TI-RSLK MAX

Texas Instruments Robotics System Learning Kit

Texas Instruments

Module 5

Lab 5: Building the robot

Lab 5: Building the robot

5.0 Objectives

The purpose of this lab is to build and test the TI-RSLK MAX robot. During debugging, power will be available to the LaunchPad from the PC via the USB cable, which creates a 3.3V supply for the MSP432. 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 build and test the TI-RSLK MAX robot.
4. You will run starter software to test the sensors and motors.

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 Project

Look at this project:
TI_RSLK_MAX (inputs from sensors and outputs to LEDs and motors)

Note: Please do not use the voltmeter, oscilloscope or logic analyzer created by TExaSdisplay 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

CW01010R00JE73.pdf   Data sheet for 10W resistor
TI-RSLK MAX construction guide document
TPS568230 data sheet
TLV1117 data sheet
Schematic of the TI-RSLK chassis board# 3671 (www.pololu.com)

5.1.3 Reading Materials

Chapter 5, "Embedded Systems: Introduction to Robotics"

5.1.4 Components needed for this lab

All the components needed in the lab are included in the TI-RSLK Max kit (TIRSLK-EVM). For this lab you will need, the six batteries that are not part of the kit. You can use the disposable 1.5V alkaline batteries or rechargeable 1.2V NiMH batteries. Black tape is also not part of the kit.

Quantity	Description	Manufacturer	Mfg P/N
1	TI-RSLK MAX kit	TI	TIRSLK-EVM
6	Rechargeable* Battery,Metal Hydride 1300 mAh, 1.2V, AA	Energizer	626831
1	Black tape*		

5.1.5 Lab equipment needed

Voltmeter, current meter

5.2 System Design Requirements

The goals of this lab are to study the behavior of batteries, test the power regulation on the TI- RSLK chassis board, build the robot, and test the inputs (bump, line sensor, and tachometer) and outputs (LEDs and motors).

The **TI-RSLK MAX** robot has a mechanism to securely hold six AA batteries during operation. We recommend six 1.2V NiMH batteries, creating nominal +7.2V for the robot. Fully charged NiMH batteries will create about 8.2V.

The standard units of energy are watt-seconds (1 W-sec is 1 J). However, we define the **energy storage** of a battery in amp-hours, because the voltage is assumed constant. 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):

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

5.3 Experiment set-up

In order to study the batteries used in the robot, we will take two wires with exposed metallic contacts on both sides. We will tape one wire to the positive side of one battery and tape a second wire to the negative side of another battery, as shown in Figure 1.

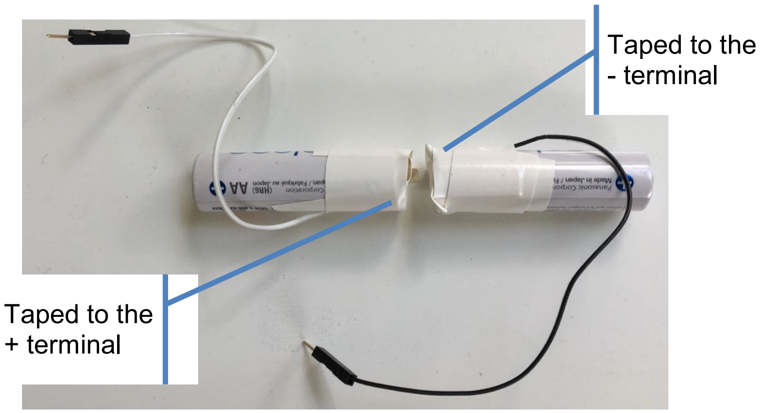

Figure 1. A possible mechanism to make temporary contacts.

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

$$P = I*V = V^2/R = I^2*R$$

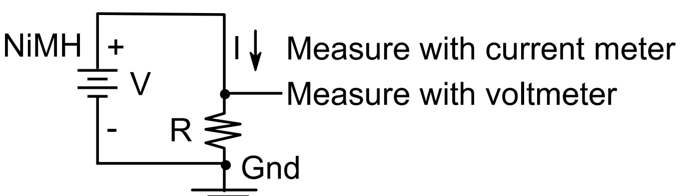

Figure 2. Battery circuit.

The current draw of the operating robot will be about 500 mA, so we will test the batteries at this current. One way to draw 500 mA will be to use four batteries and a 10-Ω resistor. The TI-RSLK MAX kit includes a 10-Ω 10-W resistor needed for this lab. Using four NiMH batteries creates a +4.8 V source, see Figure 3. In this experiment, we will use the 10-Ω resistor as a fixed load, creating a surrogate for the robot. The current draw will be about 4.8V/10Ω = 480 mA. The power will be $4.8^2/10$ = 2.3 W. At this power, the resistor will get hot, but it will operate below than its 10-W max power rating. If the battery storage is 1300 mA-hr, it will take 1300/480=3 hours to perform the discharge experiment.

If we place less than 6 batteries into the holder, the TI-RSLK MAX chassis board will not be powered.

Figure 3. TI-RSLK chassis holding 4 AA batteries.

Note: For safety reasons we recommend testing the batteries at currents less than ½ amp. Please also make sure the power dissipated the resistor is below its power specification.

The second step is to test the power regulators on the TI-RSLK chassis board. Open up to circuit diagram for the chassis board and find the TI TPS568230 switching regulator (creates 5.0V from +BAT) and the TLV1117 linear regulator (creates 3.3V from 5.0V). Insert six batteries into the holder, placing the two batteries with the taped wires adjacent to each other, and attach these two wires to a current meter. See Figure 4. Attach the battery cover, so when you flip the chassis right-side up, the batteries will not fall out. The current meter will measure the total current to the board. Note: the current meter completes the battery circuit. Attach the ground probe of a voltmeter to ground, and use the voltmeter to test various voltages on the TI-RSLK MAX chassis board (+BAT, +5V and 3.3V). Turn on power with your eyes fixed on the current meter. If the current is above 100 mA, turn it off immediately and check connections. The current draw of just the chassis board without motors or LaunchPad should be less than 10 mA. Use the voltmeter to verify the voltages on +BAT (7.2V), +5V, and +3.3V. Figure 5 shows the locations of the power-related pins on the TI-RSLK MAX chassis board. Six fully charged NiMH batteries will create over 8 V.

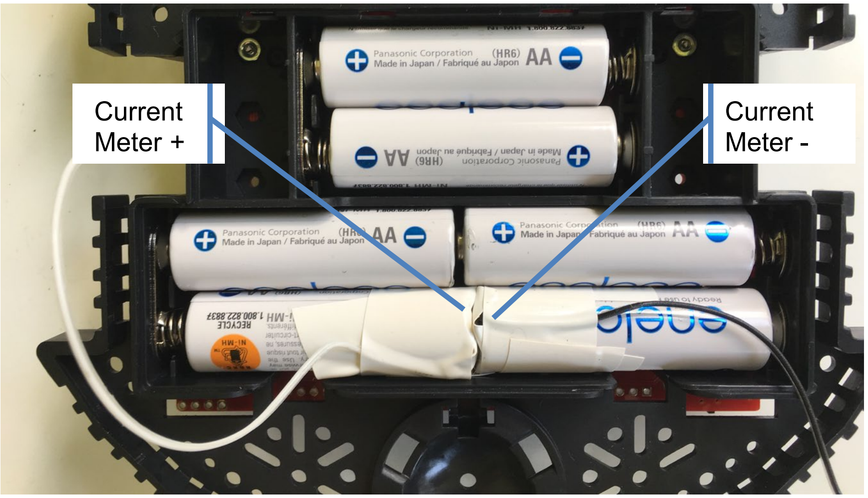

Figure 4. TI-RSLK chassis holding 6 AA batteries, allowing you to measure current to the system.

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 batteries. If you are using secondary batteries, charge the battery following the directions on the charger. Use 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:

$$E = V*I*time$$

Assuming constant current, 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.

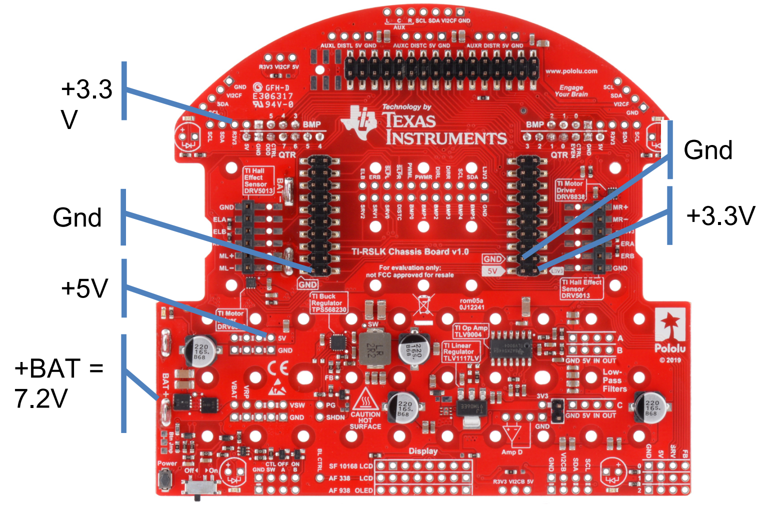

Figure 5. TI-RSLK MAX chassis board (source: Pololu.com).

Note: The +5V pin on the LaunchPad will not be powered with +5V.

You can also measure noise with a voltmeter in AC mode. We can quantify noise either as **root mean squared voltage** (Vrms) or as **peak-to-peak voltage** (Vp-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. Noise originates from the switching regulator, the motors, and the motor drive circuits.

5.4.2 Voltage Regulation

Batteries provide power to the robot. When fully charged, the voltage of six NiMH batteries will range from 7.2 to 8.4V. The purpose of a **regulator** is to provide a constant voltage. The TI's TPS568230 synchronous step down switching regulator on the TI-RSLK chassis board provides +5V output for up to 8 A. The TI's TLV1117 linear regulator on the TI-RSLK chassis board provides +3.3V output for up to 800 mA.

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Note: A common misunderstanding about regulators is to think an 8-A regulator will output 8 A. This is not correct. This 5-V 8-A regulator will output a constant 5 volts for any current draw from 0 to 8 A. The load (e.g., the robot) determines the actual current.

Connect the batteries as shown in Figure 4 and test the regulators as shown in Figure 5. 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 TI-RSLK chassis board. Once you have verified the regulators are operating properly, turn off the power, and remove the batteries.

5.4.3 Complete construction of the TI-RSLK MAX robot

Follow the TI-RSLK MAX construction guide document or the construction video on ti.com or under module lab demo 5.3. The construction guide shows how to assemble your robot and even dissemble the components, if you need to other components needed in lab 11 and lab 15. Your MSP432 LaunchPad will already have headers soldered and a jumper disconnected. **If the MSP432-LaunchPad was not part of the TIRSLK-EVM kit follow directions provided in the construction guide.**

Warning: Please ensure the +5V jumper on the MSP432 LaunchPad is disconnected or removed. Not removing this jumper will cause permanent damage to the LaunchPad and the TI-RSLK chassis board.

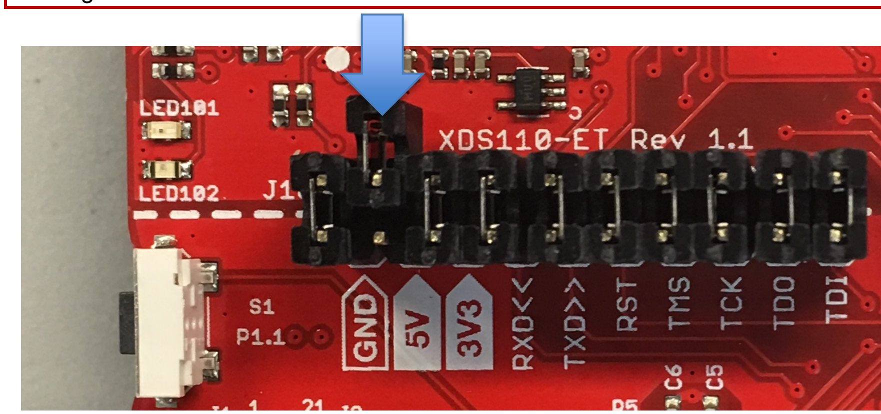

Figure 6. MSP432 LaunchPad with +5V jumper removed.

There are four power modes of the TI-RSLK MAX robot, See Table 1. As long as the +5V jumper on the LaunchPad is removed, as shown in Figure 6, you can safely switch from one power mode to another. The four modes are established by two independent actions. You could plug or unplug the USB cable between the LaunchPad and your PC. Independently, you can turn on/off battery power to the TI-RSLK MAX chassis board. See Figure 7. Leaving the slider switch in the **Off** position, you can turn on/off power to the TI-RSLK MAX chassis board by press the **Power** button.

We recommend you set the robot in **Off** mode (TI-RSLK chassis board off and the USB cable removed) when connecting or disconnecting wires to the robot or to the MSP432.

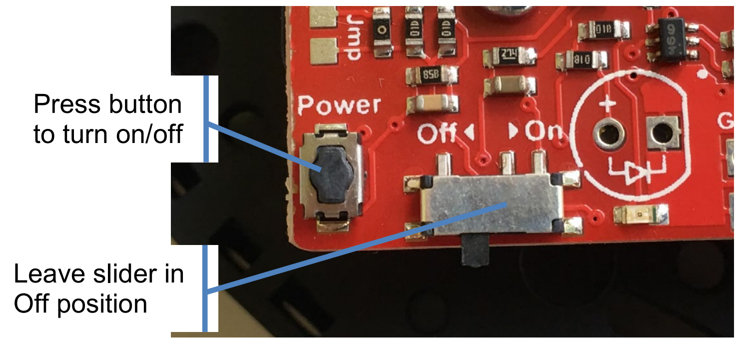

Figure 7. Power button turns on/off the TI-RSLK MAX chassis board.

If the TI-RSLK chassis board power is on, the motor driver, the line sensor, and the MSP432 are powered. Connecting the USB cable allows for debugging the MSP432 using Code Composer Studio. **Debug** mode (TI-RSLK chassis board off and the USB cable connected) can be used for debugging software that doesn't use any circuits on the chassis board. We suggest you debug software for the robot you will need **Full function** mode (TI-RSLK chassis board on and the USB cable connected). Once you are satisfied with the operation of your software, you can run the robot in **Autonomous** mode by just supplying battery power.

Mode	Batteries	USB cable	+BAT	+5V	+3.3V
Off	Off	Disconnected	Float	Float	Float
Debug only	Off	Connected	Float	Float	+3.3V
Autonomous	On	Disconnected	+7.2V	+5V	+3.3V
Full function	On	Connected	+7.2V	+5V	+3.3V

Table 1. Power modes for the TI-RSLK MAX robot.

Again, insert six batteries into the holder, placing the two batteries with the taped wires adjacent to each other, and attaching these two wires to a current meter.

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See Figure 4. Turn on power with your eyes fixed on the current meter. If the current is above 100 mA, turn it off immediately and check connections.

Measure both the DC and AC components of the +5V and +3.3V regulated power lines. Notice, if the motors are not spinning, the entire robot operates with a current draw of much less than 100 mA.

5.4.4 Testing the TI-RSLK MAX robot

The purpose of the entire curriculum is to write software for the robot. However, the **TI_RSLK_MAX** project allows you to test the functionality of the bump switches, the line sensor, the blinker LEDs, the tachometer, and the motors. Leave the two batteries with the taped wires attached to a current meter. Start TExaSdisplay and open the COM port associated with the MSP432. Build and debug this project. Within the debugger running in **Full function** mode, start the software.

First, test the line sensor by moving the robot left and right over a black tape placed over a white reflective surface. If the line sensor is about 3 mm from the tape, you should see data representing the distance of the robot to the center of the line.

Next, place the robot on blocks so it doesn't run away while the USB cable is connected. Press and hold one of the bump switches. While holding one bump switch press the other 5 bump switches verifying the software can properly recognize each of the 6 switches correctly.

When you let go of all bump switches, the two motors will activate and the speed will be displayed on TExaSdisplay. Notice the current will jump to about 500 mA while the motors are spinning.

While the motors are spinning measure both the DC and AC components of the +BAT, +5V and +3.3V power lines. Notice, if the motors are spinning, there is noise on the power 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.

When the motors are not spinning, the robot draws more than 100 mA:

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

Regulators don't work:

- Double check the connections
- Check the datasheets for the TI-RSLK MAX chassis 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?
- Why does your board use a linear regulator for +3.3V?
- Why does your board use a switching regulator for +5V?
- What does it mean that the switching regulator has 95% efficiency?
- Why does the +5V switching regulator have so much noise?

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 TI-RSLK MAX chassis board, you could build this robot, and do this lab by building your own regulator circuit. In particular, you could build the linear regular described in lecture using the LM7805 and two 10 μF 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.
- A second option if you do not have the TI-RSLK MAX chassis 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*5 is 25, but 7.2*7.2=51.84.)

5.8 Which modules are next?

In the next few labs, we begin the process of writing software to control the robot. In Module 12 we will complete the functionality of the TI-RSLK MAX chassis board when we use the motor drive circuits allowing the software to output to 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 write software to activate the motors.

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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