Julia DiTomas
Board 4 Report
ECEN 3730
Spring 2025

1. Plan of Record
   a. Block Diagram

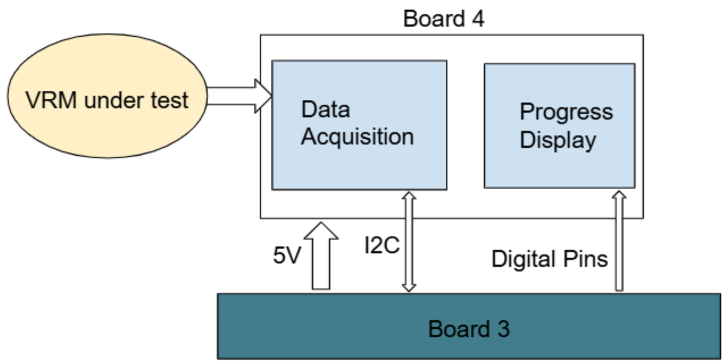


Figure 1: Board 4 simplified block diagram. The objective of this board is to build a shield for Board 3 that characterizes power supplies. The power for Board 4 comes from the 5V rail of Board 3, while the other input is the device under test.

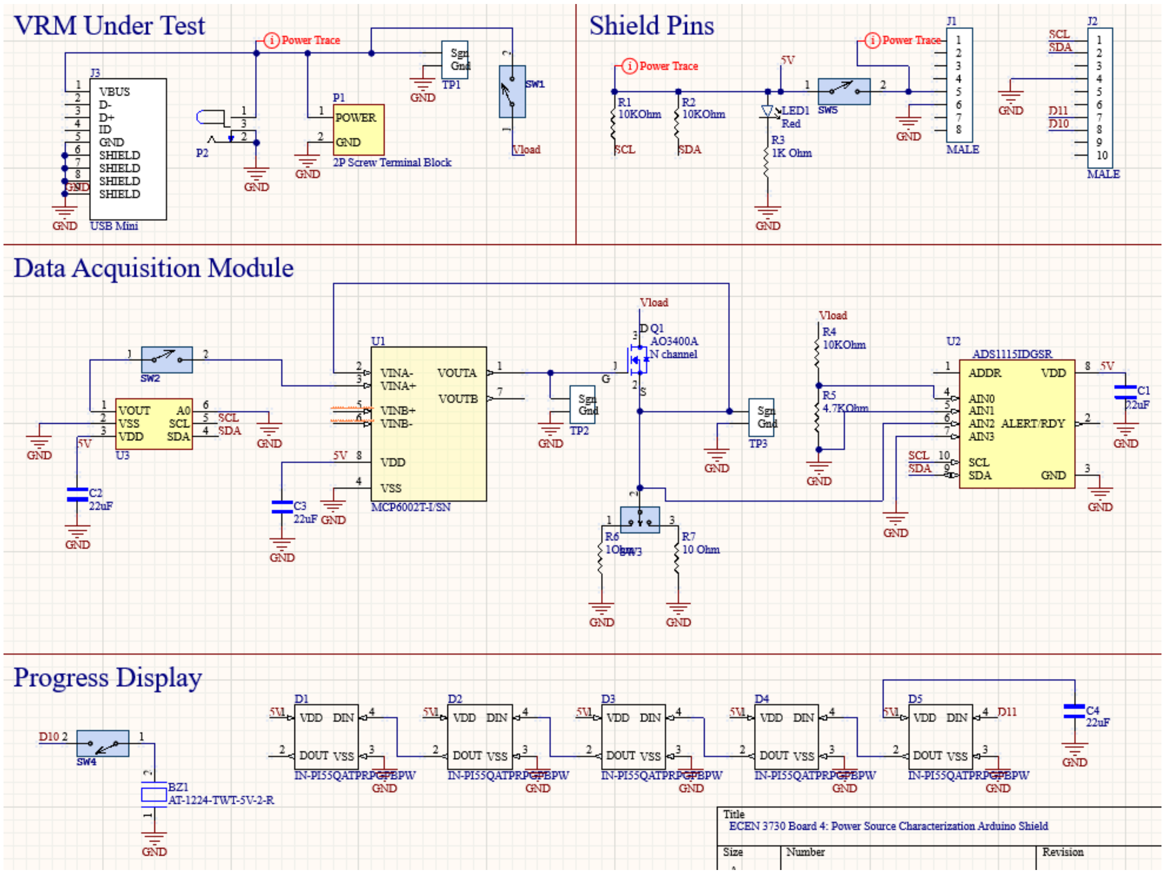
   b. Parts
      i. MCP4725 12-bit DAC: LCSC Part #C144198 (https://ww1.microchip.com/downloads/aemDocuments/documents/MSLD/ProductDocuments/DataSheets/MCP4725-Data-Sheet-20002039E.pdf)
      ii. ADS1115 16-bit ADC: LSCS Part #C37593 (https://www.ti.com/lit/ds/symlink/ads1115.pdf)

   c. Requirements
      i. The board plugs into and is powered by Board 3 (or a commercial Arduino Uno).
      ii. The VRM under test plugs into the board via a terminal block, a USB mini, or a barrel jack.
      iii. The VRM to measure may have a voltage up to 12 V.
      iv. The code controls the current drawn from the VRM under test, and the MOSFET is on with a duty cycle no greater than 10% to avoid smoking components.
      v. The board allows the user to select between a 1 Ω and 10 Ω sense resistor.

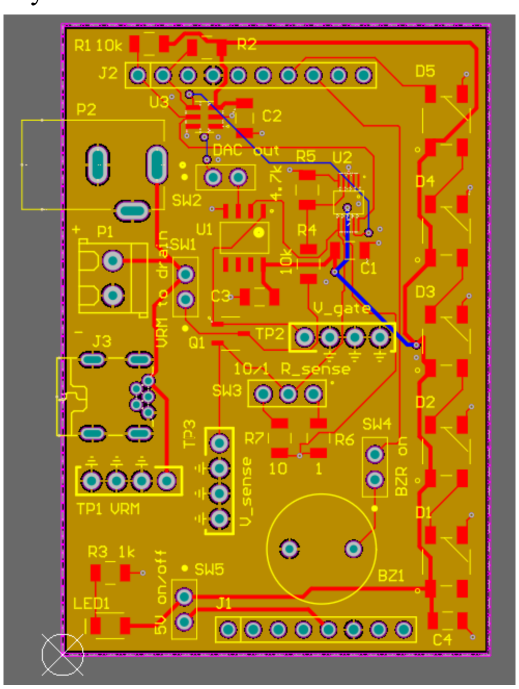
   d. Test Plan
      i. First plug into Arduino Uno, close SW5, and verify that LED1 turns on, indicating power to the board.
      ii. Upload the measurement code and check the output of the DAC matches the values written.
      iii. Plug in known VRM and check voltage at TP1.
      iv. Close SW1 to begin drawing current from and characterizing VRM. Watch voltage across sense resistor as well as output on serial monitor. Ensure they match each other as well as expectations.
         1. Run measurements again with 1 Ω sense resistor and max current set to 2.5 A in the code.

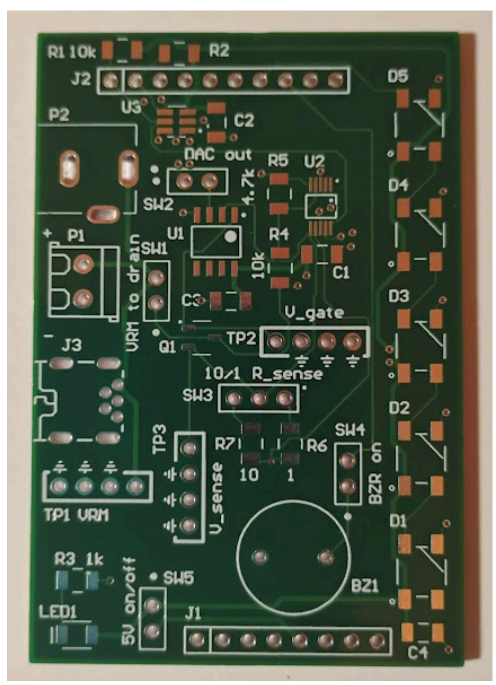
2. Board Progression

a. Schematic

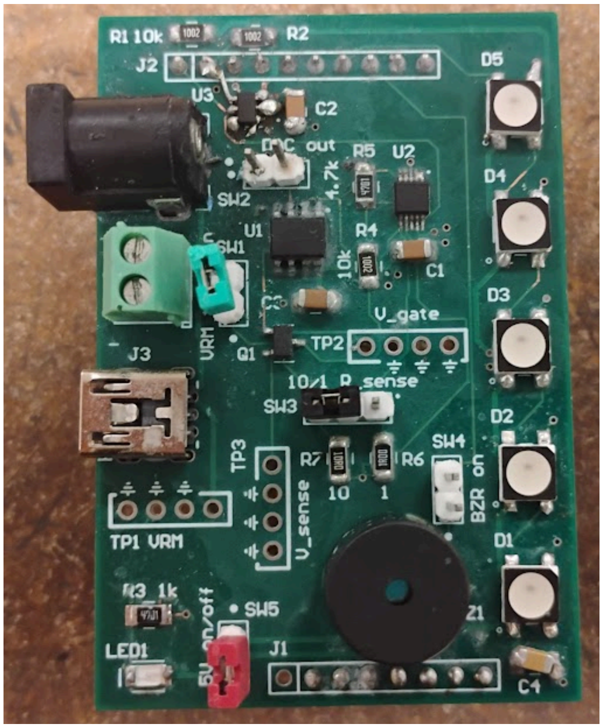


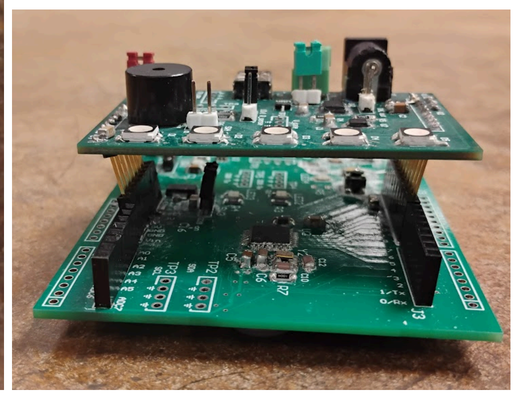
b. Layout / Bare Board



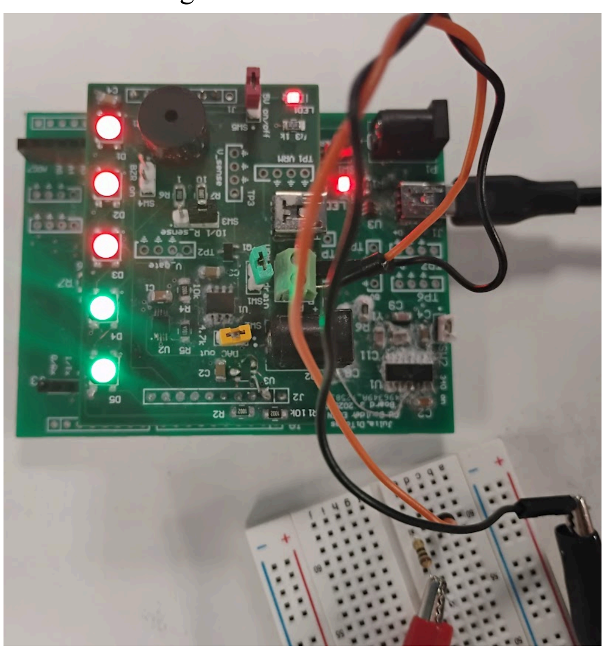


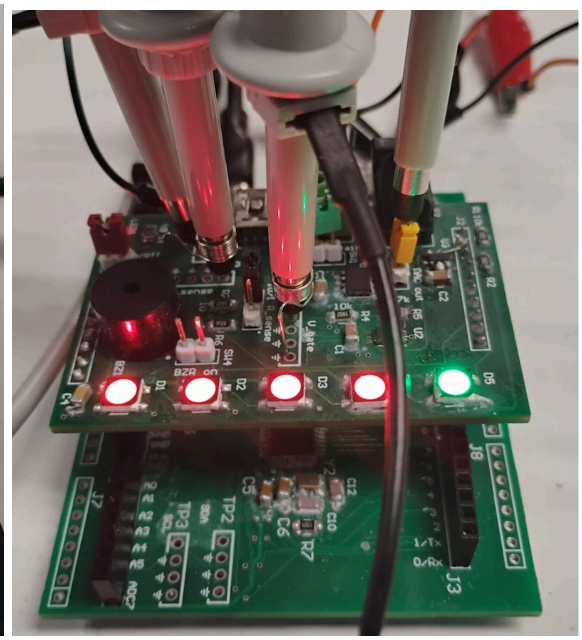
c. Assembled Board / Board Plugged into Arduino





d. Board in Testing





3. Board Power-On, Issues, and Lessons

Although my board worked in the end, I had a few errors in the design and assembly that made it difficult to get functioning, and there are certainly changes I would make if I did it again.

a. I accidentally made the headers 300 mils further apart than the corresponding pins on the Arduino (layout error). Fortunately, upon request, I was provided with extra long header pins so I could still make it work.
b. I would remove the switch connecting the DAC output to the opamp (soft design error). It is unnecessary, and slightly dangerous; if open, the input to the opamp is floating and there is a constant voltage on the MOSFET's gate.
c. I would make the whole board bigger (soft layout error). The compactness was not worth the extra difficulty when I was troubleshooting and had to resolder shorter components.
d. I would still solder the ICs first, but I would test all of their connections with a multimeter before adding other components. I had ***many*** assembly errors with the DAC and ADC. First I discovered the DAC I2C pins were not properly connected and reworked them. But then I caused a 5V-GND short. Next I decided to remove the part, clean up the pads, and start fresh. In actuality I broke the component and many of the pads. And so on. Eventually, with a lot of guidance and a little soldering wizardry from one of the fantastic TAs, I was able to get the DAC working. Then I started taking voltage measurements, which were all about a quarter of what I expected, and discovered the ADC ground was just barely resting on its pad. (This is when I *almost* gave up.)

4. Board Testing

Once the board, by some miracle, was working, I raced through my measurements out of paranoia that, surely, something would break. As it turns out, my fear was unfounded and my board continues to function. LED1 turns on when it is powered, the code is able to find both I2C devices, the output of the DAC is as written, and the ADC's measurements match what I measure with the oscilloscope. The MOSFET is only on when it is supposed to be, and there is only current through the sense resistor when it is on.

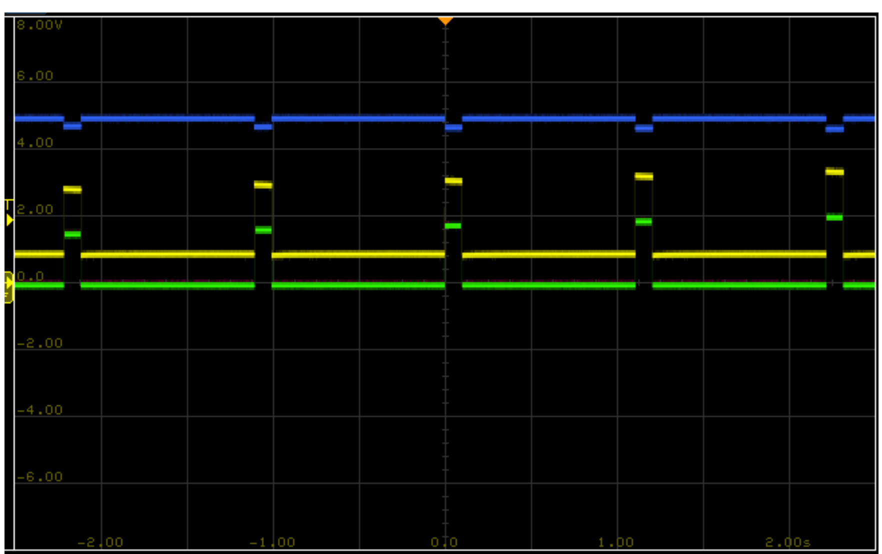


Figure 2: Voltage on MOSFET gate (yellow), voltage across sense resistor (green), and VRM voltage (blue) during measurements of the benchtop power supply set to 5 V. There is also a red trace measuring the DAC output, but it is equal to and hidden by the green trace (the other opamp input) as intended.

```
12:34:28.889 -> Starting DAC
12:34:28.889 -> Starting LED
12:34:28.889 -> Starting ADC
12:34:29.998 -> 1, 12.219, 5.0020, 4.9798, 1.8142
12:34:31.110 -> 2, 24.836, 5.0020, 4.9568, 1.8175
12:34:32.191 -> 3, 37.494, 5.0020, 4.9339, 1.8167
12:34:33.317 -> 4, 50.160, 5.0020, 4.9110, 1.8143
12:34:34.423 -> 5, 63.201, 5.0020, 4.8871, 1.8173
12:34:35.531 -> 6, 75.842, 5.0020, 4.8644, 1.8137
12:34:36.643 -> 7, 88.335, 5.0020, 4.8418, 1.8133
12:34:37.740 -> 8, 101.077, 5.0020, 4.8187, 1.8131
12:34:38.857 -> 9, 113.576, 5.0020, 4.7960, 1.8131
12:34:39.969 -> 10, 126.461, 5.0019, 4.7727, 1.8127
12:34:41.085 -> 11, 139.341, 5.0019, 4.7495, 1.8119
12:34:42.188 -> 12, 151.970, 5.0020, 4.7265, 1.8127
12:34:43.267 -> 13, 164.598, 5.0020, 4.7037, 1.8118
12:34:44.390 -> 14, 177.258, 5.0020, 4.6809, 1.8114
12:34:45.504 -> 15, 190.011, 5.0020, 4.6578, 1.8116
12:34:46.602 -> 16, 202.762, 5.0020, 4.6347, 1.8110
12:34:47.731 -> 17, 215.368, 5.0020, 4.6119, 1.8114
12:34:48.823 -> 18, 227.842, 5.0020, 4.5893, 1.8110
12:34:49.954 -> 19, 240.652, 5.0019, 4.5661, 1.8109
12:34:51.052 -> 20, 253.455, 5.0020, 4.5431, 1.8104
12:34:51.052 -> done
```

Figure 3: Serial monitor output during measurements of the benchtop power supply set to 5 V. Each measurement shows the measurement number, the current through the sense resistor, the unloaded (Thévenin) VRM voltage, the loaded VRM voltage, and the calculated Thévenin resistance respectively.

To validate the measurements, I tested a couple VRMs for which I knew what to expect: the benchtop DC power supply with added series resistors (Figure 4) and the 5V supply pin from the commercial Arduino Uno (Figure 5), which I have measured previously.

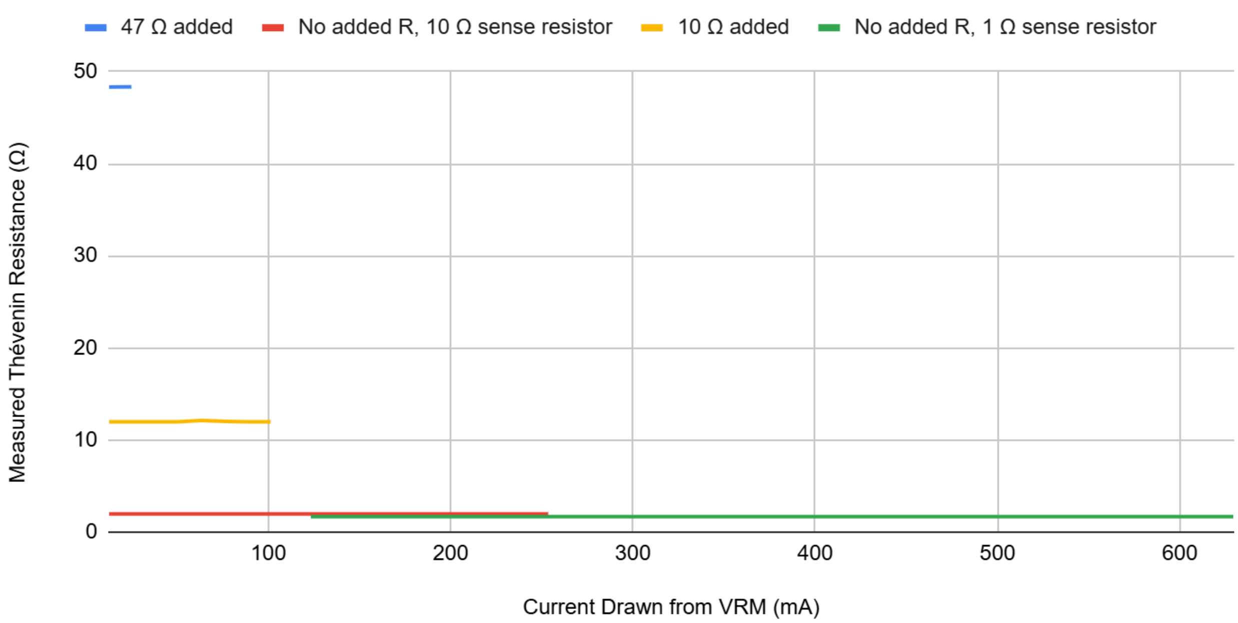


Figure 4: Thévenin resistance of the benchtop power supply set to 5 V, with and without added series resistance. Once the loaded voltage drops below 75% of the Thévenin voltage, the measurements stop.

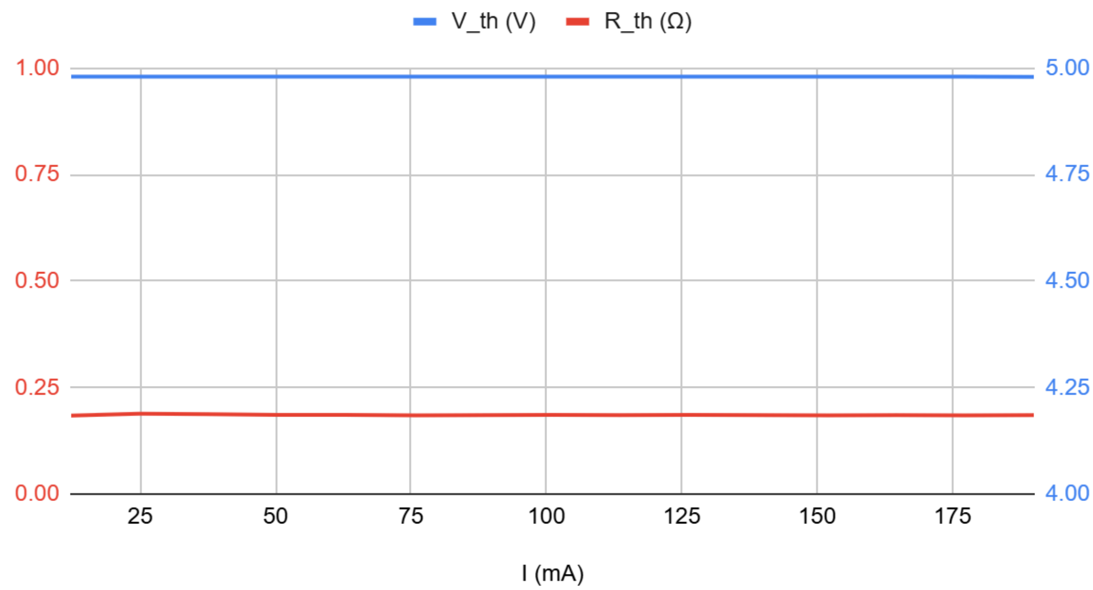


Figure 5: Thévenin resistance and voltage of the 5V supply pin from the commercial Arduino Uno. These results are consistent with my measurements from a previous lab.

Once I was satisfied that the board was functional, I added in the code for the smart LEDs and buzzer. I programmed the smart LEDs to sequentially change from red to green to represent the progress through the current levels. I programmed the buzzer to play a melody once the full set of measurements is done, or once the code stops measuring because the voltage has dropped too low. There is a demonstration of this behavior at https://youtu.be/4ynxuiDUyjY.

5. Conclusion
   There were a lot of things that I did well with this board based on what I have learned in this class already, such as clearly labelling components and including test points and isolation switches to ease debugging. There were also a few mistakes I made, especially with assembly. But on the bright side, I got to practice diagnosing problems and learn new soldering techniques. I also learned more about the components, such as the fact that if the DAC receives no I2C communication it outputs a default voltage of half Vdd, and that the MOSFET can still operate after losing a little bit of magic smoke. Once the board was working, I got to see how cool it is; I can find any power source's equivalent Thévenin model in about 20 seconds, and it has fun sound and light effects as a bonus.

6. Acknowledgements
   I wish to express my deepest gratitude to the teaching team of the PCB lab. They are all full of wisdom and always provide me with helpful advice and feedback.

7. Appendix

   a. Some additional power source characterization plots made using Board 4.

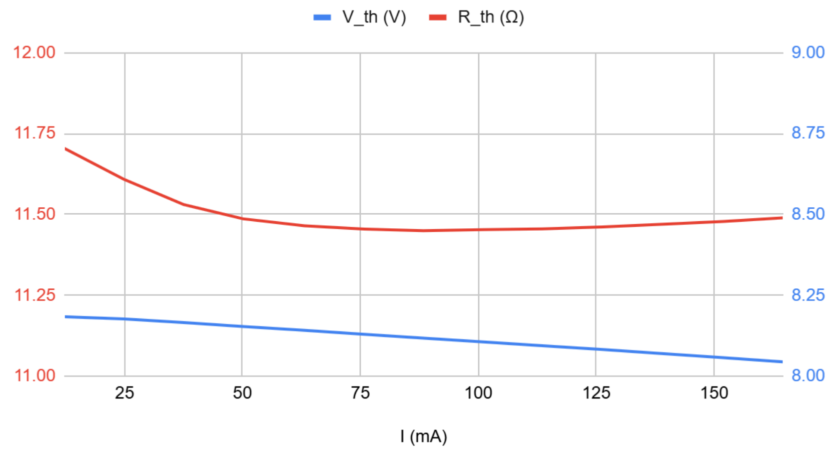


Figure 6: Thévenin resistance and voltage of a used 9V Duracell battery.

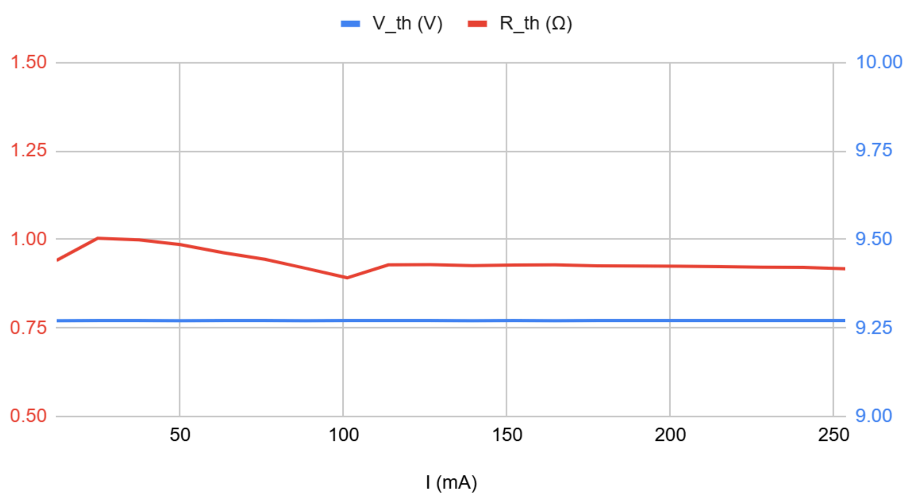


Figure 7: Thévenin resistance and voltage of 9V AC/DC wall wart.