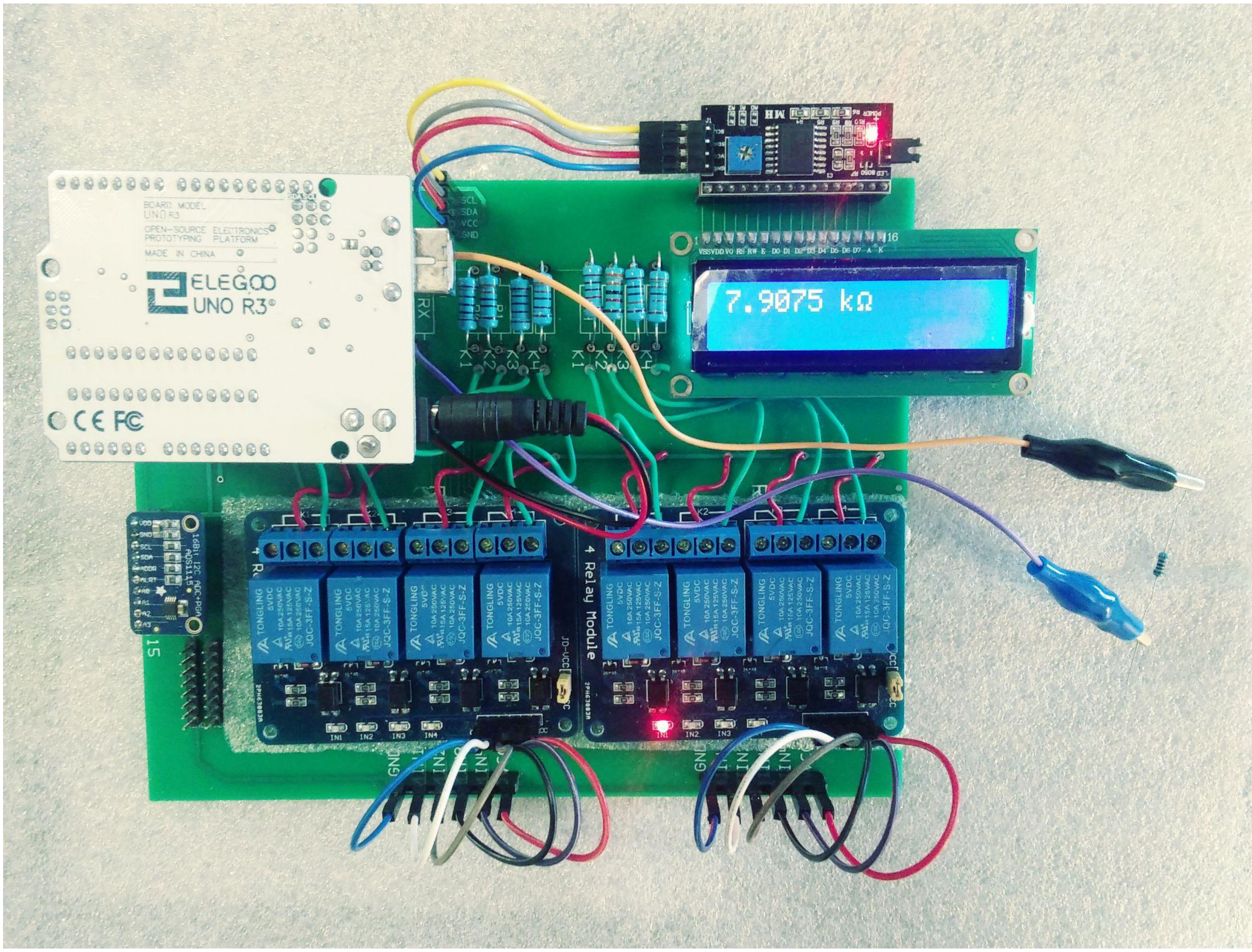
AUTO-RANGING OHMMETER

Contributors: Josh Murphy, Robin Mutali & Marcellin Kibonge



SPECIFICATIONS

Measures 1 Ω - 10 MΩ
Automatic ranging between 8 measurement scales
Accuracy <= 10% for (1 Ω - 10 Ω), Accuracy <= 1% for (10 Ω - 10 MΩ)
Displayed Resolution: 4000 counts

ACRONYMS USED

ADC	Analog to Digital Converter
GND	Ground
I2C	Inter-Integrated Circuit
IDE	Integrated Development Environment
LCD	Liquid Crystal Display
PCB	Printed Circuit Board
RMS	Root Mean Square
SCL	Serial Clock
SDA	Serial Data Access
VCC	Voltage Common Collector
VDD	Voltage Drain Drain

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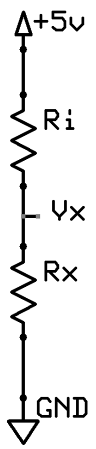
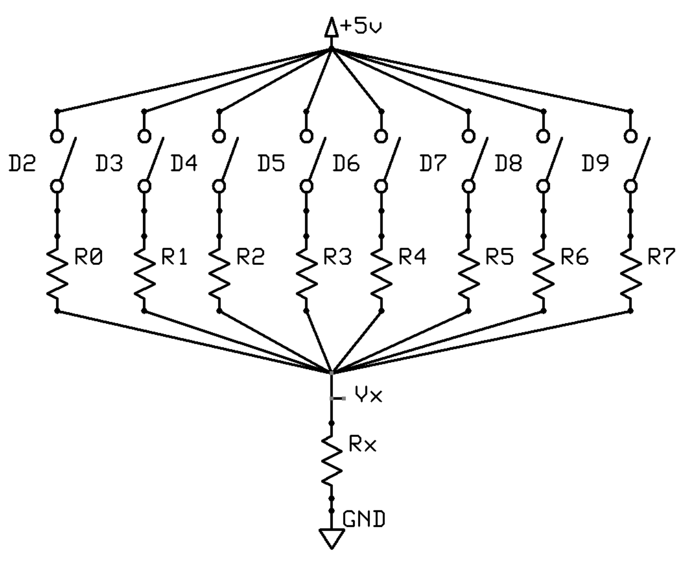
THEORY OF OPERATION

Hardware:

An Arduino UNO Microcontroller platform is used as the central control element. The Arduino UNO connects to the ADS1115 16-bit ADC which measures the output(Vx) of a voltage divider circuit. The readings from the ADC are transmitted to the Arduino over the SDA and SCL data lines via A4 and A5 pins. The 5 volt supply voltage from the Arduino is divided between a known resistance(Ri) and an unknown resistance(Rx) which are in series.



The Ri scale resistors are connected to two 4-channel relay modules. The meter auto-ranges and the correct scale resistor is selected. The scale is selected based on voltage readings taken from the Arduino's own analog input pins which are less accurate than those of the ADC but provide a rough estimate for the resistance of Rx. The relay for that scale resistor is set to 'LOW' or short circuited giving that resistor a path to the supply voltage(Vcc). These relays are controlled by the Arduino's digital pins(D2-D9). Pins A0 and A1 on the ADC are then used to measure Vx. Pin A2 on the ADC is used to measure the supply voltage.



After the value of Rx has been calculated in the software it is transmitted over the SDA and SCL data lines from the Arduino and displayed on an LCD screen to the user. This requires an I2C adapter to interface between the Arduino and the screen.

Software:

The software is a C++ based Arduino sketch created with the Arduino IDE that controls the functioning of the ohmmeter. The algorithm controls the ADC and relay channels. The sketch puts the system through a repeating loop. First the Arduino's analog pins A0 and A1 are used to obtain a rough reading for the voltage(Vx) across the resistance being measured(Rx). A0 measures the center of the voltage divider while A1 measures the voltage at GND. Although it is almost always 0.0 volts the measurement at A1 is subtracted from the measurement at A0 to find Vx. As seen in the following code a rough estimate of the resistance of Rx is calculated based on a rearrangement of the voltage divider equation(Rx = Ri / ((Vcc / Vx) - 1). Here it is assumed that Vcc = 5.0 volts and that Vx = roughVoltage.

```
roughRx = Ri / ((5.0 / roughVoltage) - 1);          //Rx resistance calculated based on Arduino analog pin readings
```

The rough measurement for Rx is compared with all the scale resistors. The branch with the scale resistor closest to this value is picked and used as Ri in the voltage divider. This is achieved with the following for loop.

```
for (int i = 0; i < 8; i++) {                        //Rough value of Rx is cycled through all resistor branches until the closest one is found
        if (abs(roughRx - RArray[i]) < RDiff) {
                RDiff = abs(roughRx - RArray[i]);
                resistorBranchIndex = i;
        }
}
```

The digital pin for the selected branch is set to 'LOW' causing the relay to close while the digital pins for the other branches are set to 'HIGH' causing their relays to open. Digital pins D2-D9 are used to control the relays.

```
for (int i = 0; i < 8; i++) {                        //Relays not connected to the resistor branch closest in resistance to Rx are set to open circuit
        if (i != resistorBranchIndex) {
                digitalWrite(i + 2, HIGH);
        }
}

digitalWrite(resistorBranchIndex + 2, LOW);          //Relay connected to resistor branch closest in resistance to Rx set to closed circuit
Ri = RArray[resistorBranchIndex];                    //Ri variable set to the value of resistor that is now in series with Rx
```

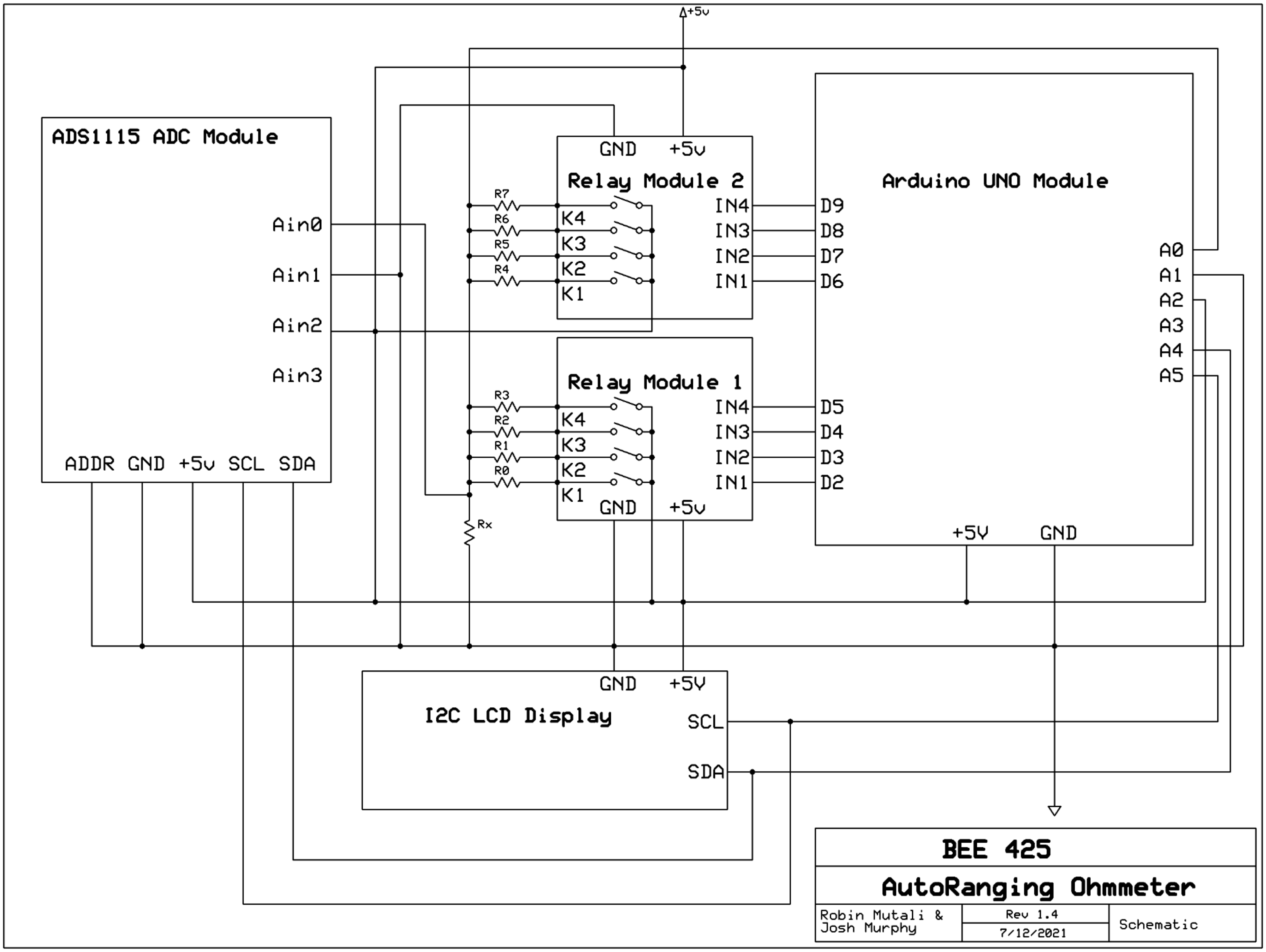
The ADC provides a much more accurate measurement of the voltages being examined and has multiple operating modes(Single Ended, Differential or Comparator Measurements). For this set up single ended mode is run to measure the supply voltage and differential is run to measure Vx(the voltage across the unknown resistor). Rx can be solved simply by using a rearrangement of the voltage divider equation(Rx = Ri / ((Vcc / Vx) - 1). As shown earlier the calculation is first done using readings from the Arduino's analog pins. Later the calculation is performed using readings from the ADC. The following code shows the calculation of Rx based on the input from the ADC where adc2V = Vcc and voltage = Vx.

```
Rx = Ri / ((adc2V / voltage) - 1);                   //Voltage divider equation used to solve for Rx
```

As will be seen in the calibration process some adjustments are made to the reading for Rx after it is calculated. The metric prefix for the final measurement is determined and it is transmitted to the LCD screen after being rounded to a 4000 counts resolution. The SDA and SCL data lines are shared, taking the input from the ADC and transmitting the output to the LCD. This loop repeats allowing the user to measure more resistances. The sketch is compiled and uploaded to the Arduino. Note that the code fragments included here are not enough to program the Arduino and are only here to demonstrate the theory of operation for the system. The full source code is required for functionality.

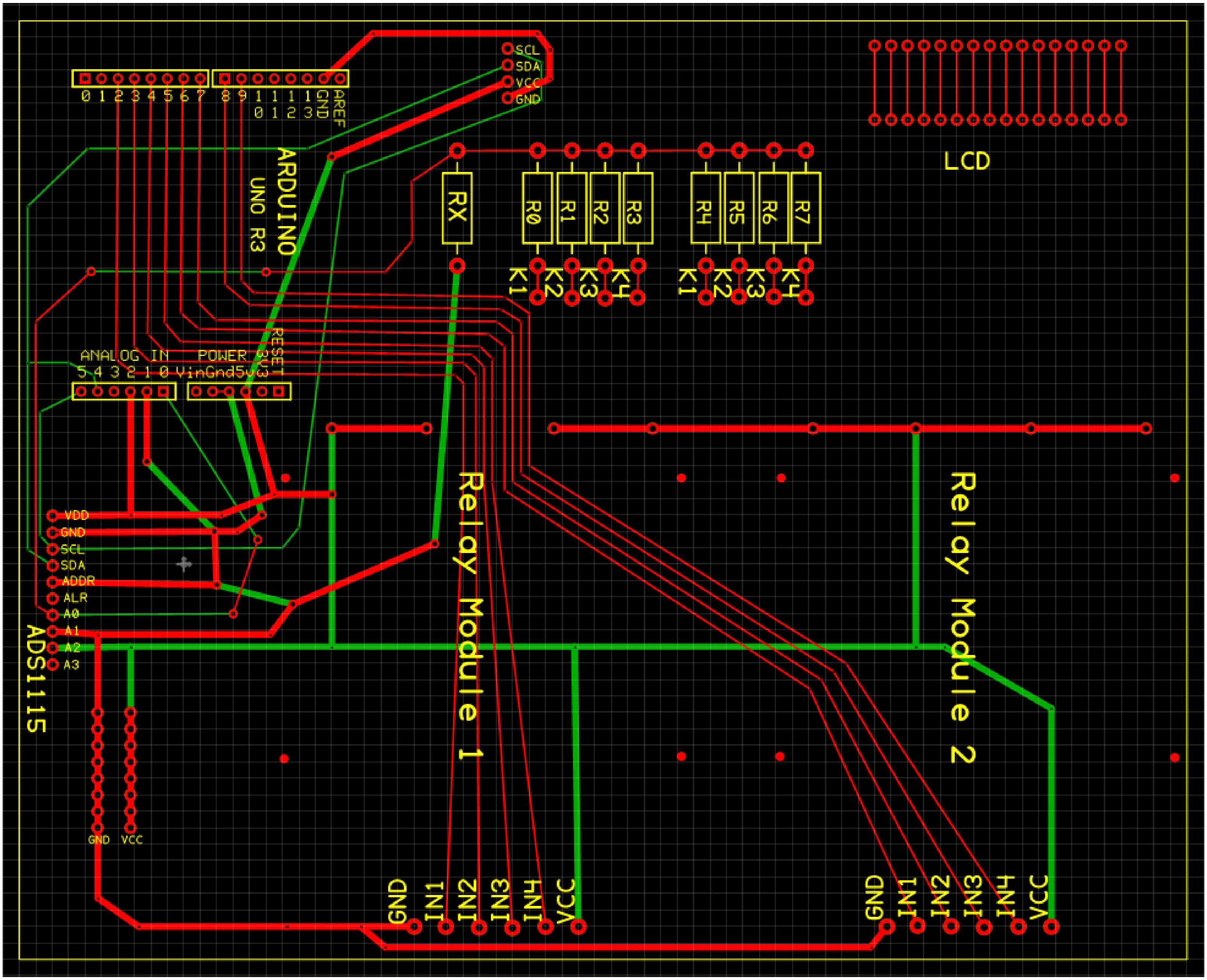
Source Code: https://github.com/Yosha42/Auto-Ranging-Ohmmeter/blob/main/OhmMeter2021/OhmMeter2021.ino

SCHEMATIC



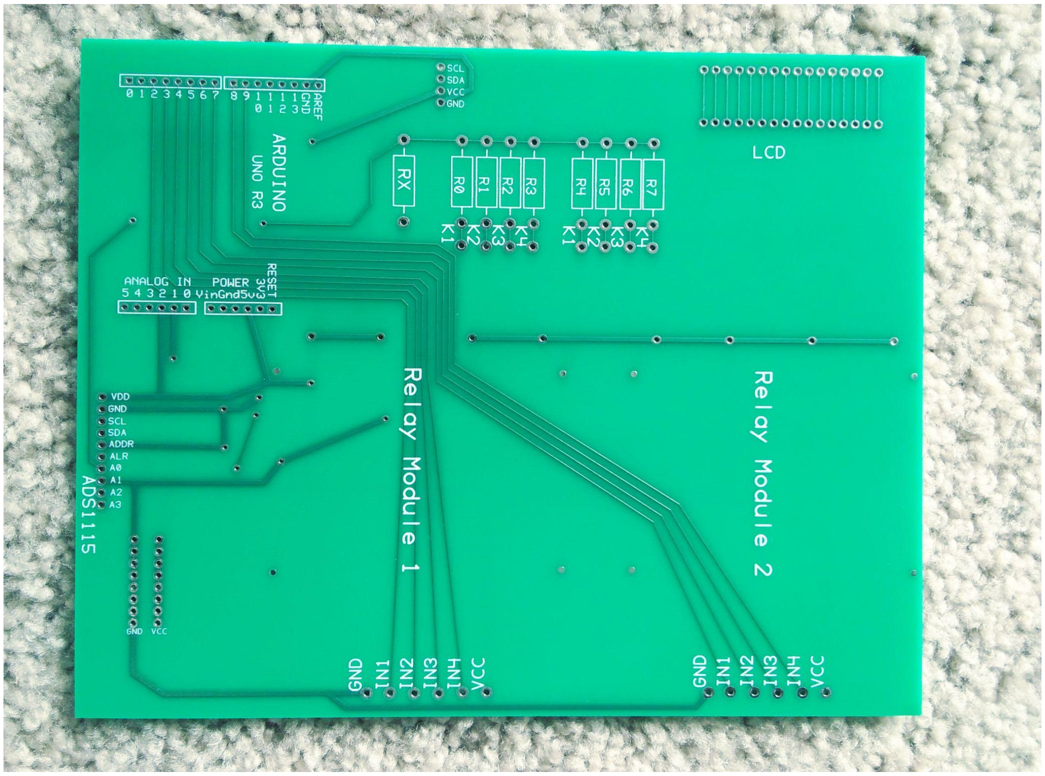
Created using ExpressPCB Plus
Arduino UNO Module - Receives inputs, performs calculations and directs the other components.
ADS1115 ADC Module - Measures voltage and transmits readings to Arduino microcontroller.
Relay Module 1 - Switches opening and closing pathways from R0-R3 to +5v.
Relay Module 2 - Switches opening and closing pathways from R4-R7 to +5v.
I2C LCD Display - Receives serial output from the Arduino to be displayed on the LCD screen.

PCB DESIGN

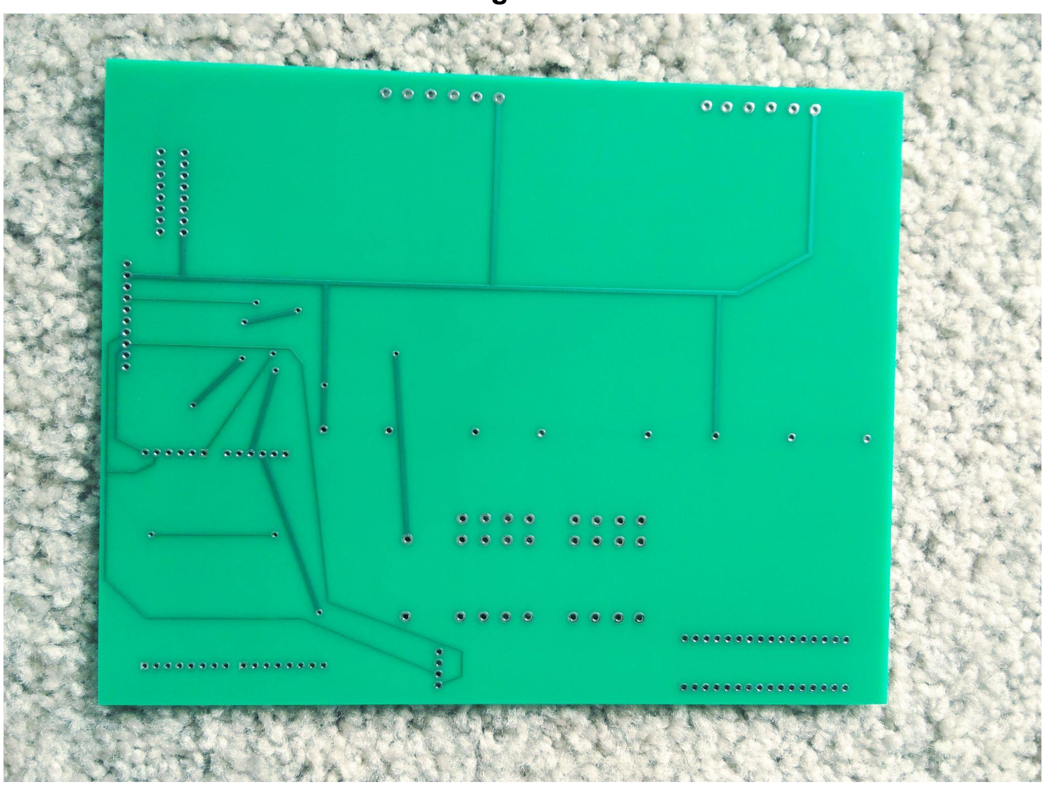


Created using ExpressPCB Plus
Size: 5.7 inches x 7.1 inches
Layer Count: 2

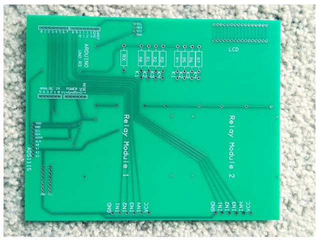
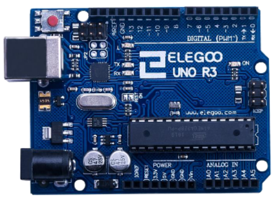
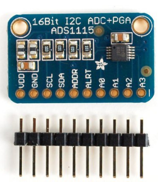
Top of PCB with Tin Lead Plating

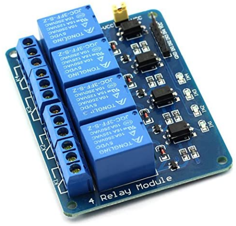


Bottom of PCB with Tin Lead Plating

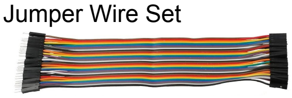


BILL OF MATERIALS

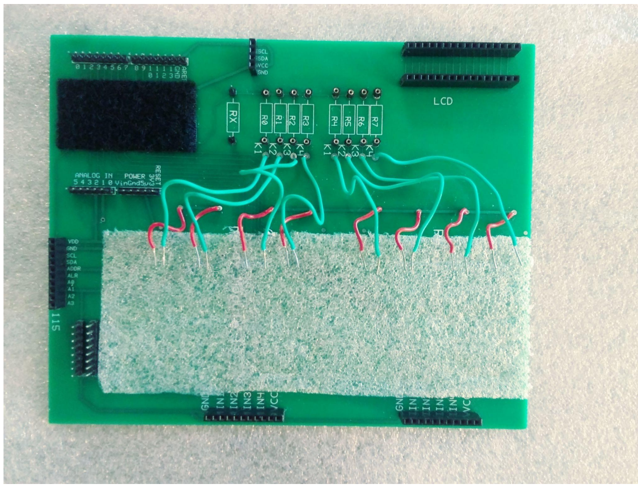
PRODUCT	QUANTITY	PURPOSE	LINKS
Tin Lead Plated PCB 	1	This board connects the components' terminals in the appropriate manner via the two layers of board traces. The board also serves as a surface to mount the components.	Purchased Through ExpressPCB Plus Layout: https://github.com/Yosha42/Auto-Ranging-Ohmmeter/blob/main/Josh%20Ohm%20Meter%20PCB.rrb Arduino Shield Footprint: https://forum.expresspcb.com/community-library/package/57/
Arduino UNO R3 	1	This Microcontroller is programmed to act as the central control element for the whole system. The Arduino receives readings from the ADC and its own analog pins to measure the voltages. The digital pins are used to control the relay switches. The Arduino performs all the calculations and the final result for resistance is transmitted to be displayed on the LCD screen.	Purchase: https://www.amazon.com/gp/product/B01CZTLHGE/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1 Datasheet: https://epow0.org/~amki/car_kit/Datasheet/ELEGOO%20UNO%20R3%20Board.pdf
ADS1115 16-Bit ADC 	1	This 16-bit ADC is used to measure the Arduino's supply voltage and the voltage across the unknown resistance which is the differential voltage between the output of the voltage divider and ground.	Purchase: https://www.adafruit.com/product/1085 Code: https://github.com/adafruit/Adafruit_ADS1X15/releases/tag/1.1.0 Datasheets: https://cdn-shop.adafruit.com/datasheets/ads1115.pdf https://cdn-learn.adafruit.com/downloads/pdf/adafruit-4-channel-adc-breakouts.pdf
LCD1602 Screen 	1	This screen displays the determined value for the unknown resistance(Rx) to the user. It has a backlight allowing the user to clearly see the result even in a dark environment.	Purchase: https://www.amazon.com/SunFounder-Serial-Module-Display-Arduino/dp/B071Y6JX3H/ref=sr_1_2?dchild=1&keywords=arduino%2BLcd&qid=1622867488&sr=8-2&th=1 Note: Screen is included with ELEGOO UNO R3 Project Most Complete Starter Kit. Code: https://github.com/WickedLukas/Newliquidcrystal_1.3.5 Datasheet: https://www.elecrow.com/download/LCD1602.pdf
I2C Adapter 	1	This module converts the I2C commands from the Arduino to the parallel communication used to control the LCD screen. This allows the screen to be controlled with only two bidirectional data lines: a serial data line and a serial clock line.	Purchase: https://www.jameco.com/webapp/wcs/stores/servlet/ProductDisplay?storeId=10001&productId=2303975&catalogId=10001&langId=-1&CID=GOOG Datasheet: http://www.handsontec.com/dataspecs/module/I2C_1602_LCD.pdf

PRODUCT	QUANTITY	PURPOSE	LINKS
4-Channel Relay Module 	2	Two relay modules each with four channels are used in the design. Each relay is connected to the supply voltage(Vcc) and to one of the eight scale resistors(R0-R7). The relay is closed and the terminals are shorted when that particular scale resistor has been selected while the other relays remain open, not giving their resistors a path to Vcc. Relays are controlled by the Arduino's digital pins.	Purchase: https://www.amazon.com/gp/product/B075CB5QPK/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1 Datasheets: https://www.handsontec.com/dataspecs/4Ch-relay.pdf https://datasheetspdf.com/pdf-file/606936/Hongfa/JQC-3F/1
1 Watt Metal Film Assorted Resistor Kit 	1	Scale resistors used in the voltage divider circuit. One of these eight scale resistors is put in series with the unknown resistance(Rx) depending on which is closest to the estimated resistance of Rx. Out of this kit one of each of the following resistors is used in the design as R0-R7. The true values of these eight resistors are measured and used in the calculation. 100Ω 330Ω 1KΩ 3.3KΩ 10KΩ 33KΩ 100KΩ 330KΩ Power can be calculated with the following formula: $P = V^2 / R$. Since the lowest impedance scale resistor used is listed as 100Ω, the greatest power taken on by one of these resistors would be $0.25W = (5v)^2 / 100\Omega$. This is well below the 1W power rating of these resistors so overpowering is not an issue.	Purchase: https://www.amazon.com/gp/product/B07Q178YZY/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
9V Battery 	1	This battery is the power supply for the Arduino.	Purchase: https://www.amazon.com/dp/B00009V2QT/ref=redir_mobile_desktop?_encoding=UTF8&aaxitk=34b0c9f6f60aac86c390f2bda4516beb&hsa_cr_id=3081462470301&pd_rd_plhdr=t&pd_rd_r=a6eb532b-d6fd-411b-8d70-14cc533aa11a&pd_rd_w=OVscA&pd_rd_wg=tukSj&ref_=sbx_be_s_sparkle_mcd_asin_1_img Note: A 9V battery is included with ELEGOO UNO R3 Project Most Complete Starter Kit.
9V to Barrel Jack Adapter 	1	This adapter connects the battery to the Arduino.	Purchase: https://www.digikey.com/en/products/detail/dfrobot/FIT0043/7597082?utm_adgroup=Battery%20Holders%2C%20Clips%2C%20Contacts&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Product_Battery%20Products_NEW&utm_term=&utm_content=Battery%20Holders%2C%20Clips%2C%20Contacts&gclid=Cj0KCQjwweyFBhDvARIsAA67M70BDC0TaLc-noAYQj-27dVpiHrI41u8J55YpLdEU37NCJY5pqEjT5QaAoauEALw_wcB Note: Adapter is included with ELEGOO UNO R3 Project Most Complete Starter Kit.

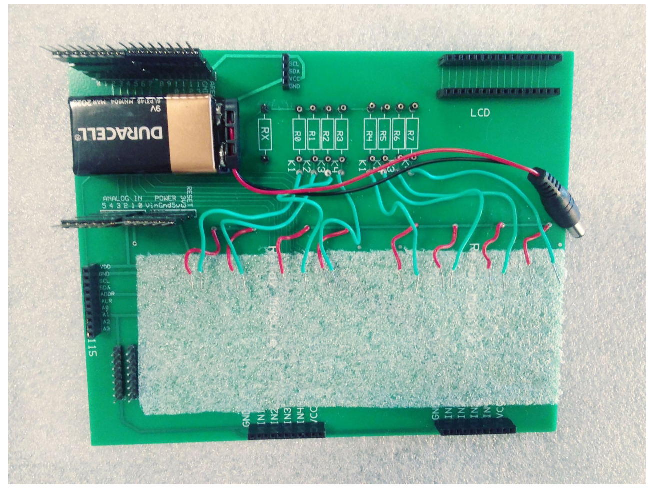
PRODUCT	QUANTITY	PURPOSE	LINKS
4.7cm Heavy Duty Stick-On Velcro Fastener 	1	Velcro is used to secure the battery to the surface of the PCB. The battery is positioned underneath the Arduino.	Purchase: https://www.amazon.com/dp/B0009JCV2C/ref=twister_B07FQ1BTR4
Packing Foam Sheet 	1	Packing foam is set on top of the PCB underneath the relay modules, preventing them from scratching the board's surface.	Purchase: https://www.amazon.com/Mighty-Gadget-Supplies-Shipping-Perforated/dp/B07K84XSZY/ref=sr_1_8?dchild=1&keywords=packing+foam+paper&qid=1622995502&sr=8-8
Break Away Female 2.54mm Pin Header Set 	1	These pin headers are soldered to the PCB at both ends of the spaces for the R0-R7 branch resistors.The resistors are inserted into these pin headers rather than being soldered directly to the board. This makes it easier to switch them out for different resistors if desired.	Purchase: https://www.amazon.com/gp/product/B0187LTEX2/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&psc=1
2.54mm Male and Female Pin Header Connector Assortment Kit 	1	Male to female and male to male pin header connectors are used to secure the Arduino, ADS1115, LCD screen, I2C adapter, relay modules and alligator clips to their spots on the PCB and create a connection from the compornts' terminals to the board's traces. Extra male to male pin headers are placed on board for Vcc and ground. Pins are through-hole soldered to the vias on the PCB.	Purchases: https://www.amazon.com/gp/product/B07CWSXY7P/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&psc=1

PRODUCT	QUANTITY	PURPOSE	LINKS
2.54mm Jumper Kit 	1	Jumper wires are used to connect the relay terminals to the PCB. Green for R0-R7 to the relays and red for the relays to Vcc. The red jumpers are cut shorter to fit more easily.	Purchase: https://www.amazon.com/gp/product/B07S88WMQH/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1
10cm Male to Female Jumper Wire Set 	1	Jumper wires are used to connect male pins on the I2C adapter and relay modules to the female headers soldered to the PCB. Red for Vcc, blue for GND, gray for SDA, yellow for SCL, white for R0 & R4 relays, brown for R1 & R5 relays, black for R2 & R6 relays and purple for R3 & R7 relays.	Purchase: https://www.amazon.com/gp/product/B07GD1R5MS/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&psc=1
20cm Alligator Clip to Female Jumper Wire Set  	1	Alligator clips on jumper wires are used to grab the unknown resistance. The orange jumper connects one clip to the junction between Rx and Ri while the blue jumper connects the other clip to GND.	Purchase: https://www.amazon.com/gp/product/B07FLXJXJC/ref=ppx_yo_dt_b_asin_title_o06_s00?ie=UTF8&th=1
Lead Free Solder Wire 	1	Solder used to connect pin headers and jumper wires to PCB vias.	Purchase: https://www.amazon.com/gp/product/B07VT4MLD1/ref=ppx_yo_dt_b_asin_title_o08_s01?ie=UTF8&psc=1

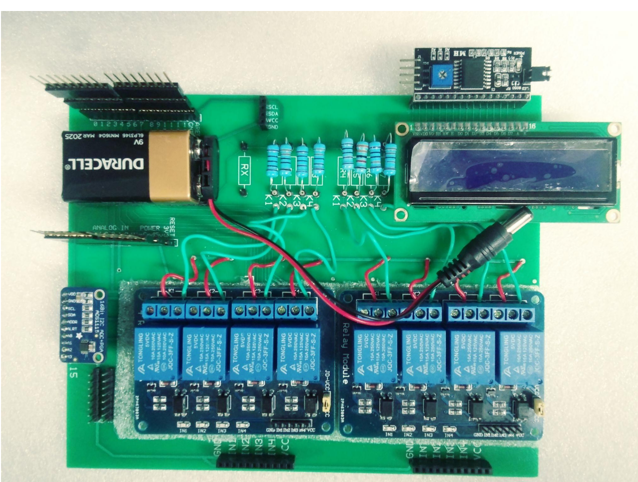
ASSEMBLY



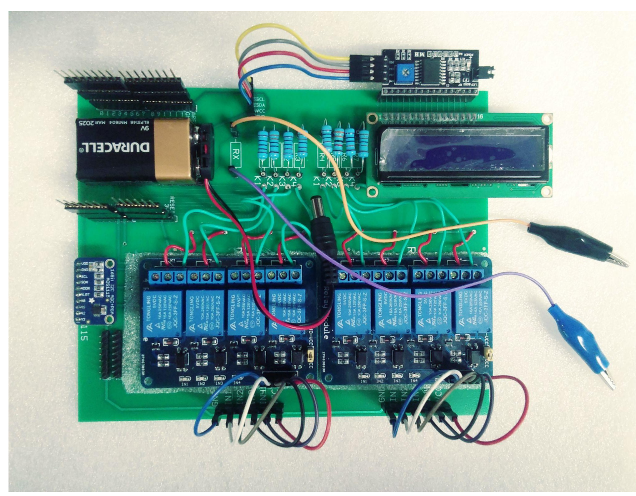
Pin headers and jumper wires are through-hole soldered to the PCB. The female break away headers for the branch resistors and the male break away headers for Rx need to be broken into single pieces. Other pin header lines are broken down into smaller sections depending on the number of holes present in each group of holes on the board. Some of the pins must be removed from the sections for each relay module as there is only a hole for every other pin. Red jumper wires are cut shorter and restripped. Soft half of Velcro fastener and cut out sheet of packing foam are placed on the board as shown.



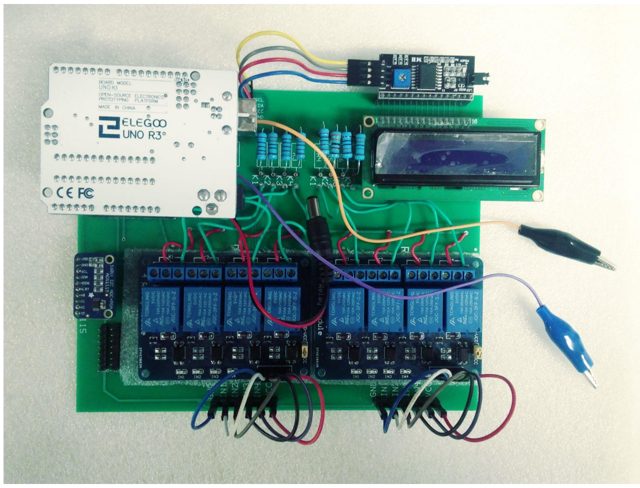
The rough half of the Velcro fastener is stuck to one face of the battery. The barrel jack adapter is attached to the battery. The Velcro is used to secure the battery to the PCB as shown. Long-pin header lines are triple stacked on top of the pins at the Arduino’s footprint on either side of the battery.



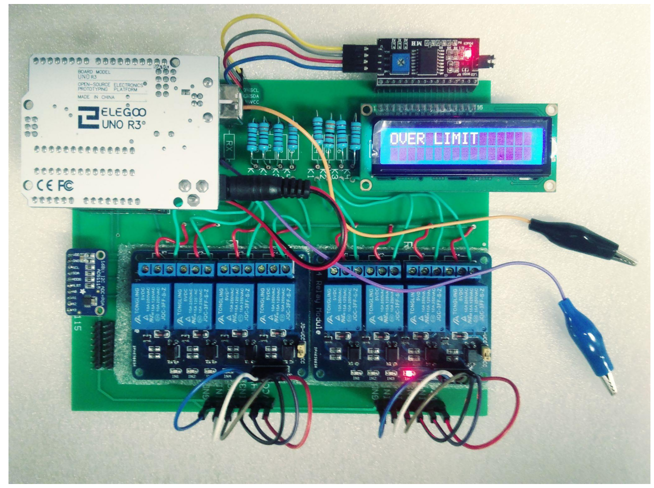
Components are stuck to the PCB as their pins are inserted into the female headers. Red and green jumper wires are inserted into the terminals of the relay modules as shown and screwed down in place.



Male to female jumper wires are used to connect I2C adapter and relay modules to their headers on the PCB. Female to alligator jumper wires are secured to the pins for the ends of Rx.

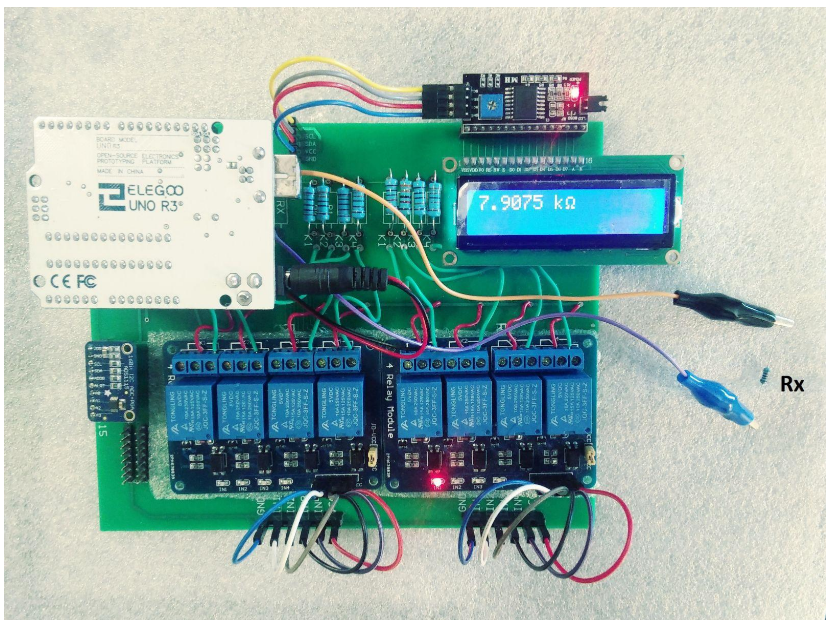


Arduino is mounted to the pin header stacks on the PCB with the bottom side facing up.



The battery is plugged into the Arduino with the barrel jack adapter.

Alligator clips are used to grab either end of Rx. Then it's resistance value is displayed on the LCD.



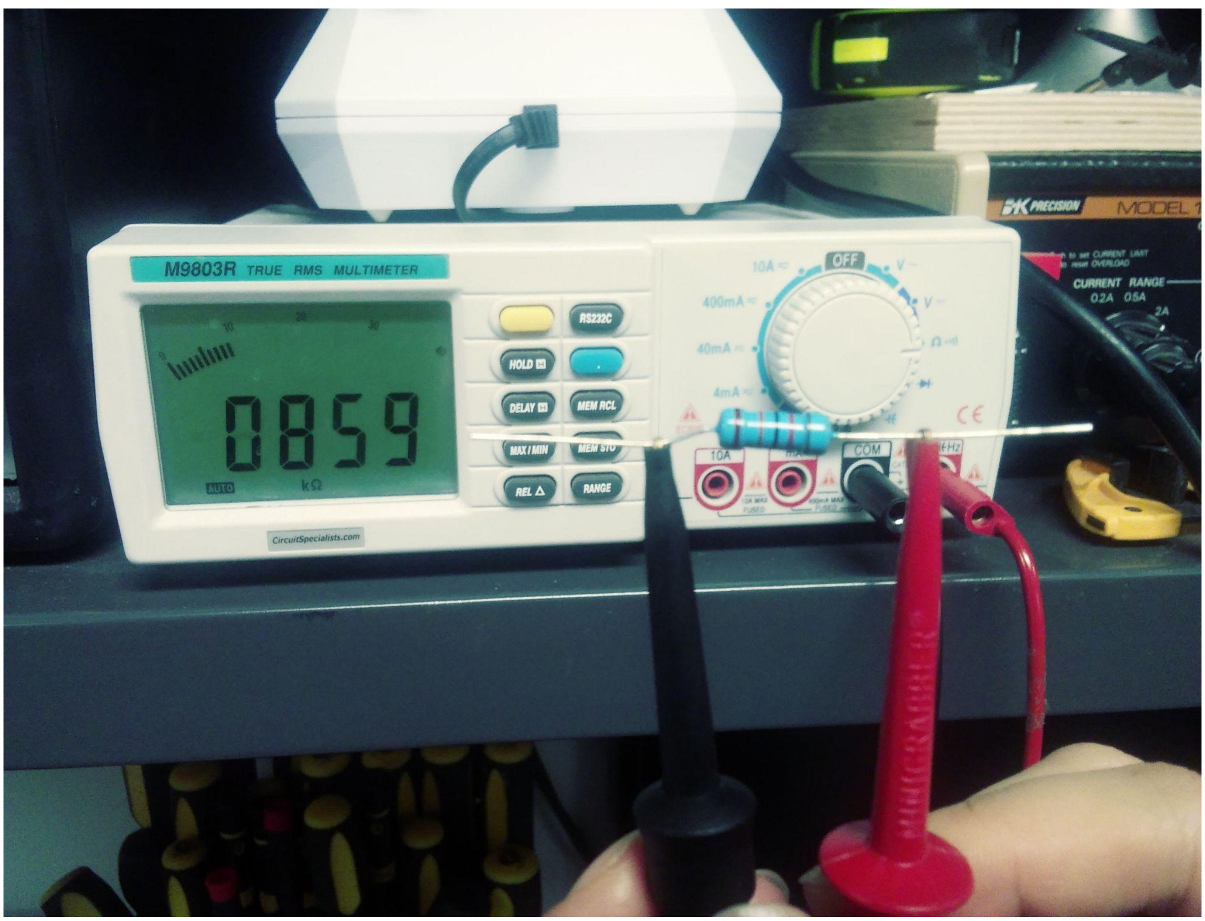
RED: VCC
BLUE: GND
ORANGE: Vx
WHITE: R0 & R4 RELAY CONTROLS
BROWN: R1 & R5 RELAY CONTROLS
BLACK: R2 & R6 RELAY CONTROLS
PURPLE: R3 & R7 RELAY CONTROLS
GREEN: (R0-R7) TO RELAYS
GREY: SDA
YELLOW: SCL

CALIBRATION PROCESS

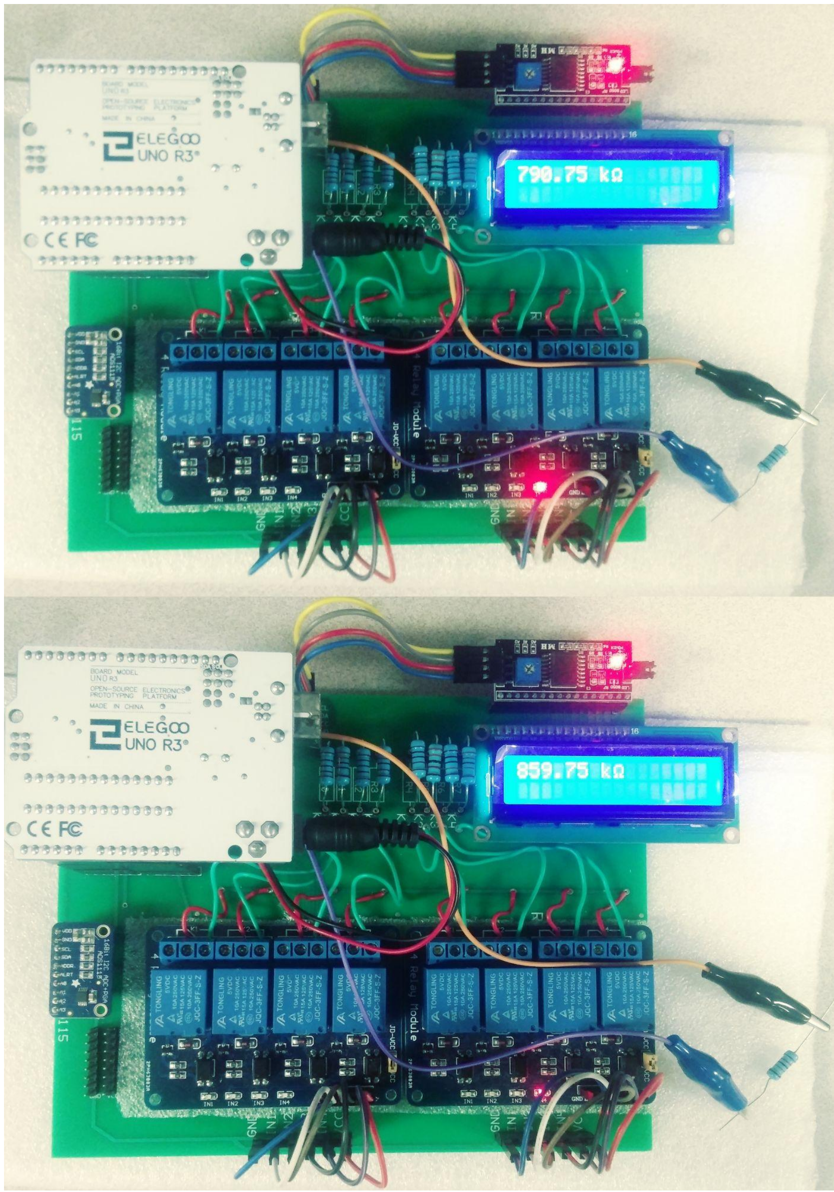
The ohmmeter can be made more accurate though the calibration process described here. Each resistor scale is examined separately and the ohmmeter is set to operate on one scale resistor at a time with auto-ranging turned off. This is achieved in the code by overriding the branch selection process and setting the variable 'resistorBranchIndex' to equal the desired branch index. When a branch is selected the resistance of a number of resistors in the approximate range for that particular scale resistor are measured with the ohmmeter. The measured values are recorded along with their actual resistance values. The actual resistance values are determined by measuring the resistors with the M9803R - True RMS Benchtop Multimeter. The following subsections each contain a spreadsheet comparing actual resistances in ohms with measured resistances in ohms.

The relationship between the measured resistance and the reverse error in measurement can be visualized by plotting the measured resistance as the predictor on the x-axis and the (actual - measured) resistance or reverse error as the response on the y-axis. These data can be plotted with the Polynomial Regression Data Fit tool which can generate a 4th degree polynomial regression function to fit the points on that plot. The output of this function is a counterfactor to offset the inaccuracy of the ohmmeter. The function is converted to Arduino code and its output is added to the original measured resistance value. Ideally this results in a final resistance measurement closer to the true resistance. The following subsections each contain a plot displaying the data points(reverse error in ohms versus measured resistance in ohms) along with the polynomial regression fitted to these points.

Resistor Measured on M9803R - True RMS Benchtop Multimeter



Resistor Measured Before(Top) and After(Bottom) Calibration Process

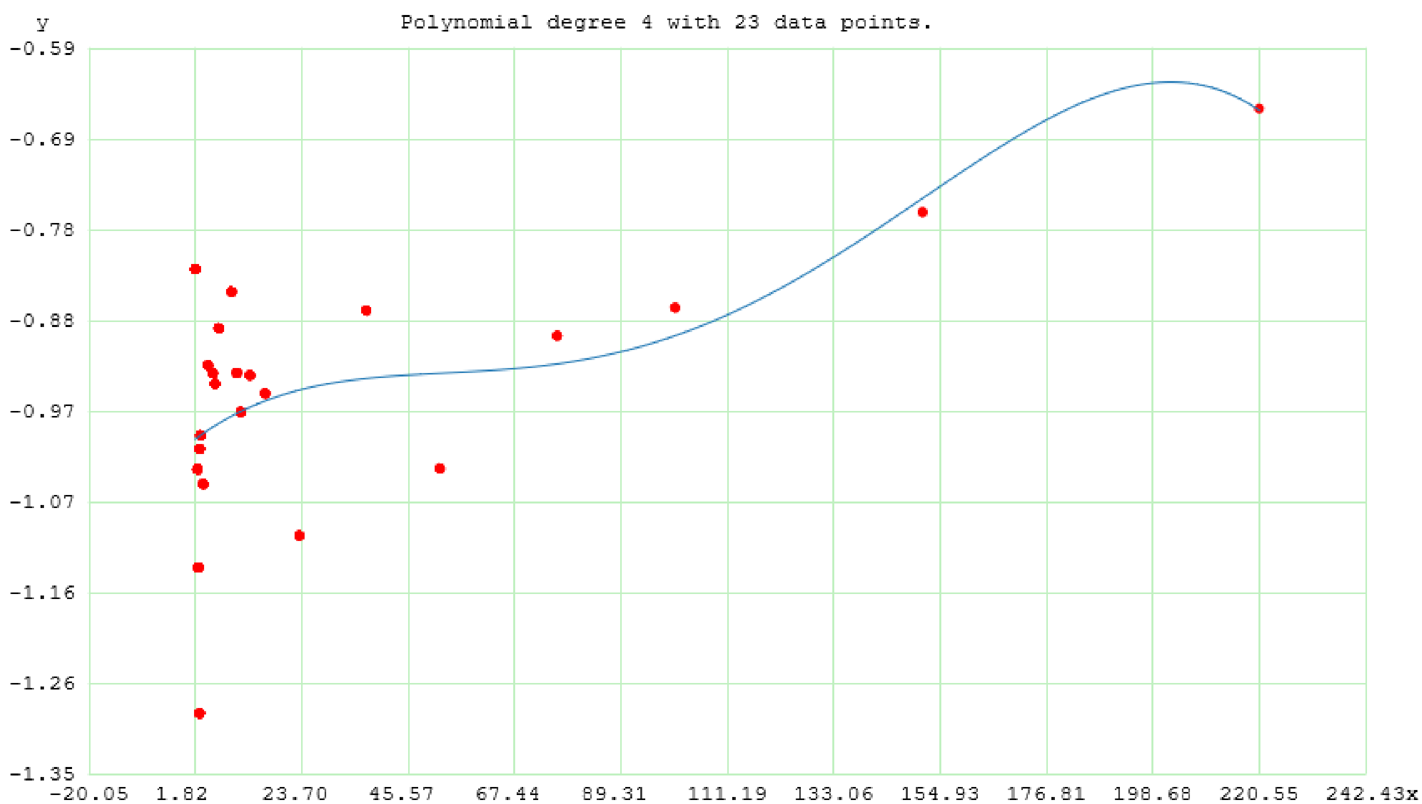


CALIBRATION OF RO

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
1	1.8224920272	1.8225	-0.8224920272	82.24920272	-0.8225	82.25	RO
1.2	2.2332401275	2.2325	-1.0332401275	86.1033439583	-1.0325	86.0416666667	RO
1.3	2.4366829395	2.4375	-1.1366829395	87.4371491923	-1.1375	87.5	RO
1.4	2.6901688575	2.69	-1.2901688575	92.1549183929	-1.29	92.1428571429	RO
1.7	2.7118213176	2.7125	-1.0118213176	59.5189010353	-1.0125	59.5588235294	RO
1.9	2.8977231979	2.8975	-0.9977231979	52.5117472579	-0.9975	52.5	RO
2.4	3.4486813545	3.4475	-1.0486813545	43.6950564375	-1.0475	43.6458333333	RO
3.5	4.4237504005	4.425	-0.9237504005	26.3928685857	-0.925	26.4285714286	RO
4.5	5.4320502281	5.4325	-0.9320502281	20.7122272911	-0.9325	20.7222222222	RO

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
4.9	5.8433232307	5.8425	-0.9433232307	19.2514945041	-0.9425	19.2346938776	R0
5.8	6.6847429275	6.685	-0.8847429275	15.2541884052	-0.885	15.2586206897	R0
8.4	9.2462425231	9.245	-0.8462425231	10.0743157512	-0.845	10.0595238095	R0
9.4	10.33182621	10.325	-0.93182621	9.9130447872	-0.925	9.8404255319	R0
10.2	11.1727952957	11.175	-0.9727952957	9.5372087814	-0.975	9.5588235294	R0
12.1	13.0341215133	13.025	-0.9341215133	7.7200125066	-0.925	7.6446280992	R0
15.2	16.1532669067	16.15	-0.9532669067	6.2714928072	-0.95	6.25	R0
22.1	23.2029495239	23.2	-1.1029495239	4.9907218276	-1.1	4.9773755656	R0
36.1	36.9660034179	36.975	-0.8660034179	2.3989014346	-0.875	2.4238227147	R0
51.1	52.1323394775	52.125	-1.0323394775	2.0202338112	-1.025	2.0058708415	R0
75.3	76.1925811767	76.2	-0.8925811767	1.1853667685	-0.9	1.1952191235	R0
99.6	100.4629898071	100.5	-0.8629898071	0.8664556296	-0.9	0.9036144578	R0
150.6	151.3624725341	151.25	-0.7624725341	0.5062898633	-0.65	0.4316069057	R0
219.9	220.5535125732	220.5	-0.6535125732	0.2971862543	-0.6	0.272851296	R0

R0 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



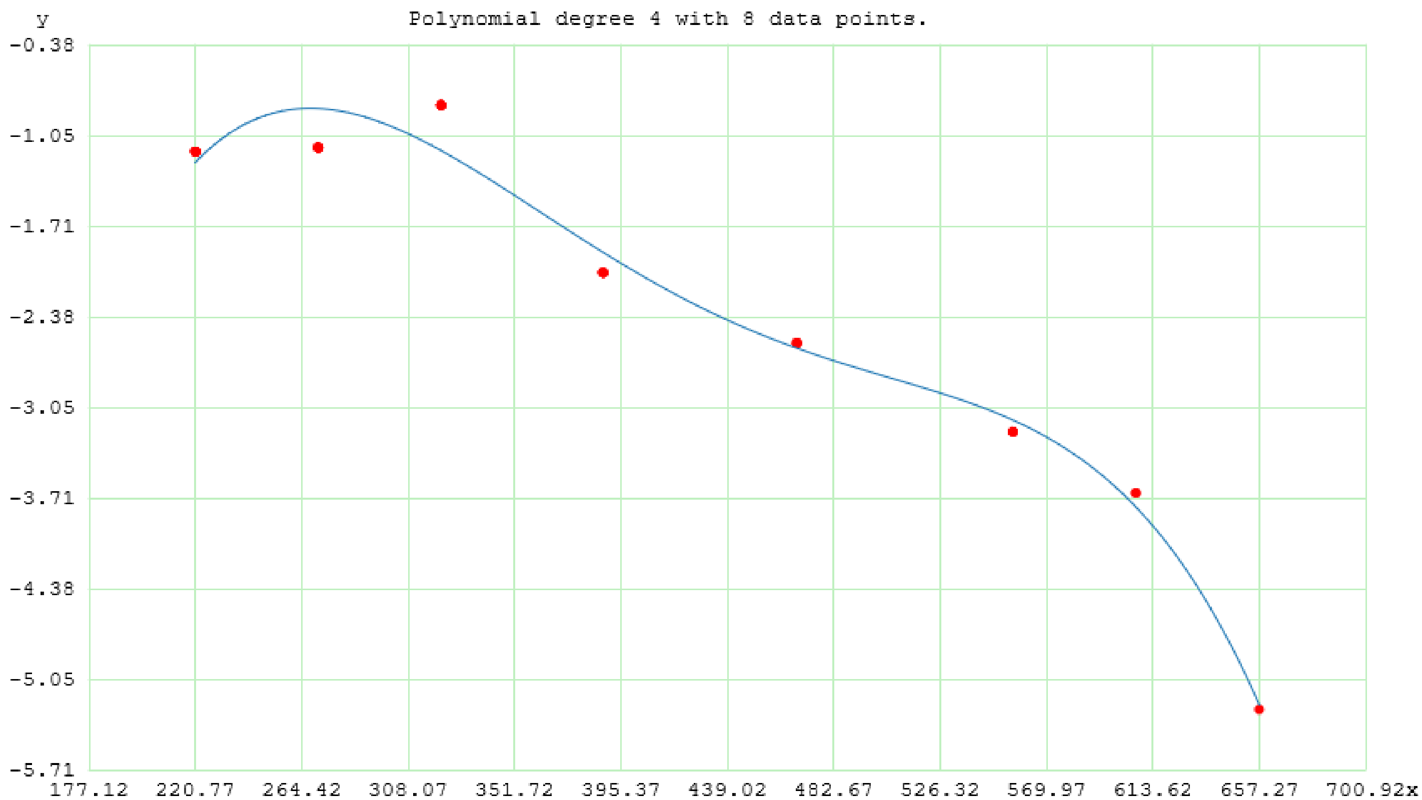
Output form: mathematical function:

$$f(x) = -1.0087015799543466e{+}000 * x^0 + 4.0743320497918902e{-}003 * x^1 + -8.1469322428050719e{-}005 * x^2 + 6.9157686317257333e{-}007 * x^3 + -1.6912410018321967e{-}009 * x^4$$

CALIBRATION OF R1

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
219.6	220.76612854	220.75	-1.16612854	0.5310239253	-1.15	0.5236794171	R1
270	271.135772705	271.25	-1.135772705	0.4206565574	-1.25	0.462962963	R1
320.8	321.6235351562	321.5	-0.8235351562	0.2567129539	-0.7	0.2182044888	R1
386	388.0549621582	388	-2.0549621582	0.5323736161	-2	0.518134715	R1
465	467.572265625	467.5	-2.572265625	0.5531754032	-2.5	0.5376344086	R1
553	556.2258911132	556.25	-3.2258911132	0.5833437818	-3.25	0.5877034358	R1
603	606.6749267578	606.75	-3.6749267578	0.60944059	-3.75	0.6218905473	R1
652	657.267211914	657.25	-5.267211914	0.807854588	-5.25	0.8052147239	R1

R1 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



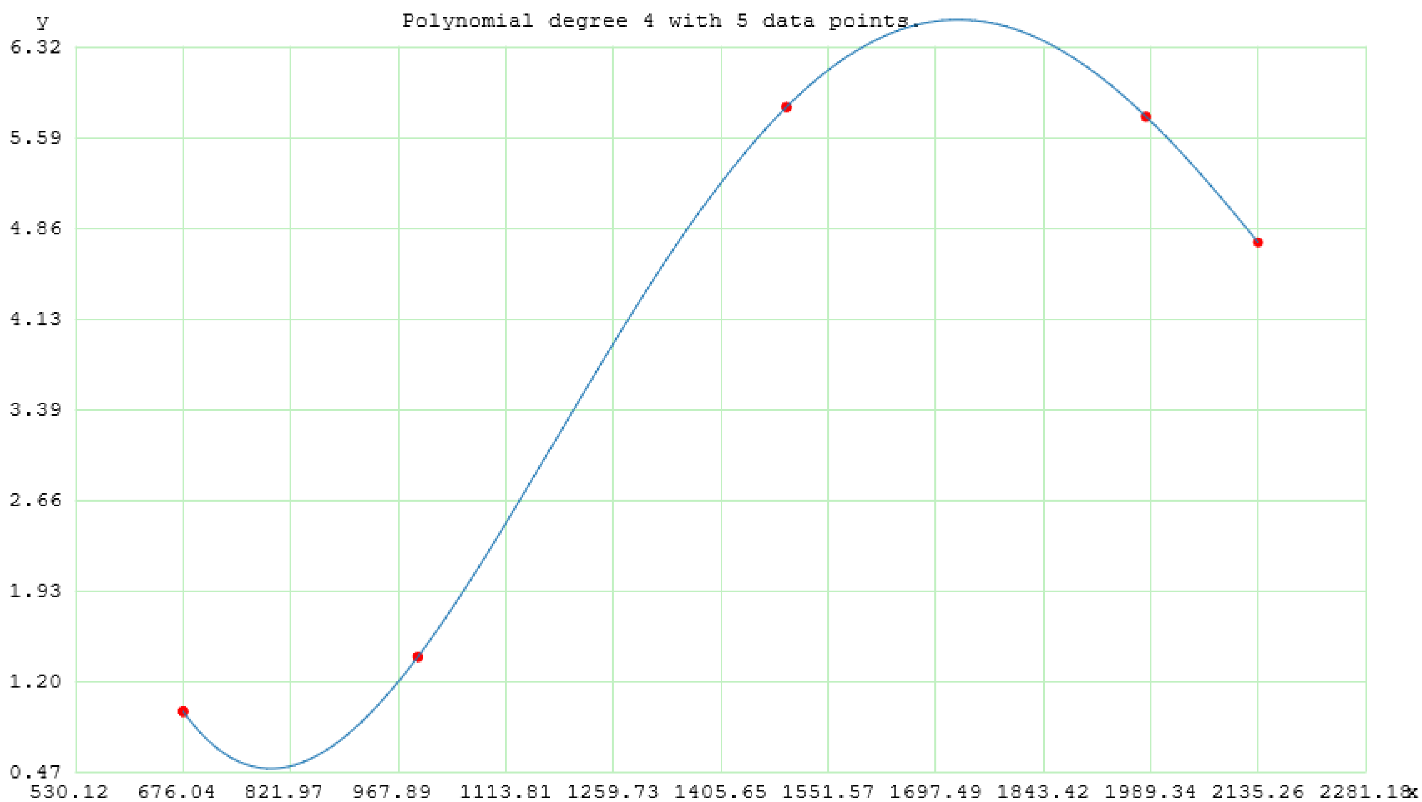
Output form: mathematical function:

f(x) = -3.0171211611623892e+001 * x^0
+ 3.1041927275360964e-001 * x^1
+ -1.1679559388185310e-003 * x^2
+ 1.8440343171380762e-006 * x^3
+ -1.0616325389725969e-009 * x^4

CALIBRATION OF R2

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
677	676.0446166992	676	0.9553833008	-0.1411201331	1	-0.1477104874	R2
996	994.6052856445	994.5	1.3947143555	-0.1400315618	1.5	-0.1506024096	R2
1501	1495.1671142578	1495	5.8328857422	-0.3885999828	6	-0.399733511	R2
1989	1983.244140625	1982.5	5.755859375	-0.289384584	6.5	-0.3267973856	R2
2140	2135.2590332031	2135	4.7409667969	-0.2215405045	5	-0.2336448598	R2

R2 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



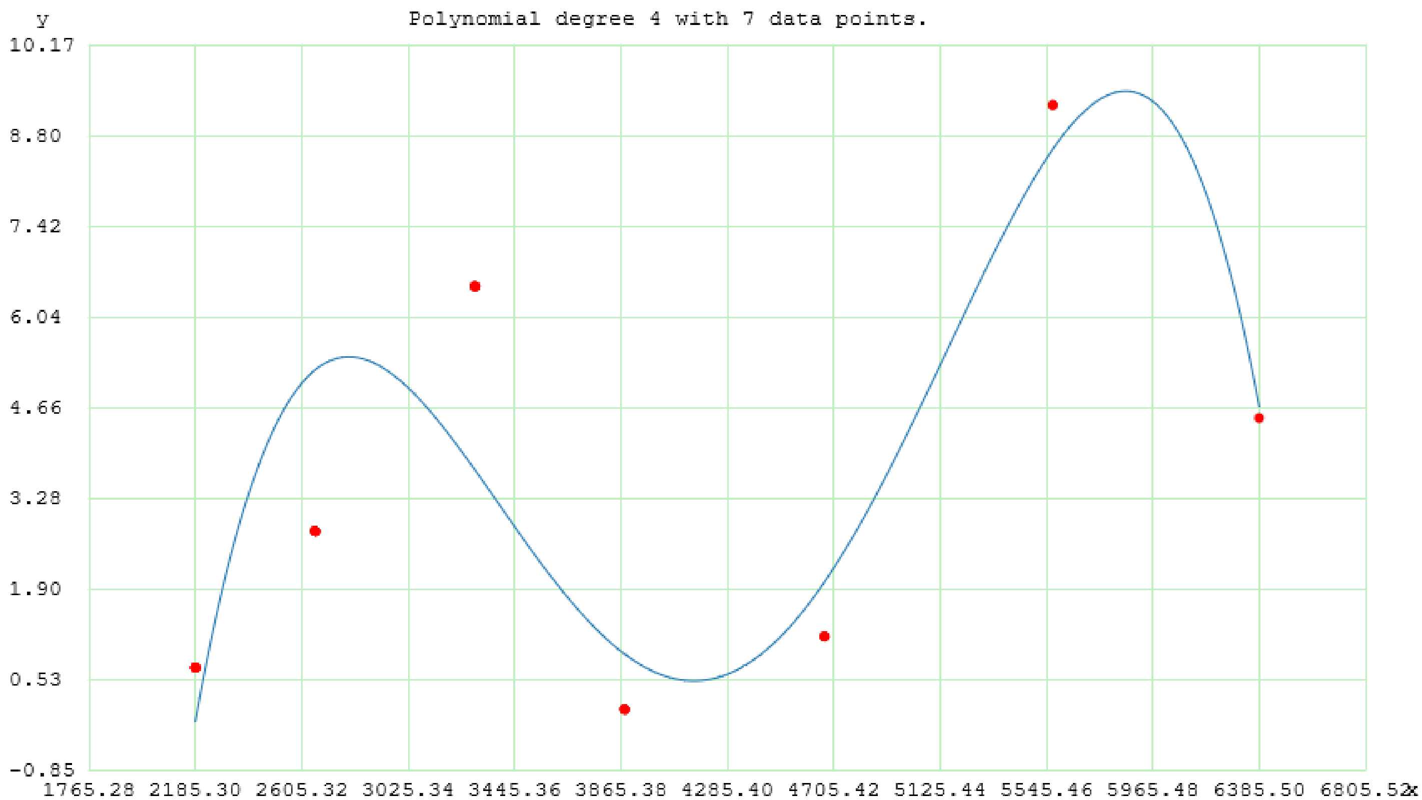
Output form: mathematical function:

$$f(x) = 3.8050144267716369e{+}001 * x^0 + -1.2341715053441385e{-}001 * x^1 + 1.3788516929628944e{-}004 * x^2 + -6.0023327366530932e{-}008 * x^3 + 8.9429964326831901e{-}012 * x^4$$

CALIBRATION OF R3

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
2186	2185.298828125	2185	0.701171875	-0.0320755661	1	-0.0457456542	R3
2661	2658.2233886718	2657.5	2.7766113282	-0.1043446572	3.5	-0.1315295002	R3
3296	3289.5004882812	3290	6.4995117188	-0.1971939235	6	-0.182038835	R3
3880	3879.9343261718	3880	0.0656738282	-0.0016926244	0	0	R3
4670	4668.8251953125	4670	1.1748046875	-0.0251564173	0	0	R3
5580	5570.7446289062	5570	9.2553710938	-0.1658668655	10	-0.1792114695	R3
6390	6385.5034179687	6385	4.4965820313	-0.0703690459	5	-0.0782472613	R3

R3 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



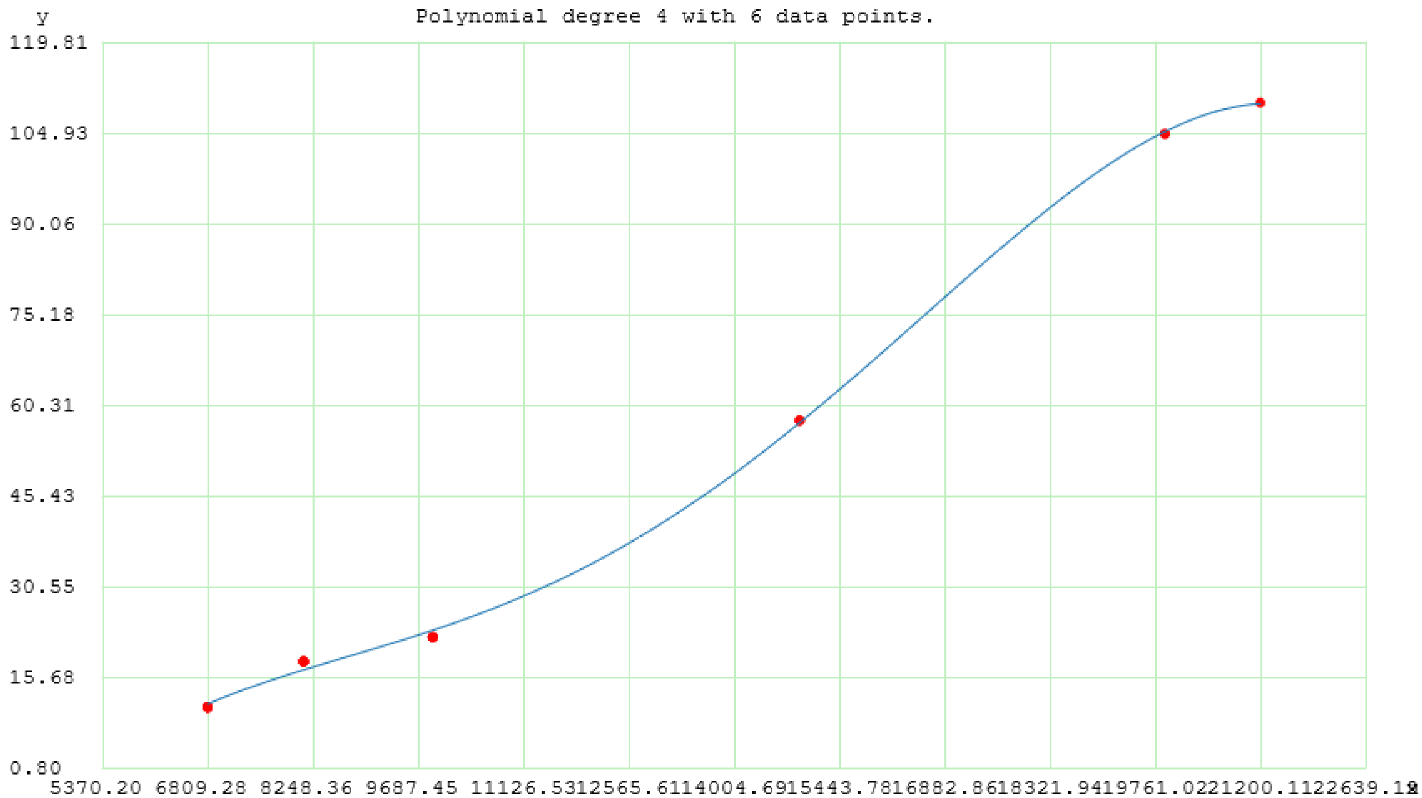
Output form: mathematical function:

$$f(x) = -3.0645335973349188e{+}002 * x^0 + 3.3322808339874338e{-}001 * x^1 + -1.2823237430990934e{-}004 * x^2 + 2.0934500325115132e{-}008 * x^3 + -1.2262451315039650e{-}012 * x^4$$

CALIBRATION OF R4

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
6820	6809.2802734375	6810	10.7197265625	-0.1571807414	10	-0.146627566	R4
8140	8121.7563476562	8122.5	18.2436523438	-0.2241234932	17.5	-0.214987715	R4
9910	9887.7509765625	9887.5	22.2490234375	-0.2245108319	22.5	-0.2270433905	R4
14960	14902.2373046875	14900	57.7626953125	-0.3861142735	60	-0.4010695187	R4
20000	19895.20703125	19900	104.79296875	-0.5239648438	100	-0.5	R4
21310	21200.107421875	21200	109.892578125	-0.515685491	110	-0.5161895824	R4

R4 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



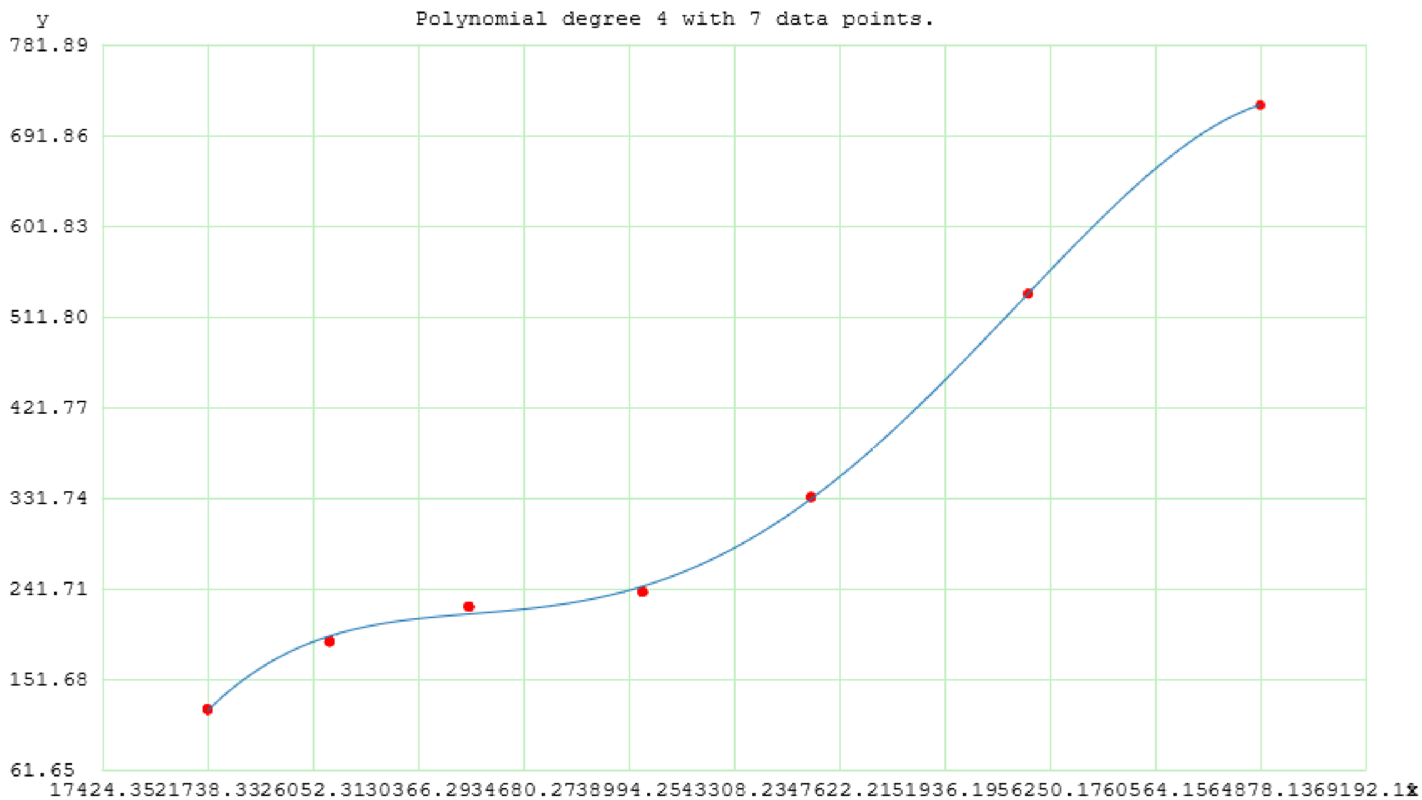
Output form: mathematical function:

$$f(x) = -1.2990448466433213e+002 * x^0 + 4.8829867274151485e-002 * x^1 + -6.2831774966867742e-006 * x^2 + 3.6590517360171962e-010 * x^3 + -7.2182993976645724e-015 * x^4$$

CALIBRATION OF R5

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
21860	21738.33203125	21750	121.66796875	-0.5565780821	110	-0.5032021958	R5
26920	26730.96875	26725	189.03125	-0.7021963224	195	-0.7243684993	R5
32670	32446.232421875	32450	223.767578125	-0.6849328991	220	-0.6734006734	R5
39800	39561.59765625	39550	238.40234375	-0.5990008637	250	-0.6281407035	R5
46800	46467.4609375	46475	332.5390625	-0.7105535524	325	-0.6944444444	R5
55900	55365.49609375	55375	534.50390625	-0.9561787232	525	-0.939177102	R5
65600	64878.1328125	64875	721.8671875	-1.100407298	725	-1.1051829268	R5

R5 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



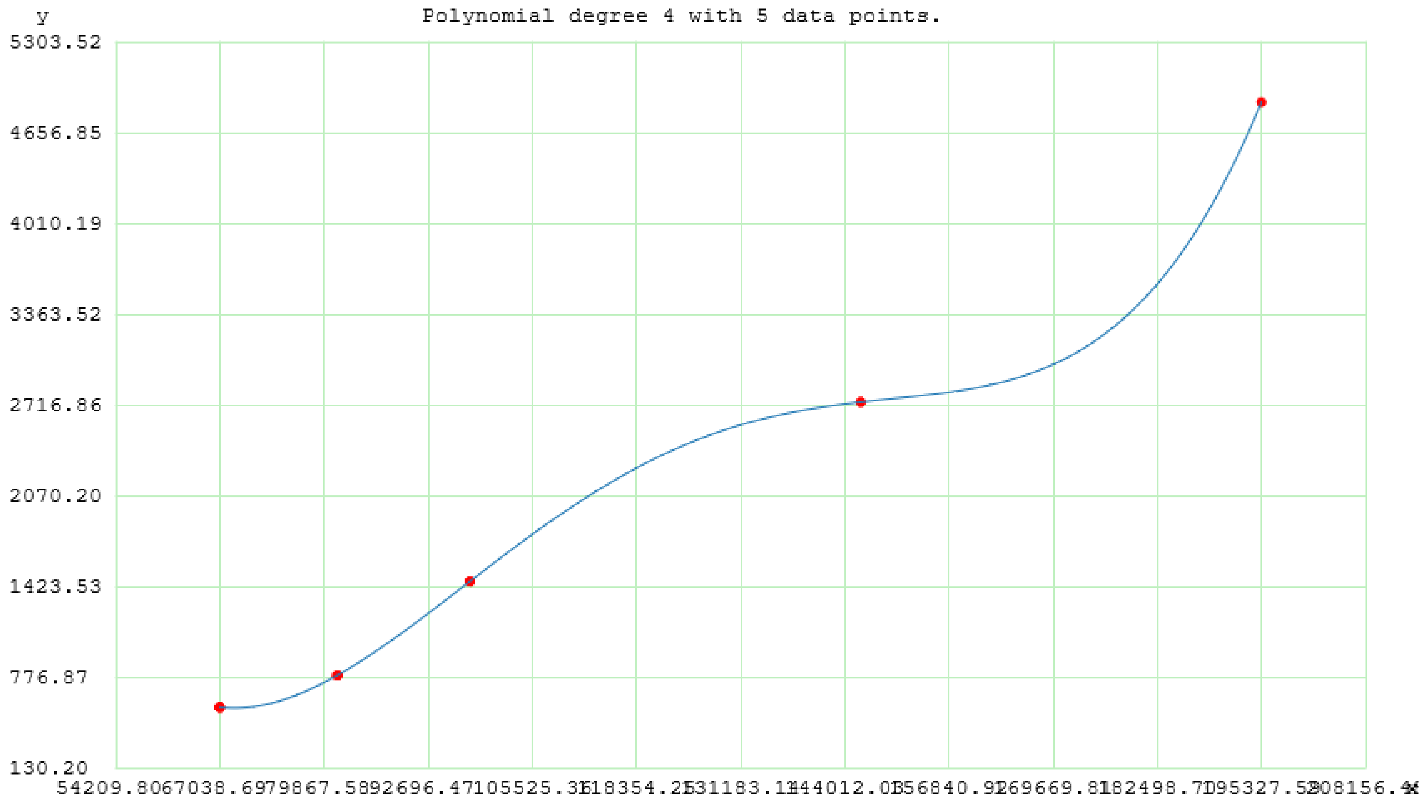
Output form: mathematical function:

f(x) = -2.6682837895516827e+003 * x^0
+ 2.9802012919653392e-001 * x^1
+ -1.1318873407960057e-005 * x^2
+ 1.8436711714578837e-010 * x^3
+ -1.0526126447491875e-015 * x^4

CALIBRATION OF R6

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
67600	67038.6875	67050	561.3125	-0.8303439349	550	-0.8136094675	R6
82300	81511.5390625	81500	788.4609375	-0.9580327309	800	-0.9720534629	R6
99300	97842.3359375	97850	1457.6640625	-1.46793964	1450	-1.4602215509	R6
148700	145964.859375	146000	2735.140625	-1.8393682751	2700	-1.815736382	R6
200200	195327.59375	195250	4872.40625	-2.4337693556	4950	-2.4725274725	R6

R6 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



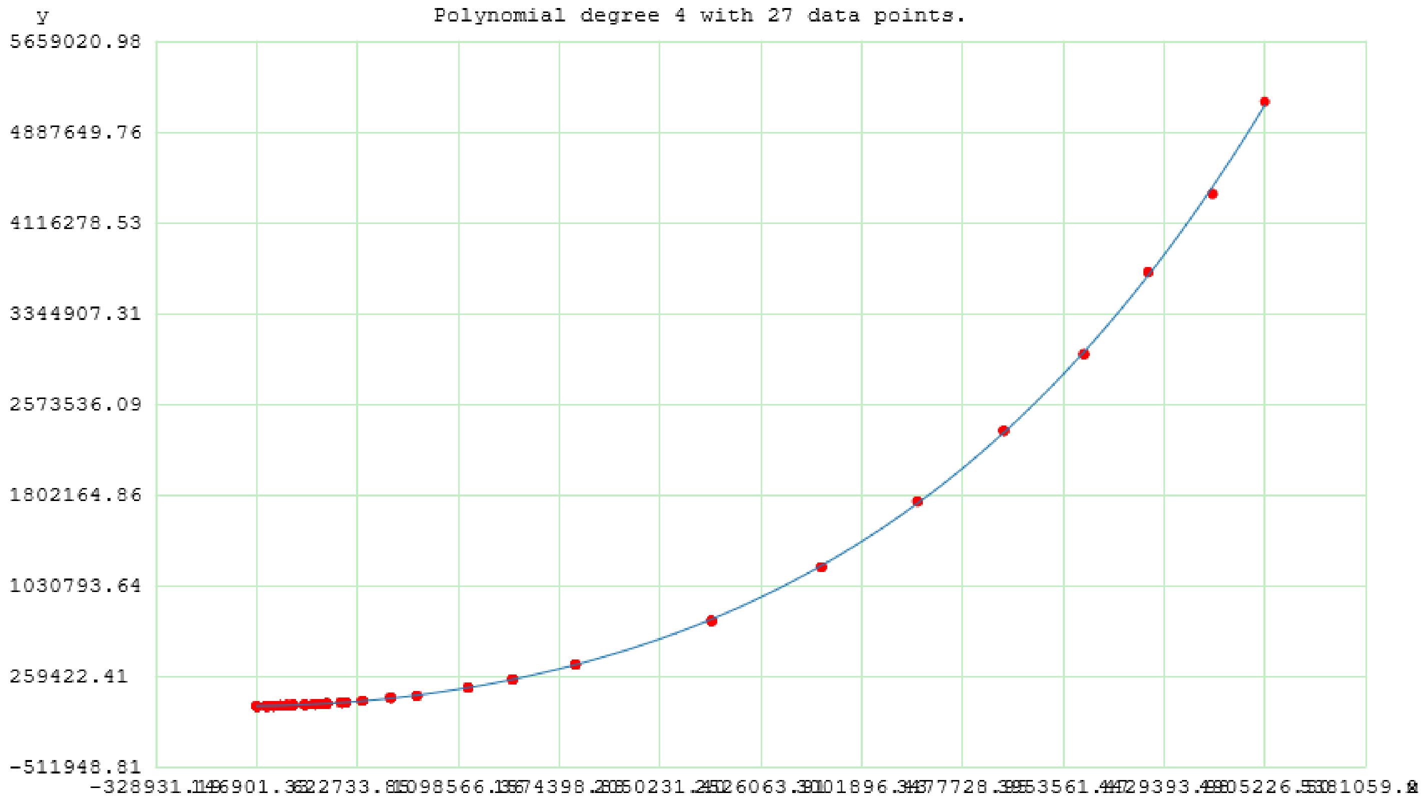
Output form: mathematical function:

f(x) = 2.1238142565083130e+004 * x^0
+ -8.2090219791235153e-001 * x^1
+ 1.1372997600431447e-005 * x^2
+ -6.4352245140838588e-011 * x^3
+ 1.3027891620169220e-016 * x^4

CALIBRATION OF R7

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
149200	146901.328125	147000	2298.671875	-1.5406647956	2200	-1.4745308311	R7
195600	192001.46875	192000	3598.53125	-1.8397399029	3600	-1.8404907975	R7
228200	223366.578125	223250	4833.421875	-2.1180639242	4950	-2.1691498685	R7
248800	241974.40625	242000	6825.59375	-2.7434058481	6800	-2.7331189711	R7
269800	260920.765625	261000	8879.234375	-3.2910431338	8800	-3.261675315	R7
303600	292797.1875	292750	10802.8125	-3.5582386364	10850	-3.5737812912	R7
333100	319587.34375	319500	13512.65625	-4.0566365206	13600	-4.0828580006	R7
390000	374236.03125	374250	15763.96875	-4.0420432692	15750	-4.0384615385	R7
438000	418010.84375	418000	19989.15625	-4.5637343037	20000	-4.5662100457	R7
474000	452033.8125	452000	21966.1875	-4.6342167722	22000	-4.641350211	R7
505000	478791.6875	478750	26208.3125	-5.1897648515	26250	-5.198019802	R7
579000	545294.0625	545250	33705.9375	-5.8214054404	33750	-5.829015544	R7
604000	567588.8125	567500	36411.1875	-6.0283423013	36500	-6.0430463576	R7
695000	646288.875	646250	48711.125	-7.008794964	48750	-7.0143884892	R7
855000	779950.0625	780000	75049.9375	-8.7777704678	75000	-8.7719298246	R7
995000	902606.25	902500	92393.75	-9.2858040201	92500	-9.2964824121	R7
1306000	1145136.75	1145000	160863.25	-12.3172473201	161000	-12.3277182236	R7
1588000	1355649.25	1355000	232350.75	-14.6316593199	233000	-14.6725440806	R7
2010000	1652027.625	1652500	357972.375	-17.8095708955	357500	-17.7860696517	R7
3023000	2294171.75	2295000	728828.25	-24.1094359907	728000	-24.0820377109	R7
4000000	2813211.75	2812500	1186788.25	-29.66970625	1187500	-29.6875	R7
5010000	3265674.25	3265000	1744325.75	-34.8168812375	1745000	-34.8303393214	R7
6020000	3673211	3672500	2346789	-38.9832059801	2347500	-38.9950166113	R7
7050000	4052105	4052500	2997895	-42.5233333333	2997500	-42.5177304965	R7
8050000	4355392.5	4355000	3694607.5	-45.8957453416	3695000	-45.900621118	R7
9020000	4658938.5	4660000	4361061.5	-48.3487971175	4360000	-48.3370288248	R7
10050000	4905226.5	4905000	5144773.5	-51.1917761194	5145000	-51.1940298507	R7

R7 Scale: Reverse Error(Ω) Versus Measured Resistance(Ω)



Output form: mathematical function:

$$
\begin{aligned}
f(x) = {} & 5.3223750858051280e+003 * x^0 \\
& + -2.4281582980199931e-002 * x^1 \\
& + 1.3858975736226595e-007 * x^2 \\
& + -4.2059331915537060e-015 * x^3 \\
& + 4.1271826356625583e-021 * x^4
\end{aligned}
$$

ADJUSTMENT FACTORS IN ARDUINO CODE

```
if (resistorBranchIndex == 7){ //Rx measurements for all Ri scales adjusted by parabolic adjustment factors generated through the calibration process
    Rx = Rx + (5.3223750858051280 * pow(10,3) + -2.4281582980199931 * pow(10,-2) * Rx + 1.3858975736226595 * pow(10,-7) * pow(Rx,2) + -4.2059331915537060 * pow(10,-15) * pow(Rx,3) + 4.1271826356625583 * pow(10,-21) * pow(Rx,4));
    } else if (resistorBranchIndex == 6){
     Rx = Rx + (2.1238142565083130 * pow(10,4) + -8.2090219791235153 * pow(10,-1) * Rx + 1.1372997600431447 * pow(10,-5) * pow(Rx,2) + -6.4352245140838588 * pow(10,-11) * pow(Rx,3) + 1.3027891620169220 * pow(10,-16) * pow(Rx,4));
    } else if (resistorBranchIndex == 5){
     Rx = Rx + (-2.6682837895516827 * pow(10,3) + 2.9802012919653392 * pow(10,-1) * Rx + -1.1318873407960057 * pow(10,-5) * pow(Rx,2) + 1.8436711714578837 * pow(10,-10) * pow(Rx,3) + -1.0526126447491875 * pow(10,-15) * pow(Rx,4));
    } else if (resistorBranchIndex == 4){
     Rx = Rx + (-1.2990448466433213 * pow(10,2) + 4.8829867274151485 * pow(10,-2) * Rx + -6.2831774966867742 * pow(10,-6) * pow(Rx,2) + 3.6590517360171962 * pow(10,-10) * pow(Rx,3) + -7.2182993976645724 * pow(10,-15) * pow(Rx,4));
    } else if (resistorBranchIndex == 3){
     Rx = Rx + (-3.0645335973349188 * pow(10,2) + 3.3322808339874338 * pow(10,-1) * Rx + -1.2823237430990934 * pow(10,-4) * pow(Rx,2) + 2.0934500325115132 * pow(10,-8) * pow(Rx,3) + -1.2262451315039650 * pow(10,-12) * pow(Rx,4));
    } else if (resistorBranchIndex == 2){
     Rx = Rx + (3.8050144267716369 * pow(10,1) + -1.2341715053441385 * pow(10,-1) * Rx + 1.3788516929628944 * pow(10,-4) * pow(Rx,2) + -6.0023327366530932 * pow(10,-8) * pow(Rx,3) + 8.9429964326831901 * pow(10,-12) * pow(Rx,4));
    } else if (resistorBranchIndex == 1){
     Rx = Rx + (-3.0171211611623892 * pow(10,1) + 3.1041927275360964 * pow(10,-1) * Rx + -1.1679559388185310 * pow(10,-3) * pow(Rx,2) + 1.8440343171380762 * pow(10,-6) * pow(Rx,3) + -1.0616325389725969 * pow(10,-9) * pow(Rx,4));
    } else if (resistorBranchIndex == 0){
     Rx = Rx + (-1.0087015799543466 * pow(10,0) + 4.0743320497918902 * pow(10,-3) * Rx + -8.1469322428050719 * pow(10,-5) * pow(Rx,2) + 6.9157686317257333 * pow(10,-7) * pow(Rx,3) + -1.6912410018321967 * pow(10,-9) * pow(Rx,4));
    }
```

ACCURACY TESTING RESULTS

After the calibration process is complete and the adjustment factors are coded in, the auto-ranging feature is re-enabled and a new set of resistors is tested. The following spreadsheet compares the actual resistance in ohms of the resistors tested to their measured resistance in ohms. The actual resistance values are found with the M9803R - True RMS Benchtop Multimeter.

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
1	1.0049465894	1.005	-0.0049465894	0.49465894	-0.005	0.5	R0
1.1	1.0569708347	1.0575	0.0430291653	-3.9117423	0.0425	-3.8636363636	R0
1.2	1.1905952644	1.19	0.0094047356	-0.7837279667	0.01	-0.8333333333	R0
1.3	1.2722225189	1.2725	0.0277774811	-2.1367293154	0.0275	-2.1153846154	R0
1.4	1.3376681804	1.3375	0.0623318196	-4.4522728286	0.0625	-4.4642857143	R0
1.5	1.4917980194	1.4925	0.0082019806	-0.5467987067	0.0075	-0.5	R0
1.7	1.7218115329	1.7225	-0.0218115329	1.2830313471	-0.0225	1.3235294118	R0
1.9	1.8044419288	1.805	0.0955580712	-5.0293721684	0.095	-5	R0
2	2.0420801639	2.0425	-0.0420801639	2.104008195	-0.0425	2.125	R0
2.4	2.314969778	2.315	0.085030222	-3.5429259167	0.085	-3.5416666667	R0
2.7	2.7188856601	2.72	-0.0188856601	0.6994688926	-0.02	0.7407407407	R0
3.4	3.4477519989	3.4475	-0.0477519989	1.4044705559	-0.0475	1.3970588235	R0
4.5	4.4801893234	4.48	0.0198106766	-0.4402372578	0.02	-0.4444444444	R0
4.9	4.9168806076	4.9175	-0.0168806076	0.3445021959	-0.0175	0.3571428571	R0
5.3	5.3460712432	5.345	-0.0460712432	0.8692687396	-0.045	0.8490566038	R0
5.8	5.742023468	5.7425	0.057976532	-0.9995953793	0.0575	-0.9913793103	R0
7	6.9492592811	6.95	0.0507407189	-0.7248674129	0.05	-0.7142857143	R0
8.4	8.3734474182	8.3725	0.0265525818	-0.3161021643	0.0275	-0.3273809524	R0
9.4	9.4225788116	9.4225	-0.0225788116	0.2402001234	-0.0225	0.2393617021	R0
10	10.0133228302	10.025	-0.0133228302	0.133228302	-0.025	0.25	R0
10.2	10.2359695434	10.225	-0.0359695434	0.3526425824	-0.025	0.2450980392	R0
12.1	12.0844144821	12.075	0.0155855179	-0.1288059331	0.025	-0.2066115702	R0
13.1	13.1335840225	13.125	-0.0335840225	0.256366584	-0.025	0.1908396947	R0
15.2	15.1564264297	15.15	0.0435735703	-0.2866682257	0.05	-0.3289473684	R0
18	17.9726085662	17.975	0.0273914338	-0.1521746322	0.025	-0.1388888889	R0
22.2	22.1753292083	22.175	0.0246707917	-0.1111296923	0.025	-0.1126126126	R0
27.3	27.4669761657	27.475	-0.1669761657	0.6116343066	-0.175	0.641025641	R0
33.1	33.2242851257	33.225	-0.1242851257	0.3754837634	-0.125	0.3776435045	R0
39.3	39.352897644	39.35	-0.052897644	0.1345996031	-0.05	0.1272264631	R0
43.1	43.1219291687	43.125	-0.0219291687	0.0508797418	-0.025	0.0580046404	R0
51.2	51.3271827697	51.325	-0.1271827697	0.2484038471	-0.125	0.244140625	R0
56.1	56.025691986	56.025	0.074308014	-0.1324563529	0.075	-0.1336898396	R0
68	68.0156021118	68.025	-0.0156021118	0.0229442821	-0.025	0.0367647059	R0
75.3	75.4627227783	75.475	-0.1627227783	0.2160993072	-0.175	0.2324037185	R0
81.7	81.8268203735	81.825	-0.1268203735	0.1552268953	-0.125	0.152998776	R0
91.1	91.1030273437	91.1	-0.0030273437	0.0033230996	0	0	R0
99.9	99.9616699218	99.95	-0.0616699218	0.0617316535	-0.05	0.0500500501	R0
121.9	121.9257659912	122	-0.0257659912	0.0211369903	-0.1	0.0820344545	R0

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
150.3	150.2840576171	150.25	0.0159423829	-0.0106070412	0.05	-0.0332667997	R0
179.8	179.9695129394	180	-0.1695129394	0.0942786092	-0.2	0.1112347052	R0
199.5	199.3469390869	199.25	0.1530609131	-0.0767222622	0.25	-0.1253132832	R0
209.4	209.6268005371	209.75	-0.2268005371	0.1083097121	-0.35	0.1671442216	R0
219.5	219.5642700195	219.5	-0.0642700195	0.0292801911	0	0	R1
250.2	250.7306518554	250.75	-0.5306518554	0.2120910693	-0.55	0.2198241407	R1
268.3	268.5357055664	268.5	-0.2357055664	0.087851497	-0.2	0.0745434215	R1
298.2	298.0116882324	298	0.1883117676	-0.0631494861	0.2	-0.0670690812	R1
341.8	341.1976318359	341.25	0.6023681641	-0.176234103	0.55	-0.1609128145	R1
360.8	360.4088134765	360.5	0.3911865235	-0.1084219854	0.3	-0.0831485588	R1
384	384.191619873	384.25	-0.191619873	0.0499010086	-0.25	0.0651041667	R1
428	427.8620605468	427.75	0.1379394532	-0.0322288442	0.25	-0.058411215	R1
463	462.4689331054	462.5	0.5310668946	-0.1147012731	0.5	-0.1079913607	R1
518	518.4896850585	518.5	-0.4896850585	0.0945337951	-0.5	0.0965250965	R1
553	552.5528564453	552.5	0.4471435547	-0.0808577857	0.5	-0.0904159132	R1
596	595.9840698242	596	0.0159301758	-0.0026728483	0	0	R1
625	624.7790527343	624.75	0.2209472657	-0.0353515625	0.25	-0.04	R1
645	643.9145507812	644	1.0854492188	-0.1682867006	1	-0.1550387597	R1
679	679.1760864257	679.25	-0.1760864257	0.0259331997	-0.25	0.0368188513	R2
812	812.0294799804	812	-0.0294799804	0.0036305395	0	0	R2
991	990.5026855468	990.5	0.4973144532	-0.0501830932	0.5	-0.0504540868	R2
1203	1202.6239013671	1202.5	0.3760986329	-0.0312633943	0.5	-0.0415627598	R2
1504	1504.7116699218	1505	-0.7116699218	0.0473184788	-1	0.0664893617	R2
1803	1803.7360839843	1802.5	-0.7360839843	0.0408255122	0.5	-0.0277315585	R2
1984	1984.019165039	1985	-0.019165039	0.0009659798	-1	0.0504032258	R2
2134	2135.134765625	2135	-1.134765625	0.0531755213	-1	0.0468603561	R2
2188	2187.1530761718	2187.5	0.8469238282	-0.0387076704	0.5	-0.0228519196	R3
2257	2258.0812988281	2257.5	-1.0812988281	0.0479086765	-0.5	0.0221533008	R3
2701	2702.2436523437	2702.5	-1.2436523437	0.0460441445	-1.5	0.055534987	R3
2994	2993.603515625	2992.5	0.396484375	-0.0132426311	1.5	-0.0501002004	R3
3284	3283.9892578125	3285	0.0107421875	-0.0003271068	-1	0.0304506699	R3
3571	3568.7473144531	3567.5	2.2526855469	-0.0630827652	3.5	-0.0980117614	R3
3890	3893.39453125	3892.5	-3.39453125	0.0872630141	-2.5	0.0642673522	R3
4290	4290.17578125	4290	-0.17578125	0.004097465	0	0	R3
4650	4649.3408203125	4650	0.6591796875	-0.0141759073	0	0	R3
5090	5088.1826171875	5087.5	1.8173828125	-0.0357049668	2.5	-0.0491159136	R3
5600	5605.71484375	5605	-5.71484375	0.1020507813	-5	0.0892857143	R3
5980	5981.6083984375	5982.5	-1.6083984375	0.0268962949	-2.5	0.0418060201	R3
6410	6412.05078125	6412.5	-2.05078125	0.0319934672	-2.5	0.0390015601	R3
6800	6796.9165039062	6797.5	3.0834960938	-0.0453455308	2.5	-0.0367647059	R4
7480	7475.7348632812	7475	4.2651367188	-0.0570205444	5	-0.0668449198	R4
8140	8130.1938476562	8130	9.8061523438	-0.120468702	10	-0.1228501229	R4
9020	9013.76953125	9015	6.23046875	-0.0690739329	5	-0.0554323725	R4
9930	9919.3916015625	9920	10.6083984375	-0.106831807	10	-0.1007049345	R4
11900	11882.134765625	11875	17.865234375	-0.15012802	25	-0.2100840336	R4
14890	14879.8681640625	14875	10.1318359375	-0.0680445664	15	-0.1007387508	R4

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
18040	18054.1953125	18050	-14.1953125	0.078687985	-10	0.0554323725	R4
19930	19923.3359375	19925	6.6640625	-0.0334373432	5	-0.0250878073	R4
21310	21320.2265625	21325	-10.2265625	0.0479895002	-15	0.0703894885	R4
21880	21859.96484375	21850	20.03515625	-0.0915683558	30	-0.1371115174	R5
23770	23783.56640625	23775	-13.56640625	0.0570736485	-5	0.021034918	R5
27360	27348.4765625	27350	11.5234375	-0.0421178271	10	-0.0365497076	R5
29780	29801.548828125	29800	-21.548828125	0.0723600676	-20	0.0671591672	R5
32680	32645.49609375	32650	34.50390625	-0.1055811085	30	-0.0917992656	R5
35890	35871.47265625	35875	18.52734375	-0.0516225794	15	-0.0417943717	R5
39260	39178.3515625	39175	81.6484375	-0.2079685112	85	-0.216505349	R5
42600	42566.1015625	42575	33.8984375	-0.0795737969	25	-0.058685446	R5
45600	45573.96484375	45575	26.03515625	-0.0570946409	25	-0.0548245614	R5
50700	50649.0078125	50650	50.9921875	-0.1005763067	50	-0.0986193294	R5
55700	55647.453125	55650	52.546875	-0.0943390934	50	-0.0897666068	R5
64600	64632.9375	64625	-32.9375	0.0509868421	-25	0.0386996904	R5
67700	67737.34375	67725	-37.34375	0.0551606352	-25	0.0369276219	R6
75400	75188.234375	75200	211.765625	-0.2808562666	200	-0.2652519894	R6
82200	82055.5859375	82050	144.4140625	-0.1756862074	150	-0.1824817518	R6
91700	91618.4375	91625	81.5625	-0.0889449291	75	-0.0817884406	R6
98700	98966.2265625	98975	-266.2265625	0.2697330927	-275	0.2786220871	R6
118700	118794.453125	118750	-94.453125	0.0795729781	-50	0.0421229992	R6
149600	149326.0625	149250	273.9375	-0.1831133021	350	-0.2339572193	R6
183500	183111.265625	183000	388.734375	-0.211844346	500	-0.272479564	R6
199800	199174.546875	199250	625.453125	-0.3130396021	550	-0.2752752753	R6
205100	206124.90625	206000	-1024.90625	0.4997105071	-900	0.4388103364	R7
214700	215411.875	215500	-711.875	0.3315673032	-800	0.3726129483	R7
229400	229757.28125	229750	-357.28125	0.1557459677	-350	0.1525719268	R7
249300	249369.546875	249250	-69.546875	0.0278968612	50	-0.0200561572	R7
271400	270503.75	270500	896.25	-0.3302321297	900	-0.3316138541	R7
297500	298821.5	298750	-1321.5	0.4442016807	-1250	0.4201680672	R7
329200	328673	328750	527	-0.1600850547	450	-0.1366950182	R7
349200	347759.3125	347750	1440.6875	-0.4125680126	1450	-0.4152348225	R7
399000	399785.1875	399750	-785.1875	0.1967888471	-750	0.1879699248	R7
448000	448530.46875	448500	-530.46875	0.1184082031	-500	0.1116071429	R7
484000	483355.875	483250	644.125	-0.1330836777	750	-0.1549586777	R7
514000	514449.46875	514500	-449.46875	0.0874452821	-500	0.0972762646	R7
548000	547564.0625	547500	435.9375	-0.0795506387	500	-0.0912408759	R7
603000	603927.0625	604000	-927.0625	0.1537417081	-1000	0.1658374793	R7
650000	651190.75	651250	-1190.75	0.1831923077	-1250	0.1923076923	R7
701000	701208.875	701250	-208.875	0.029796719	-250	0.0356633381	R7
774000	775718.75	775750	-1718.75	0.2220607235	-1750	0.2260981912	R7
793000	792331.6875	792250	668.3125	-0.0842764817	750	-0.0945775536	R7
842000	841850.125	841750	149.875	-0.0177998812	250	-0.0296912114	R7
923000	921000.75	921000	1999.25	-0.216603467	2000	-0.2166847237	R7
990000	988192.125	988250	1807.875	-0.1826136364	1750	-0.1767676768	R7
1026000	1023463.5625	1022500	2536.4375	-0.2472161306	3500	-0.3411306043	R7

Actual	Measured	Measured on LCD	Actual – Measured	% Error	Actual - Measured on LCD	% Error on LCD	Scale
1569000	1572858	1572500	-3858	0.2458891013	-3500	0.2230720204	R7
2007000	2007586	2007500	-586	0.0291978077	-500	0.0249128052	R7
2541000	2545671.5	2545000	-4671.5	0.1838449429	-4000	0.1574183392	R7
3024000	3021517	3022500	2483	-0.0821097884	1500	-0.0496031746	R7
3531000	3548131.25	3547500	-17131.25	0.4851670915	-16500	0.4672897196	R7
4040000	4049442.5	4050000	-9442.5	0.2337252475	-10000	0.2475247525	R7
4580000	4578228	4577500	1772	-0.0386899563	2500	-0.0545851528	R7
5190000	5171918	5172500	18082	-0.3484007707	17500	-0.3371868979	R7
5730000	5727244	5727500	2756	-0.0480977312	2500	-0.0436300175	R7
6210000	6200812	6200000	9188	-0.1479549114	10000	-0.1610305958	R7
6530000	6524492	6525000	5508	-0.0843491577	5000	-0.0765696784	R7
7190000	7177848	7177500	12152	-0.1690125174	12500	-0.173852573	R7
7790000	7766943.5	7767500	23056.5	-0.2959756098	22500	-0.2888318357	R7
8080000	8071966.5	8072500	8033.5	-0.099424505	7500	-0.0928217822	R7
8550000	8588065	8587500	-38065	0.4452046784	-37500	0.4385964912	R7
9140000	9169604	9170000	-29604	0.3238949672	-30000	0.3282275711	R7
9550000	9584618	9585000	-34618	0.3624921466	-35000	0.3664921466	R7
10380000	10342014	10350000	37986	-0.3659537572	30000	-0.289017341	R7

CITATIONS

Datasheets

[1] ELEGOO UNO R3 https://epow0.org/~amki/car_kit/Datasheet/ELEGOO%20UNO%20R3%20Board.pdf

[2] Adafruit. ADS1115 Breakout Board https://cdn-learn.adafruit.com/downloads/pdf/adafruit-4-channel-adc-breakouts.pdf

[3] Adafruit. ADS1115 https://cdn-shop.adafruit.com/datasheets/ads1115.pdf

[4] LCD1602 https://www.elecrow.com/download/LCD1602.pdf

[5] Serial I2C TWI Module http://www.handsontec.com/dataspecs/module/I2C_1602_LCD.pdf

[6] 4 Channel 5V Optical Isolated Relay Module https://www.handsontec.com/dataspecs/4Ch-relay.pdf

[7] JQC-3FF RELAY https://datasheetspdf.com/pdf-file/606936/Hongfa/JQC-3FF/1

Software Tools

[1] ExpressPCB Plus https://www.expresspcb.com/

[2] Arduino IDE https://www.arduino.cc/en/software

[3] Polynomial Regression Data Fit https://arachnoid.com/polysolve/

Code and Design Resources

[1] Arduino Resistance Meter basics http://electronoobs.com/eng_arduino_tut10.php

[2] OHM Sign for LCD https://www.hackmeister.dk/2010/08/custom-lcd-characters-with-arduino/

[3] ADS1115 Library https://github.com/adafruit/Adafruit_ADS1X15/releases/tag/1.1.0

[4] LCD1602 Library https://github.com/WickedLukas/Newliquidcrystal_1.3.5

[5] Arduino Relay Module example http://arduinolearning.com/amp/code/5-volt-4-channel-arduino-relay-module-example.php

[6] OhmMeter2021 Source Code https://github.com/Yosha42/Auto-Ranging-Ohmmeter/blob/main/OhmMeter2021/OhmMeter2021.ino

[7] Ohm Meter Schematic https://github.com/Yosha42/Auto-Ranging-Ohmmeter/blob/main/Ohm%20Meter%20Schematic.sch

[8] Arduino Shield Footprint https://forum.expresspcb.com/community-library/package/57/

[9] Ohm Meter PCB Layout https://github.com/Yosha42/Auto-Ranging-Ohmmeter/blob/main/Josh%20Ohm%20Meter%20PCB.rrb

Spreadsheets

[1] OhmMeter Calibration https://github.com/Yosha42/Auto-Ranging-Ohmmeter/blob/main/OhmMeter%20Calibration.ods

[2] Accuracy Test https://github.com/Yosha42/Auto-Ranging-Ohmmeter/blob/main/Accuracy%20Test.ods