University of Colorado - Boulder

ECEN 5730
Practical PCB Design Manufacture — Fall 2024

Lab 21-22 Report - VRM Characterizer Instrument Droid

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Introduction

In Labs 21 and 22, we explored the functionality and design of a VRM (Voltage Regulator Module) Characterizer Instrument Droid, a customized measurement system implemented on a solderless breadboard (SBB) to analyze Thevenin voltage and resistance characteristics of various voltage sources. Using components like an ADS1115 ADC, MCP4725 DAC, and a MOSFET driver, the instrument allows us to evaluate Thevenin resistance as a function of current load and provides insights into power source performance under different load conditions.

Principle of VRM Characterization

The instrument droid operates by loading the VRM with a known current and measuring the resulting voltage drop. The DAC controls the current through a MOSFET, while the ADC records the voltage across the sense resistor and VRM. By varying the DAC output, the current load can be adjusted to analyze how Thevenin resistance behaves over a range of currents, capturing critical characteristics such as inrush and steady-state behaviors.

Setup

Circuit Overview

The SBB circuit includes a 16-bit ADC (ADS1115), a 12-bit DAC (MCP4725), an op-amp, and a MOSFET. These components work together to enable precise control and measurement of the VRM voltage and current. A voltage divider provides a reference for the VRM voltage, while a sense resistor is used to monitor current. Both the ADC and DAC are connected via I2C, allowing communication with the microcontroller.

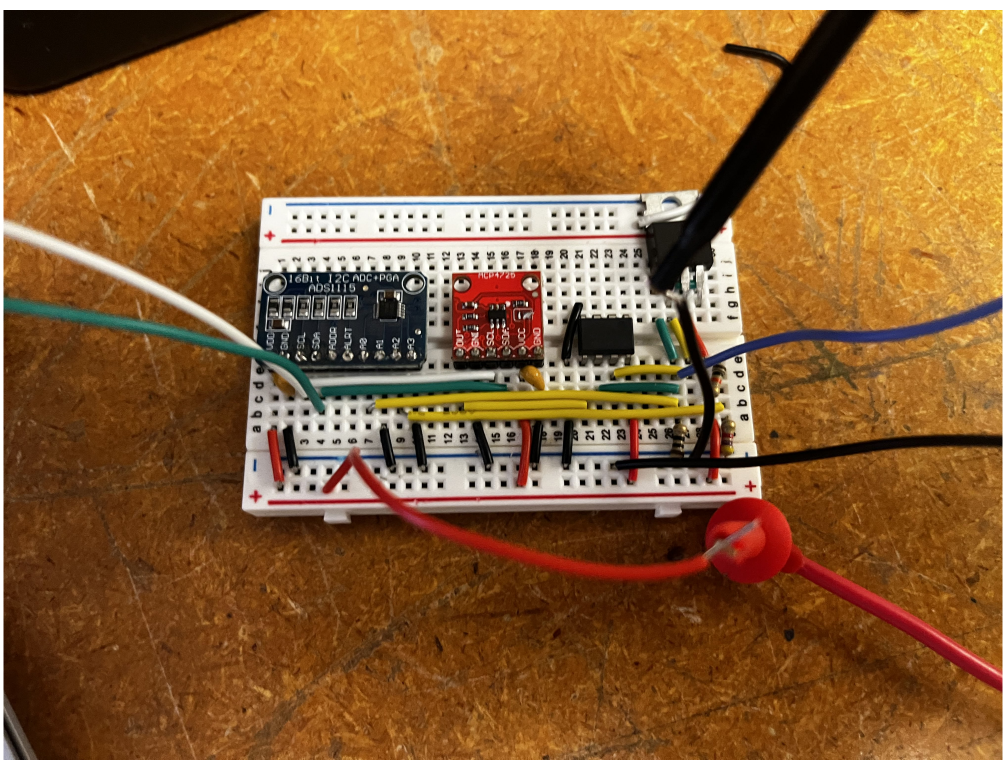

Figure 1: SBB Circuit with ADS1115, MCP4725, Op-Amp, and MOSFET

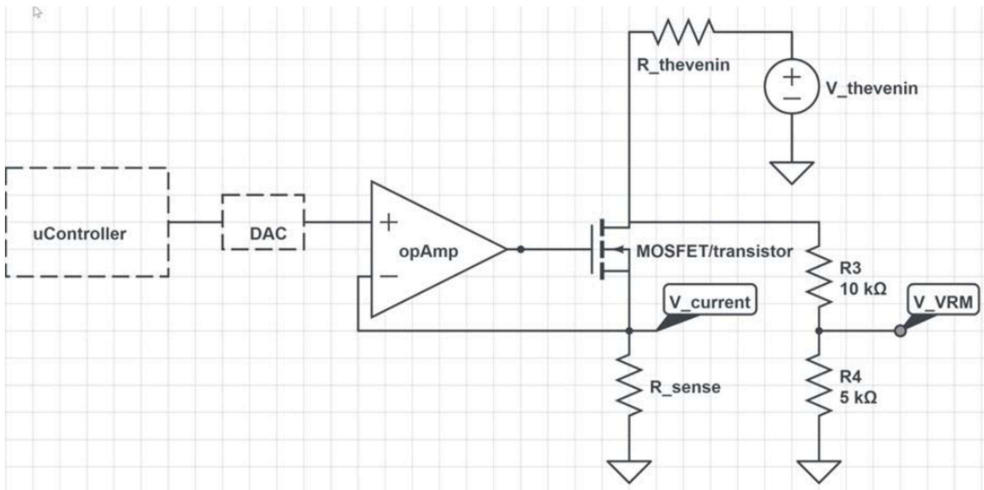

Figure 2: Circuit Schematic of the VRM Characterizer Instrument Droid

DAC Testing

To confirm the DAC's functionality, we used a setup script to generate a square wave across potential I2C addresses (0x60 to 0x65). By identifying the correct address (0x61), we confirmed the ability to adjust voltage output using the DAC.

```
#include <Wire.h>
#include <Adafruit_MCP4725.h>
Adafruit_MCP4725 dac;
float DAC_ADU_per_v = 4095.0 / 5.0; //conversion from volts to ADU
int V_DAC_ADU; // the value in ADU to output on the DAC
void setup() {
 Serial.begin(115200);
 dac.begin(0x61); // address is either 0x60, 0x61, 0x62,0x63, 0x64 or 0x65
 dac.setVoltage(0, false); //sets the output current to 0 initially
}
void loop() {
 V_DAC_ADU = 0 * DAC_ADU_per_v; dac.setVoltage(V_DAC_ADU, false); //sets the output current to 0 initially
 V_DAC_ADU = 3.0 * DAC_ADU_per_v; dac.setVoltage(V_DAC_ADU, false); //sets the output current to 0 initially
}

```

Figure 3: DAC Setup Code Testing Square Wave Output for Address Detection

Results

Steady-State DAC Performance

The oscilloscope capture below verifies DAC performance with the address 0x61, showing that the DAC correctly outputs the programmed square wave, confirming its operational status and correct addressing.

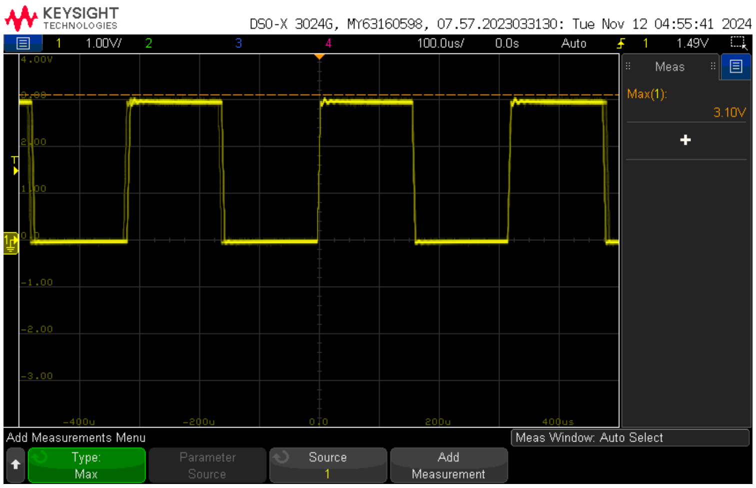

Figure 4: Oscilloscope Trace Showing DAC Square Wave at Address 0x61

Thevenin Resistance Calculation

To measure Thevenin resistance, we varied current levels through code adjustments, recording voltage across VRM and sense resistor. This allowed us to calculate Thevenin resistance based on the voltage and current data obtained. The columns are time, index, current, thevenin voltage, loaded voltage, and thevenin resistance respectively.

```
10:20:46.974 -> 1, 12.510, 4.6092, 4.4823, 10.1447
10:20:48.099 -> 2, 24.938, 4.6086, 4.4516, 6.2965
10:20:49.176 -> 3, 37.574, 4.6085, 4.4320, 4.6969
10:20:50.300 -> 4, 50.165, 4.6082, 4.4179, 3.7936
10:20:51.375 -> 5, 62.812, 4.6082, 4.4051, 3.2342
10:20:52.502 -> 6, 75.630, 4.6081, 4.3953, 2.8132
10:20:53.619 -> 7, 88.188, 4.6081, 4.3858, 2.5211
10:20:54.740 -> 8, 100.698, 4.6079, 4.3774, 2.2896
10:20:55.818 -> 9, 113.039, 4.6082, 4.3702, 2.1056
10:20:56.941 -> 10, 125.582, 4.6083, 4.3643, 1.9427
10:20:58.061 -> 11, 138.443, 4.6082, 4.3571, 1.8136
10:20:59.136 -> 12, 150.950, 4.6082, 4.3507, 1.7059
10:21:00.259 -> 13, 163.450, 4.6083, 4.3440, 1.6170
10:21:01.380 -> 14, 176.120, 4.6084, 4.3379, 1.5362
10:21:02.464 -> 15, 188.667, 4.6083, 4.3333, 1.4574
10:21:03.580 -> 16, 201.361, 4.6082, 4.3276, 1.3935
10:21:04.703 -> 17, 213.886, 4.6082, 4.3226, 1.3351
10:21:05.780 -> 18, 226.339, 4.6084, 4.3173, 1.2861
10:21:06.901 -> 19, 238.851, 4.6084, 4.3123, 1.2398
10:21:08.024 -> 20, 251.340, 4.6085, 4.3079, 1.1960
10:21:08.024 -> done
```

Figure 5: Example Output Showing Current and Voltage Measurement Steps

Power Supply Comparisons

We tested multiple power sources, including 5V and 9V wall warts and lab power supplies. As expected, wall warts exhibited higher Thevenin resistance due to limitations in load regulation, particularly at lower currents. The 5V wall wart showed a resistance of approximately 10-1 ohms, while lab power supplies remained around 1-0.1 ohms, with resistance decreasing exponentially as current increased.

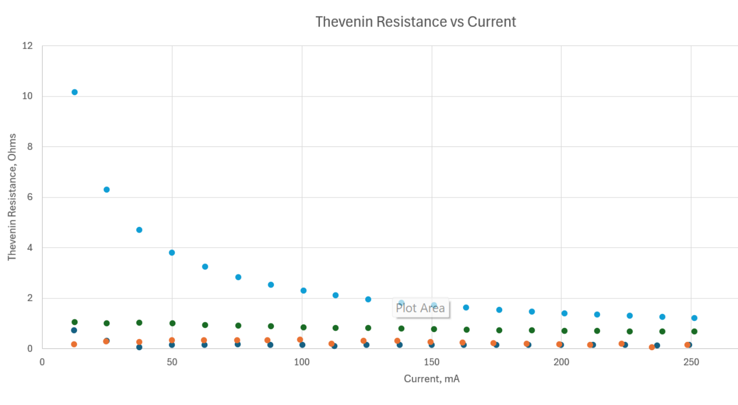

Figure 6: Thevenin Resistance vs. Current for Different Power Supplies

Discussion

The results underscore the role of VRM and power source characteristics in regulating output under variable loads. Wall wart adapters exhibited higher Thevenin resistance, leading to voltage drops at higher loads. This insight is essential for selecting power sources in sensitive applications, as it demonstrates that certain adapters may not provide stable voltage under fluctuating load conditions.

Conclusion

This lab provided valuable insights into VRM characteristics and power source behaviors. By constructing and testing the VRM Characterizer Instrument Droid, we demonstrated a method to measure Thevenin resistance accurately and observed the limitations of different power supplies. Future designs should consider the balance between capacitance and load regulation in power-sensitive circuits.