ECE 461/561 EMBEDDED SYSTEM DESIGN
PROJECT 4: *THIS SIDE UP* ENERGY OPTIMIZATION

OVERVIEW

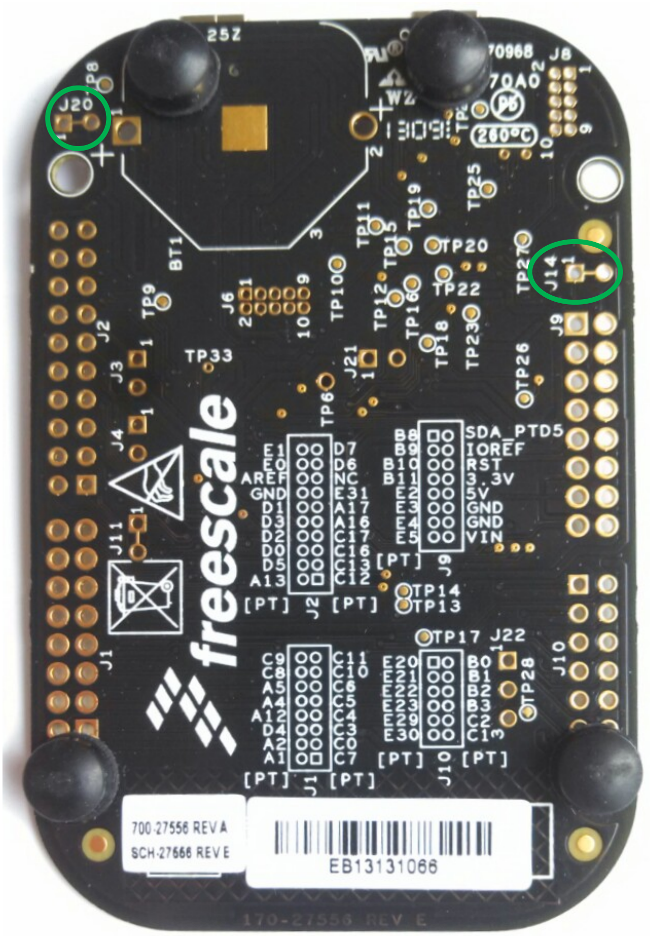
For this project you will create a device which monitors its orientation. If it tilts too far from horizontal it will flash the LED red or yellow to warn the user. Otherwise the LED flashes green. Your goal is to minimize its energy use, maximizing battery life.

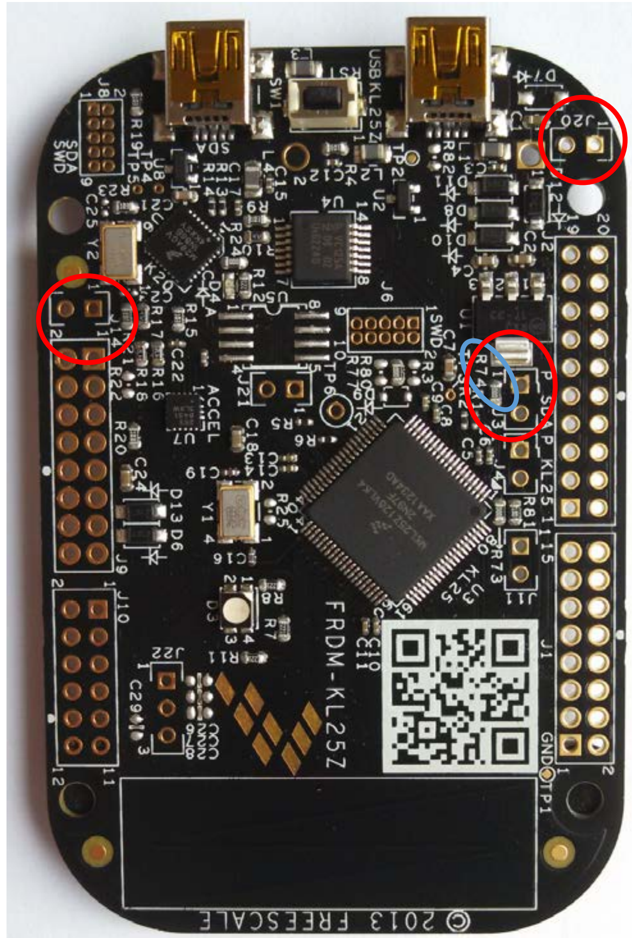
DETAILS

SYSTEM REQUIREMENTS

- Start with the KL25Z Freedom board and make modifications as needed.
- Determine the orientation at least every 500 ms using the MMA8451 accelerometer. The X, Y and Z accelerations can be converted to roll and tilt angles (in degrees) using these equations:
  - roll = $\text{atan2}(a_y, a_z)*180/\pi$
  - pitch = $\text{atan2}(a_x, (a_y^2 + a_z^2)^{1/2})*180/\pi$
- Flash the RGB LED at a frequency of 2 Hz to provide visual status information on the orientation of the system.
  - Color
    - Green: OK, <15 degrees
    - Yellow: Warning, >= 15 degrees
    - Red: Failure, >= 30 degrees
  - Timing
    - The LED must flash visibly every 500 ms.

HARDWARE MODIFICATIONS





Cut 2 traces

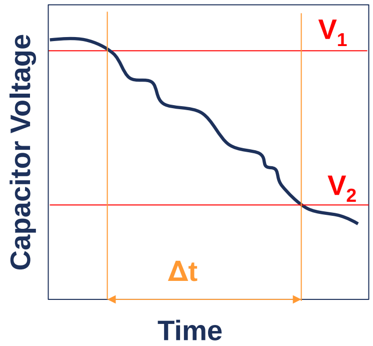
Remove 1 resistor
Add 3 headers

Modify your Freedom board as follows:

1. Remove resistor R74 to enable debug circuit current measurement.
2. Populate J3 (labeled P_SDA) with a 2 pin header. Insert a shorting jumper on J3 when you wish to use the debug MCU (e.g. debugging, or downloading new code).
3. Cut the trace on the back of J14 to disconnect the target MCU's reset line from the debug MCU. Populate J14 with a 2 pin header. Insert a shorting jumper on J14 when you wish to use the debug MCU.
4. Cut the trace on the back of J20 to allow measurement of output current from the U1 linear voltage regulator. Populate J20 with a 2 pin header. Do not place a shorting jumper on J20, as diode D12 is needed to prevent current from flowing from the ultracapacitor back to the voltage regulator.

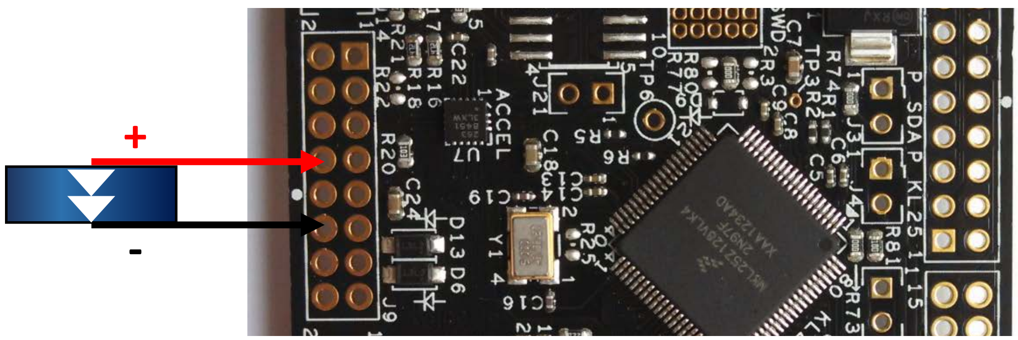
ENERGY MEASUREMENT

Mount the ultracapacitor capacitor on the P3V3 rail, charge it and use it to power the system. The amount of time the system runs will indicate the total energy used, enabling you to calculate the average power used.



$$Energy = C\frac{V_1^2 - V_2^2}{2}$$
$$Average\ Power = C\frac{V_1^2 - V_2^2}{2t}$$

Insert the ultracapacitor on the P3V3 rail, connecting the negative pin to ground (J9 pin 12) and the positive pin to P3V3 (J9 pin 8).



RECOMMENDED APPROACH AND HINTS

- Planning
  - Work through the energy measurement lab exercise to understand the basic concepts.
  - Build a power and energy model in a spreadsheet to help guide your design and optimization. You should plan how to optimize the system's energy use before you starting coding, and use the model as you proceed with your optimization.
- Software structure
  - Use the low-power timer LPTMR to wake the processor periodically.
- Disabling unused components
  - Disconnect the debugger (power and reset line) when running your timing tests.
  - Disable the clock signals to unused MCU peripherals using the SIM_CG registers.
- Using low-power modes
  - Operate devices (peripherals and MCU) in their low power modes when possible.
- Minimizing active power use
  - Reduce execution time of code.
  - Change the current-limiting resistors for LEDs.
  - Replace polling with interrupts. Have the MMA8451 interrupt the MCU when new data is ready.
  - Use PWM to light the LEDs, or shorten the LED pulses.
  - Compensate for the dependence of LED brightness on supply voltage (which falls as the ultracapacitor discharges).
  - Run the I^2C communication link as fast as possible.
- Debugging
  - When using the debugger (MDK), you may need to disable the __wfi() calls.
  - Use logic analyzer to monitor active times for the processor and inertial sensor. Use one or more digital output bits as debug signals for visibility into the system.
- Testing

  - Once you have optimized your system, test times can grow quite long. Speed up testing by charging the ultracapacitor only partially (e.g. for a shorter amount of time, and/or to a lower voltage), or by discharging it only partially (e.g. until 2.7 V).

SUBMISSION

GENERAL

1. You may complete this project individually (10% extra credit) or with one partner.
2. Your LED flashes must be visible in normal indoor lighting conditions.
3. Your code may be examined for possible plagiarism by using MOSS (http://theory.stanford.edu/~aiken/moss/).

DELIVERABLES

- Electronic Submission
  - Project archive with source code.
- Extra Credit (10 pts): report indicating optimizations and performance impacts.

GRADING

The following factors will be used to determine your grade.

- Correct functionality.
- System energy use. To get full credit, the system must run off the ultracapacitor (charged for 30 seconds according to the testing process below) for at least the following time. Extra credit will be given for longer times.
  - ECE 461: 240 seconds (4 minutes)
  - ECE 561: 480 seconds (8 minutes)
- Code quality. The instructors may deduct points for remarkably bad coding practices (for example functions longer than a page, magic numbers, non-descriptive names). These are described online at http://users.ece.cmu.edu/~eno/coding/CCodingStandard.html. If you have a question about what is acceptable, please post it on the class discussion forum so others can learn as well.

TESTING PROCESS

1. Discharge ultracap by shorting its leads for at least one minute.
2. Power Freedom board by connecting USB cable.
3. Connect shorting jumper on J20 so P3V3 rail is at 3.3 V.
4. Connect ultracap to J9 pins 8 and 12 to charge it at 3.3 V for 30 seconds.
5. Disconnect ultracap from J9 and allow to float for ½ minute until voltage stabilizes. Measure this voltage and use it for your starting point in energy calculations (e.g. 2.760 V @ 30 sec, 2.750 V @ 60 seconds, 2.743 V @ 90 seconds)
6. Remove power from Freedom board by disconnecting USB cable.
7. Remove shorting jumper from J20 so P3V3 rail does not drive voltage regulator.
8. Connect ultracap to J9 pins 8 and 12 and measure run time of system.
9. Tilt profile during testing
   a. First 20 seconds of each minute: <15 degrees, green
   b. Second 20 seconds of each minute: >15 and <30 degrees, yellow
   c. Third 20 seconds of each minute: >30 degrees, red