



Module 2

Lab 2: Voltage, Current and Power



Lab 2: Voltage, Current and Power

2.0 Objectives

The purpose of this lab is to review basic electronics needed to interface sensors and actuators to the microcontroller.

1. You will learn about voltage, current, and power.
2. You will perform experiments with resistors, capacitors, and LEDs.
3. You will discover both DC and AC responses of circuits.
4. You will use a voltmeter to perform the DC analysis
5. You will use a signal generator and oscilloscope to perform the AC analysis

Good to Know: When interfacing any two physical devices (e.g., sensors to the microcontroller, or microcontroller to an actuator), it is important to manage the voltage and current levels between the devices. Furthermore, when dealing with time-varying signals, resistance, capacitance, and inductance all affect the behavior.

2.1 Getting Started

2.1.1 Software Starter Projects

If you do not have access to a real signal generator and oscilloscope, you can run this project to activate the **TE_xaS scope: TE_xaS**. The project implements an oscilloscope on pin P4.4. It also creates a square wave out on P4.5. You can adjust the frequency of the squarewave by changing the FREQ constant in the **main.c** file.

2.1.2 Student Resources

CarbonFilmResistor.pdf Data sheet for resistor
 CeramicCapacitor.pdf Data sheet for ceramic capacitor
 LTL-10223W.pdf Data sheet for 10 mA red LED
 HLMP-4700.pdf Data sheet for 2 mA red LED

2.1.3 Reading Materials

Volume 1 Section 1.7, Chapter 3, and Section 5.3
Embedded Systems: Introduction to the MSP432 Microcontroller",

Volume 2 Sections 1.1, 2.1, and 2.5
Embedded Systems: Real-Time Interfacing to the MSP432 Microcontroller",

2.1.4 Components needed for this lab

Quantity	Description	Manufacturer	Mfg P/N
1	MSP-EXP432P401R LaunchPad	TI	MSP-EXP432P401R
1	Red 10mA 5mm,	Lite-On	LTL-10223W
1	Red 2mA 5mm,	Broadcom	HLMP-4700
1	Carbon 1/6W, 5%, 220 ohms	Yageo	CFR-12JB-220R
1	Carbon 1/6W, 5%, 470 ohms	Yageo	CFR-12JB-470R
1	Carbon 1/6W, 5%, 22k	Yageo	CFR-12JB-22K
1	Carbon 1/6W, 5%, 33k	Yageo	CFR-12JB-33K
1	Ceramic, Z5U, -20/+80%, 0.47 µF	Kemet	C320C474M5U5TA

2.1.5 Lab equipment needed

Oscilloscope (one or two channels at least 10 kHz sampling)
Signal generator (10 Hz to 1000 Hz waveforms)



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2.2 System Design Requirements

The goal of this lab is to measure the current through and voltage across resistors, capacitors and LEDs.

For resistors, you will observe Ohm's Law:

$$V/I = R$$

When experimenting with resistors, you will work with DC voltages (e.g., constant, not time-varying). Although you will experiment with DC voltages, Ohm's Law will also apply to AC responses as well.

For capacitors, you will observe the reactance of a capacitor:

$$V/I = X = 1/(2\pi fC)$$

where V is the AC amplitude of the voltage, and I is the AC amplitude of the current. The reactance of the capacitor at DC will be infinite (DC means $f=0$). So at DC, the capacitor will not conduct any current. Thus, when experimenting with capacitors, you will work with AC voltages.

LEDs are semiconductor devices with a nonlinear voltage/current response. Your goal is to experimentally observe this nonlinear response. Just like resistors, you will study the DC voltage-current response of LEDs. This nonlinear response will also apply to AC voltages.

2.3 Experiment set-up

If you have an actual signal generator and scope, you should use them. However, if you do not have access to a signal generator and scope, you can use the **TExaS** project running on the LaunchPad together with the **TExaSdisplay** application running on the PC.

To use the TExaS oscilloscope, connect the TI's LaunchPad development board to a USB port on your PC, build and debug the TExaS project. Notice the initialization is performed with SCOPE as the mode.

Warning: Ensure the voltages you are analyzing remain between 0 and 3.3V.

The TExaS project software must be running on the MSP432, and the LaunchPad must be connected to the PC via its USB cable. Connect the signal you wish to measure to P4.4.

To observe the signal perform the following tasks:

1. Run the **TExaSdisplay** application on your PC
2. Execute **COM->OpenNextPort** until the MSP432 is connected
3. Execute **View->Oscilloscope** to see the scope

Within the **TExaSdisplay** application, you can press F6/F7 to adjust the time scale, and press the Up/Down arrows to adjust the trigger threshold. The sampling rate is fixed at 10 kHz, the range is 0 to 3.3V, and the precision is 8 bits.

2.4 System Development Plan

2.4.1 Ohm's Law

You will use four different resistors {e.g., 220, 470, 22k and 33k}. Any four resistors in the 220 to 33k range will suffice. If you have an ohmmeter, measure the actual resistance of the four resistors. If you do not have an ohmmeter, you can assume the resistance value is as defined by the resistance color code.

Using the four resistors, build four circuits similar to Figure 1, using the LaunchPad 3.3V as the power source (e.g., 220+22k, 470+22k, 470+33k, and 22k+33k). You must connect both 3.3V and ground to the circuit.

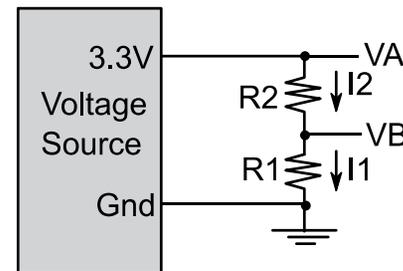


Figure 1. Resistance circuit.



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For each circuit, measure VA and VB. The voltage across R2 is VA-VB. Calculate

$$I2 = (VA-VB)/R2$$

$$I1 = VB/R1$$

Ohm's Law is true if the calculation of I2 equals I1. If you have a current meter, you could also compare the calculation of I1 and I2 to the actual measured current.

For each circuit calculate the power dissipated in each resistor

$$P2 = (VA-VB)*I2$$

$$P1 = VB*I1$$

In summary, fill in the fields of Table 1.

R2	VA-VB	I2	P2	R1	VB	I1	P1
220				22k			
470				22k			
470				33k			
22k				33k			

Table 1. Experimental verification of Ohm's Law

2.4.2 Reactance of a Capacitor

You will use the circuit shown in Figure 2 to study the behavior of capacitors. As mentioned earlier, we will study the circuit in the AC, or time-varying mode. You will use a signal generator to create an AC signal on VA, and use an oscilloscope to measure the AC signal across VA-VB and on VB. It is best if the shape of the AC signal is sinusoidal, but we could perform the lab with other waveform shapes, such as square wave.

This circuit is most interesting at its cutoff frequency defined below:

$$f_c = 1/(2\pi RC)$$

For example, if R=470 ohms and C is 0.47μF, the cutoff frequency is 720 Hz. You may perform this analysis with any values of R and C with a cutoff frequency between 100 and 1000 Hz.

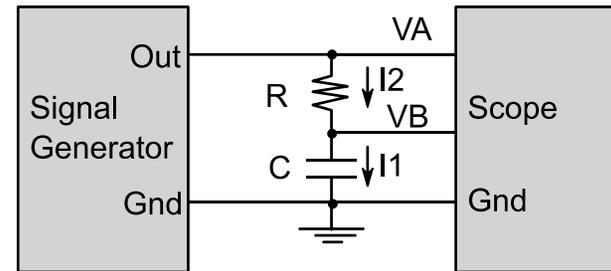


Figure 2. Resistance-capacitor circuit.

Perform AC voltage measurements at four different frequencies. Calculate reactance, $X = 1/(2\pi fC)$, for frequency.

Calculate

$$I2 = (VA-VB)/R$$

$$I1 = VB/X$$

Theoretically, the calculation of I2 should equal I1. In summary, fill in the fields of Table 2.

f	R	VA-VB	I2	C	X	VB	I1
100	470			0.47μF			
500	470			0.47μF			
720	470			0.47μF			
1000	470			0.47μF			

Table 2. Experimental verification of capacitor reactance.

If you are using the **TEXAS** oscilloscope make sure the voltages remain within the 0 to 3.3V range. The Texas project will also generate a square wave out of P4.5 that you could use as an AC signal source. You can adjust the square wave frequency.



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2.4.3. Voltage-current response of an LED

Begin by reviewing the data sheet of your LED. Choose resistor values that will produce LED currents within the normal operating range of the LED. The 220, 470, 690 ohm values are appropriate for a 10 mA LED. If you have an LED that operates around 1 mA, choose resistors around 1k. You will build the circuit shown in Figure 3.

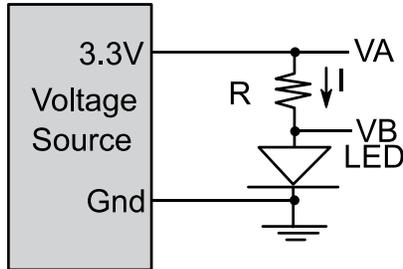


Figure 3. LED test circuit.

Perform LED measurements with four resistance values. E.g., 220 ohms, 470, 690, and 22k ohms. The 690 ohms resistance can be obtained by placing the 220 and 470 resistors in series. For each configuration, calculate the current across the resistor. Calculator power dissipated in the LED.

$$I = (V_A - V_B) / R$$
$$P = I * V_B$$

Try operating the LED connected backwards. You will observe no current flows and the LED is dark. Compare the measured results with the LED data sheet. In summary, fill in the fields of Table 3. Notice the brightness depends on electrical power dissipated in the LED.

R	V _A -V _B	V _B	I	P
220				
470				
690				
22k				

Table3. Experimental measurements in the LED circuit

2.5 Troubleshooting

Measurements don't match theory:

- The most common mistake is the circuit is wired incorrectly.
- Double check you are using the correct resistor and capacitor values.
- This is an experimental lab. Due to the inaccuracies of the measurement devices, your results will not perfectly match theory.

LED doesn't light:

- Excess current will easily damage an LED. If you have damaged your LED, have an instructor check your circuit before applying power to another LED.
- As mentioned earlier, current flows only one way through the LED. The longer lead should have the higher voltage.

2.6 Things to think about

In this section, we list thought questions to consider after completing this lab. These questions are meant to test your understanding of the concepts in this lab. The goal of this module is for you to experience voltage, current, and power as seen in resistors, capacitors, and LEDs.

- What is voltage?
- What is current?
- What is power?
- What is Ohm's Law?
- Does Ohm's Law apply to capacitors and LEDs?
- What controls the brightness of the LED?
- What would happen (don't actually do it) if you placed +5V directly across the LED?
- What happens to the power dissipated in a resistor?



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2.7 Additional challenges

In this section, we list additional activities you could do to further explore the concepts of this module. For example,

- For the capacitor circuit, use a dual trace scope to look at (VA-VB) (an indirect measure of capacitor current) and VB (direct measure of capacitor voltage) at the same time. Even though both voltage and current are AC, notice they are not in phase.
- The complex impedance model of a capacitor ($Z=1/(j2\pi fC)$). Notice that $X = |Z|$. The total impedance in Figure 2 is $R+Z$. The gain of the circuit (VB/VA) can be calculated as $Z/(R+Z)$. Calculate the gain of the circuit at its cutoff frequency.
- Perform the LED experiment on two different LEDs. What is the same? What is different?

2.8 Which modules are next?

We will use the next few labs to overview the processor architecture, and review software development. Module 5 will present the power module, and then we can add modules that will become the robot explorer:

- Module 3) Present the processor architecture and develop assembly code.
- Module 4) Introduce C and develop some functions needed for the robot.
- Module 5) Begin construction of the robot, including battery and voltage regulation
- Module 6) Learn how to input and output on the pins of the microcontroller
- Module 7) Study finite state machines as a method to control the robot

2.9 Things you should have learned

In this section, we review the important concepts you should have learned in this module:

- Understand voltage and current in a resistor.
- Understand voltage and current in a capacitor, knowing how frequency affects reactance.
- Understand voltage and current in an LED, knowing the response is extremely nonlinear. Know that electrical power is converted to optical power (brightness).
- Know how to use a voltmeter and oscilloscope.

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