your Serial Monitor. Heat it up by holding the sensor between your fingers or a hair dryer and cool it down by fanning the sensor.

DISCUSSION:

Section 1:

1) Comment on the usefulness of LTSpice for simulating circuits. Compare simulated values to measured values of your (modified) level-shifting circuit.

2) After you attached your buzzer to your level shifting circuit, did the circuit provide enough voltage across and enough current through your buzzer to make it buzz? Why or why not?

Section 2:

1) What other device (other than a voltage follower) can be used to compensate for the loading effect of a motor or other load that requires more current than a voltage follower can provide?

2) What conclusion can you draw about the effectiveness of a voltage follower's ability to prevent loading?

Section 3:

1) Copy and paste your Arduino program here.