**GNG5140 - Engineering Design**

**Revised Prototype and Test Phase of 3D Electroplating Printer**



Submitted by

[3D Electroprinter]

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**Abstract**

*The final design changes for the project were made, anything up to this point has been completed, and the only actions left for the project are specifically for presentation to both the client and during design day. A minimal viable prototype will be presented at design day with the prototype showing simple hydrolysis being performed by a 3D printer with an attached anode to the print head. The current prototype functions as expected from previous deliverables, and shows good promise for the future of this project, hopefully acting as a basis for future design changes from other projects.*

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**List of Acronyms**

| **Acronym** | **Definition** |
| --- | --- |
| FDM | Fused Deposition Modeling |
| HBT | Hydrogen Bubble Templating |
| SLA | Stereolithography |
| PLA | Polylactic Acid |
| UI | User Interface |
| MOBO | Motherboard |
| DAC | Digital to Analog Convertor |
| CVC | Current to Voltage Convertor |
|  |  |
|  |  |
|  |  |
|  |  |

# Introduction

The revised prototype phase acted as an extension of the testing phase for our purposes, as there were several changes to the prototype that the team saw necessary for the prototype to function correctly. Most important, there was some time dedicated to looking at modification of the Gcode for initial prototypes, as well as the printing of the counter electrode holder’s final design. With these two things completed, the team has conducted a simple test-print using a hydrolysis reaction on the 3D printer to show the basic feasibility of the design. There are also several suggestions for future work, as well as a look into the draft of the user manual that will be released alongside the prototype. An important note is that the need for quantitative data has not been met to a satisfactory level by the team, a majority of the information gained from the testing phase has been qualitative in nature in regards to the printer's precision, and much of the quantitative data is in the electroplating sphere. This was not intended, but due to a lack of time and resources to perform the intended movement tests, there have been several assumptions used for the print movement testing that will be discussed below, as well as some concerns for future projects to look into in regard to how to modify the printer further for the precise movement needed for this project.

# Revised Global Solution and System Concept

One of the changes to the design was to the anode holder that was used preliminarily. The new anode holder was proposed after the hot-end shroud of the printer could be removed and we could access the back panel which had two screw points for an easy attachment. This meant that the overall design could be simplified and reduced in size, which led to the print shown below in figure x.

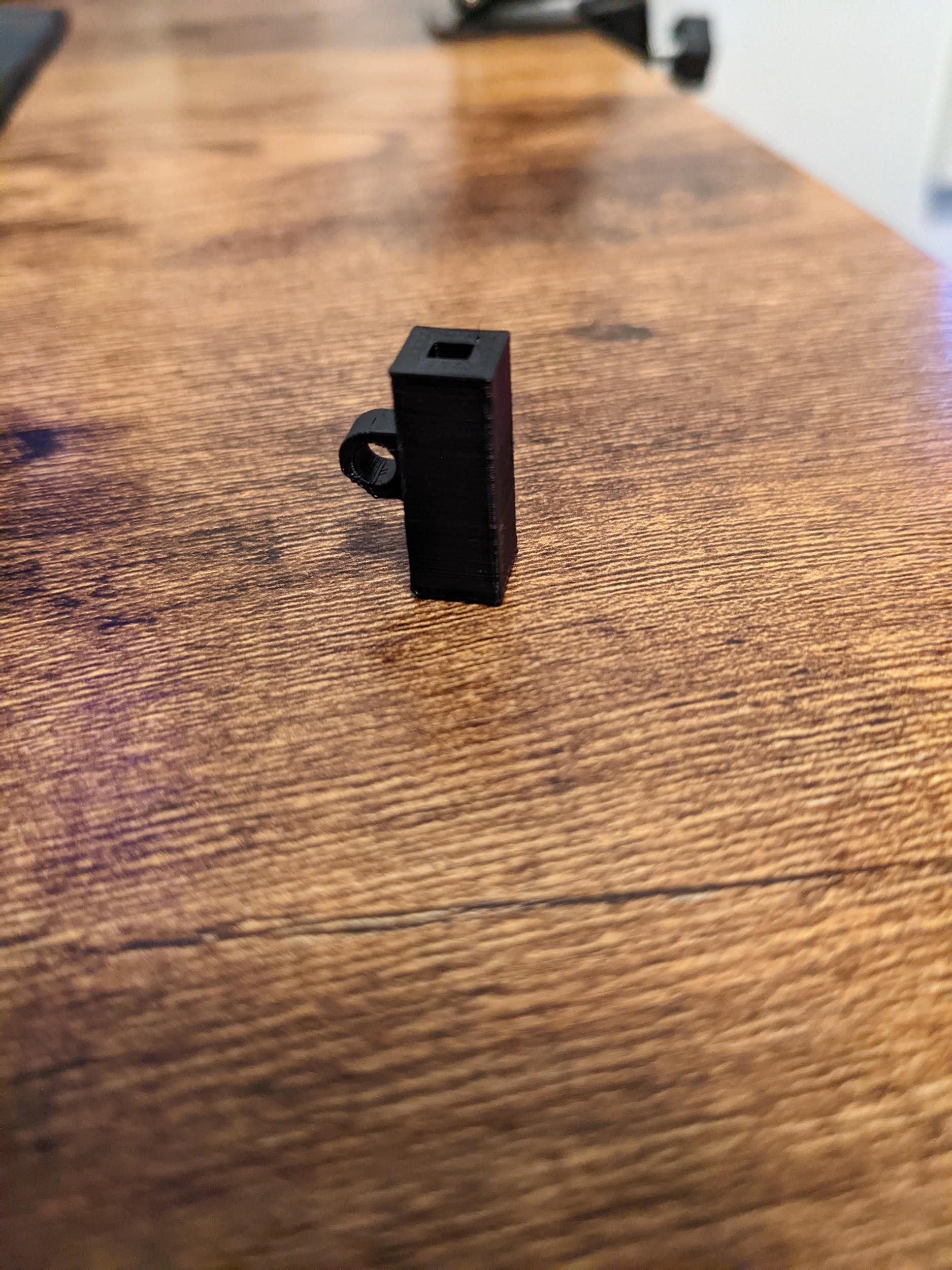


Figure x: Anode holder

This holder is much simpler in design and just uses a simple cylindrical hole that is clearance fit for the hot end rod that comes with the printer. While this anode holder is not universal, it does work for the current design as the hot-end cleaning rod fits neatly into the cylindrical extrude. It can also be attached directly to the front of the printer at a fixed distance away from the hot end. This makes it exceptionally easy to explain the distance changes in the user manual, which will be discussed further below. There were very few other changes to the printer itself, and a majority of the tasks in this deliverable were focused on the testing of the prototype itself, which will be further discussed below as well.

The Gantt chart will be strikingly similar to the last chart shown in the team’s previous report with one crucial difference, the tasks that were assigned have been completed, and several new tasks have been added. It should be noted that many of these tasks spanned both deliverables, so these were being worked on continuously as one larger testing phase, and as such the schedule itself looked to be further behind last report, but with this report every single deliverable has been updated and arrived on time.

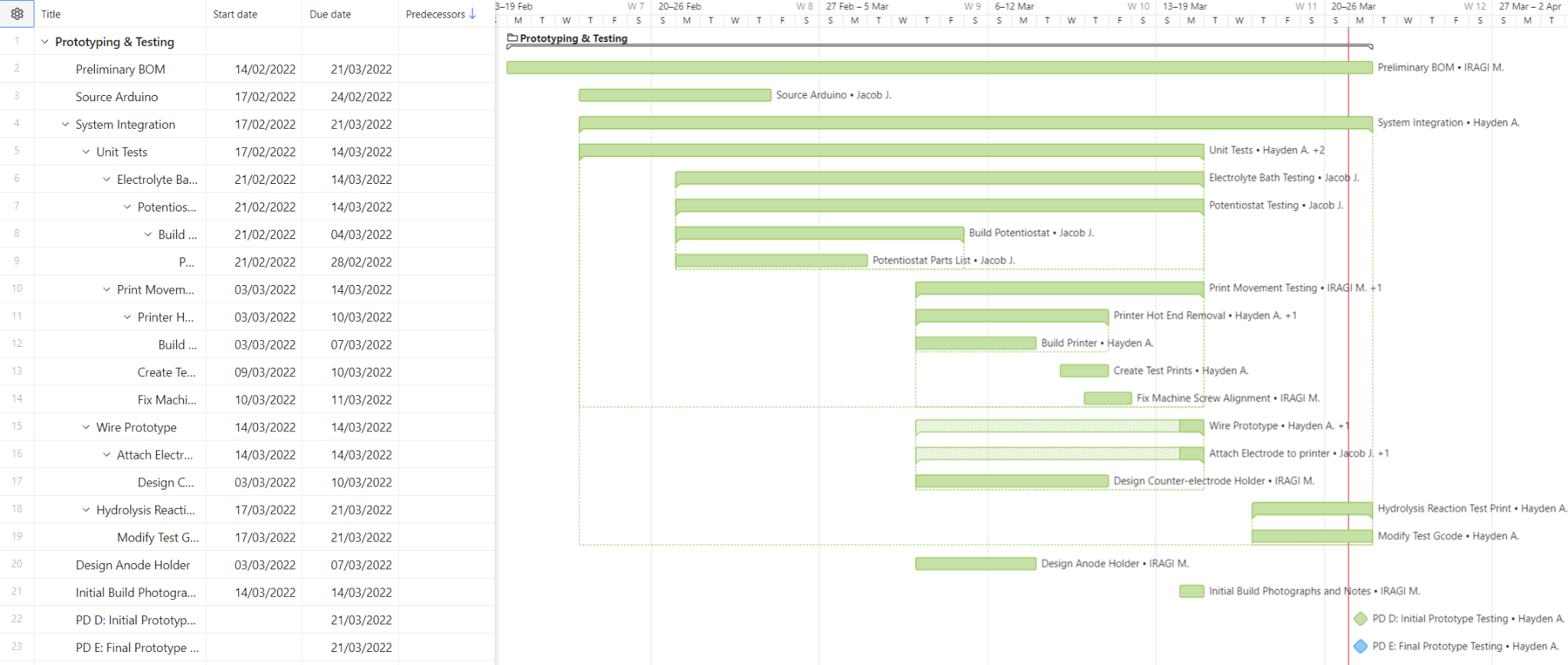


Figure x: Gantt Chart

Lastly, the bill of materials that this project has used has also been kept up to date, with several new purchases since our last report. As of now, the final price for this prototype comes to $414.01 after taxes and shipping with the latest lead time being a full week. We are currently $85.99 under budget which is fortunate given that there are replacement parts that will need to be ordered from the potentiostat, as well as a few loose ends such as an electroplating bath that have not been shown here. We do not expect any reason to request an extension of the budget at this time, and foresee staying under budget. This BOM has not been modified since the last deliverable, and as such this section has been kept similar between reports.

| **Item #** | **Name** | **System** | **Price** | **Shipping** | **Tax** | **Lead Time** | **Received?** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **1** | Creality Ender 3D Printer | Movement | $ 329.99 |  |  | 1 week | Y |
| **2** | Arduino Uno R3 | potentiostat | $31.48 | $ 8.00 | $ 4.74 | 3 days | Y |
| **3** | op amp TLV4110IP | potentiostat | $3.85 |  |  | 3 days | Y |
| **4** | op-amp MCP6022-E/P | potentiostat | $2.51 |  |  | 3 days | Y |
| **5** | Cables w/alligator clips | potentiostat | $3.44 |  |  | 3 days | Y |
| **6** | 2 uF capacitor | potentiostat | $2.73 |  |  | 3 days | Y |
| **7** | breadboard | potentiostat | $7.33 |  |  | 3 days | Y |
| **8** | 1Ω resistor | potentiostat | $0.15 |  |  | 3 days | Y |
| **9** | 10kΩ resistor | potentiostat | $0.14 |  |  | 3 days | Y |
| **10** | 1kΩ resistor | potentiostat | $0.14 |  |  | 3 days | Y |
| **11** | 9kΩ resistor | potentiostat | $0.14 |  |  | 3 days | Y |
| **12** | 20Ω resistor for testing | potentiostat | $0.14 |  |  | 3 days | Y |
| **13** | jumper cables x10 | potentiostat | $4.13 |  |  | 3 days | Y |
| **14** | jumper cables x30 | potentiostat | $3.44 | $ 8.00 | $ 3.66 | 3 days | Y |

Table x: BOM of Current Prototype

# 3D Printer Prototype Modifications

There are several modifications that had to be made to the Ender3 before preliminary testing could be done. Alongside the ones discussed in the previous report, there are several that come up as maintenance (Wiring and Machine Screw fix), and others that come up as additions (Counter-electrode holder and Z-axis switch fix). These will be discussed further below, but it should be noted that some of the intended modifications will take place in the following week before the release on design day.

### Z-Axis Switch New 0-Level

The Z-Axis switch was preliminary calibrated to limit the movement of the extruder whenever it comes into direct contact of the printing bed. The switch fixed at the bottom of the extrusion beam (Z- axis stand) and on the top of the base of the printer raising to almost the same level of the printing bed. The 0-level was reached whenever the hotend could move toward the bed and the gantry touches the Switch.

For electroplating process, we need a container for the electrolyte solution. This container has a height and thickness that prevents the gantry from reaching the Z-axis switch that was set at approximately the printing bed’s level. This situation required us to move the switch a level easily accessible by the gantry by taking into consideration the height of the container.

We moved the switch from the initial point to the new desired 0- level by sliding it through the extrusion of the Z-axis beam.

### Counter-electrode Holder

The previous holder was designed out of assumption preliminary made of the electrode’s dimensions and properties, also we assumed that the hotend needed to be removed. After getting advice from Prof. Baranova and making some preliminary testing, we found out that we only need a simple needle as electrode for this prototype and there is no need for us to remove the extruder. For easy fixation of the holder to the gantry, we adapted the design of the counter electrode holder to the existing mounting plate of the hotend. The holder was designed for an electrode of diameter 0.4mm.

### Machine Screw

The machine screw for the Ender3 was another very difficult part to get working correctly. Along with the timing belt the machine screw was slightly off-center from the intended build which caused a plethora of slipping on the motor. This slipping would then cause the Z-axis (which was calibrated off of how many turns the motor went through) to be slightly off in accuracy, sometimes causing the print head to hit the print-bed. The machine screw was removed, cleaned, and all the aligning parts were taken off, inspected, and it was determined that the motor itself was slightly off center, but the machine screw itself had already been damaged. Overall, the machine screw itself still functions, and the slipping has been reduced after cleaning and greasing the entire unit. It is important to check the alignment of the printer, potentially removing the machine screw motor and ensuring that it has not slipped back into a misaligned position every week. This could cause a lot of maintenance, so a more permanent solution is ideal.

### Wiring

As of now there remains no integration between the printer and the potentiostat, and given the challenges there are no plans to do so before design day. The potentiostat remains powered by an external laptop. The arduino and breadboard sit next to the printer, with long leads connecting them to the anode and cathode. The anode is connected via alligator clip. At this time the leads to the anode and cathode are loosely draped across the printer’s frame, but future plans are to tape or zip tie them to the printer frame and the disused filament feed tube to reduce the risk of them in the machinery. Figure #### shows the printer with the wiring and a provisional bath attached. Part of the hot end has been removed, but some fans remained wired in and were taped out of the way for now.

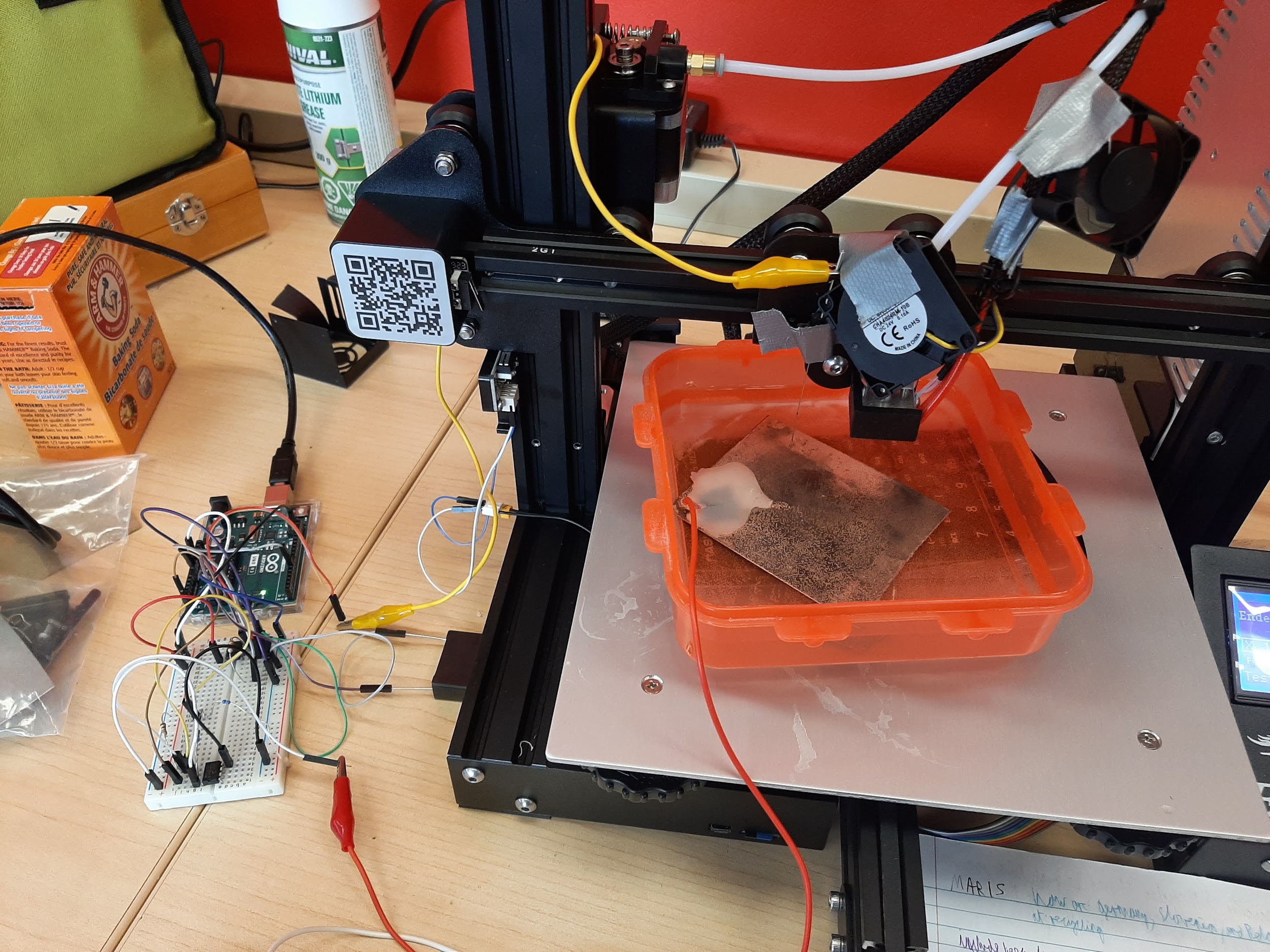


figure ####: Printer wiring

### Modification of Gcode

One important factor to getting the print to run correctly is the modification of the Gcode of the printer itself. This Gcode is written in a language called “Marlin”(<https://marlinfw.org>) which is an open source coding language used by a plethora of different 3D printers already. This Gcode is relatively easy to modify, but there are some restrictions when it comes to utilizing this printer. First and foremost there is only a single input on this printer, a scroll dial with a single button press. This means that the overall ways that the commands can operate is limited, with only “click to continue” being an option as well as utilizing the scroll wheel for changing the intensity of a signal. This meant that the current changes to the Gcode were relatively simple and focused on two particular problems that we found when utilizing the Ender3. First and foremost is the homing of the print-head before and after a print. This was easy enough and was done by adding four lines of code that utilized the G1/G0(<https://marlinfw.org/docs/gcode/G000-G001.html>) and M0(<https://marlinfw.org/docs/gcode/M000-M001.html>) commands. These two commands are both linear movement commands and unconditional stop commands respectively. With both of these the printer could be told to go to a print position far above the initial point and then go down from there instead of hitting the glass walls of the electroplating device. This was a success, but one issue still lies with the speed of the printer which is the second factor. One brute-force solution is to utilize the M0 command with another command (S#) which would allow for a pause of “#” seconds every time a line goes through. Looking at the Gcode in the appendix it would be easy to see that this method would not only be tedious, but could be potentially disastrous when it comes to the amount of chance for errors to set in. This is why the next proposal was to utilize a second coding language, such as MatLab or C to add additional lines to the files code. For example, the “G1” commands are used when filament is supposed to be extruded, this is what the F modifier to this command means, its an extrusion speed. This means that a code that was written in such a way to say “If (First two letters) == G1” then “Insert M0 S5” this would freeze the printer over every point that needs to be plated for 5 seconds. This would be exceptionally easy to do, and would minimize the amount of errors involved. While this is currently being developed, it will likely not be made in time for design day, and a modified form of the code done by hand will likely be used in its place. The possibilities of an integrated or new user interface would be discussed further in the closing remarks, but this Gcode is exceptionally easy to modify so this may be an avenue for modification for future teams.

# Electroplating Modifications

An unfortunate limitation the team has run in to is that it will not be possible to perform testing with actual nickel chloride solution over the course of this semester. Discussions with university staff have led to the conclusion that the bureaucratic overhead would prevent access to the wet lab space necessary for such work in a timely manner. Thus any further electrochemical testing will only involve electrolyzing baking soda solution.

## 4.1 Potentiostat design update

Over the past week the potentiostat design has been simplified somewhat. The previous design as intended before the high-current amplifier’s defect was discovered (as described in our previous report) was considered overly complex. Without a summing amplifier, the low-current op-amp buffering the DAC output was redundant since it fed into the high-current amplifier which itself was wired as a buffer. This first low-current amplifier could thus be removed and the electroplating cell’s amplifier could be fed a signal directly from the DAC. While looking for the replacement amplifier we discovered that the TLV4110 came in a version with two amplifiers in the same integrated circuit chip; the TLV4112. There seemed to be no obvious reason why the amplifier used in the CVC could not also be able to support a high current even if that capacity would be unused. This led to the concept of using the TLV4112 for both amplifiers, creating a potentiostat that required only one chip rather than two or three. Unfortunately this proved to be a failure during testing: The TLV4112 was incapable of true rail-to-rail operation and thus with its negative power supply at zero volts (ground) its output could not drop entirely to zero volts. This meant it would have a non-zero output even when the potentiostat had an open circuit and thus no current flowing. While this would not be an immediately crippling problem the design simplicity was not worth such a known flaw, and a separate MCP6022 was re-added to operate the CVC.

The re-designed potentiostat ran into difficulty measuring current. Frequently it would record an erratic current much lower than what it should given the resistance applied between positive and negative electrodes, with the measured current constantly changing. In these scenarios measuring the current with an external ammeter recorded a current that was stable, but still much lower than expected. After much testing it was determined that the problem was the 1 ohm resistor of the CVC not making good contact with the rest of the circuitry in the breadboard, causing intermittent breaking of the current. Replacing that resistor with another identical one had the same issues. It was noted that the resistor model had thinner leads than the others used in the project. While it is highly unexpected that this would cause such problems, we must conclude it did. As an emergency patch the 1 ohm resistor was replaced with a 10 ohm resistor that was on hand. While this gives the CVC more resistance than is desired, it solves the contact problem. Increasing that resistance 10-fold results in the CVC outputting 10 times as much voltage for a given current, which means the CVC’s amplifier reached its voltage range limits above 50 mA. Since upping the resistance from 1 to 10 ohms itself effectively amplified the signal 10-fold, the resistors were removed from the circuit and the CVC’s amplifier operates as a buffer amplifier. A schematic of the revised circuitry as well as images of the finalized potentiostat design are included in figure ####

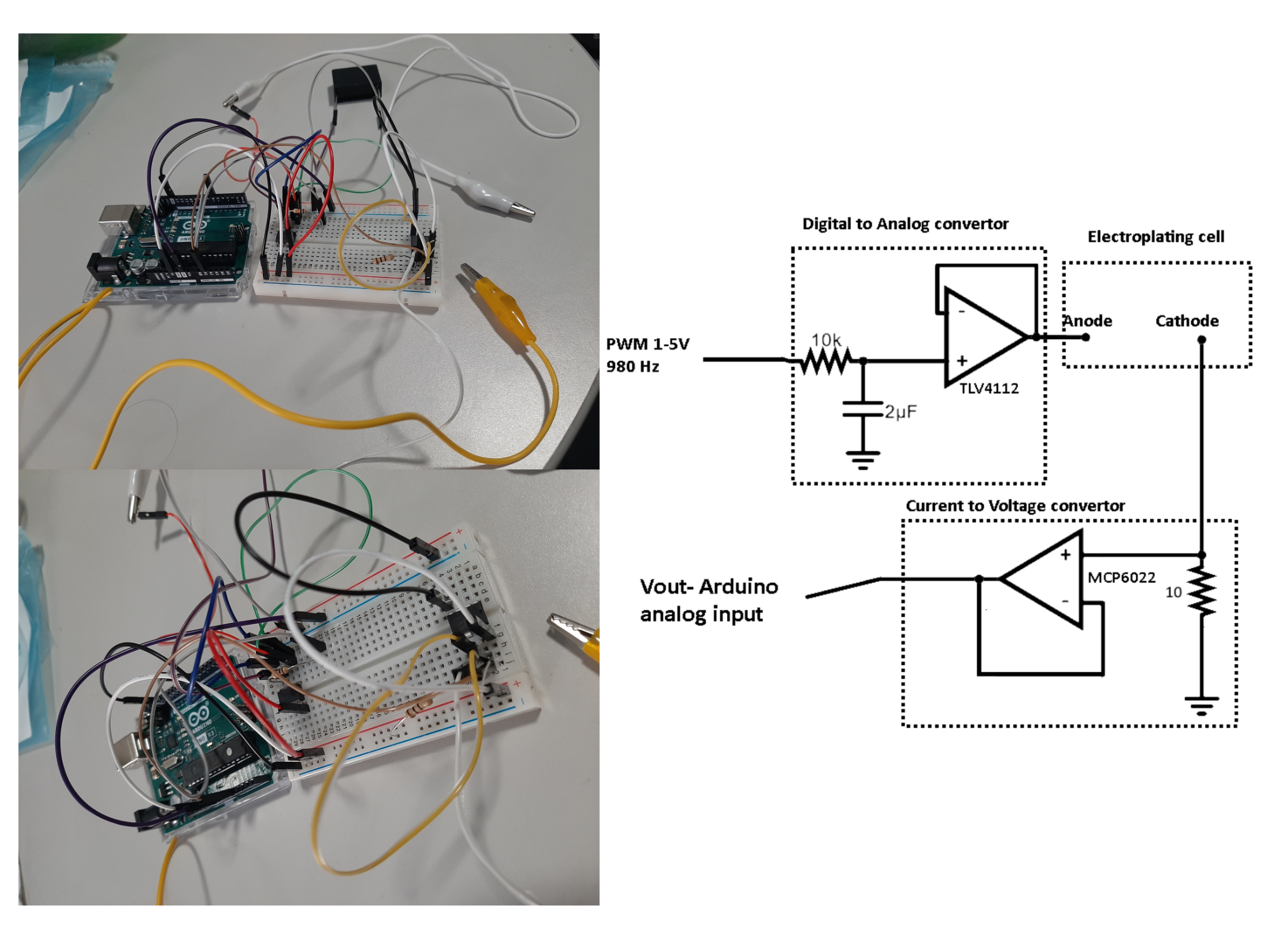


Figure ####: Images (left) and circuit schematic (right) of the current and likely final potentiostat design.

Further complications occur: Attempting to use the potentiostat to obtain the polarization curve of a 20 ohm resistor (effectively 30 ohms due to the altered CVC) revealed the potentiostat could not deliver a current above 140 mA, despite the amplifier being nominally rated to provide 300 mA. There’s no obvious cause for this, and it’s just a limitation to work with for now.

Despite the failure to reduce the design to a single integrated circuit, the complexity of the writing is still somewhat reduced compared to the first iteration. The 10 ohm resistance is not ideal but should be workable. The arduino and breadboards have proven finicky enough as is so given we have a functional relatively high-current device we are not making further changes at this point in the project. It is the team’s recommendation that in the future someone with formal electrical engineering training is brought on to work on the potentiostat, because our experience so far has shown that what is nominally simple circuitry can experience many subtle complications.

### 4.2 Electrodes

Discussion with Professor Baranova, an electrochemistry professor at the University of Ottawa, informed us that a graphite anode would NOT be stable, since it would react over time with the oxygen evolved at that electrode. However, she informed us that in a basic environment (as the electroplating solution would be due to ammonium chloride being present, or baking soda solution) common iron is stable and can be used for an inert anode. Initially the team intended to use a sewing needle as the anode, but a more practical option was found: The 3D printer included a long needle-like tool intended for clearing out the extruder on the printer’s hot end. Its length with a wider section at the base made it ideal for adaptation to use as the anode.

For the cathode, we obtained a rectangular plate of copper metal (dimensions: 7.5 cm by 9 cm) - the idea initially was that due to its color nickel plating would be clearly visible on it, but will not come to pass before design day. We wanted the plate to lie flat on the basin bed, which precluding attaching it with an alligator clip. Instead a cut wire was stripped of its insulation and the individual copper strands spread out. These were flattened onto a corner of the plate and duct taped down. We wanted to waterproof the tape. Any sort of proper waterproofing coating not being available, we covered it with candle wax instead. A future design will need a proper epoxy coating or such, but but is uncertain if that can be achieved before this semester ends. The current cathode is shown in figure ####

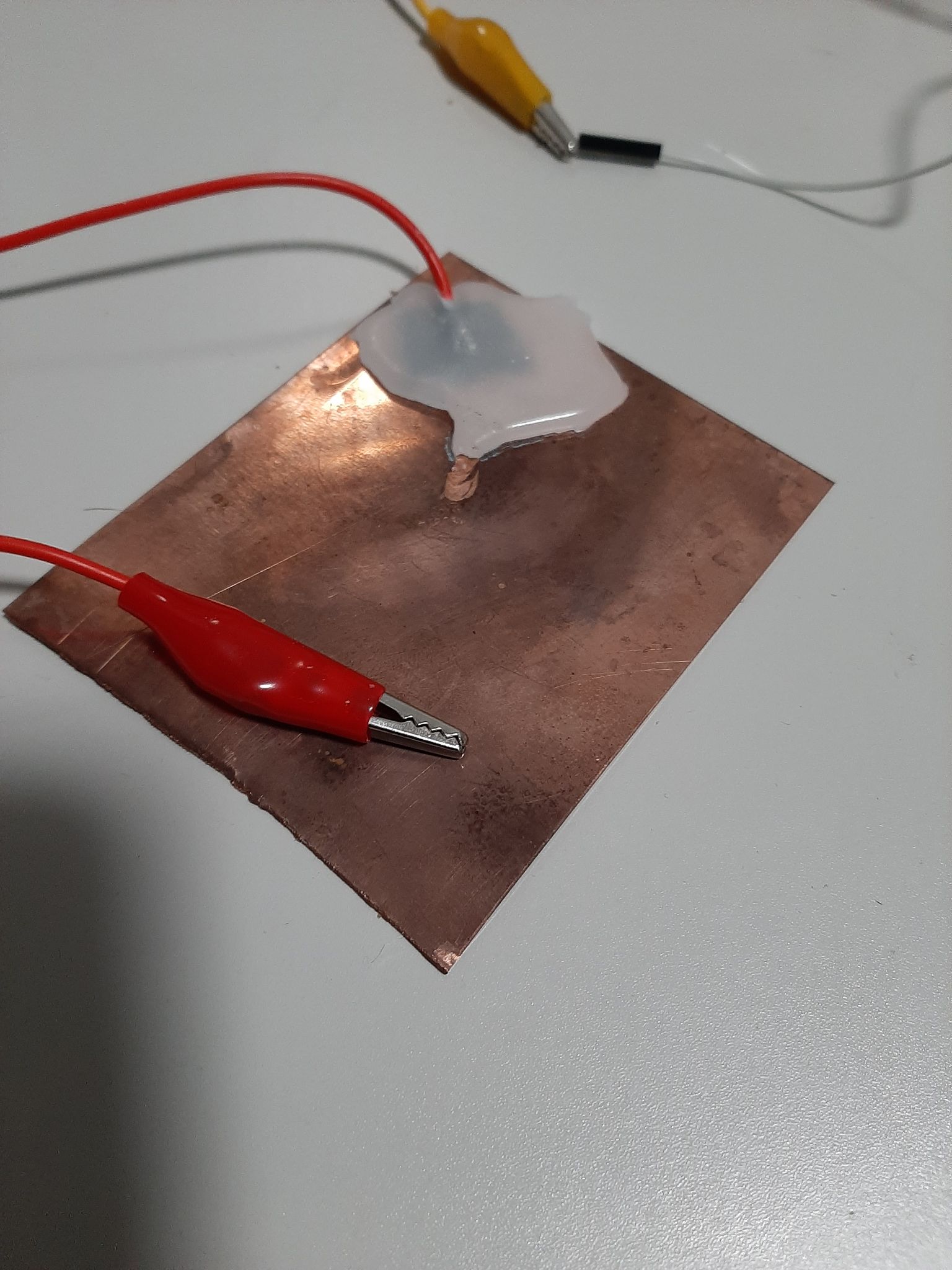


figure ####: Cathode plate

# Movement Testing

The movement testing of the 3D printer has been difficult due to a lack of testing equipment for this particular machine. One of the assumptions being made in the movement testing is that the machine code is largely accurate, and that when the machine is moving 1 mm, that this is an accurate assumption. While this may be true of the XY movement, this assumption did not hold up when modifying the Z-movement, which will be discussed further in the next section. The testing for the movement has primarily been qualitative with very little quantitative data, besides those found in the code themselves.

### Z-Axis Precision

The Z-axis precision has not been determined yet due to the issue above with the machine screw. A test was derived for this, which was to visualize each layer being printed on a webcam, and then use a background to measure the movement of the printer, but this is primarily helpful for large movements. The “step” of the printer has a minimum distance of 0.06 mm which is nearly impossible to visualize with the cameras we had available. The only way to “measure” this was to utilize a single-layer test print (such as the one the team used in the final print), and to test the width of the print itself, but this became difficult due to the uneven bed leveling that was spoken about in the previous report. The Z-axis precision is nominally 0.06 mm, but due to slip in the screw and inaccurate bed leveling, this can not be confirmed.

### Print Speed

The print speed was discussed in the last section, and thus will be kept brief. The print speed is still overridden by the firmware in the printer that takes any value below its minimum as a “default”, but as discussed above in the modification of the Gcode, this can be circumvented. Effectively, the printer has a minimum step similar to that of the Z-axis of 0.06 mm, but this is usually not used due to the printer being run continuously. With the modifications intended for the Gcode, the print speed would be unimportant to the outcome of the project, and instead this print precision would dominate because of the pause feature that has been implemented in the Gcode. As such there will need to be further testing the week before design day to fully understand how this can affect the print, but nominally the print precision is 0.06 mm, with the print speed becoming a non-factor due to changes in our process.

# Electroplating Testing

### Bed Heating

Due to a lack of thermistor or thermocouples that the team could quickly access this has not been performed as of this date. We expect that the heating elements on the electroplating should not have a large impact on the overall performance, but the testing will be performed the Thursday before design day to ensure that any unforeseen events do not hamper the prototypes ability to function.

### “plating” geometry investigation

As the whole aim of this project was to localize the electrodeposition of nickel, before the potentiostat was attached to the 3D printer a stand-alone test of the bath was performed with the anode position hand-controlled. The aim was to determine what area the current would spread over. Done in baking soda solution, current flow would be indicated by bubble formation (oxygen at the anode, hydrogen at the cathode). As preliminary testing had shown oxygen bubbles to be larger and more visible, for this test the electrodes were wired “backwards” (the plate serving as the anode and a needle as the cathode). A photograph of this is shown in figure ####

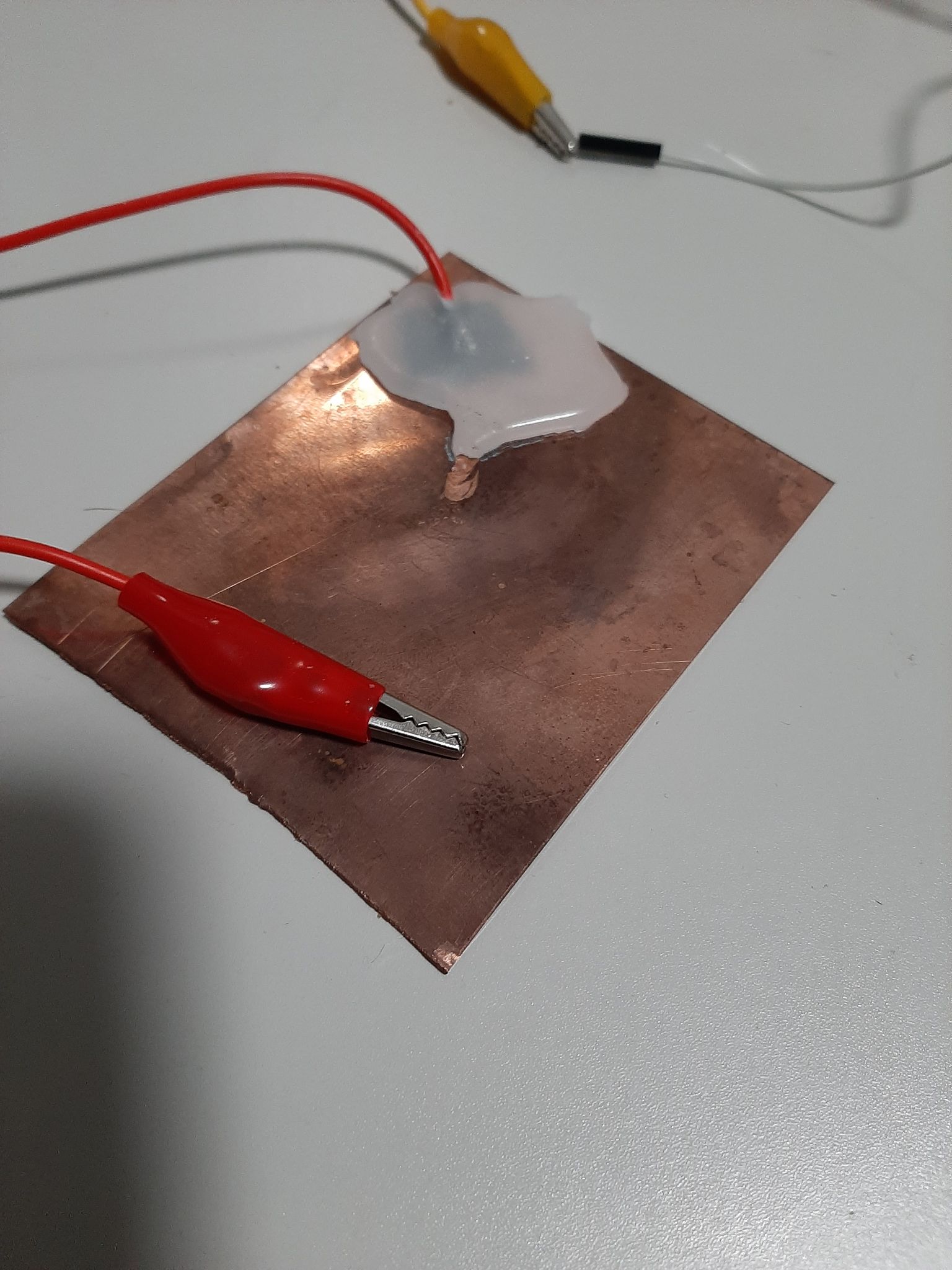


Figure ####: Spread of bubbles on the cathode plate

The results were not good. Even with the needle held a very short distance from the plate, bubbles were spread across an area of more than a square centimeter. With the potentiostat’s current limits, achieving the needed current density of 2 A/cm would be impossible under these conditions. Our hypothesis is that the electric field spreads out from the sides of the needle, not just the tip, so if a substantial length of the needle is submerged it allows the current to be spread across a wide area. Since a very shallow bath with the plate just below the surface was judged impractical, the best solution would be to insulate the anode except for its tip. This is not a trivial matter since whatever material the insulation would be will need to be compatible with the electroplating solution.

# System Testing

The systems testing for this has utilized the Gcode below, and was run without any issue. The Gcode has been modified, as a 20 mm increase in the Z-axis was not enough room to change out the electroplating sample, but this has been increased to 50 mm. The overall systems testing was a resounding success as the printer itself worked as expected. The only further systems testing to be conducted will be the utilization of the pause feature after every point to ensure that the printer can slow down enough to allow for electroplating to happen. This will be completed Thursday alongside the bed heating testing.

### Simple Test Print

The test print worked as expected utilizing the Gcode provided. The anode holder had several malfunctions with it and had to be additionally secured using tape, but a new anode holder has been printed and will be added in for design day. The Gcode itself performed well, stopping both before and after the print to ensure enough time to retract the counter-electrode before the print head moved. This has been modified to 50 mm instead of 20 mm, but this change is minor. The actual method of creating a test print is still rather tedious and will require extraordinary work from a software or hardware engineer to create a satisfying user interface that can modify the Gcode correctly. Electrochemically, the bath worked with hydrogen bubble formation on the cathode plate following the movement of the anode. But as mentioned above, the current was not localized to a tight area.

# Conclusions and Recommendations for Future Work

The function of the printer has been realized, and it is able to now confidently use the printer’s movement systems to transport a counter electrode across a piece to be plated. As of now, the prototype is in its infancy, there are several problems with it that are likely not to be solved immediately within this prototype. Specifically, the most important is an express way for the user to modify the Gcode in a meaningful way without needing a background in hardware to understand it. The user manual will try to alleviate these problems to the best of its ability, but a new solution must be found. There is also the matter of the Z-axis screw and the largely unknown precision of the printer itself. Both of these issues will require more in depth testing to be conducted, and a more accurate measurement device to be purchased by the next team, with potentially replacing the Z-axis unit entirely or in pieces. Another large concern from an accuracy standpoint is two-fold. Firstly, this prototype has never been tested with an electroplating solution, and has been solely tested using a hydrolysis reaction. The team does not expect this to be a huge problem, though there will be safety concerns given the open design of the model. These could be alleviated by looking at designs that SLA printers utilize to protect against resin fumes and resin toxicity. The other side is the uninsulated counter electrode that the team has been using. This creates a large area where the plating takes place instead of a precise one, which is an issue when it comes to further prototypes. How and what this insulation will be made of or attached to is unknown to this team, and as such it is considered outside the scope given the approaching design day. This will have to be considered in the future for any viable prototype to accurately print. The potentiostat has also been found to be more limited in its current draw than was expected. Overall though, this prototype has set out to do exactly what the team has intended, and a viable prototype is ready to be cleaned up, and presented during design day.

# Bibliography

[1]

# APPENDICES

## Arduino code

Current stability investigation

#define outputV 4.0

int output, value;

float outCurrent;

void setup() {

// put your setup code here, to run once:

Serial.begin(9600);

pinMode(6, OUTPUT);

}

void loop() {

output = (outputV/5)\*255;

analogWrite(6,output);

value = analogRead(A1);

outCurrent = 1000\*(value/1023.0)\*0.5; //writing the .0 forces it into float rather than integer division

Serial.print(outCurrent);

Serial.print(" mA, at ");

Serial.print(outputV);

Serial.println(" V");

//Serial.println(value); //for debugging

delay(500);

}

Resistor polarization curve

#define outputPin 6

float volts, outCurrent;

int output, input;

void setup() {

// put your setup code here, to run once:

Serial.begin(9600);

pinMode(outputPin, OUTPUT);

Serial.println("potential(V);current(A)");

}

void loop() {

// put your main code here, to run repeatedly:

for(volts = 0; volts <5; volts=volts+0.1)

{output = (volts/5)\*255;

analogWrite(outputPin,output);

delay(100);

input = analogRead(A1);

outCurrent =(input/1023.0)\*0.5; //writing the .0 forces it into float rather than integer division

Serial.print(volts);

Serial.print(";");

Serial.println(outCurrent,5); //print to 5 decimal places

}

Serial.println("end");

delay(10000); //gives time to stop and unplug

}

simple electrolysis

#define outputV 3.0

int output, value, n;

float outCurrent, averageI ;

void setup() {

// put your setup code here, to run once:

Serial.begin(9600);

pinMode(6, OUTPUT);

averageI = 0;

n = 1;

}

void loop() {

output = (outputV/5)\*255;

analogWrite(6,output);

value = analogRead(A1);

outCurrent = 1000\*(value/1023.0)\*0.5; //writing the .0 forces it into float rather than integer division

averageI = (averageI\*(n-1)+outCurrent)/n;

n++;

Serial.print(outCurrent);

Serial.print(" mA, at ");

Serial.print(outputV);

Serial.println(" V");

if(n%10==0)//only print the average every to measurements, less to edit

{Serial.print("moving average is ");

Serial.println(averageI);}

//Serial.println(value);

delay(500);

}

## Gcode

M190 S40.000000

M109 S40.000000

;Sliced at: Sun 20-03-2022 10:21:01

;Basic settings: Layer height: 0.06 Walls: 1.2 Fill: 40

;Print time: 7 minutes

;Filament used: 0.022m 0.0g

;Filament cost: None

;M190 S40 ;Uncomment to add your own bed temperature line

;M109 S40 ;Uncomment to add your own temperature line

G21 ;metric values

G90 ;absolute positioning

M82 ;set extruder to absolute mode

M107 ;start with the fan off

G28 X0 Y0 ;move X/Y to min endstops

G28 Z0 ;move Z to min endstops

G1 Z15.0 F6000 ;move the platform down 15mm

G92 E0 ;zero the extruded length

G1 F200 E3 ;extrude 3mm of feed stock

G92 E0 ;zero the extruded length again

G1 F6000

;Put printing message on LCD screen

M117 Printing...

;Layer count: 1

;LAYER:0

G0 F6000 X97.400 Y97.400 Z40.000 ;Additional Raising Gives Time to Set Up Electroplating

M0 Click to continue ;Only Click after Electroplating has been set up.

;TYPE:SKIRT

G0 F6000 X97.400 Y97.400 Z0.300

G1 F60 X122.600 Y97.400 E1.25723

G1 X122.600 Y122.600 E2.51447

G1 X97.400 Y122.600 E3.77170

G1 X97.400 Y97.400 E5.02893

G0 F6000 X97.800 Y97.800

G1 F60 X122.200 Y97.800 E6.24625

G1 X122.200 Y122.200 E7.46357

G1 X97.800 Y122.200 E8.68090

G1 X97.800 Y97.800 E9.89822

G1 F4800 E3.89822

G0 F6000 X101.600 Y101.600

;TYPE:WALL-INNER

G1 F4800 E9.89822

G1 F60 X102.400 Y101.600 E9.93813

G1 X102.400 Y102.400 E9.97804

G1 X101.600 Y102.400 E10.01795

G1 X101.600 Y101.600 E10.05786

G0 F6000 X101.200 Y101.200

;TYPE:WALL-OUTER

G1 F60 X102.800 Y101.200 E10.13769

G1 X102.800 Y102.800 E10.21751

G1 X101.200 Y102.800 E10.29734

G1 X101.200 Y101.200 E10.37716

G0 F6000 X102.198 Y102.198

G1 F4800 E4.37716

G0 F6000 X102.400 Y105.600

;TYPE:WALL-INNER

G1 F4800 E10.37716

G1 F60 X102.400 Y106.400 E10.41707

G1 X101.600 Y106.400 E10.45699

G1 X101.600 Y105.600 E10.49690

G1 X102.400 Y105.600 E10.53681

G0 F6000 X102.800 Y105.200

;TYPE:WALL-OUTER

G1 F60 X102.800 Y106.800 E10.61664

G1 X101.200 Y106.800 E10.69646

G1 X101.200 Y105.200 E10.77628

G1 X102.800 Y105.200 E10.85611

G0 F6000 X102.260 Y105.795

;TYPE:FILL

G1 F60 X102.203 Y105.739 E10.86009

G1 F4800 E4.86009

G0 F6000 X102.400 Y109.600

;TYPE:WALL-INNER

G1 F4800 E10.86009

G1 F60 X102.400 Y110.400 E10.90001

G1 X101.600 Y110.400 E10.93992

G1 X101.600 Y109.600 E10.97983

G1 X102.400 Y109.600 E11.01974

G0 F6000 X102.800 Y109.200

;TYPE:WALL-OUTER

G1 F60 X102.800 Y110.800 E11.09957

G1 X101.200 Y110.800 E11.17939

G1 X101.200 Y109.200 E11.25922

G1 X102.800 Y109.200 E11.33904

G0 F6000 X102.260 Y110.038

;TYPE:FILL

G1 F60 X101.961 Y109.739 E11.36014

G1 F4800 E5.36014

G0 F6000 X101.600 Y113.600

;TYPE:WALL-INNER

G1 F4800 E11.36014

G1 F60 X102.400 Y113.600 E11.40005

G1 X102.400 Y114.400 E11.43996

G1 X101.600 Y114.400 E11.47987

G1 X101.600 Y113.600 E11.51979

G0 F6000 X101.200 Y113.200

;TYPE:WALL-OUTER

G1 F60 X102.800 Y113.200 E11.59961

G1 X102.800 Y114.800 E11.67943

G1 X101.200 Y114.800 E11.75926

G1 X101.200 Y113.200 E11.83908

G0 F6000 X101.739 Y113.760

;TYPE:FILL

G1 F60 X102.238 Y114.259 E11.87429

G1 F4800 E5.87429

G0 F6000 X102.400 Y117.599

;TYPE:WALL-INNER

G1 F4800 E11.87429

G1 F60 X102.400 Y118.400 E11.91425

G1 X101.600 Y118.400 E11.95416

G1 X101.600 Y117.599 E11.99413

G1 X102.400 Y117.599 E12.03404

G0 F6000 X102.800 Y117.199

;TYPE:WALL-OUTER

G1 F60 X102.800 Y118.800 E12.11391

G1 X101.200 Y118.800 E12.19374

G1 X101.200 Y117.199 E12.27361

G1 X102.800 Y117.199 E12.35344

G0 F6000 X101.995 Y118.259

;TYPE:FILL

G1 F60 X101.739 Y118.003 E12.37150

G1 F4800 E6.37150

G0 F6000 X105.600 Y118.400

;TYPE:WALL-INNER

G1 F4800 E12.37150

G1 F60 X105.600 Y117.599 E12.41146

G1 X106.400 Y117.599 E12.45137

G1 X106.400 Y118.400 E12.49133

G1 X105.600 Y118.400 E12.53125

G0 F6000 X105.200 Y118.800

;TYPE:WALL-OUTER

G1 F60 X105.200 Y117.199 E12.61112

G1 X106.800 Y117.199 E12.69094

G1 X106.800 Y118.800 E12.77082

G1 X105.200 Y118.800 E12.85064

G0 F6000 X106.237 Y118.258

;TYPE:FILL

G1 F60 X105.740 Y117.760 E12.88574

G1 F4800 E6.88574

G0 F6000 X105.600 Y114.400

;TYPE:WALL-INNER

G1 F4800 E12.88574

G1 F60 X105.600 Y113.600 E12.92566

G1 X106.400 Y113.600 E12.96557

G1 X106.400 Y114.400 E13.00548

G1 X105.600 Y114.400 E13.04539

G0 F6000 X105.200 Y114.800

;TYPE:WALL-OUTER

G1 F60 X105.200 Y113.200 E13.12522

G1 X106.800 Y113.200 E13.20504

G1 X106.800 Y114.800 E13.28487

G1 X105.200 Y114.800 E13.36469

G0 F6000 X106.260 Y114.038

;TYPE:FILL

G1 F60 X105.961 Y113.739 E13.38579

G1 F4800 E7.38579

G0 F6000 X109.600 Y113.600

;TYPE:WALL-INNER

G1 F4800 E13.38579

G1 F60 X110.399 Y113.600 E13.42565

G1 X110.399 Y114.400 E13.46556

G1 X109.600 Y114.400 E13.50542

G1 X109.600 Y113.600 E13.54534

G0 F6000 X109.200 Y113.200

;TYPE:WALL-OUTER

G1 F60 X110.799 Y113.200 E13.62511

G1 X110.799 Y114.800 E13.70493

G1 X109.200 Y114.800 E13.78471

G1 X109.200 Y113.200 E13.86453

G0 F6000 X110.198 Y114.198

G1 F4800 E7.86453

G0 F6000 X110.399 Y117.599

;TYPE:WALL-INNER

G1 F4800 E13.86453

G1 F60 X110.399 Y118.400 E13.90449

G1 X109.600 Y118.400 E13.94436

G1 X109.600 Y117.599 E13.98432

G1 X110.399 Y117.599 E14.02418

G0 F6000 X110.799 Y117.199

;TYPE:WALL-OUTER

G1 F60 X110.799 Y118.800 E14.10406

G1 X109.200 Y118.800 E14.18383

G1 X109.200 Y117.199 E14.26370

G1 X110.799 Y117.199 E14.34348

G0 F6000 X110.259 Y118.037

;TYPE:FILL

G1 F60 X109.960 Y117.738 E14.36457

G1 F4800 E8.36457

G0 F6000 X113.599 Y117.599

;TYPE:WALL-INNER

G1 F4800 E14.36457

G1 F60 X114.399 Y117.599 E14.40449

G1 X114.399 Y118.400 E14.44445

G1 X113.599 Y118.400 E14.48436

G1 X113.599 Y117.599 E14.52432

G0 F6000 X113.199 Y117.199

;TYPE:WALL-OUTER

G1 F60 X114.799 Y117.199 E14.60415

G1 X114.799 Y118.800 E14.68402

G1 X113.199 Y118.800 E14.76385

G1 X113.199 Y117.199 E14.84372

G0 F6000 X114.202 Y117.738

;TYPE:FILL

G1 F60 X114.259 Y117.794 E14.84771

G1 F4800 E8.84771

G0 F6000 X114.399 Y114.400

;TYPE:WALL-INNER

G1 F4800 E14.84771

G1 F60 X113.599 Y114.400 E14.88762

G1 X113.599 Y113.600 E14.92753

G1 X114.399 Y113.600 E14.96744

G1 X114.399 Y114.400 E15.00736

G0 F6000 X114.799 Y114.800

;TYPE:WALL-OUTER

G1 F60 X113.199 Y114.800 E15.08718

G1 X113.199 Y113.200 E15.16700

G1 X114.799 Y113.200 E15.24683

G1 X114.799 Y114.800 E15.32665

G0 F6000 X113.801 Y113.802

G1 F4800 E9.32665

G0 F6000 X117.599 Y113.600

;TYPE:WALL-INNER

G1 F4800 E15.32665

G1 F60 X118.400 Y113.600 E15.36661

G1 X118.400 Y114.400 E15.40653

G1 X117.599 Y114.400 E15.44649

G1 X117.599 Y113.600 E15.48640

G0 F6000 X117.199 Y113.200

;TYPE:WALL-OUTER

G1 F60 X118.800 Y113.200 E15.56628

G1 X118.800 Y114.800 E15.64610

G1 X117.199 Y114.800 E15.72597

G1 X117.199 Y113.200 E15.80580

G0 F6000 X117.738 Y114.202

;TYPE:FILL

G1 F60 X117.795 Y114.259 E15.80982

G1 F4800 E9.80982

G0 F6000 X117.599 Y117.599

;TYPE:WALL-INNER

G1 F4800 E15.80982

G1 F60 X118.400 Y117.599 E15.84978

G1 X118.400 Y118.400 E15.88974

G1 X117.599 Y118.400 E15.92971

G1 X117.599 Y117.599 E15.96967

G0 F6000 X117.199 Y117.199

;TYPE:WALL-OUTER

G1 F60 X118.800 Y117.199 E16.04954

G1 X118.800 Y118.800 E16.12942

G1 X117.199 Y118.800 E16.20929

G1 X117.199 Y117.199 E16.28916

G0 F6000 X118.197 Y118.197

G1 F4800 E10.28916

G0 F6000 X118.400 Y110.400

;TYPE:WALL-INNER

G1 F4800 E16.28916

G1 F60 X117.599 Y110.400 E16.32913

G1 X117.599 Y109.600 E16.36904

G1 X118.400 Y109.600 E16.40900

G1 X118.400 Y110.400 E16.44891

G0 F6000 X118.800 Y110.800

;TYPE:WALL-OUTER

G1 F60 X117.199 Y110.800 E16.52879

G1 X117.199 Y109.200 E16.60861

G1 X118.800 Y109.200 E16.68849

G1 X118.800 Y110.800 E16.76831

G0 F6000 X118.038 Y110.259

;TYPE:FILL

G1 F60 X117.738 Y109.960 E16.78944

G1 F4800 E10.78944

G0 F6000 X114.399 Y109.600

;TYPE:WALL-INNER

G1 F4800 E16.78944

G1 F60 X114.399 Y110.400 E16.82935

G1 X113.599 Y110.400 E16.86927

G1 X113.599 Y109.600 E16.90918

G1 X114.399 Y109.600 E16.94909

G0 F6000 X114.799 Y109.200

;TYPE:WALL-OUTER

G1 F60 X114.799 Y110.800 E17.02891

G1 X113.199 Y110.800 E17.10874

G1 X113.199 Y109.200 E17.18856

G1 X114.799 Y109.200 E17.26839

G0 F6000 X113.795 Y110.259

;TYPE:FILL

G1 F60 X113.738 Y110.202 E17.27241

G1 F4800 E11.27241

G0 F6000 X110.399 Y110.400

;TYPE:WALL-INNER

G1 F4800 E17.27241

G1 F60 X109.600 Y110.400 E17.31227

G1 X109.600 Y109.600 E17.35218

G1 X110.399 Y109.600 E17.39205

G1 X110.399 Y110.400 E17.43196

G0 F6000 X110.799 Y110.800

;TYPE:WALL-OUTER

G1 F60 X109.200 Y110.800 E17.51173

G1 X109.200 Y109.200 E17.59156

G1 X110.799 Y109.200 E17.67133

G1 X110.799 Y110.800 E17.75116

G0 F6000 X109.801 Y109.802

G1 F4800 E11.75116

G0 F6000 X106.400 Y109.600

;TYPE:WALL-INNER

G1 F4800 E17.75116

G1 F60 X106.400 Y110.400 E17.79107

G1 X105.600 Y110.400 E17.83098

G1 X105.600 Y109.600 E17.87089

G1 X106.400 Y109.600 E17.91080

G0 F6000 X106.800 Y109.200

;TYPE:WALL-OUTER

G1 F60 X106.800 Y110.800 E17.99063

G1 X105.200 Y110.800 E18.07045

G1 X105.200 Y109.200 E18.15028

G1 X106.800 Y109.200 E18.23010

G0 F6000 X106.260 Y109.796

;TYPE:FILL

G1 F60 X106.203 Y109.739 E18.23412

G1 F4800 E12.23412

G0 F6000 X106.400 Y106.400

;TYPE:WALL-INNER

G1 F4800 E18.23412

G1 F60 X105.600 Y106.400 E18.27404

G1 X105.600 Y105.600 E18.31395

G1 X106.400 Y105.600 E18.35386

G1 X106.400 Y106.400 E18.39377

G0 F6000 X106.800 Y106.800

;TYPE:WALL-OUTER

G1 F60 X105.200 Y106.800 E18.47360

G1 X105.200 Y105.200 E18.55342

G1 X106.800 Y105.200 E18.63324

G1 X106.800 Y106.800 E18.71307

G0 F6000 X105.802 Y105.802

G1 F4800 E12.71307

G0 F6000 X109.600 Y105.600

;TYPE:WALL-INNER

G1 F4800 E18.71307

G1 F60 X110.399 Y105.600 E18.75293

G1 X110.399 Y106.400 E18.79284

G1 X109.600 Y106.400 E18.83271

G1 X109.600 Y105.600 E18.87262

G0 F6000 X109.200 Y105.200

;TYPE:WALL-OUTER

G1 F60 X110.799 Y105.200 E18.95239

G1 X110.799 Y106.800 E19.03222

G1 X109.200 Y106.800 E19.11199

G1 X109.200 Y105.200 E19.19182

G0 F6000 X109.739 Y106.203

;TYPE:FILL

G1 F60 X109.796 Y106.260 E19.19584

G1 F4800 E13.19584

G0 F6000 X113.599 Y106.400

;TYPE:WALL-INNER

G1 F4800 E19.19584

G1 F60 X113.599 Y105.600 E19.23575

G1 X114.399 Y105.600 E19.27566

G1 X114.399 Y106.400 E19.31557

G1 X113.599 Y106.400 E19.35549

G0 F6000 X113.199 Y106.800

;TYPE:WALL-OUTER

G1 F60 X113.199 Y105.200 E19.43531

G1 X114.799 Y105.200 E19.51513

G1 X114.799 Y106.800 E19.59496

G1 X113.199 Y106.800 E19.67478

G0 F6000 X114.037 Y106.259

;TYPE:FILL

G1 F60 X113.738 Y105.959 E19.69591

G1 F4800 E13.69591

G0 F6000 X117.599 Y105.600

;TYPE:WALL-INNER

G1 F4800 E19.69591

G1 F60 X118.400 Y105.600 E19.73588

G1 X118.400 Y106.400 E19.77579

G1 X117.599 Y106.400 E19.81575

G1 X117.599 Y105.600 E19.85566

G0 F6000 X117.199 Y105.200

;TYPE:WALL-OUTER

G1 F60 X118.800 Y105.200 E19.93554

G1 X118.800 Y106.800 E20.01536

G1 X117.199 Y106.800 E20.09524

G1 X117.199 Y105.200 E20.17506

G0 F6000 X117.760 Y105.740

;TYPE:FILL

G1 F60 X118.259 Y106.238 E20.21023

G1 F4800 E14.21023

G0 F6000 X118.400 Y102.400

;TYPE:WALL-INNER

G1 F4800 E20.21023

G1 F60 X117.599 Y102.400 E20.25019

G1 X117.599 Y101.600 E20.29011

G1 X118.400 Y101.600 E20.33007

G1 X118.400 Y102.400 E20.36998

G0 F6000 X118.800 Y102.800

;TYPE:WALL-OUTER

G1 F60 X117.199 Y102.800 E20.44985

G1 X117.199 Y101.200 E20.52968

G1 X118.800 Y101.200 E20.60955

G1 X118.800 Y102.800 E20.68938

G0 F6000 X118.259 Y101.995

;TYPE:FILL

G1 F60 X118.003 Y101.739 E20.70744

G1 F4800 E14.70744

G0 F6000 X114.399 Y101.600

;TYPE:WALL-INNER

G1 F4800 E20.70744

G1 F60 X114.399 Y102.400 E20.74735

G1 X113.599 Y102.400 E20.78726

G1 X113.599 Y101.600 E20.82718

G1 X114.399 Y101.600 E20.86709

G0 F6000 X114.799 Y101.200

;TYPE:WALL-OUTER

G1 F60 X114.799 Y102.800 E20.94691

G1 X113.199 Y102.800 E21.02674

G1 X113.199 Y101.200 E21.10656

G1 X114.799 Y101.200 E21.18639

G0 F6000 X114.258 Y102.237

;TYPE:FILL

G1 F60 X113.760 Y101.739 E21.22152

G1 F4800 E15.22152

G0 F6000 X110.399 Y101.600

;TYPE:WALL-INNER

G1 F4800 E21.22152

G1 F60 X110.399 Y102.400 E21.26143

G1 X109.600 Y102.400 E21.30130

G1 X109.600 Y101.600 E21.34121

G1 X110.399 Y101.600 E21.38107

G0 F6000 X110.799 Y101.200

;TYPE:WALL-OUTER

G1 F60 X110.799 Y102.800 E21.46090

G1 X109.200 Y102.800 E21.54067

G1 X109.200 Y101.200 E21.62049

G1 X110.799 Y101.200 E21.70027

G0 F6000 X110.037 Y102.259

;TYPE:FILL

G1 F60 X109.738 Y101.960 E21.72136

G1 F4800 E15.72136

G0 F6000 X106.400 Y101.600

;TYPE:WALL-INNER

G1 F4800 E21.72136

G1 F60 X106.400 Y102.400 E21.76128

G1 X105.600 Y102.400 E21.80119

G1 X105.600 Y101.600 E21.84110

G1 X106.400 Y101.600 E21.88101

G0 F6000 X106.800 Y101.200

;TYPE:WALL-OUTER

G1 F60 X106.800 Y102.800 E21.96084

G1 X105.200 Y102.800 E22.04066

G1 X105.200 Y101.200 E22.12049

G1 X106.800 Y101.200 E22.20031

G0 F6000 X105.802 Y102.198

M107

G1 F4800 E16.20031

G0 F6000 X105.802 Y102.198 Z5.275

;End GCode

M104 S0 ;extruder heater off

M140 S0 ;heated bed heater off (if you have it)

G91 ;relative positioning

G1 E-1 F300 ;retract the filament a bit before lifting the nozzle, to release some of the pressure

G1 Z+50 E-5 X-20 Y-20 F6000 ;move Z up a bit and retract filament even more (Raised more for electroplating)

M0 Click to continue ;Remove Specimen During this time

G28 X0 Y0 ;move X/Y to min endstops, so the head is out of the way

M84 ;steppers off

G90 ;absolute positioning

M81