



# Module 5

Lab 5: Battery and Voltage Regulation



# Lab 5: Battery and Voltage Regulation

## 5.0 Objectives

The purpose of this lab is to build the electronics needed to power the robot. During debugging, +5V power will be available from the PC via the USB cable. However, during autonomous running, the robot will derive power from batteries. In this module,

1. You will learn about voltage, current, and power for the battery.
2. You will perform experiments with the battery.
3. You will configure the driver board needed for the robot.
4. You will run the MSP432 LaunchPad under battery power.

**Good to Know:** Power management is an important aspect of embedded systems. Many considerations affect system performance. These considerations include, but are not limited to, voltage, current, battery life, size, weight, and power-line ripple (noise).

## 5.1 Getting Started

### 5.1.1 Software Starter Projects (none)

**Note:** Please do not use the voltmeter, oscilloscope or logic analyzer created by TExaS for this lab. Voltages applied to inputs of the MSP432 must remain between 0 and 3.3V. Voltages outside this range will damage the MSP432.

### 5.1.2 Student Resources

Yageo LR_SQP NSP_2013.pdf	Data sheet for 10W resistor
MotorDriverPowerDistribution.pdf	Data sheet for power board
Keystone_4-40-NylonStandoff.pdf	Holds up LaunchPad
Keystone_4-40-Screw.pdf	Attach standoff to Romi Chassis
Keystone_4-40-Nut.pdf	Holds LaunchPad
Keystone_4-40-Standoff.pdf	Holds breadboard
Pololu Romi Chassis User's Guide.pdf	How to build the robot

### 5.1.3 Reading Materials

Volume 1 Section 1.1  
 Embedded Systems: Introduction to the MSP432 Microcontroller",  
 or  
 Volume 2 Section 9.2  
 Embedded Systems: Real-Time Interfacing to the MSP432 Microcontroller"

Read the specifications on the Motor Driver and Power Distribution board website <https://www.pololu.com/product/3543>, <https://www.pololu.com/docs/0J68>

### 5.1.4 Components needed for this lab

Quantity	Description	Manufacturer	Mfg P/N
1	MSP-EXP432P401R LaunchPad	TI	MSP-EXP432P401R
1	Romi Chassis Kit - Red	Pololu	3502
1	Motor Driver and Power Distribution Board for Romi	Pololu	3543
1	Rechargeable Battery, Pack of 4, Metal Hydride 1300 mAh, 1.2V, AA	Energizer	626831
1	Wirewound 5W, 5%, 10 ohm	WELWYN	WHS5-10RJTO75
4	0.5 in 4-40 machine screw	Pololu	1962
4	1.375in 4-40 Nylon standoff	Keystone	4809
2	0.187in 4-40 metal nut	Keystone	4694
2	0.75in 4-40 metal standoff	Keystone	2204
2	0.5in 4-40 Nylon machine screw	Keystone	9529



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## 5.1.5 Lab equipment needed

Oscilloscope (one or two channels at least 10 kHz sampling)  
Voltmeter, current meter

## 5.2 System Design Requirements

The two goals of this lab are to study the behavior of batteries and configure the **Motor Driver and Power Distribution Board (MDPDB)** for use in the robot. The ultimate goal is to create a regulated +5V power source for the robot. The LaunchPad should require less than 100 mA at +5V.

The robot needs a mechanism to securely hold the batteries during operation. The **Romi Chassis** (<https://www.pololu.com/docs/0J68>) has mechanical support for six AA batteries. In this lab, we assume you have six 1.2V NiMH batteries, creating +7.2V for the robot. Fully charged NiMH batteries will create about 8.2V. Refer to the data sheet for the power board for other configurations.

We define the **energy storage** of a battery in amp-hours, because the voltage is assumed constant. The standard units of energy are watt-seconds (1 W-sec is 1 J). One can estimate the operation time of a battery-powered embedded system by dividing the energy storage by the average current required to run the system. The **power budget** embodies this concept. Let E be the energy storage specification of the battery in mA-hour and  $t_{life}$  be the desired lifetime of the product (in hours); then we can estimate the average current our system is allowed to draw (in mA):

$$\text{Average Current} \leq E / t_{life}$$

## 5.3 Experiment set-up

In order to test the robot's batteries, we begin by constructing the battery storage components for the Romi Chassis. Figure 1 shows the bottom of the chassis with the six NiMH batteries. Without the **MDPDB** attached, there should be about  $4 \times 1.2V = 4.8V$  across BAT1+ to BAT1-, and there should be about  $2 \times 1.2V = 2.4V$  across BAT2+ to BAT2-. The **MDPDB** will connect BAT1- to BAT2+, and it will connect BAT2- to ground, so there will be 7.2V from BAT1+ to ground.

You should perform the experiment described in 5.4.1 before soldering the **MDPDB** to the battery terminals.

Note: For safety reasons we recommend testing the battery at currents less than 1/2 amp. Please also make sure the power to the resistor is within limits.

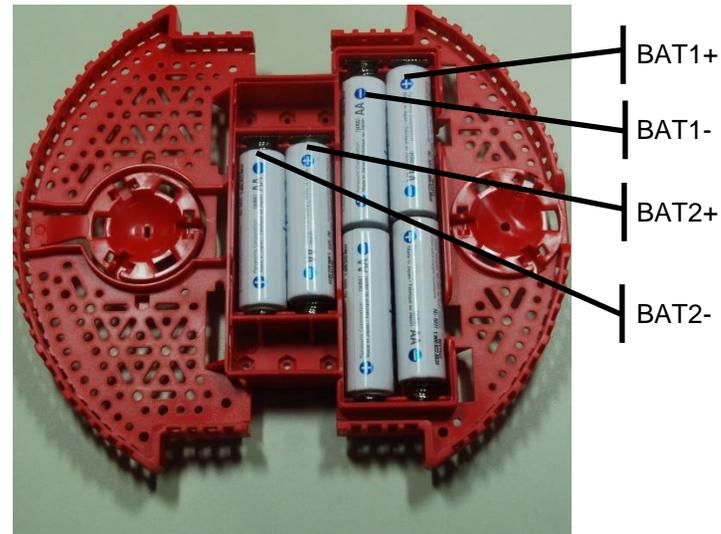


Figure 1. Romi Chassis holds 6 AA batteries.

The first step is to study the behavior of your battery using a simple set up as shown in Figure 2. It is important to limit the power to the resistor to less than its power rating. The power delivered to a resistor is

$$P = I \cdot V = V^2 / R = I^2 \cdot R$$

The resistor listed in the BOM (components needed) has a 10W rating. One possible configuration uses the four NiMH batteries (BAT1+ to BAT1-) to create a +4.8 V battery source. In this experiment we will use the 10 Ω resistor as a fixed load. The current draw will be  $4.8V / 10\Omega = 480 \text{ mA}$ . The power will be  $4.8^2 / 10 = 2.3W$ . At this power, the resistor will get hot, but it will operate below than the 10W max power rating. Because the battery storage is 1900 mA-hr, it will take  $1900 / 480 = 4$  hours to perform the discharge experiment.



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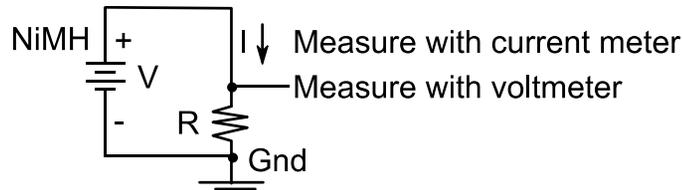


Figure 2. Battery circuit.

The second step is to configure the **MDPDB** for use on the robot. Figure 3 shows the locations of the power-related pins on the motor driver board.

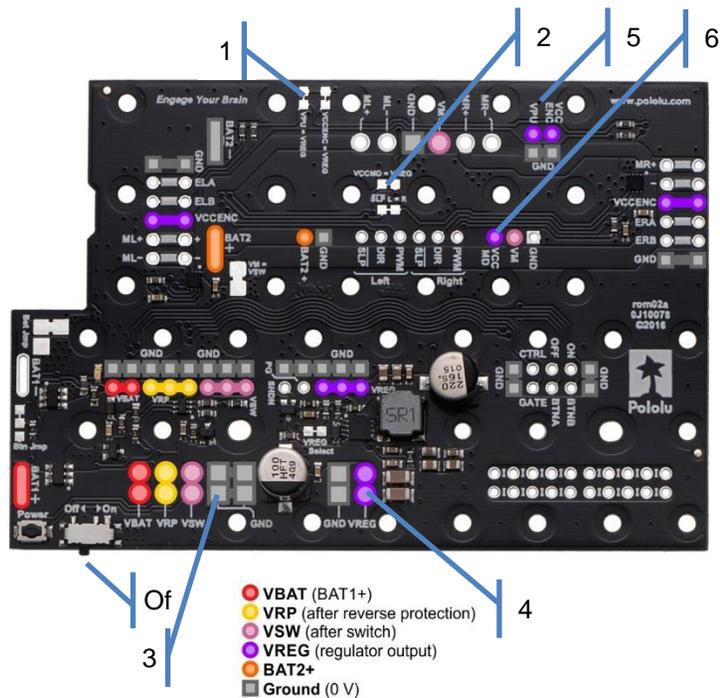


Figure 3. Motor Driver and Power Distribution Board for Romi Chassis

(source : Pololu.com)

Follow these steps to configure the motor driver board for the robot:

- 1) Cut the VPU—VREG jumper on **the MDPDB**
- 2) Cut the VCCMD—VREG jumper on the **MDPDB**
- 3) Solder a ground wire from the **MDPDB** to ground on the LaunchPad  
We suggest you review the entire MDPDB User's Guide  
Make sure not to use holes needed later for the motors
- 4) Connect VREG (+5V) from the **MDPDB** to +5V on the LaunchPad  
You will need a way to connect/disconnect +5V.  
We suggest you solder one end of a wire to the VREG signal on the **MDPDB** and use a female header to connect it to +5V on the LaunchPad.
- 5) Connect VPU from the **MDPDB** to 3.3V on the LaunchPad
- 6) Connect VCCMD from the **MDPDB** to 3.3V on the LaunchPad
- 7) Solder a wire with a male header to the +3.3V power. Solder a second wire with a male header to ground. These two will be used to bring power to the solderless breadboard (shown in Figure 4).

Figure 4 shows the partially completed power system.

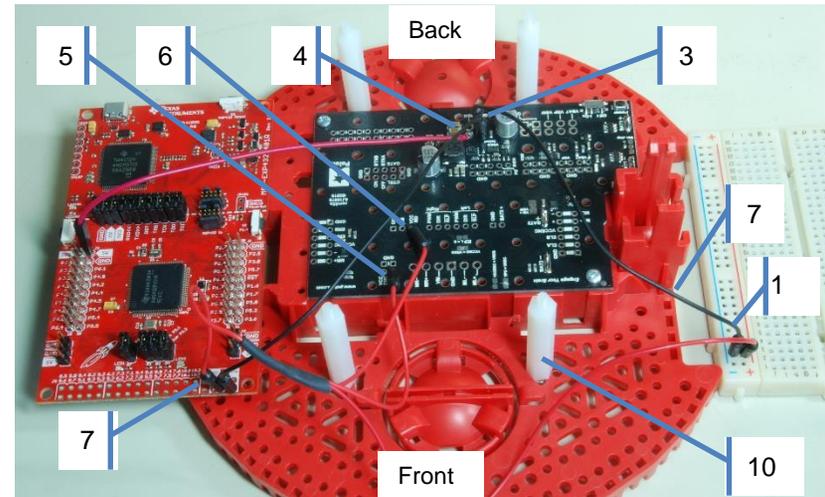


Figure 4. Motor Driver and Power Distribution Board connected to the LaunchPad. Grounds connected. VREG (MDPDB) to +5V (LaunchPad). +3.3V (LaunchPad) to VPU (MDPDB) and VCCMD (MDPDB).



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Follow these steps to mechanically attach the boards to the chassis:

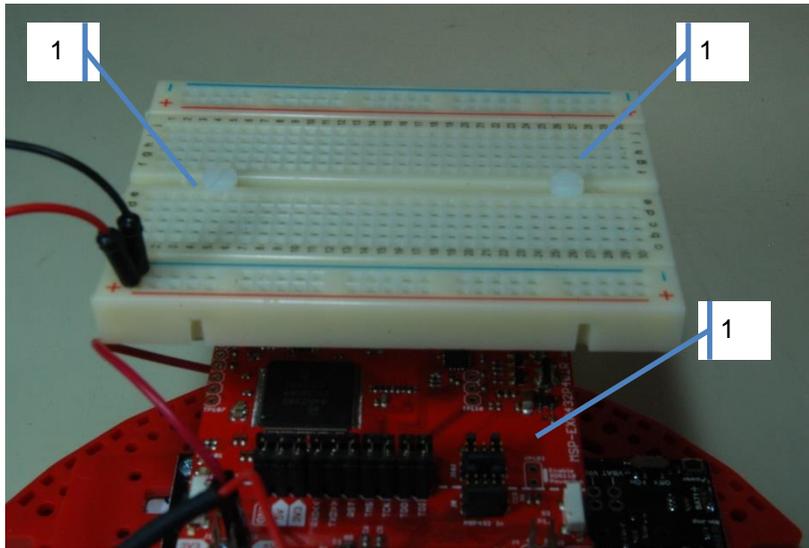


Figure 5. Solderless breadboard attached to the robot.

- 8) Drop the four battery terminals from the top, looking at Figure 1 and orienting the Bat+ signals with the positive side of the battery (tab) and the Bat- signals with the negative side of the battery (spring). Screw the **MDPDB** to the chassis using the two screws and nuts provided in the **MDPDB** kit. See Figure 1 and follow directions from Pololu.
- 9) Double check the positive and negative alignment. Solder the four battery terminals from the chassis to the **MDPDB**. We suggest you solder the terminals after it is aligned with the screws and nuts. The board can still be detached from the robot by removing the screws and squeezing the battery springs. See Figure 1 and follow directions from Pololu.
- 10) Attach four 1.375in 4-40 Nylon standoffs to the robot chassis using 0.25in screws. Align the standoffs with the four holes on the LaunchPad. Depending on where you choose to mount the LaunchPad, you may have to increase the side of the hole on the chassis to ¼ inch to accept the 4-40 screw.

- 11) Place the LaunchPad on top of the standoffs orienting the USB cord out the back of the robot (the LaunchPad shown in Figure 4 will not be rotated before placement). Use two nuts in the front and two 0.75in 4-40 metal standoffs in the back to secure the LaunchPad.
- 12) Drill two ¼ inch holes in the solderless breadboard to align with the two 0.75 inch standoffs. Attach the breadboard to the standoffs using two ½ inch Nylon screws. See Figure 5.
- 13) Attach the +3.3V and ground wires to the breadboard.

**Warning:** Disconnect the VREG↔+5V wire when the LaunchPad USB cable is connected to the PC. Connect the VREG↔+5V wire when the robot is running on battery power.

### 5.4 System Development Plan

#### 5.4.1 Total energy stored in a battery

In this lab you will determine total energy stored in the battery (Ni-MH).

First, charge the battery following the directions on the charger. Using the circuit shown in Figure 2, measure the current and voltage. Measure the time it takes for the voltage to drop below 80% of its nominal value. It should take hours to discharge the battery. Calculate the **energy storage** in Joules:

$$E = V \cdot I \cdot \text{time}$$

Also, calculate the storage in mA-hr, and compare the measured value with the specification from the manufacturer.

Recharge the batteries and measure the **noise** on the battery (without connecting it to any circuits) using the oscilloscope in AC mode. We can quantify noise either as **root mean squared voltage** ( $V_{rms}$ ) or as **peak-to-peak voltage** ( $V_{p-p}$ ). You will notice batteries are very low noise. However, there will be very large noises on the power once we connect it up to the robot caused by the switching regulator, the motors, and the motor drive circuits.



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## 5.4.2 Voltage Regulation

Batteries provide voltage and current. However, when operating within specifications voltage of the six NiMH batteries will range from 7.2 to 8.4V. The purpose of the **regulator** is to provide a constant voltage. The regulator on the MDPDB provides +5V output for up to 3A.

Connect the batteries to the regulator circuit on the motor board. In this lab, do not connect the LaunchPad, motors or other external circuits, just the batteries and the **MDPDB**. (You will connect the motors in Lab 12). Turn on the power and measure the battery voltage and the regulator output voltage using the voltmeter in DC voltage mode. The goal is to create a +5V regulated power source for the LaunchPad. Six fully charged NiMH batteries may have a voltage above 8V. If you have +7.2 V battery voltage, but not +5V regulated output, review the documentation for the **MDPDB**.

Once you have verified the regulator is operating properly, turn off the power, and connect the +5V regulated voltage to the LaunchPad +5V line via a current meter, as shown in Figure 6. The LaunchPad is not to be connected to the PC during these measurements. Use a voltmeter in DC mode to verify the voltage levels on the +5V and +3.3V lines. The MSP432 running at 48 MHz should draw less than 100 mA.

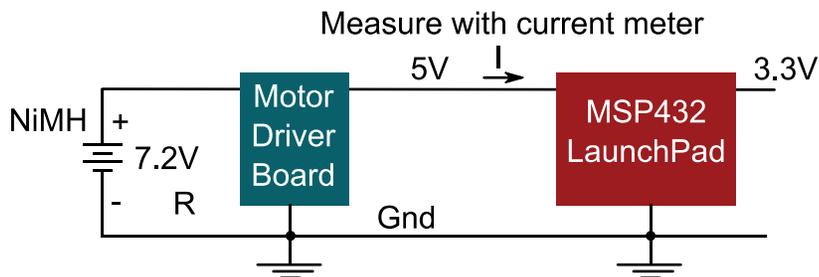


Figure 6. Block diagram of power system.

Since the +5V input to the LaunchPad is used to create the +3.3V line, the current measured on the +5V signal includes current dissipated at +5V and at +3.3V.

Use the oscilloscope in AC mode to measure the noise on the +5V and +3.3V lines.

## 5.5 Troubleshooting

### Batteries show no voltage:

- Double check the connections.
- Check the instructions for the charger.
- Recharge the batteries.

### 1.2V NiMH batteries are above 1.2V:

- A fully charged NiMH may be as much as 1.4V.

### LaunchPad draws more than 100 mA:

- Double check the connections.
- Above 100 mA may mean the LaunchPad is damaged

### Regulator doesn't work:

- Double check the connections
- Check the datasheets for the motor board

## 5.6 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 does the regulator do?
- Does your board use a linear regulator or a switching regulator? I.e., what is the purpose of the inductor in the circuit?
- What does it mean that the regulator has 90% efficiency?
- Why does the regulator have so much noise?



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## 5.7 Additional challenges

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

- If you do not have the Pololu motor board, you could build this robot, and do this lab by building your own linear regulator circuit. In particular, you could build the linear regular described in lecture using the LM7805 and two 10  $\mu$ F capacitors. Since the dropout voltage of the LM7805 is 2V, you will need a battery voltage greater than 7V. The disadvantage of this approach is efficiency. When you perform the noise analysis, you will find it low noise because the LM7805 is a linear regulator. However, a 7.2 to 5V drop at 100 mA will dissipate 0.22 W in the LM7805, causing the LM7805 to get hot. To run this test program, rename **Program4\_1** to **main**, and rename the actual **main** to **main2**. Run **Program4\_1** and compare your results with expected values. It is ok if your results differ by  $\pm 1$  (which could be due to rounding).
- Linear regulators are inexpensive, and low noise, but they are not very efficient.
- A second option if you do not have the Pololu motor board is to build your own switching regulator circuit. In particular, you could build the switching regular described in lecture using the LM2596-5.0, a diode, an inductor, and two capacitors. Since the dropout voltage of the LM2596-5.0 is 2V, you will need a battery voltage greater than 7V. Because it is efficient, it will not get hot. Furthermore, this regulator is very student-friendly, handling overload current and even shorts to ground. Switching regulators are efficient, but they are harder to build and generate noise on the power line.
- Another way to power the robot is to use a portable cell-phone charger. A portable cell-phone charger includes a Lithium Ion battery, a charger, and +5V regulator. These systems come in various sizes and energy storage capacities. They have two USB connectors, one for charging and one for +5V power (used to charge cell phones). To use this power source, you simply plug the USB charger into the LaunchPad using a micro-USB cable. The disadvantage of this approach is the motors will need to be powered with the +5V supply. Recall power is  $V^2/R$ . If the resistance of the motor is fixed, a +5V motor voltage is only 50% of the power as compared to a +7.2V voltage (notice that  $5^2$  is 25, but  $7.2^2=51.84$ .)

## 5.8 Which modules are next?

In the next few labs, we begin the process of connecting input sensors and output actuators to the microcontroller. In Module 12 we will complete the functionality of the Motor Driver and Power Distribution Board when we use the motor drive circuits to allow the software to control the two motors.

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

Module 8) Interface actual switches and LEDs to the microcontroller.

This will allow for more inputs and outputs increasing the system complexity.

Module 12) We will interface the motors to the robot.

## 5.9 Things you should have learned

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

- Understand voltage, current, and energy of a battery.
- Be able to measure DC voltage, AC voltage, and current.
- Understand basic operation and purpose of a voltage regulator.
- Know how to use a voltmeter and oscilloscope,

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