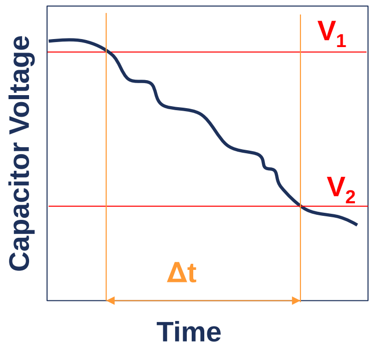
POWER AND ENERGY LAB: FREEDOM BOARD ENERGY MEASUREMENT

OVERVIEW

In this you will examine how to measure the energy consumed by the Freedom board in order to calculate the average power used. You will mount a 0.1 F 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. The program flashes the LED every half second allowing you to measure elapsed time easily.



$$Energy = \boldsymbol{C}\frac{\boldsymbol{V_1^2} - \boldsymbol{V_2^2}}{\boldsymbol{2}}$$

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

HARDWARE

Modify your Freedom board as follows:

1. Remove resistor R73 to enable target MCU current measurement. The MCU's current will flow through a 10 ohm resistor (R81), producing a voltage drop of 10 times the current. Divide the voltage drop by 10 to determine MCU current. *Note that putting an ammeter across J4 will give an inaccurate reading because the ammeter's internal shunt resistor will be in parallel with R81, reducing the effective resistance, voltage drop and current reading.*
2. Remove resistor R74 to enable debug circuit current measurement. Populate J3 with a 2 pin header. Insert a shorting jumper on J3 when you wish to debug.
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 debug.
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.

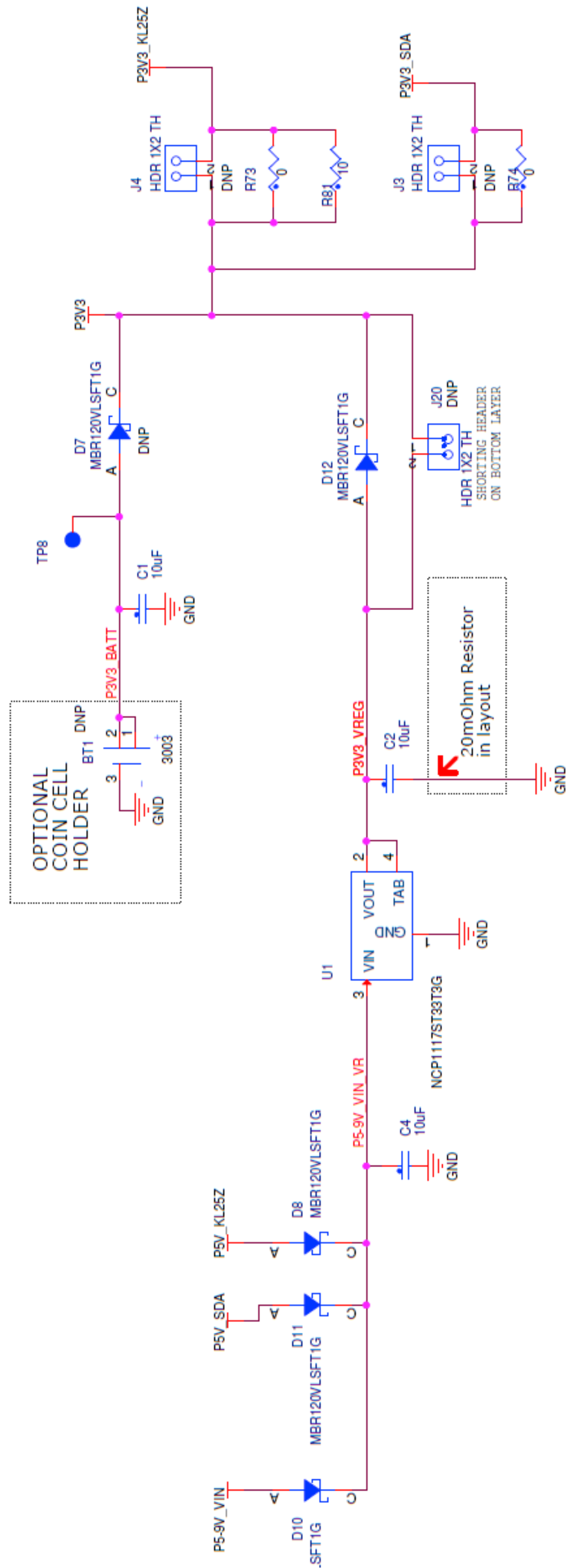


Figure 1. Freedom KL25Z Power Supply

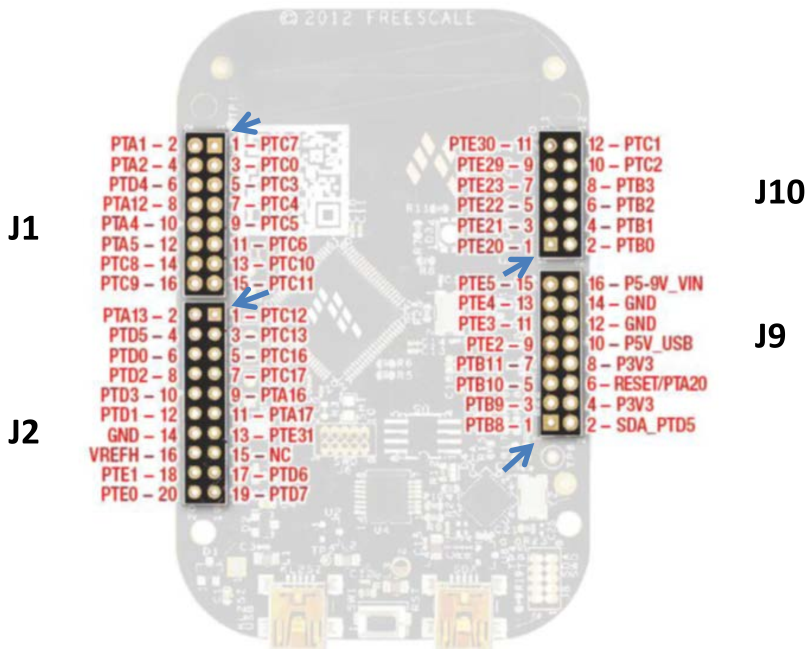


Figure 2. Freedom KL25Z I/O connectors with pin 1 marked on each with an arrow.

TEST EQUIPMENT NEEDED

- Voltmeter
- Stopwatch

SOFTWARE

Vmin	Vmax	Color
3.0	n/a	Flashing Blue
2.6	3.0	Flashing Magenta
2.2	2.6	Flashing Green
1.7	2.2 V	Flashing Red

The test program flashes the RGB LED once per second based on the P3V3_KL25Z supply rail voltage, using the color scheme shown above.

PROCEDURE

MCU PROGRAMMING

For these experiments you will evaluate the energy consumption within the Freedom board.

1. Power the Freedom board with the USB connection. Verify that shorting jumpers are on J3 and J14. Download the test program to the MCU's flash and let it run without using the debugger.
2. Remove the shorting jumpers from J3 and J14.
3. Connect a voltmeter to the P3V3 supply rail. What is the voltage? _________

3.106 V – there is a 200 mV drop from the protection diode D12.

ULTRACAPACITOR ANALYSIS

4. 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).
5. Allow the ultracapacitor to charge for 10 seconds, and then remove it from J9. Connect it to a voltmeter and record the voltage after 10 seconds.
6. Repeat the two previous steps to complete the following table.

Iteration	Total Elapsed Charging Time	Voltage immediately after disconnection	Voltage 30 seconds after disconnection
1	10 sec	3.100 V	3.004 V
2	20 sec	3.102	3.093
3	30 sec	3.104	3.100
4	40 sec	3.105	3.102

BASIC ENERGY MEASUREMENT PROCEDURE

7. 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).
8. Allow the capacitor to charge for a constant amount of time (e.g. 20 seconds) and then disconnect the USB cable. Count how many times the LED flashes in order to determine elapsed time (two flashes per second).
   __________seconds

   8 s

9. What was the initial voltage on the P3V3 supply rail voltage? __________V

   3.1 V

10. What was the final voltage (i.e. when the LED stopped flashing)?____________ V

    1.7 V

11. How much energy was used?

    Energy = $C (V_1^2 – V_2^2)/2$ = 336 mJ

12. What was the average power consumption?

    Power = Energy / time = 42 mW

ENERGY MEASUREMENT WITH DEBUG MCU DISABLED

13. Remove the shorting jumpers on J3 and J14. Repeat the charging and measurement procedure above. How long did the system operate? ____________s

    15 s

14. What was the initial voltage on the P3V3 supply rail voltage? __________V

    3.1 V

15. What was the final voltage (i.e. when the LED stopped flashing)?____________ V

    1.7 V

16. How much energy was used?

    Energy = C $(V_1^2 – V_2^2)/2$ = 336 mJ

17. What was the average power consumption?

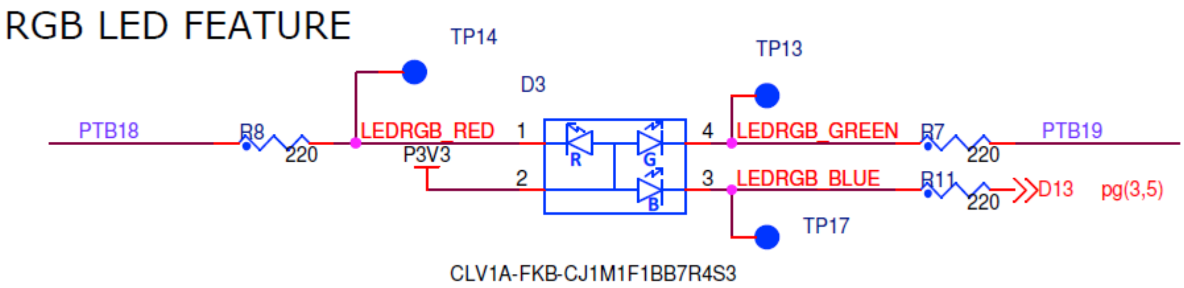
    Power = Energy / time = 22.4 mW

ENERGY MEASUREMENT WITH MCU IN LOW-LEAKAGE STOP MODE

1. Change the code in config.h to enable sleep modes – ensure USE_SLEEP_MODES is defined to be 1. Recompile and download the program. Remember to place the shorting jumpers on J3 and J14 to enable programming but remove them afterward. Repeat the charging and measurement procedure above. Use a stopwatch because the elapsed times will be quite large.
2. Complete the following table. By monitoring how long the LED is the same color you can determine how much power it used on average in the corresponding voltage range.

Color	Elapsed Time	Time in voltage range	Vinitial	Vfinal	Energy Used	Average Power Used
Blue	0:38	38	3.1	3.0 V	30.5 mJ	803 uW
Magenta	1:24	46	3.0	2.6	112 mJ	2435 uW
Green	8:57	7:33	2.6	2.2	96 mJ	212 uW
Red	12:37	3:40	2.2	1.7	97.5 mJ	443 uW

3. How does the average power use in the 1.7 - 2.2 V range compare to the power use in the 2.2 – 2.6 V range? What is the most likely explanation? *Hint: examine the schematic below and the datasheet for the LED.*



The red LED draws much more current than the green LED. Both have the same series resistor value (220 ohms), but the forward voltage for the red LED is much lower than the green LEDs, leading to more current. You can measure this with a multimeter.

4. Extra Credit: Estimate what fraction of the power was used by the LEDs in each of the states. The LEDs have a 20% duty cycle.

PLACING THE ULTRACAPACITOR ON A 5 VOLT RAIL

5. The ultracapacitor used is rated for 5.5 V. Consider moving the ultracapacitor to the 5V supply rail in order to increase the run time.
    a. How would this help? How much longer do you think it could run?

    The ultracapacitor will store much more energy, so the circuit should run longer.
    Energy = $C (V_1^2 – V_2^2)/2$
    With a 5 V charge, it will provide 1.1055 J of energy before reaching 1.7 V.
    This is compared with 0.336 J at 3.1 V. So it could run up to 1.1055/0.336 = 3.29x longer.

    b. Can you think of any drawbacks?

    The linear voltage regulator will be active and will consume a large amount of power.

    c. Try moving the ultracapacitor the 5V supply rail and evaluating the performance. Note that there are various protection diodes (see the schematic) so the capacitor needs to be in different positions for charging and discharging.

    - Plug the ultracapacitor + lead into P5V_USB (J9 pin 10) and – lead into ground (J9 pin 14) to charge it.
    - After it is charged, remove it, rotate it 180 degrees, and plug the + lead into P5-9V_VIN (J9 pin 16) and the – lead into ground (J9 pin 12).

    A run time of about 1 minute should be expected.