ANALOG MULTIMETER

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1 INTRODUCTION

The aim of this project was to demonstrate how to use the d'Arsonal's Galvanometer in the designing of analog measurement instruments, specifically, a voltmeter, ammeter and ohmmeter integrated as one multi-meter unit. Explore the challenges, calculations and considerations that need to be made during the design, construction and calibration process.

This was done for the following range specifications:

a. Voltmeter – 0 to 50 V
b. Ammeter – 0 to 100 mA
c. Ohmmeter – 1 to 100 Ohm – while taking into account 10% of battery variation

The control objective for the system was the current, $I_{m,}$ through the galvanometer.

2 SYSTEM DIAGRAM

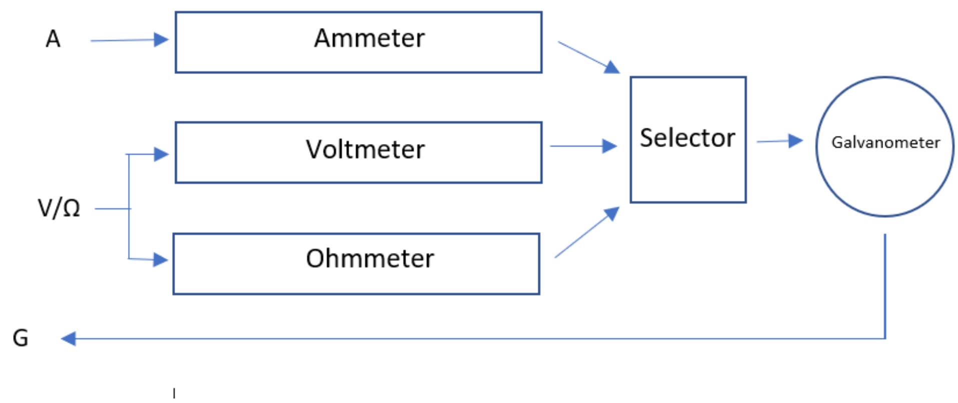


Figure 1 Multitmeter Setup

In this setup, we have 3 different circuitries: for the ammeter, voltmeter, and ohmmeter respectively. All three can generate a current I_m , one of which passes through the Galvanometer, depending on which circuitry the selector is toggled to. This generates a corresponding reading on one of the three scales on the galvanometer.

The input variables or measurable device must be connected to a common ground on one end, while the other end must be connected to their 'A' input, if a the current through the device is required, or 'V/Ω', if the voltage or resistance is required.

3 METHODOLOGY & MATERIALS

3.1 Galvanometer Modelling

The first step in the process of realizing a multimeter design was to figure out model for the available Galvanometer and understand its bounds. This required finding to essential parameters: its internal resistance R_m and the full-scale deflection current I_{FSD}.

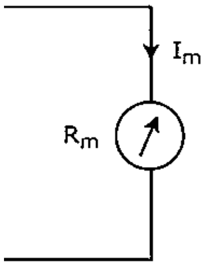


Figure 2 D'Arsonal Galvanometer Electrical Model + Real Imagel

The internal resistance, $\mathbf{R_m}$, was measured using DMM (Digital Multimeter and was averaged across four readings to be **218.4 Ohms**.

The full-scale deflection current was measured by gradually applying a low-voltage across the Galvanometer's terminals, with an Ammeter connected in series to register the current. The voltage increase resulted in an proportional increase in the current I_m through the Galvanometer. This in-turn caused proportional deflection in the Galvanometer's pointer. The current at which this pointer reached its fartherest position was noted down as the full-scale deflection current, $\mathbf{I_{FSD}}$**,** which was averaged over 4 readings turned out to be **4.195 mA.**

$\mathbf{R_m}$	218.4 Ohms
$\mathbf{I_{FSD}}$	4.195 mA

3.2 Design Calcuation's

The second step essential step was determining the type of circuitry and the values of its various components used to measure different quantities with the multimeter.
(The calculations of the values given below can be seen in Appendix 6.1).

3.2.1 The Ammeter

The Ammeter designed was of shunt-type, and as such had shunt-resistance in parallel to the Galvanometer to limit the follow of current I_m through it. Instead, a proportional low-valued current followed through it such that at maximum range it was equal to the full-scale deflection current.

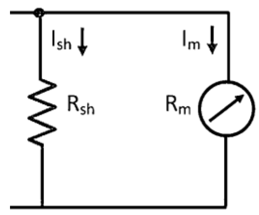


Figure 3 Ammeter Design

R_{sh}	9.56 Ohms
Closest Practical Resistor Combination	10 || 220 (Error: 0.055%)

3.2.2 The Voltmeter

The voltmeter designed was of series-type, with a simple multiplier resistance in series with the Galvanometer. It worked on the principle of the voltage divider rule, by increasing the voltage drop across the multiplier resistance, while leaving a low-valued proportional voltage across the Galvanometer's internal resistance such that at maximum input range $V_{i\text{-}Rm}/R_m = I_{FSD}$

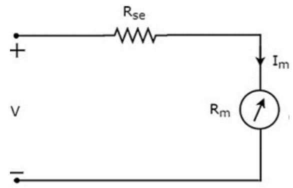


Figure 4 Voltmeter Design

R_{se}	11700 Ohms
Closest Practical Resistor Combination	680K || 12K (Error: 0.77%)

3.2.3 The Ohmmeter

The Ohmmeter design was of series type. It utilized a 9V battery to supply a potential to the circuit, a fixed resistance for current limiting, and a variable resistance for zero-control (to cater to small drops in batteries voltage level). It was designed such that under 1 Ohm of resistance at the input:

$$V_{battery}/R_{total} = I_{FSD}$$

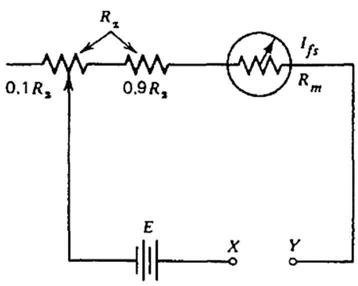


Figure 5 Ohmmeter Design

$0.9R_x$	1734.31 Ohms
Closest Practical Resistor Combination	2.2K || 8.2K
$0.1R_x$	192.70 Ohms
Closest Practical Resistor Combination	1K Variable Resistor Used
$R_{half\text{-}scale(x\text{-}y)}$	2145.411 Ohms

3.3 Design Simulation

The following simulations were performed on PSpice. These simulations confirmed out experimental

3.3.1 The Ammeter

We can clearly observe that as our input current range varies from 0 – 100 mA, the current I_m also increase linearly with it up-till the full-scale deflection current 4.195 mA

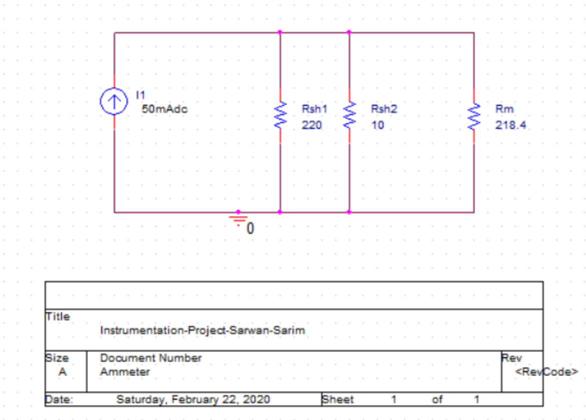


Figure 6 Ammter Simulation Circuit

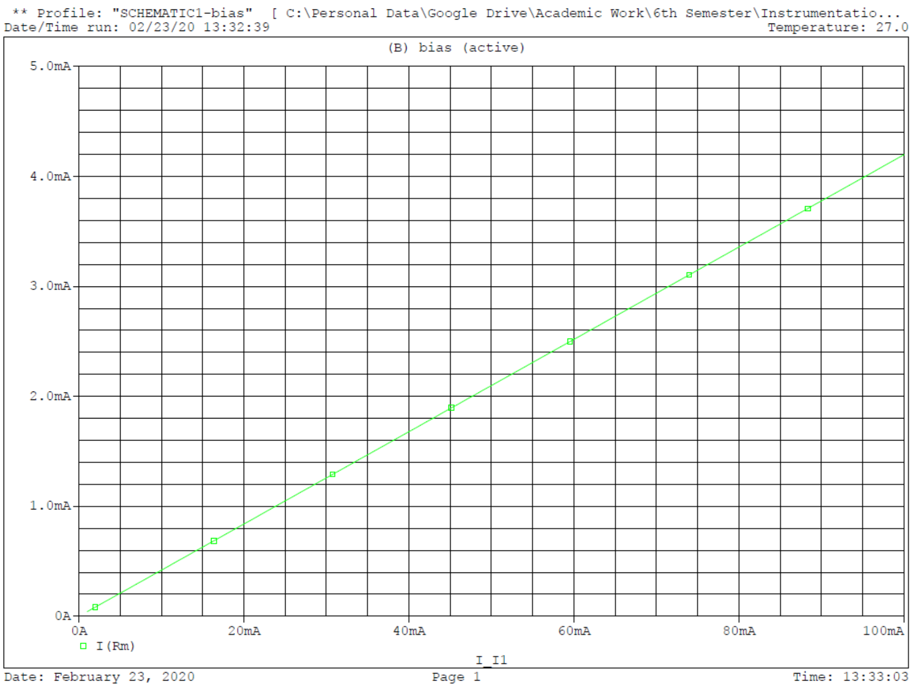
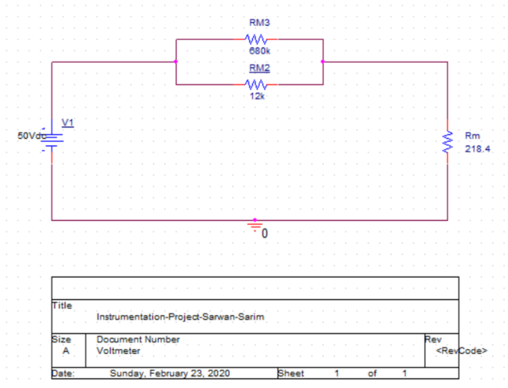


Figure 7 Ammeter Simulation Results: I_I1 vs I(Rm)

3.3.2 The Voltmeter

We can clearly observe that as our input voltage range varies from 0 – 50 V, the current I_m also increases linearly with it up-till the full-scale deflection current 4.195 mA



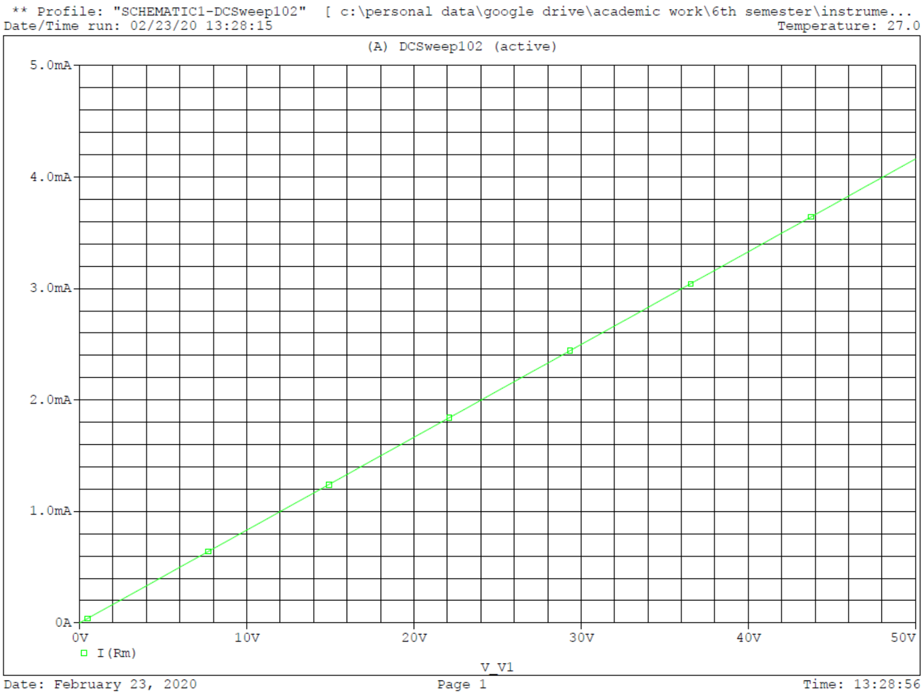


Figure 8 Voltmeter Simulation Results: V_V1 vs I(Rm)

3.3.3 The Ohmmeter

We observe that as our input resistance range varies from 1 – 100K Ohms, the current I_m decreases in an inverse proportion, with full-scale deflection current 4.195 mA at 1 Ohm's of resistance, while approximately 0 mA at 100K Ohms or as resistance approaches infinity. Simulations considering changing battery levels can be seen in Appendix 6.2

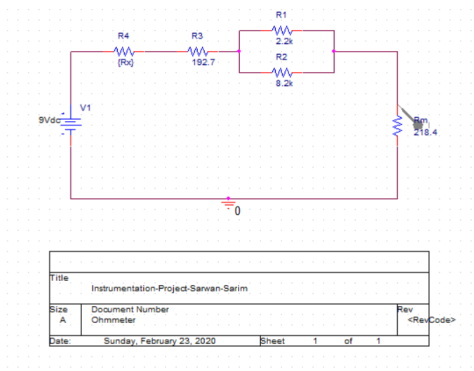
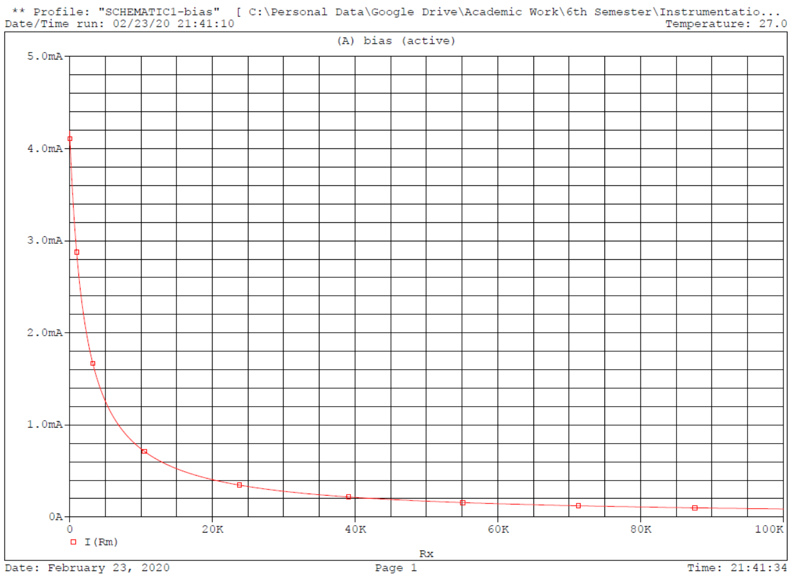


Figure 9 Ohmmeter Simulation Circuit



3.4 Design Integration

After the simulations verified our theoretical calculations, we proceeded with implementing the circuitry on the veroboad. A major concer at this point was to integrate all three circuitries: the ammeter, voltmeter and ohmmeter onto one circuit, while optimizing space, minimizing interference, and preserving their respective functions. After the trail and error of a few sketches, the following design was concluded:

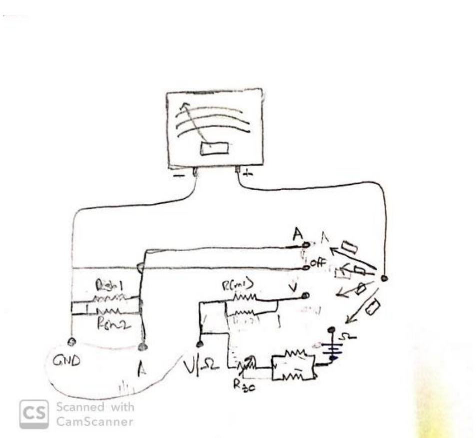


Figure 10 Model Design

It was implemented on a Veroboard, and as such required a decent amount of soldering. The quality of the Veroboard posed a major hurdle in proper soldering. Pictures of the finished product are added below.
Some considerations and compensations that were made while integrating and implementing the circuit on the Veroboard included adding additional series resistance to compensate for short-fall on measured vs labelled resistance values on the utilized resistors. This was particularly the case with the voltmeter and ohmmeter resistance.

Furthmore, instead of using slide switches to toggle in between the multi-meter's 3 modes, we decided to use a setup that incorporated female-socket's which allowed a jump wire to enable one of the three modes. The rational behind this approach to switching was that the use of slide switches gave rise to risk of having two modes simultaneously enabled, which could lead to incorrect readings or destroying the circuitry or Galvanometer in certain cases.

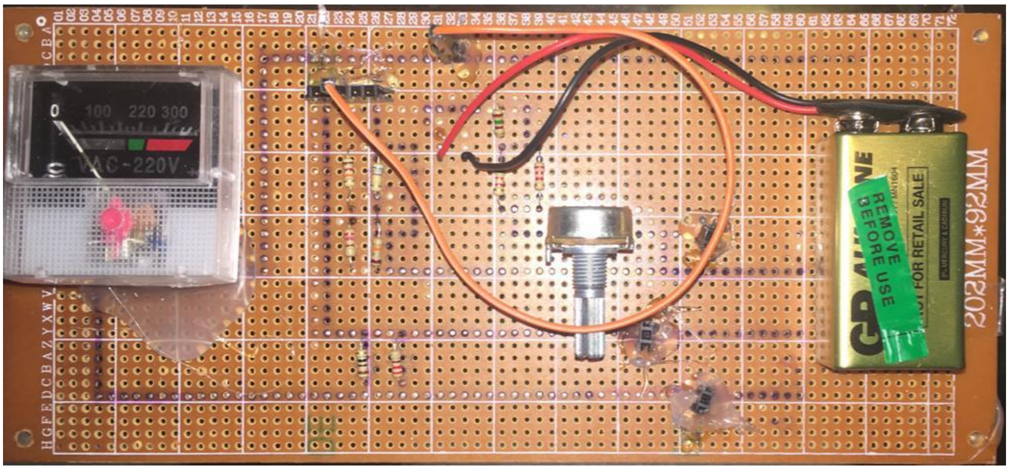


Figure 11 Veroboard Implementation: Front

4 Results & Remarks

4.1 System Validation

To conduct whether our implemented system operates similar to how it was simulated on PSpice. We will test our system at a few test points as an Ammeter, Voltmeter and Ohmmeter. (Other results are in appendix 6.4)

4.1.1 The Ammeter

The Ammeter was tested for the value ranges of 25 mA, 50 mA, 75 mA and 100 mA using a battery approximately at 9V and a 390, 220, 120, and 100 Ohm resistor respectively, exploiting the I = V/R relation. The results below show that the Ammeter has a fair or reasonable degree of accuracy for an analog instrument.

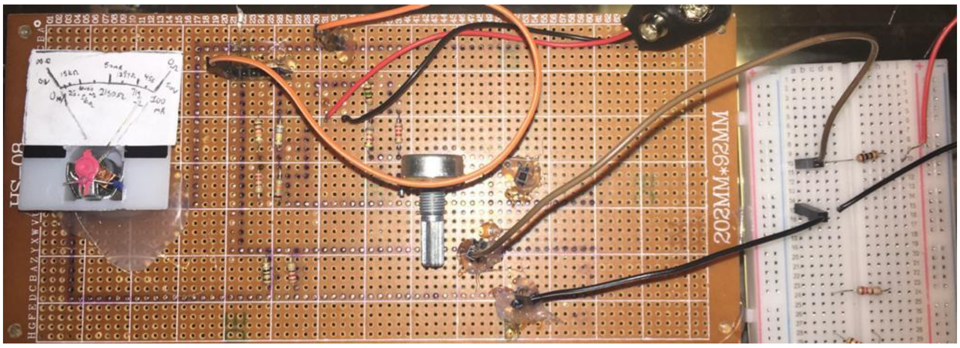


Figure 12 Ammeter Hardware Results: ~ 25 mA, ~ 50 mA, ~ 75 mA, ~ 100 mA (On-scale)

4.1.2 The Voltmeter

I was unable to test the voltmeter at all ranges, however, it was evident from the one test point that I did test, that it isn't as accurate as the ammeter. It shows a reading of 11 - 12 V whereas the actual reading lies around 9 V's.

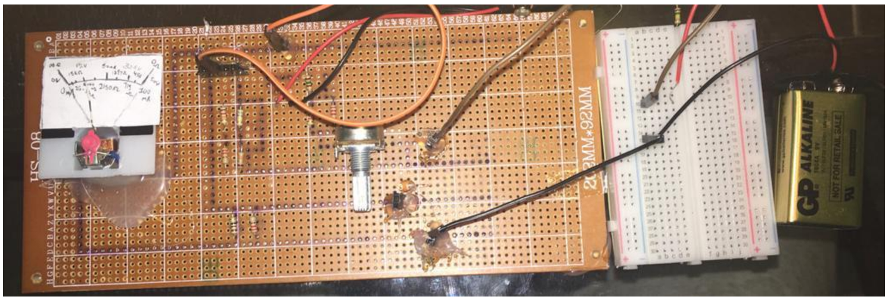


Figure 13 Voltmeter Hardware Results: ~ 12 V (On-scale)

4.1.3 The Ohmmeter

The Ohmmeter was tested on the values 1 Ohm, 680 Ohm, 2.2k Ohms, 6.8k Ohms, 15k Ohms, and 100 k Ohms (Full-scale deflection to no-deflection) respectively. The results below showed that the Ohmmeter also worked to a reasonable degree of accuracy, and somewhat similar to results obtained in the case of the Ammeter, with regard to its accuracy.

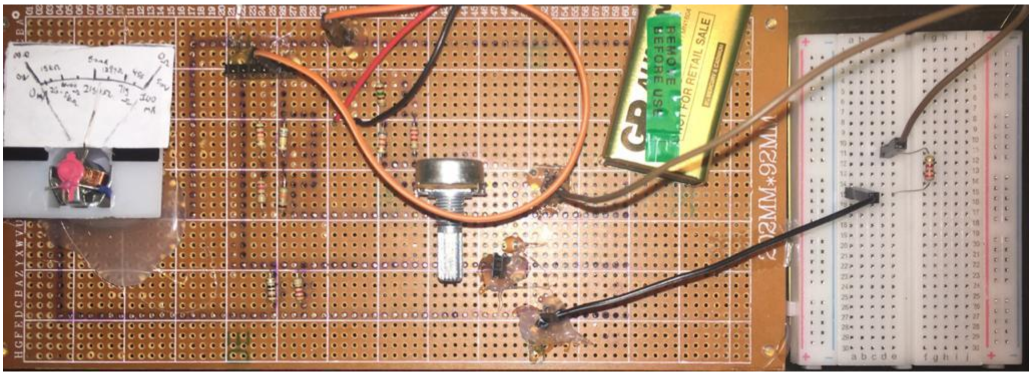


Figure 14 Ohmmeter Hardware Results: ~ 2000 Ohms

5 Conclusion

To conclude, we see that there is similarity between our hardware and software implementions. This reflects the partial success of our system. Though the hardware implementation do not exactly replicate perfect theoretical results, as in the case of the software, but there is still a reasonable degree of accuracy in the hardware's results for a given input, as can be seen above, more specifically, in the case of the Ammeter and Ohmmeter, as shown above.

There is however one concern that needs to be addressed, which is the battery-adjustment zero-control for the Ohmmeter. There is strong mathematical reason to believe that zero-control in series with R_m should not be sufficient for complete adjustment, instead rather a better method would be to install the zero-control resistor in Paralell with $R_{m.}$ However, such a method would require that the current I_m be of the order of micro, which isn't the case. To achieve such a scenario, we may need to modifiy the internal resistance of the galvanometer with a fixed resistance, as to decrease $I_{m.}$ So that could be improvement that could be made to the existing implementation, one that we realized slightly late.

6 Appendix

6.1.1 Design Calculations

6.1.1.1. The Ammeter

Using full-scale deflection conditions (i.e. 100 mA Input):

$$V_m = R_m * I_{FSD} = 218.4 * 4.195 * 10^{-3} = 0.9162\ V$$

$$I_{sh} = I_{INPUT} - I_{FSD} = 100 - 4.195 = 95.805\ mA$$

$$V_{sh} = V_m$$

$$R_{sh} = \frac{V_m}{I_{sh}} = \frac{0.9162}{95.805*10^{-3}} = 9.56\ Ohms$$

6.1.1.2. The Voltmeter

Using full-scale deflection conditions (i.e. 50 V Input):

$$R_{se} = \frac{V_{in} - I_m R_m}{I_m} = \frac{50}{4.195*10^{-3}} - 218.4 = 11700\ Ohms$$

6.1.1.3. The Ohmmeter

Using maximum input (i.e. Input resistance = 0):

$$R_x = \frac{E}{I_{FSD}} - R_m = \frac{9}{4.195* 10^{-3}} - 218.4 = 1927.011$$

6.2 Simulation Results

6.2.1.1.The Ohmmeter

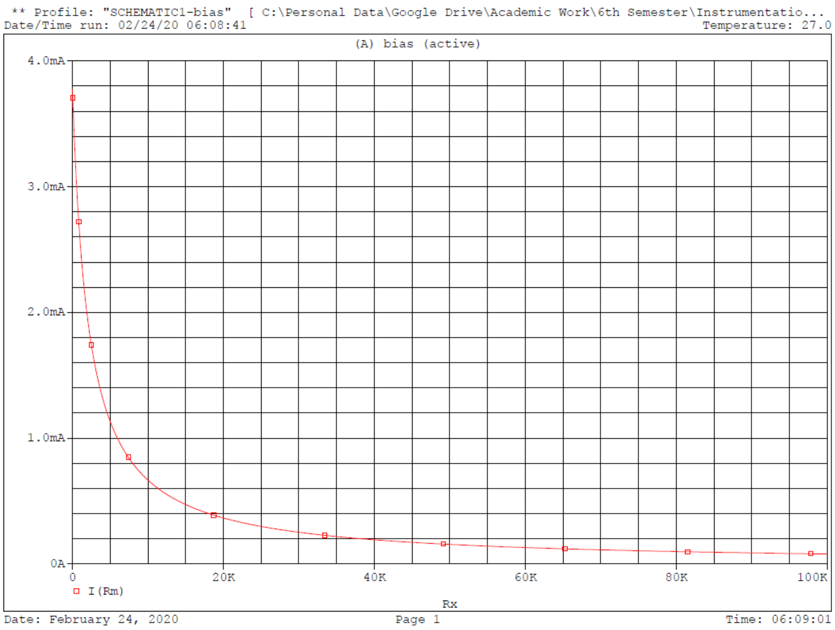


Figure 15 Ohmmeter Simulation Result: R_Rx vs I(Rm) @ 8.1 V Battery Level

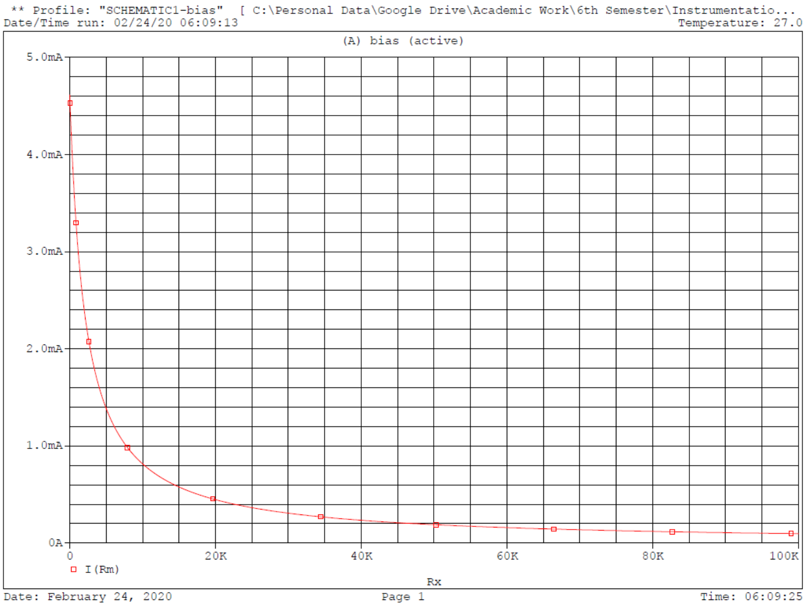
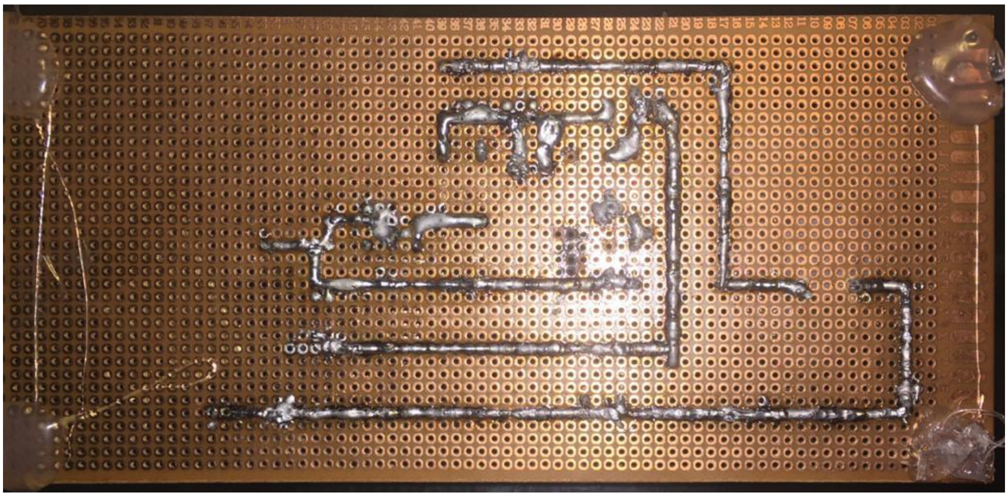


Figure 16 Ohmmeter Simulation Result: R_Rx vs I(Rm) @ 9.9 V Battery Level

6.3 Veroboard



6.4 Hardware Implementation Results

6.4.1 The Ammeter

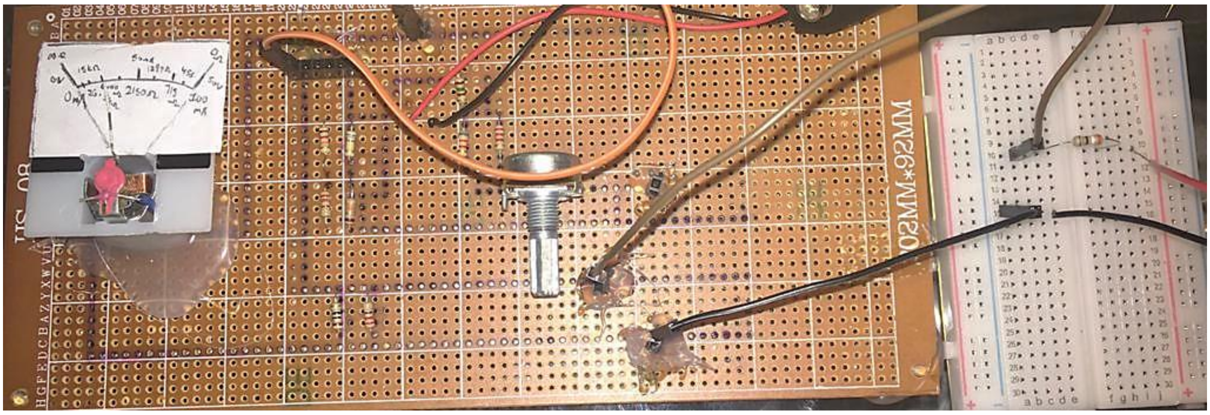


Figure 17 Ammter at 25 mA

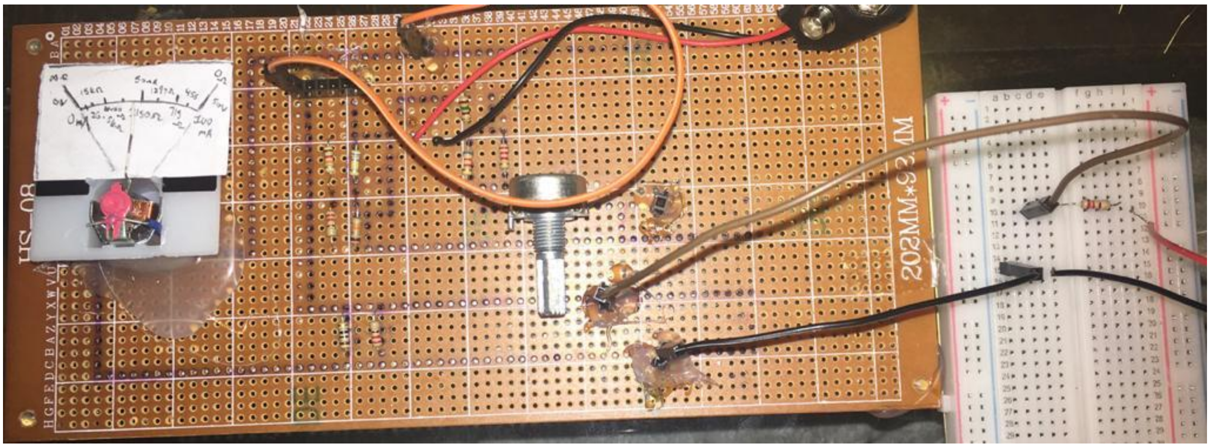


Figure 18 Ammeter at 50 mA

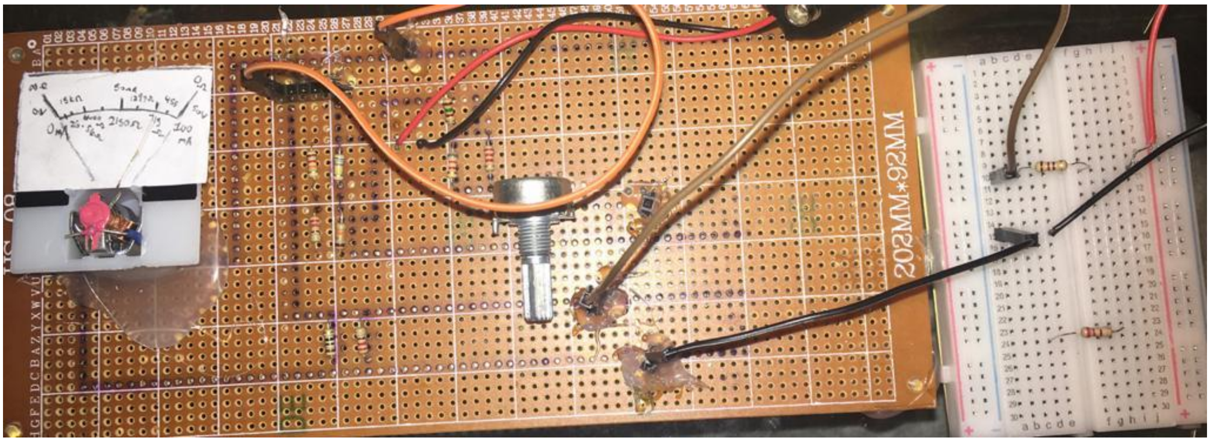


Figure 19 Ammeter at 75 mA

6.4.2 The Ohmmeter