# UNIVERSAL CIRCUIT FABRICATOR

## UNIVERSITY of CENTRAL FLORIDA

# WHO IS UCF?

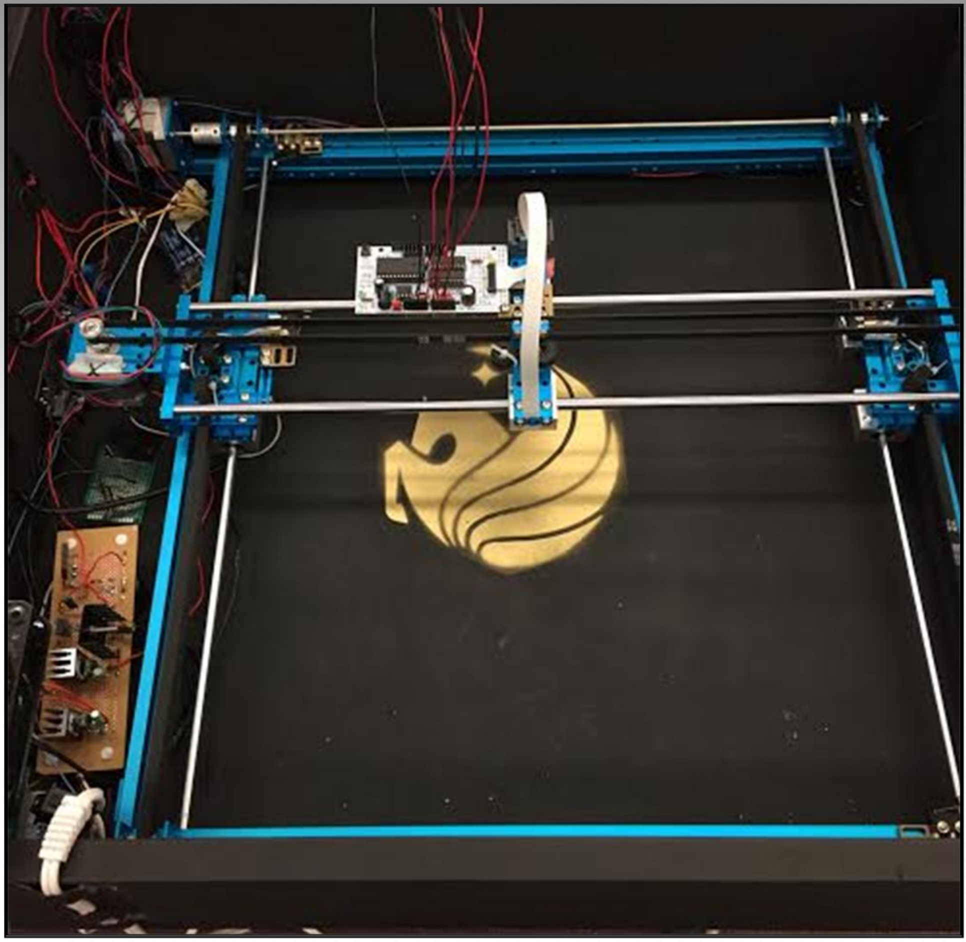
- Hector Melendez, EE
- Martin Dayuta, EE
- Kyle Scott, EE

GROUP 18

Sponsored by: BOEING

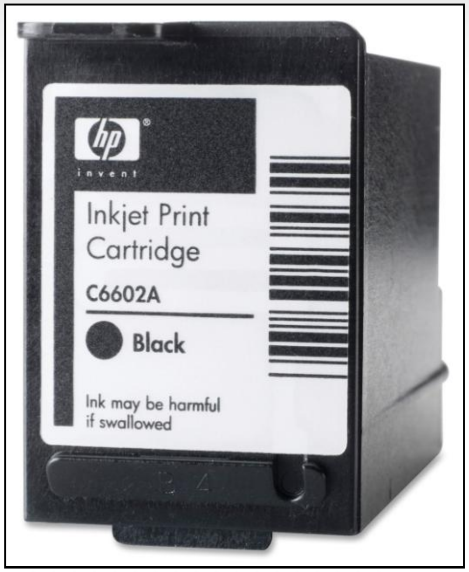
# GOALS AND OBJECTIVES

- The Universal Circuit Fabricator is a device that can print conductive ink traces on a nonconductive surface
- The goal is to allow a user to design a circuit schematic that is printed into a 2D ink trace
- The purpose is to help users prototype circuits without the use of a breadboard



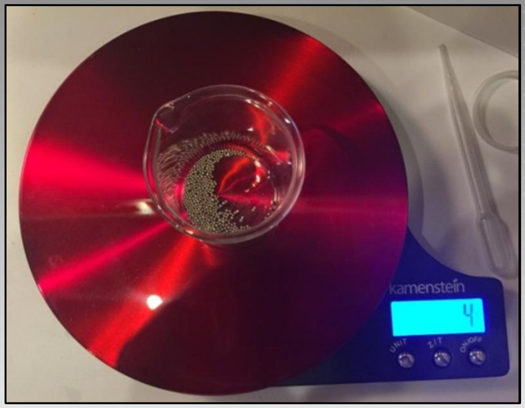
# CONDUCTIVE INK RESEARCH

- Conductive Ink Choices
  - The optimal ink formula was selected by choosing the ink with the best performance to price ratio, keeping in mind the importance of low resistivity (Ω•m)
  - Some of the conductive ink configurations require annealing to transform the ink into a finalized state.
    - Annealing is the process of heating a material and allowing it to cool down slowly in an effort to fuse the material into a continuous structure.
- Conductive Ink Design Requirements
  - The HP C6602 inkjet cartridge must be able to store the conductive ink without leaking.
  - The HP C6602 inkjet cartridge print head must be able to print a continuous line of conductive ink.
  - The conductive ink must cure to a solid finalized state

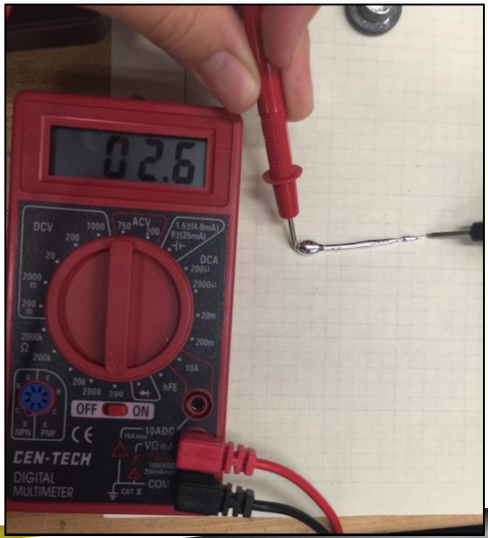


# GALLIUM-INDIUM INK

- 75.5% Gallium
- 24.5% Indium
- Heated to 50° C to fuse the elements into an alloy

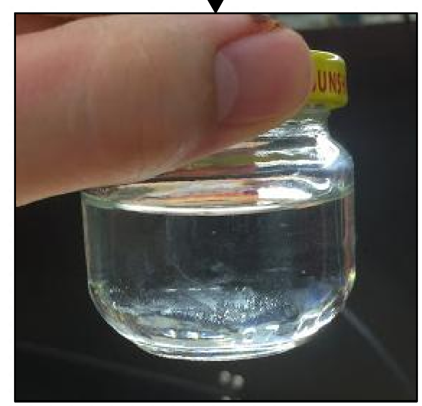



- The Gallium – Indium Ink is liquid at room temperature.The viscosity of the ink and its inability to cure at room temperature violates our design requirements.



# SILVER ACETATE INK

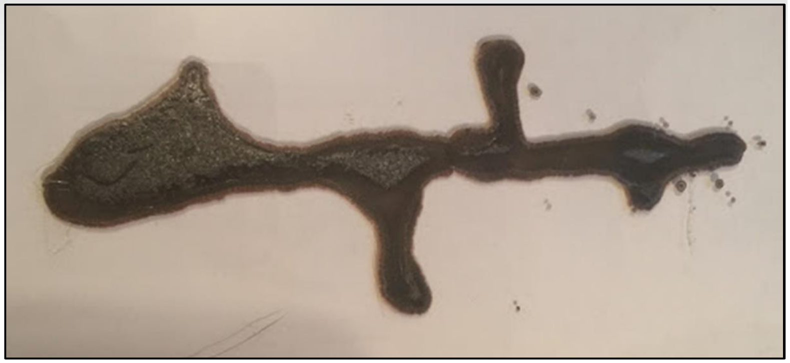
- 1g Silver Acetate
- 2.5ml Ammonia Hydroxide
- 0.2ml Formic Acid

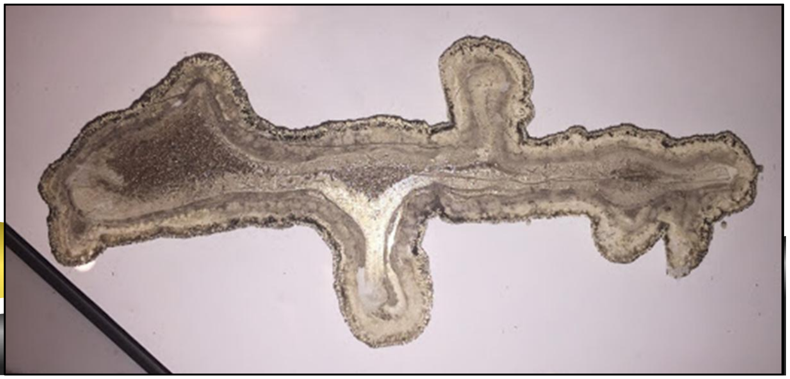


- Silver Acetate and Ammonia Hydroxide are combined using magnetic stir plate
- Formic Acid is added to solution drop by drop
- Solution is left to react overnight in air tight container
- Ink is filtered using 0.5 µm syringe filter to remove silver particles formed by premature reaction

# SILVER ACETATE INK

- As the clear ink dries, the ammonia evaporates and the formic acid reacts with the silver acetate to form elemental silver
- The Silver Acetate Ink is annealed by heating to 100°C forming a continuous conductive bond



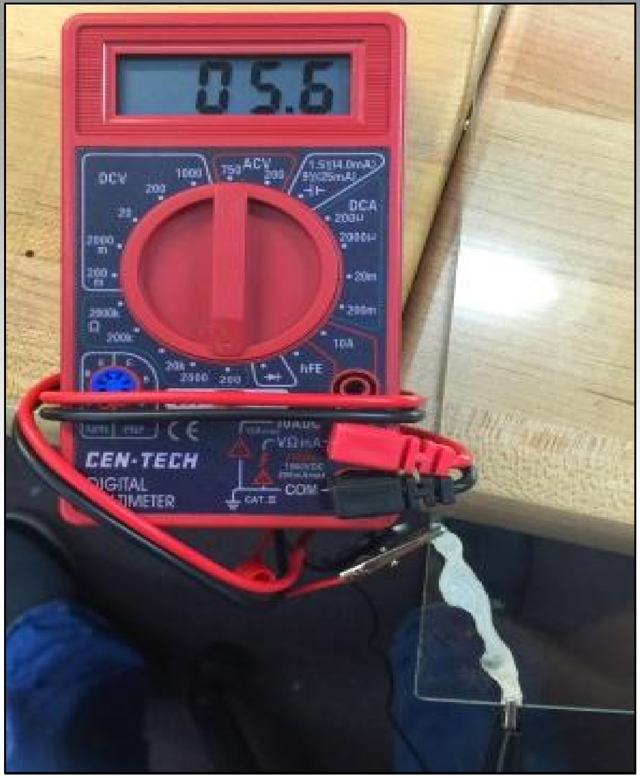


# ANNEALING TIME LAPSE

# CONDUCTIVE INK DECISION

We chose to use the Silver Acetate ink because:

- Silver Acetate ink is particle free and conducts electricity
- Silver Acetate ink is less expensive to produce than Gallium-Indium
- After annealing, the Silver Acetate is no longer viscous



# PRINT SUBSTRATE RESEARCH

- Printing Substrate Design Requirements:
- The substrate must be able to resist high temperatures (at least 100°C)
- The substrate must have a high resistivity (non-conductive)
- Low in cost

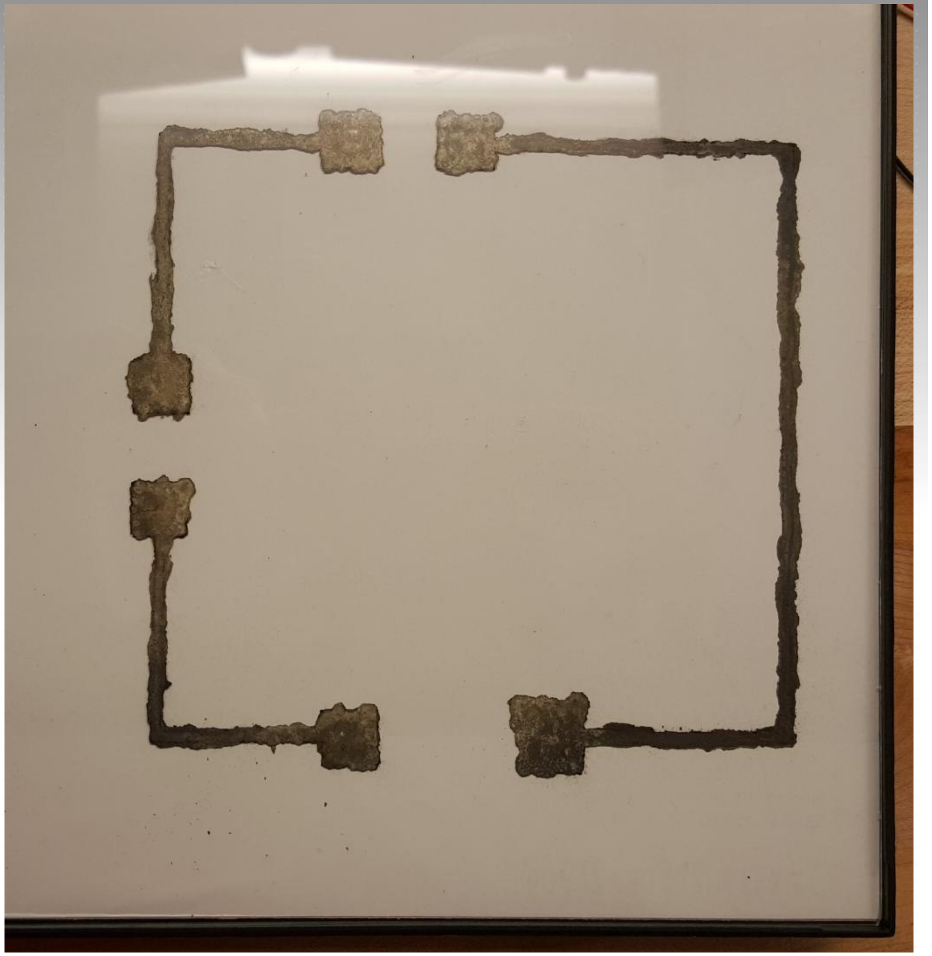
# PRINT SUBSTRATE OPTIONS

- Possible Substrate Choices:
  - Glass - A smooth surface that can withstand the annealing process. It provides a solid insulating surface for the conductive ink to adhere to without leakage current into the substrate
  - Acrylic Film – Similar properties of glass, less fragile, but less heat resistive. It can be flexible depending on the thickness.
  - PET transparency - Thermoplastic polyester film. Also known as Mylar® Film, which has a large range of uses. This polyester film is heat resistant up to 440°F, but a flexible substrate might crack the fused conductive ink traces

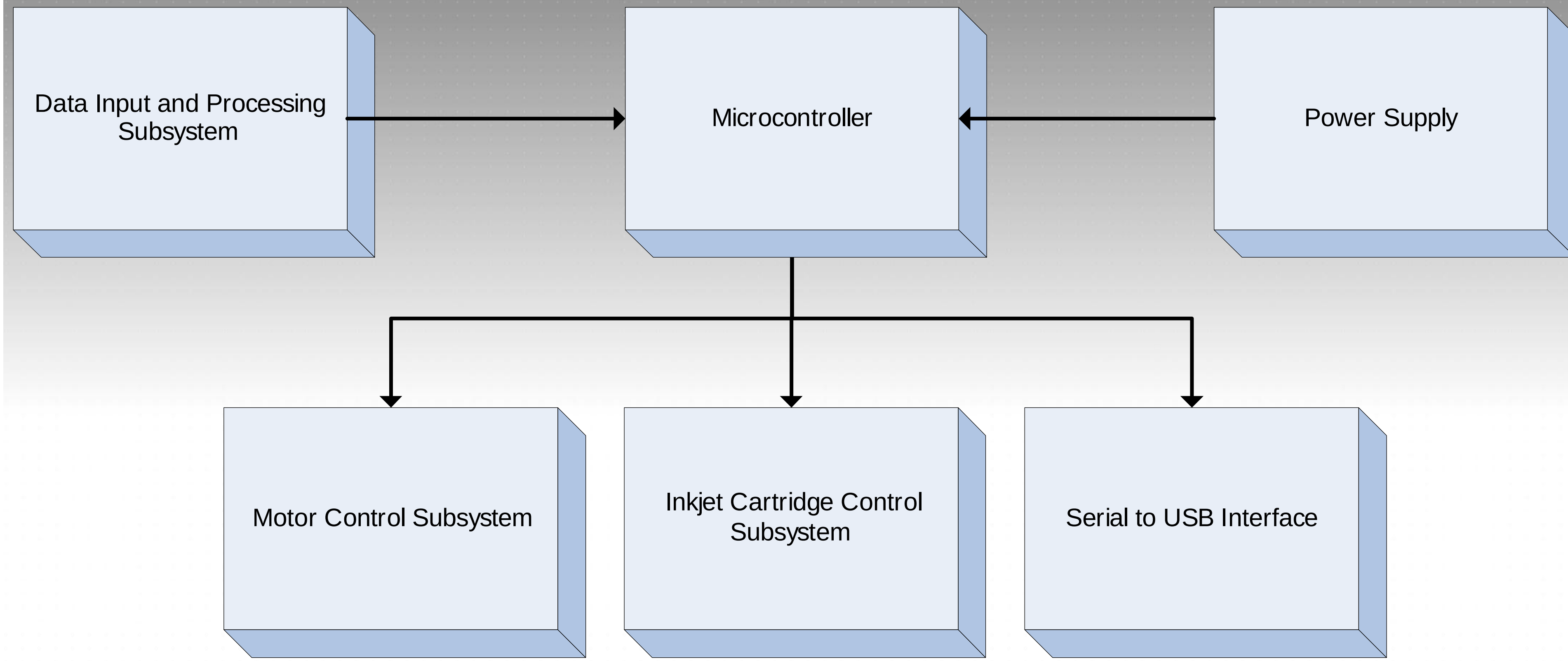
# PRINT SUBSTRATE DECISION

We chose to use Glass because:

- Glass can withstand the high temperatures of annealing
- Glass is rigid and inflexible providing a surface that will avoid cracking the solidified conductive ink



# UCF: System Block Diagram

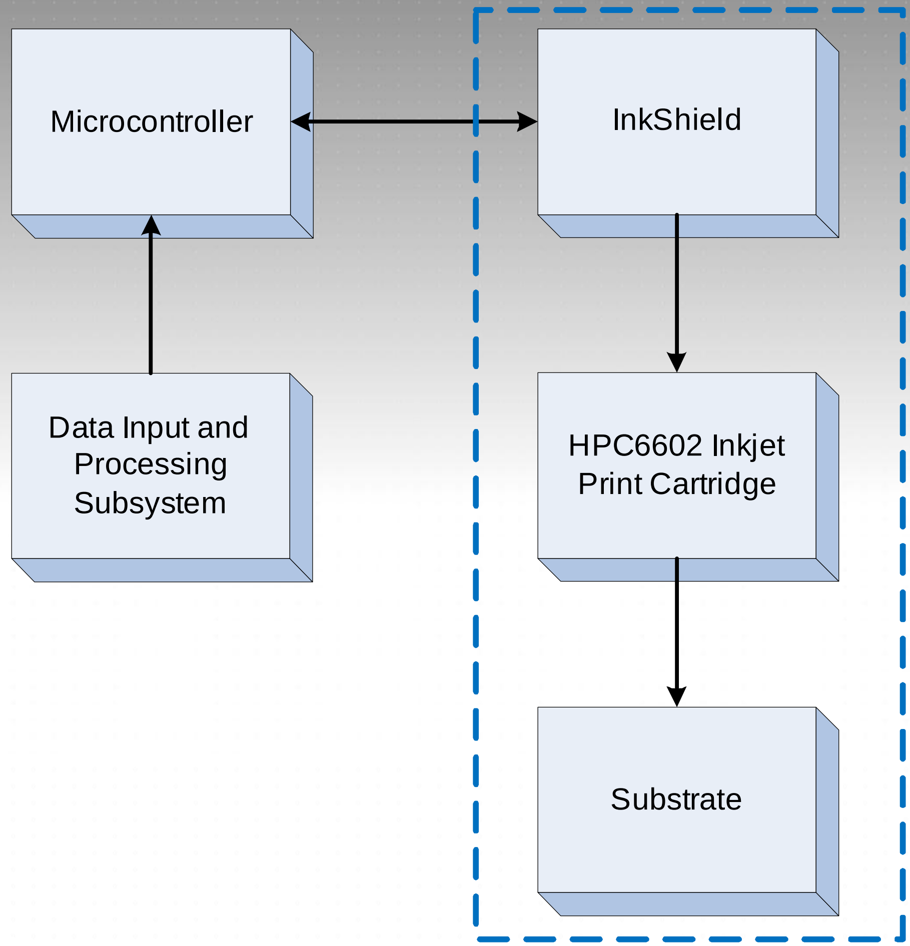


# INKJET CONTROL SYSTEM

presented by: Kyle Scott

# INKJET CARTRIDGE CONTROL SYSTEM

- Responsible for controlling the flow of conductive ink from the HP 6602 inkjet cartridge
- Microcontroller receives G-code commands from an input file to start and stop the flow of ink



# REQUIREMENTS & SPECIFICATIONS

## Printing Process

- The UCF has the ability to print continuous conductive traces with a maximum line thickness of 10 mm
- Conductive traces have a resistivity $\rho \leq 10^{-3}$ Ω•m
- The bed surface surface allows for a printing area of 10 by 10 inches.

$$\rho = \frac{E}{J} = R \cdot \frac{A}{l}$$

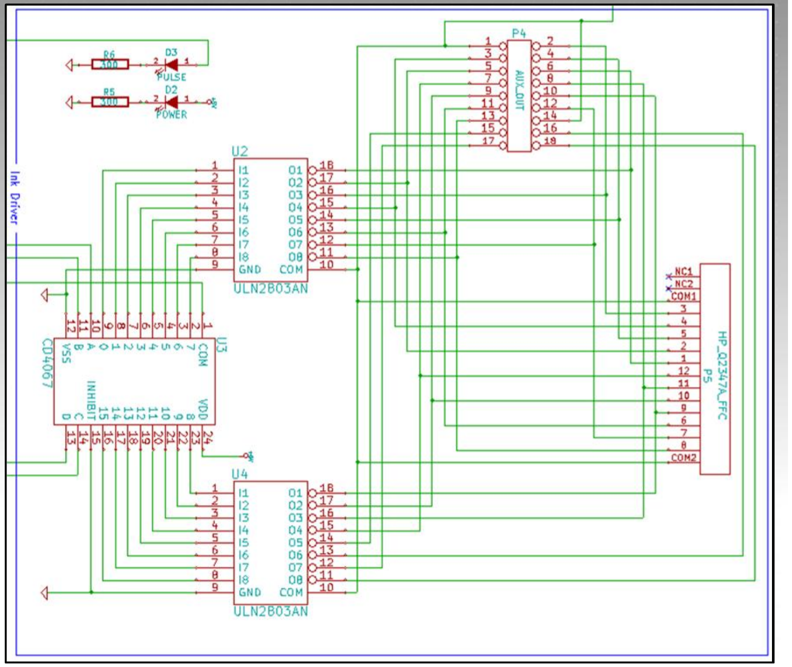
$$\sigma = \frac{1}{\rho}$$

| Material | Resistivity ρ (Ω·m) |
| --- | --- |
| Superconductors | 0 |
| Metals | $10^{-8}$ |
| Semiconductors | variable |
| Electrolytes | variable |
| Insulators | $10^{16}$ |

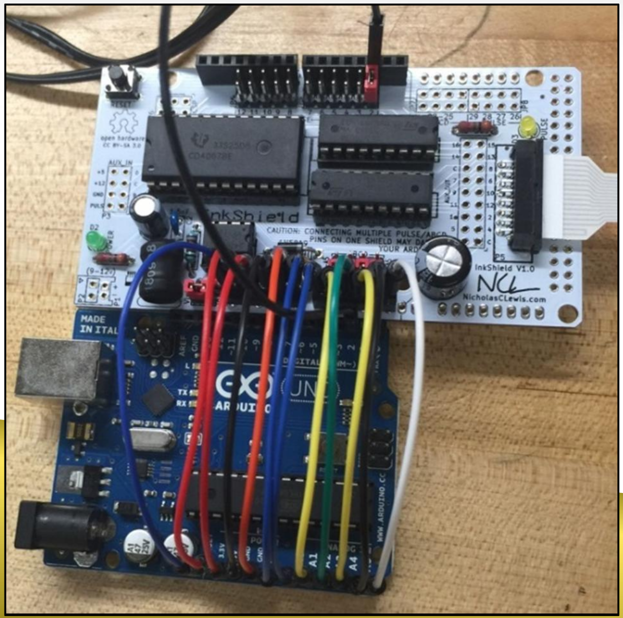
Typical Resistivity Values

# INKSHIELD

- Supplies 20V to HP C6602 inkjet cartridge via boost converter
- Sold as kit with through-hole design including components
- Open source libraries
- HP C6602 is 96dpi with 12 inkjet nozzles

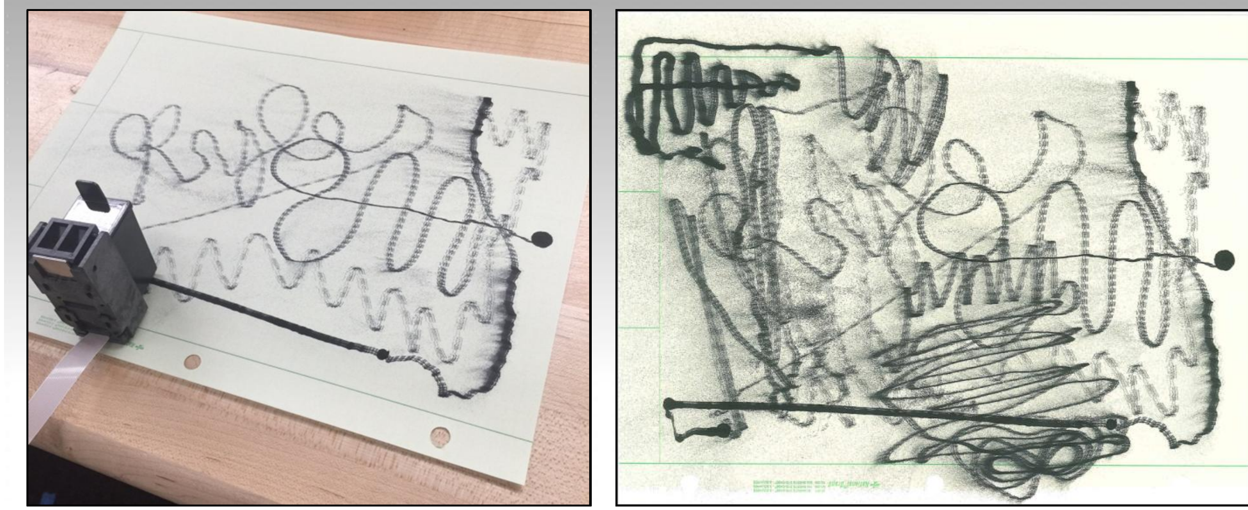


InkShield Schematic

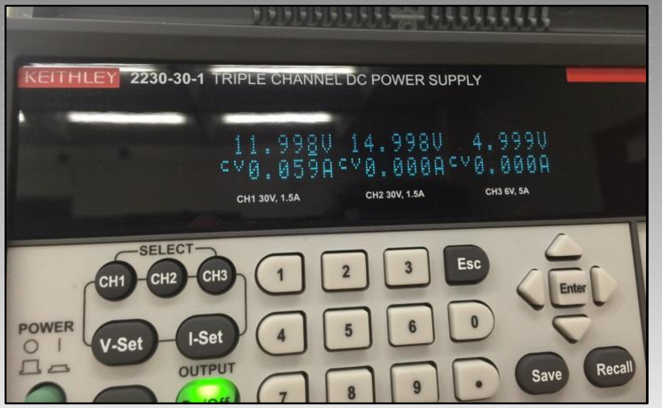


InkShield Board interfaced with prototype microcontroller

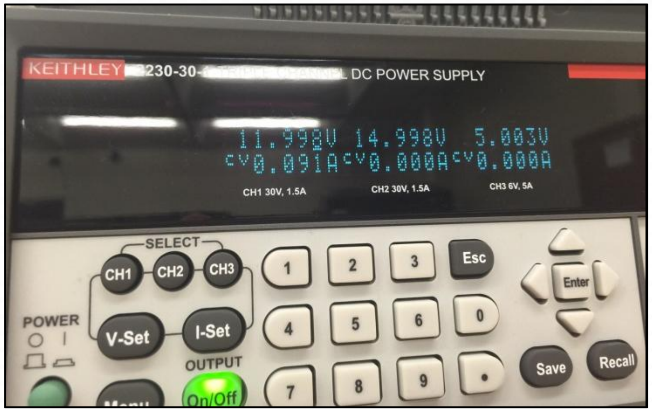
# PROTOTYPING



Moving the print head by hand




0.708 W power dissipation when cartridge is disconnected



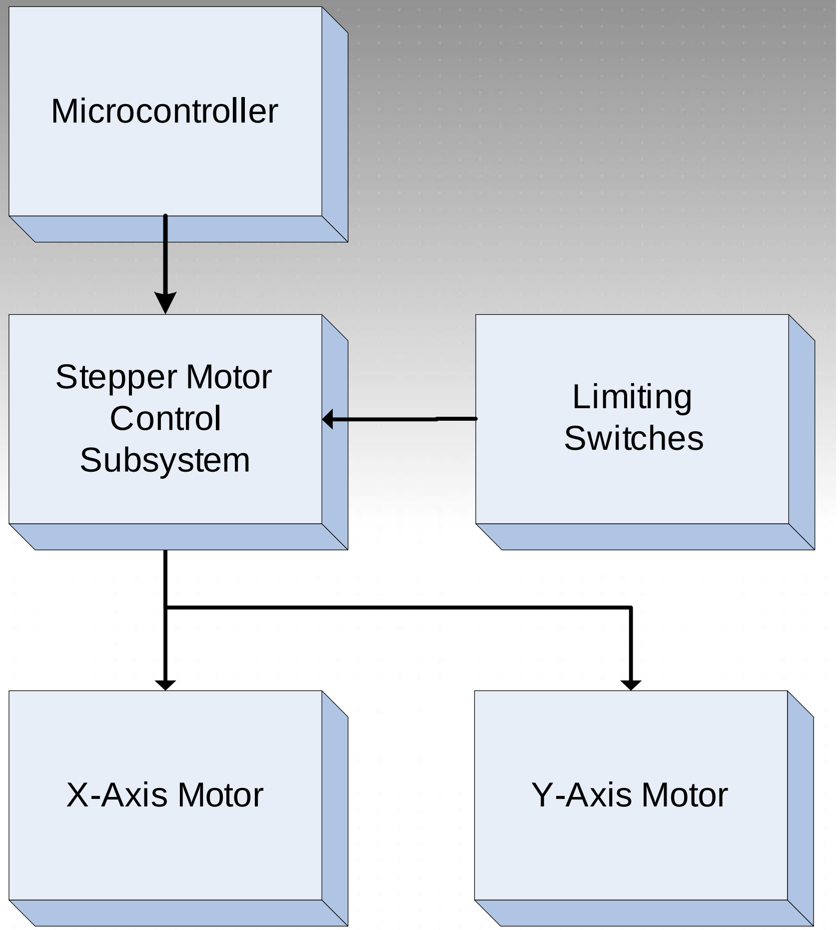

1.092 W power dissipation when cartridge is spraying ink

# MOTOR CONTROL SYSTEM

presented by: Martin Dayuta

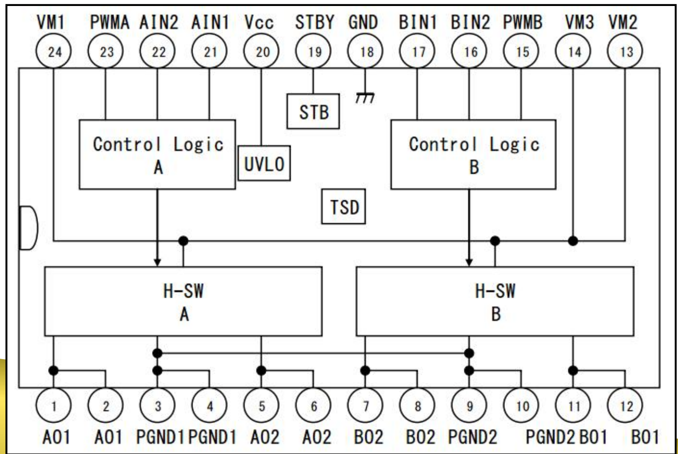
# MOTOR CONTROL SYSTEM

- Responsible for controlling the movement of the X and Y stepper motors
- Microcontroller receives instructions from the user and subsequently transmit the data to the motor control system to turn the stepper motors
- Microcontroller receives signal from the limiting switches to stop motion at the end of the frame and to complete the homing sequence

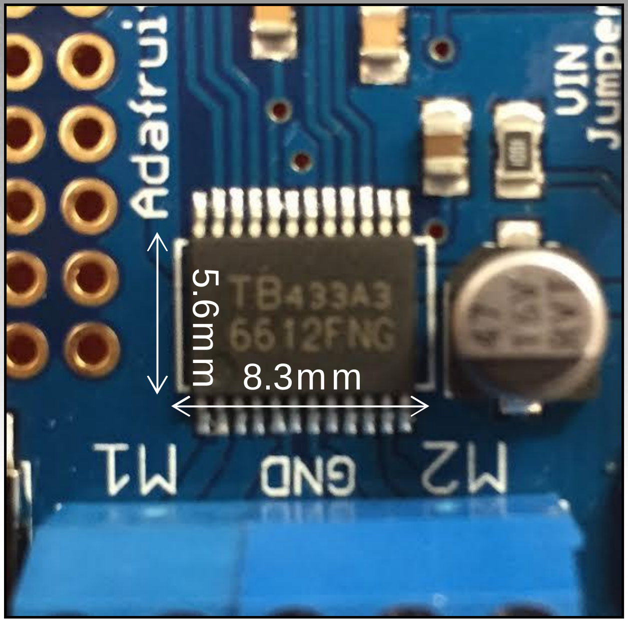


# TB6612 MOTOR CONTROL DRIVER

- TB6612FNG is a driver IC for DC motors with a MOSFET structure
- 1.2A per channel
- 3A peak current capability
- Each chip contains 2 H-Bridges
- Can run motors on 4.5VDC to 13.5VDC



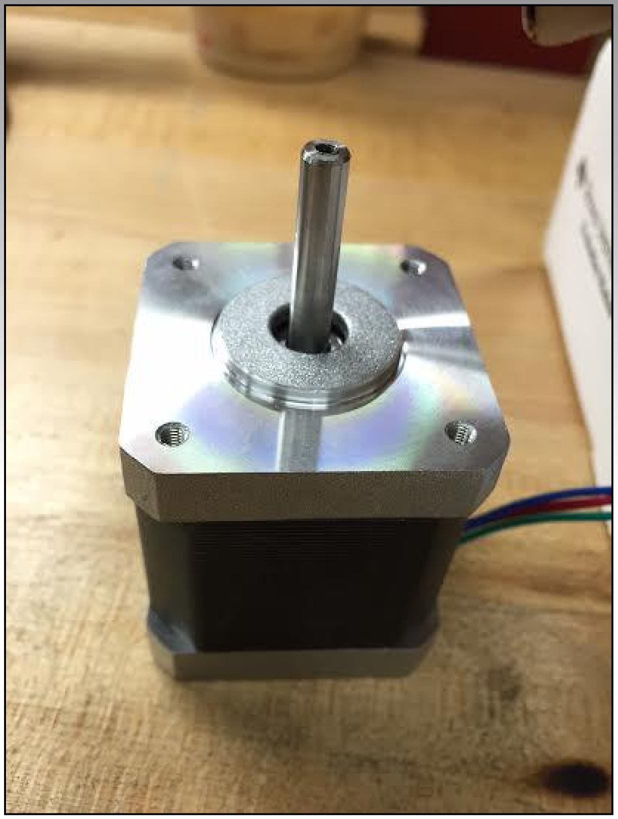

TB6612 Block Diagram




TB6612 on Prototype Motor Control Board

# STEPPER MOTOR

- NEMA-17 bipolar motor
- 400 steps per revolution; 0.9° per step
- 12V rated voltage
- 1.7A max current
- Stepper motors are used for their precise speed control and accurate positioning due to their discrete steps.



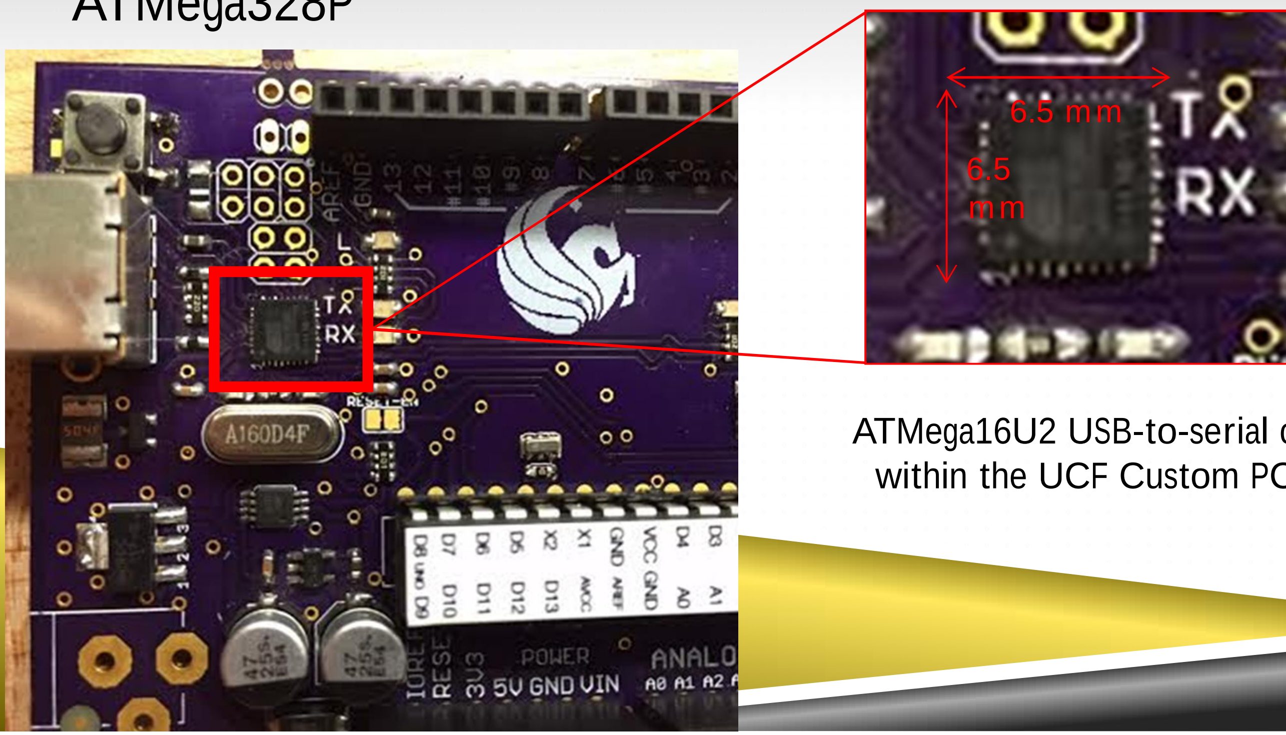
NEMA-17 Stepper Motor

# DATA COLLECTION & PROCESSING

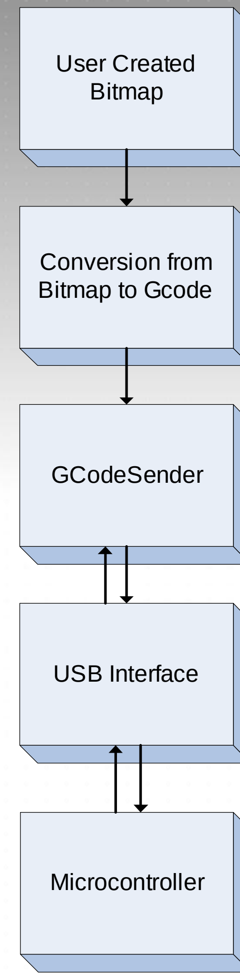
presented by: Hector Melendez

# DATA INPUT & PROCESSING SYSTEM

- UCF contains a USB connector for input file transmission
- Allows user to input custom layout trace designs through a G-code file
- ATMega16U2 USB-to-serial chip facilitates serial communication between host PC and ATMEL ATMega328P




ATMega16U2 USB-to-serial chip within the UCF Custom PCB



# ATMEGA16U2

## Data Transmission

- The ATMega16U2 communicates with the microcontroller via TX and RX (Digital Pins 0 and 1) on the ATMega328P
  - The ATMega16U2 transmits and receives the serial communication over USB and appears as a virtual COM port to software on the computer
- The input file is a .txt file written in G-code
  - The input file is saved on an external computer

# G-CODE

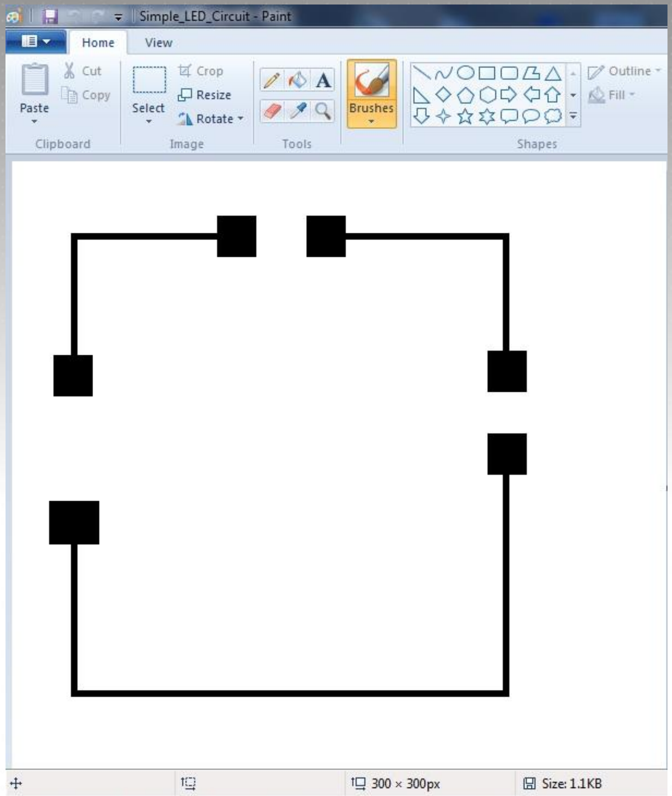
- G-code is widely used in the 3D printing industry for xyz planar translation and print/extrusion control.
- The UCF reads G-code text file to control the motor control system and inkjet control system.

| | |
|---|---|
| G00 | [X(steps)] [Y(steps)] [F(feedrate)]<br>linear move – no ink |
| G01 | [X(steps)] [Y(steps)] [F(feedrate)]<br>linear move – spray ink |
| G04 | P[seconds] – delay |
| G28 | move to Home-Position/Origin |
| G92 | [X(steps)] [Y(steps)] - change logical position |
| M18 | release motors |
| M100 | this help message |
| M114 | report position and feedrate |

UCF G-code commands

# FILE TYPE SELECTION

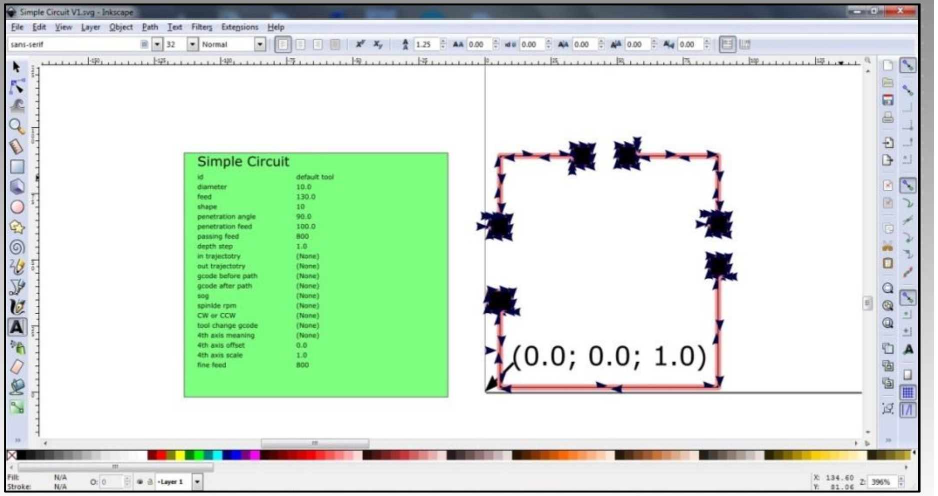
- Our team has decided on using a method that is open source and user friendly for creating UCF print files
  - The user creates a custom circuit trace design using Microsoft Paint or another image editor that exports a bitmap file (.bmp)



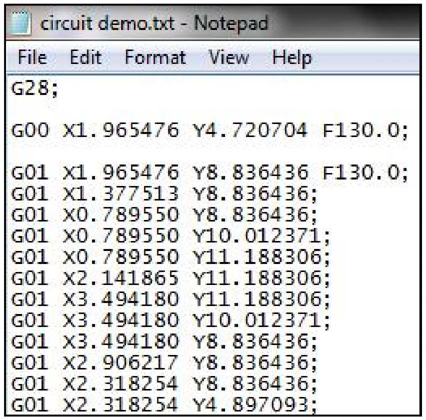

Schematic bitmap created in Microsoft Paint

# G-CODE GENERATION USING INKSCAPE

- The user created bitmap is converted to G-Code commands using Inkscape
- Inkscape is an open-source vector graphics editor
  - Inkscape has an extension named Gcodetools that traces the outline of the bitmap file
  - The outline is then converted into a G-Code path and saved as a text file of G-Code commands




Inkscape converting bitmap to G-code

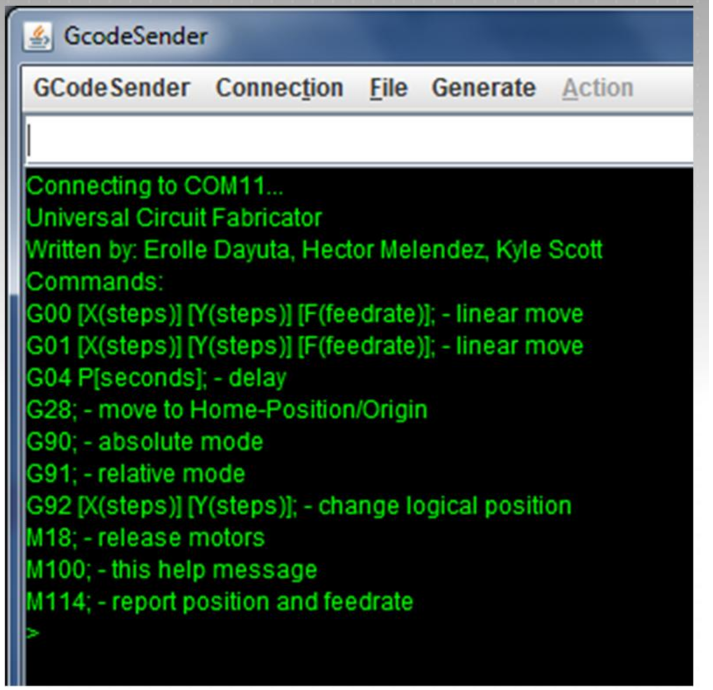



```
G28;

G00 X1.965476 Y4.720704 F130.0;

G01 X1.965476 Y8.836436 F130.0;
G01 X1.377513 Y8.836436;
G01 X0.789550 Y8.836436;
G01 X0.789550 Y10.012371;
G01 X0.789550 Y11.188306;
G01 X2.141865 Y11.188306;
G01 X3.494180 Y11.188306;
G01 X3.494180 Y10.012371;
G01 X3.494180 Y8.836436;
G01 X2.906217 Y8.836436;
G01 X2.318254 Y8.836436;
G01 X2.318254 Y4.897093;
```

G-code generated by Inkscape

# GCODESENDER

- GcodeSender is an open source Java based GRBL compatible cross platform G-Code sender
- The UCF uses this program to interface with the customized G-Code interpreter software via USB serial port
- Individual G-Code commands can be sent to the UCF by the user as well as a text file containing multiple G-Code commands
- Feedback on location of print head is displayed while printing

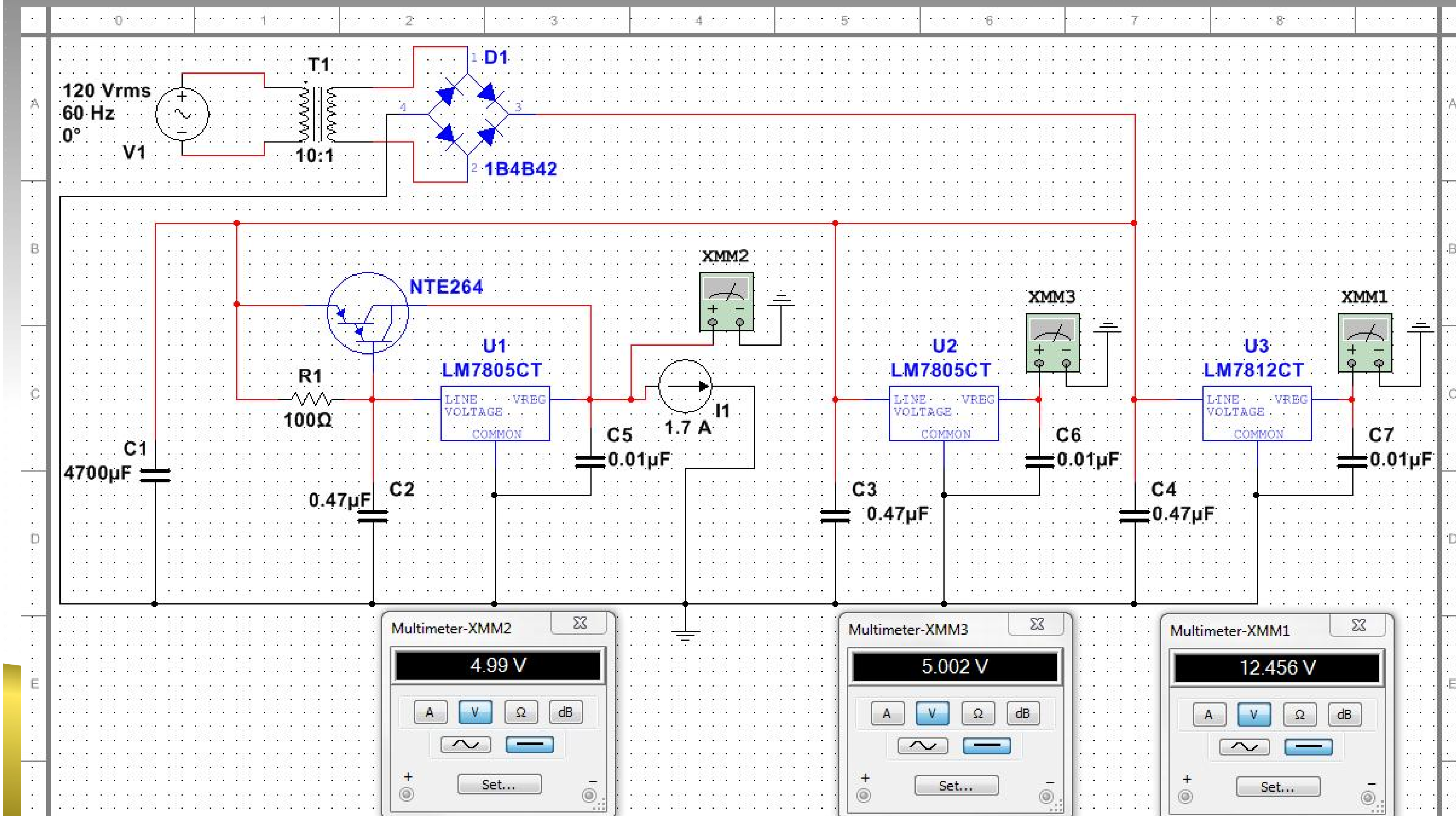



GUI of GcodeSender

# POWER SUPPLY

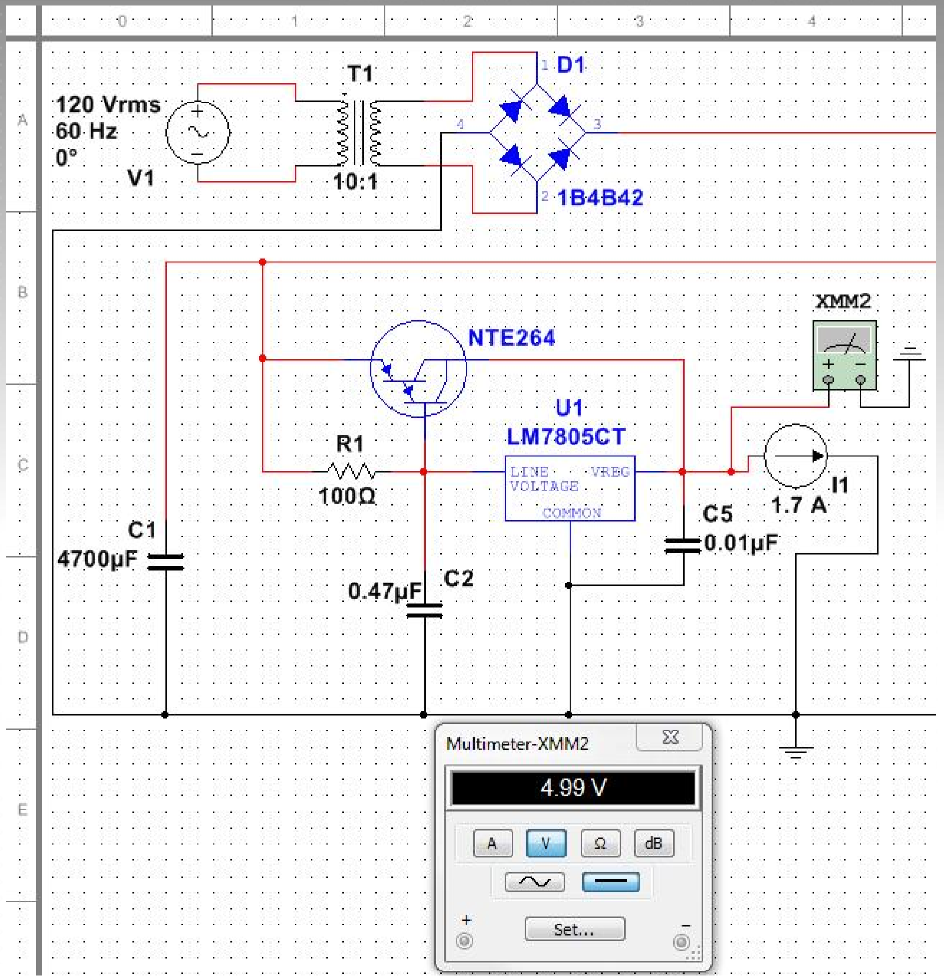
presented by: Kyle Scott

# POWER SUPPLY SIMULATION



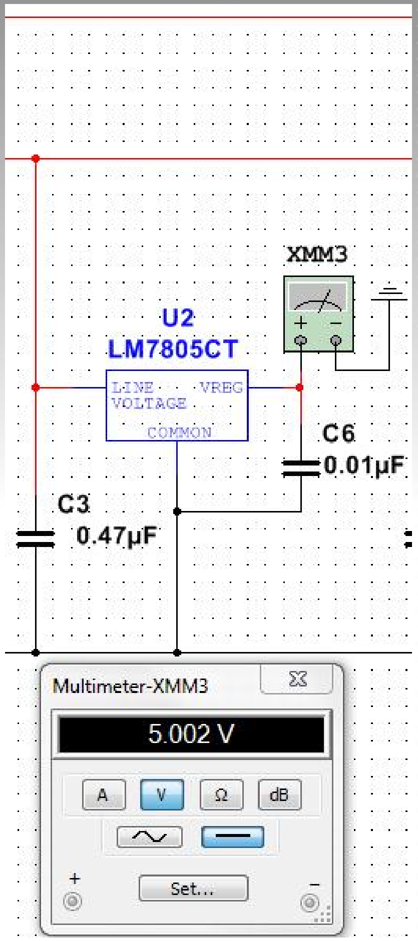
# MOTOR SUBSYSTEM POWER

- LM7805 Linear Voltage Regulator outputs 5 VDC from full wave bridge rectifier output (~15 VDC)
  - 1.5A max rated current draw
- NTE264 PNP Darlington pair power transistor in parallel acts as a bypass for high current
  - Current follows path of least resistance through the transistor
- Allows 1.7A draw (8.5 W dissipated)



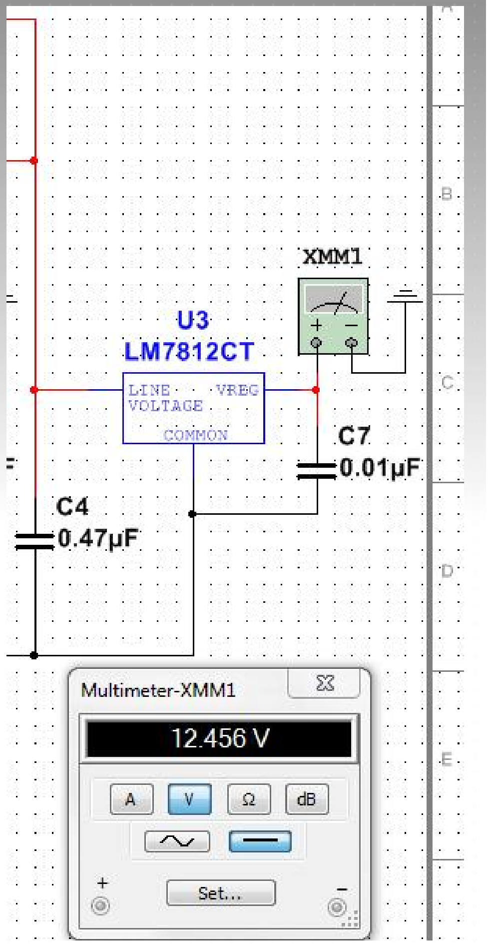
# HARDWARE LIMITING SWITCH POWER

- LM7805 Linear Voltage Regulator outputs 5 VDC from full wave bridge rectifier output (~15 VDC)
  - 1.5A max rated current draw
- Hardware switches consume negligible current when closed due to pull down resistors
  - ~ 10mA draw (0.05 W dissipated)
- No need for bypass transistor



# INKSHIELD AND COOLING FAN POWER

- LM7812 Linear Voltage Regulator outputs 12 VDC from full wave bridge rectifier output (~15 VDC)
  - 1.5A max rated current draw
- InkShield subsystem consumes small current when spraying ink
  - ~ 90mA draw (1.092 W dissipated)
- Cooling Fan used to cool heat sink of motor control power transistor
  - ~ 370mA draw (4.4 W dissipated)
- No need for bypass transistor

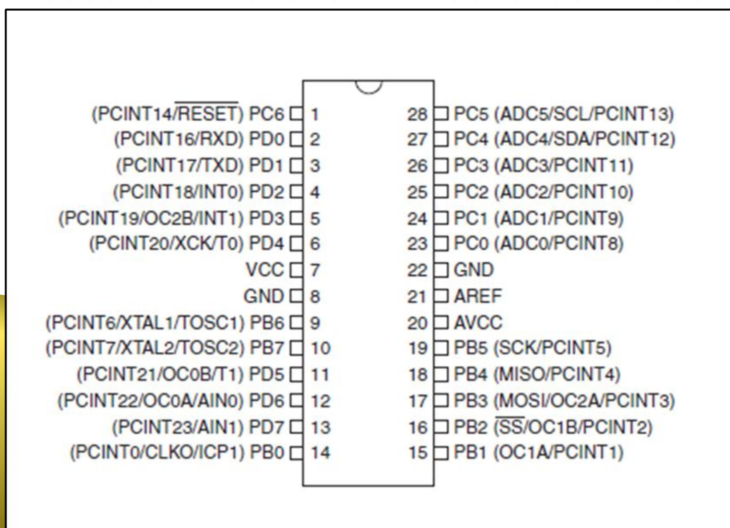


# MICROCONTROLLER

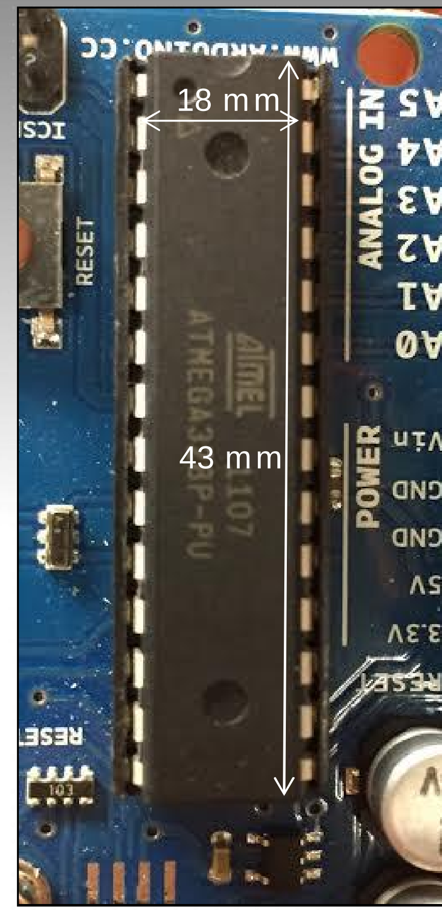
presented by: Martin Dayuta

# ATMEL ATMEGA328

- Low power 8 bit RISC microcontroller
- Clock frequency operation at 20 MHz
- 6 channel 10-bit analog to digital converter
- Operates from 1.8 – 5.5V
- Chosen due to ease of PCB design and integration with InkShield inkjet controller. The IDE also provides ease of use.

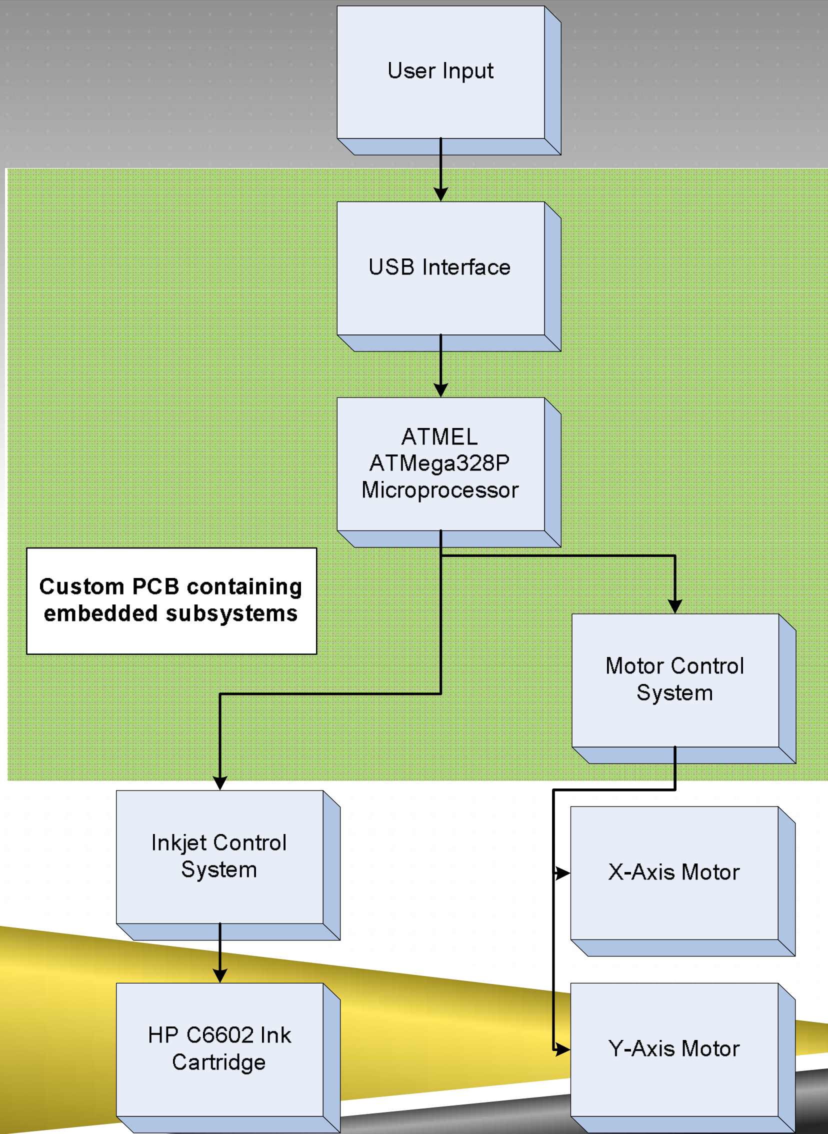



ATMega328 Schematic

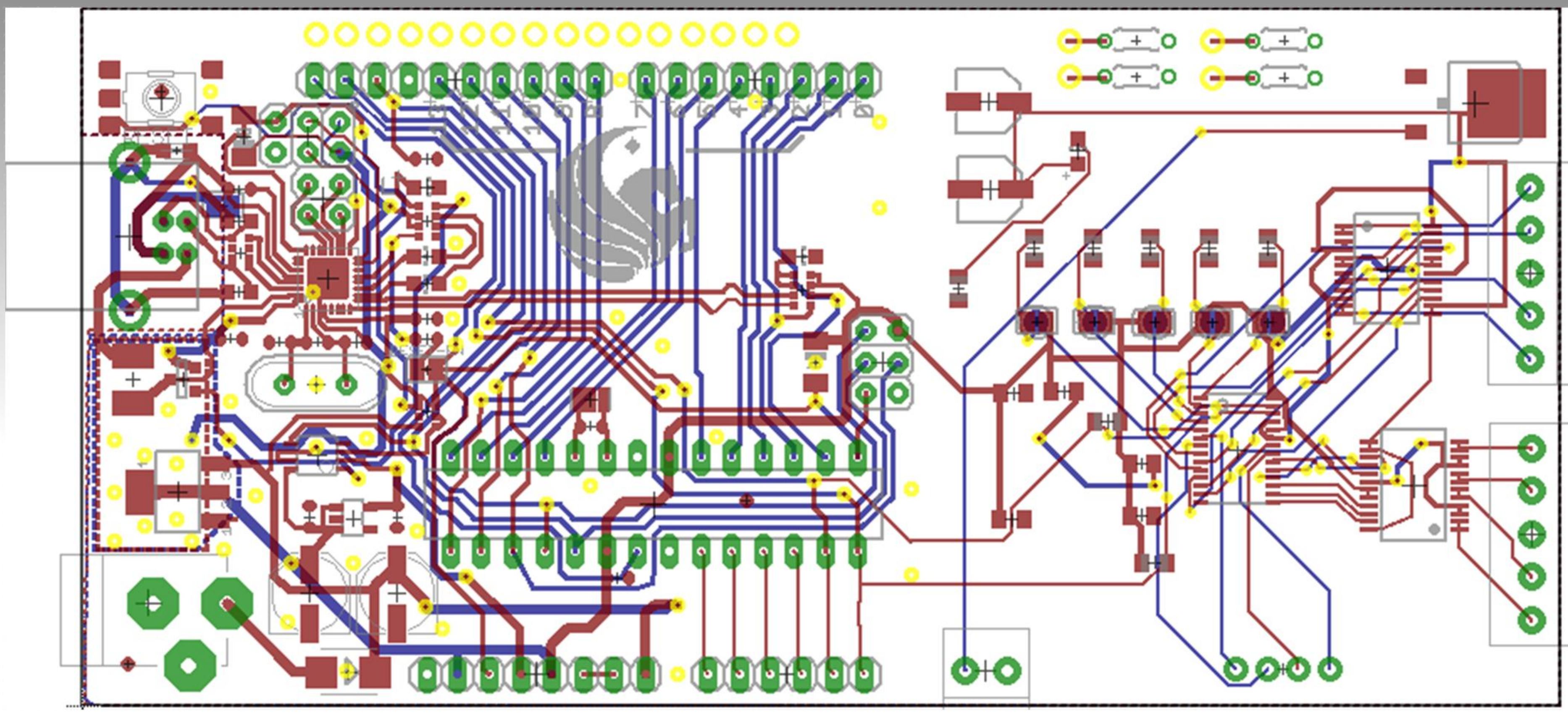



ATMega328 on prototype microcontroller

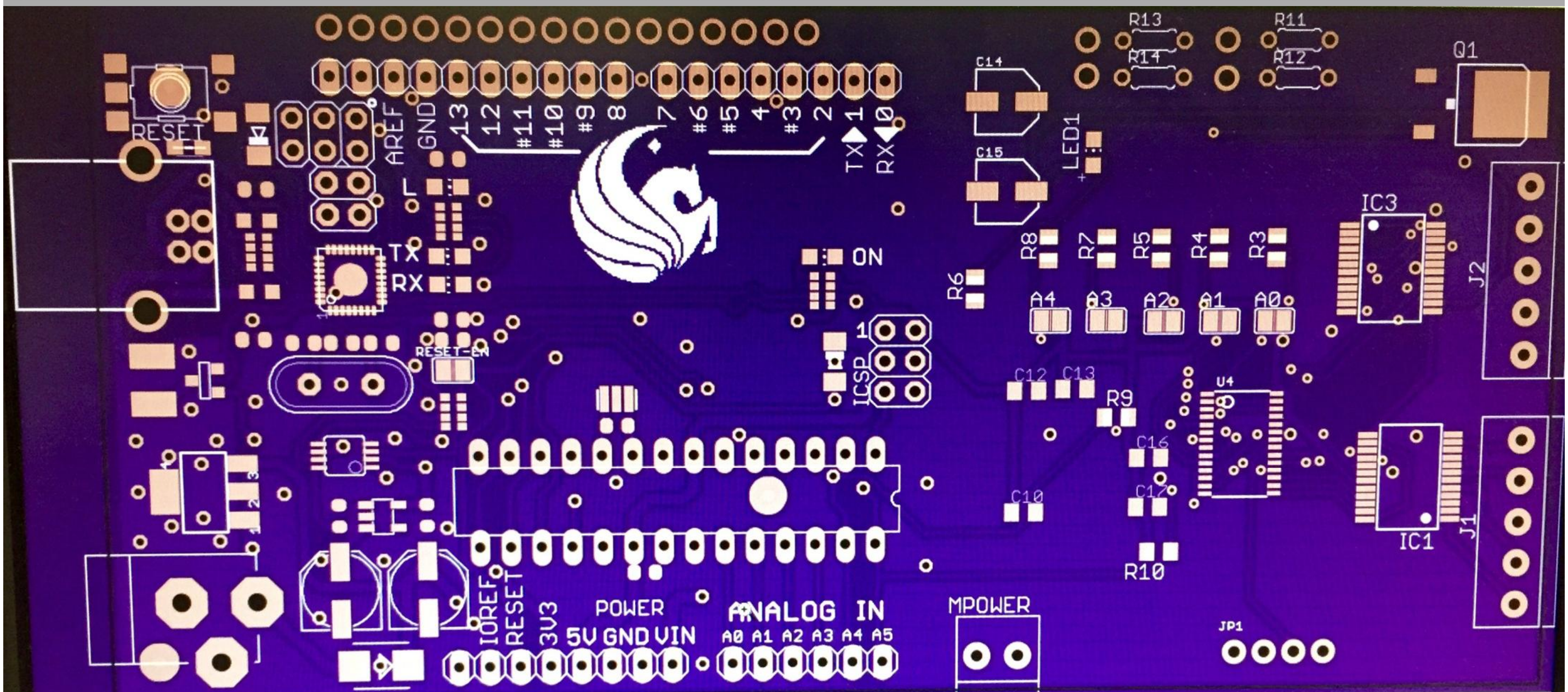
# MICROCONTROLLER SYSTEM



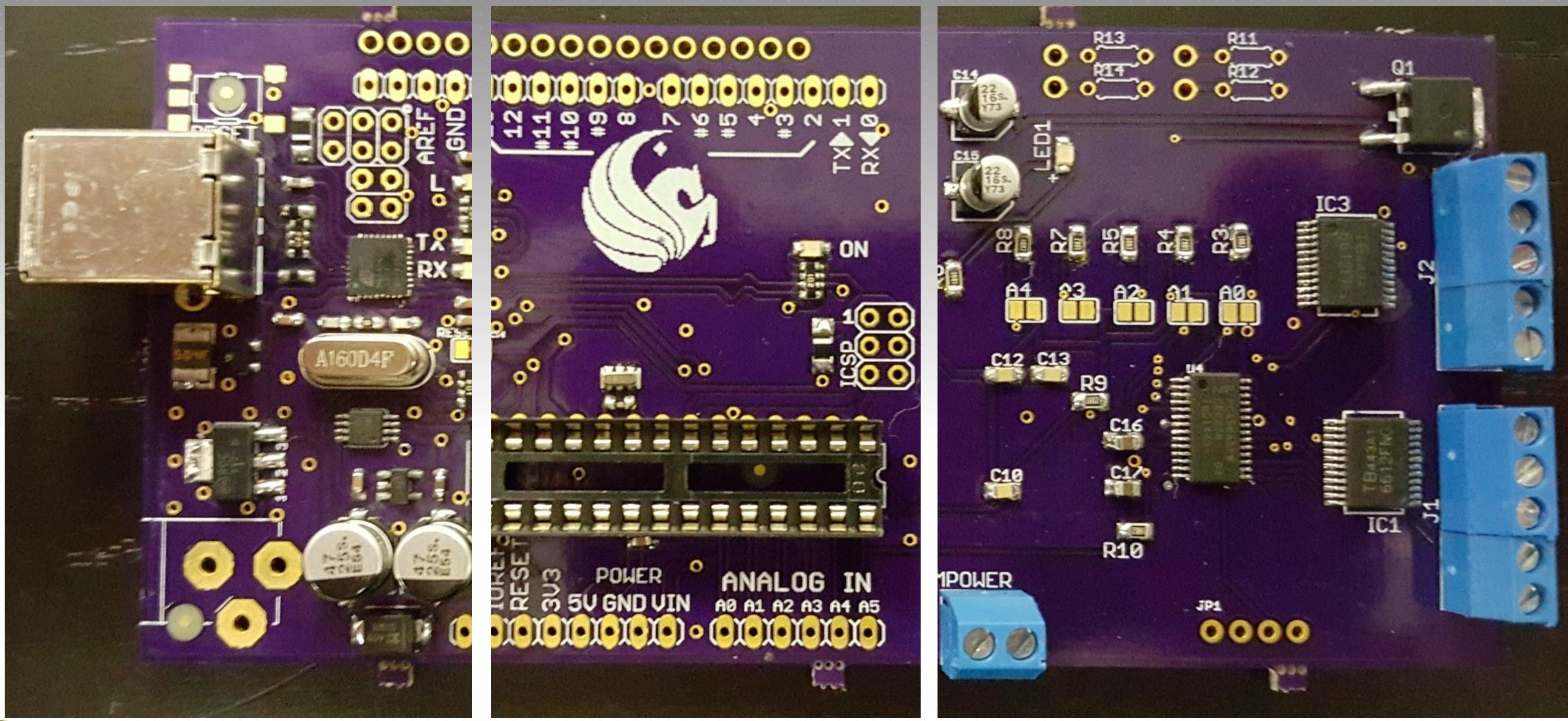
# PCB LAYOUT IN EAGLE



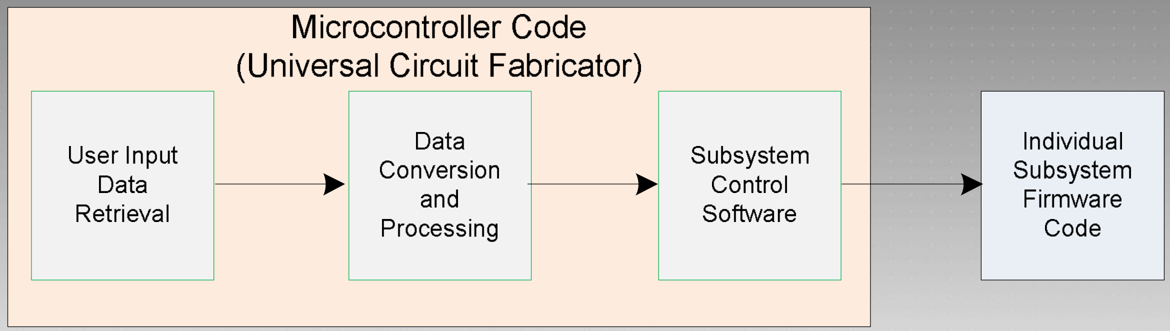
# PCB LAYOUT FROM OSHPARK



# ASSEMBLED PCB

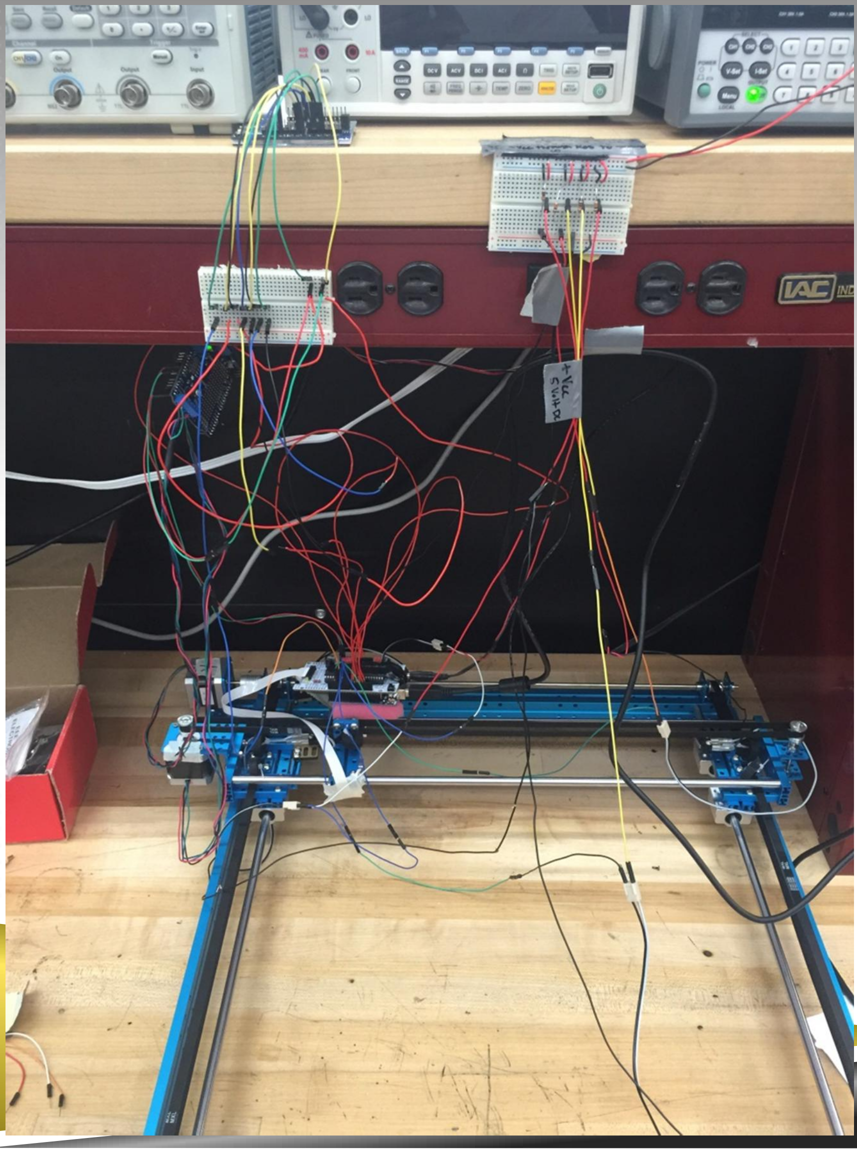


# MICROCONTROLLER CODE



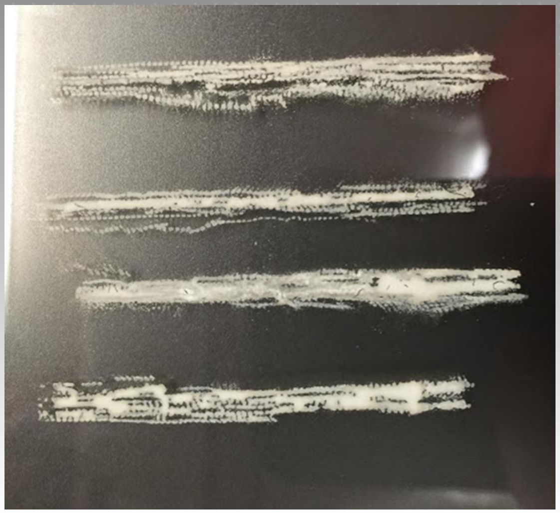

| Function Name | Type | Description |
|---|---|---|
| Buffer[ ] | string | Raw data received from user input |
| processCommand() | function | Processing and converting the packaged data that leaves the microcontroller and be used for the subsequent individual subsystem codes. |
| Line() | function | Uses Bresenham's line algorithm to move both motors to create an approximation of a straight line between two points |
| oneStep() | function | Used within Line to instruct the motor to step in the forward or backward direction at a certain step rate. |
| spray_ink() | function | Used within oneStep to turn on the nozzle(s) on the print cartridge to start spraying conductive ink |

# DEVELOPMENT BOARD PROTOTYPE



# CHALLENGES

- After several hours, the silver acetate ink clogs the nozzles, causing discontinuity in the traces. After a while, the ink cartridge stops working
- The USB to serial chip used in our final PCB design were out of sync with the microprocessor, so within our design, we used another ATMega328P board for serial communication.



# BUDGET

| Project Spending | |
| --- | --- |
| Syringe Filters | $23.93 |
| Sterile Vials | $5.75 |
| Beakers | $9.35 |
| Silver Nitrate | $29.95 |
| Sodium Acetate | $10.67 |
| Ammonium Hydroxide | $24.95 |
| Formic Acid | $21.18 |
| Gallium and Indium | $55.95 |
| Stir Plate | $42.00 |
| Stepper Motors x2 | $43.03 |
| Printer Frame | $210.00 |
| Stepper Motor Booster | $25.00 |
| Adafruit Stepper Servo Shield | $30.09 |
| Touch Shield | $34.95 |
| Ink Shield | $60.00 |
| Ink Cartridge | $38.89 |
| Printed Circuit Board Fabrication | $55.34 |
| PCB Parts | $42.68 |
| Glass Sheets | $20.00 |
| AC to DC Power Supply | $10.16 |
| **Total** | **$805.74** |
| **Budget** | **$687.00** |

# Questions?