WHO IS UCF?

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- Martin Dayuta, EE
- Kyle Scott, EE

GROUP 18

Sponsored by: Boeing
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 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.
- 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
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.
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
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
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.
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

- Data Input and Processing Subsystem
- Microcontroller
- Power Supply
- Motor Control Subsystem
- Inkjet Cartridge Control Subsystem
- Serial to USB Interface
- 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
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 \( \rho \leq 10^{-3} \ \Omega \cdot m \).
- The bed surface allows for a printing area of 10 by 10 inches.

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

\[
\sigma = \frac{1}{\rho}
\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity ( \rho ) (( \Omega \cdot m ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superconductors</td>
<td>0</td>
</tr>
<tr>
<td>Metals</td>
<td>( 10^{-8} )</td>
</tr>
<tr>
<td>Semiconductors</td>
<td>variable</td>
</tr>
<tr>
<td>Electrolytes</td>
<td>variable</td>
</tr>
<tr>
<td>Insulators</td>
<td>( 10^{16} )</td>
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</table>

Typical Resistivity Values
- 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
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
- 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
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
- 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.
DATA COLLECTION & PROCESSING

presented by: Hector Melendez
- 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

Diagram:

1. User Created Bitmap
2. Conversion from Bitmap to Gcode
3. GCodeSender
4. USB Interface
5. Microcontroller
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 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.

<table>
<thead>
<tr>
<th>UCF G-code commands</th>
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</thead>
<tbody>
<tr>
<td>G00 [X(steps)] [Y(steps)] [F(feedrate)] linear move – no ink</td>
</tr>
<tr>
<td>G01 [X(steps)] [Y(steps)] [F(feedrate)] linear move – spray ink</td>
</tr>
<tr>
<td>G04 P[seconds] – delay</td>
</tr>
<tr>
<td>G28 move to Home-Position/Origin</td>
</tr>
<tr>
<td>G92 [X(steps)] [Y(steps)] - change logical position</td>
</tr>
<tr>
<td>M18 release motors</td>
</tr>
<tr>
<td>M100 this help message</td>
</tr>
<tr>
<td>M114 report position and feedrate</td>
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</table>
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.
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.
- 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
POWER SUPPLY

presented by: Kyle Scott
POWER SUPPLY SIMULATION
- 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)
- 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
- **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
- 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.
PCB LAYOUT IN EAGLE
### 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
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.
<table>
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Questions?