VEX VRC 2023-2024:

REVERSE ENGINEERING ONLINE CHALLENGE REPORT

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1. Introduction

The 5 members of our robotics team are passionate students dedicated to using teamwork to continuously improve our robot designs, learn from what we observe, and enthusiastically take up new projects.

Due to the autonomous and mechanical emphasis of building our robot in VEX, we decided to reverse-engineer an everyday technology that combines these components for the Reverse Engineering Challenge. After debating on disassembling a variety of gadgets—from sewing machines to calculators—we settled on the perfect combination: a printer.

Figure 1.1. The HP ENVY 5055 All-In-One Printer that we no longer use.

From advertising pamphlets to printing out reports, printers allow us to *share* our ideas with the public. Thus, we decided to discover how printers function: specifically, how they coordinate mechanical and technical components to print out words on a page according to how we've designed it; how they'll prevent jams; and how they're able to scan and create copies of pages. We hope to uncover all of these mysteries throughout our process and use our newfound knowledge to improve our own robot designs!

Figure 1.2. Notable features of the HP ENVY 5055 All-In-One Printer.

2. Approach

Our plan for this challenge:

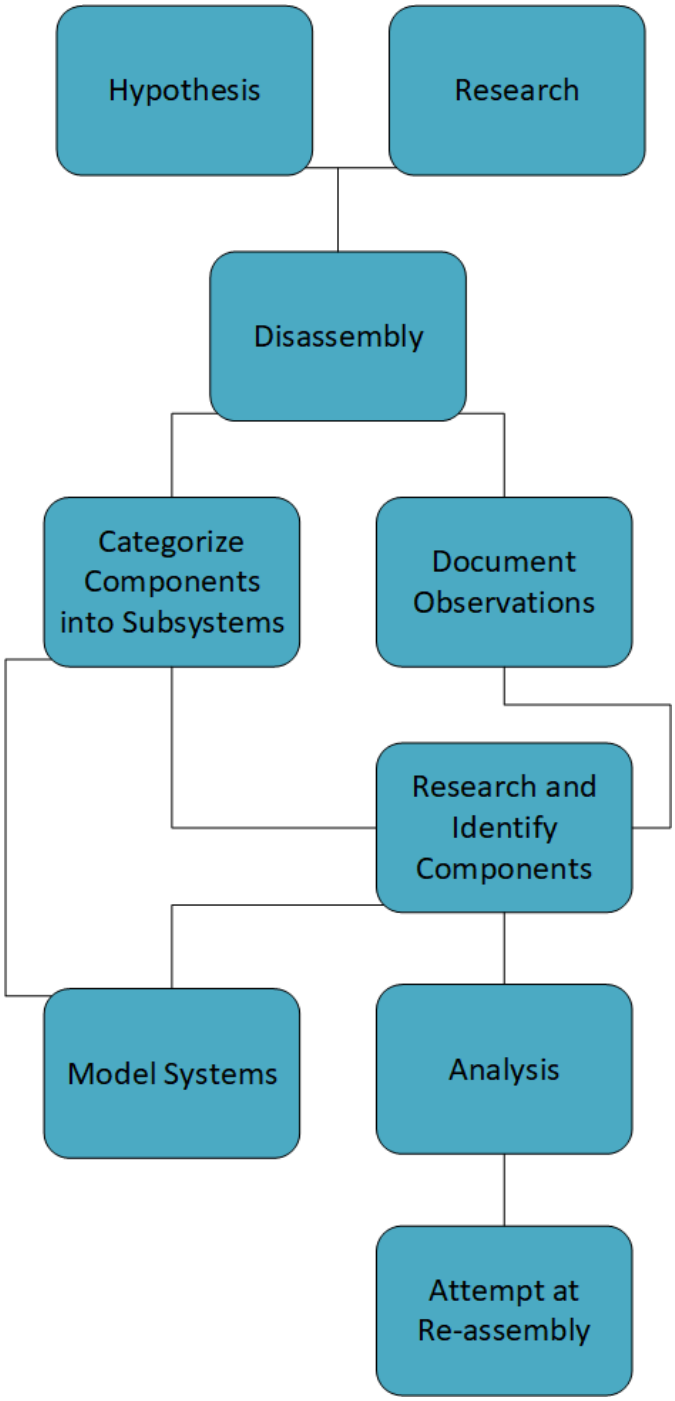


Figure 2.1. Plan for disassembly of the printer and documenting observations.

3. Hypothesis and Research

Hypothesis:
From our pre-existing knowledge of a 3D printer, we think that rollers roll paper from the paper tray into an ink sprayer system that sprays the paper in controlled patterns.

The scanner will use light and digital imaging to scan the documents.

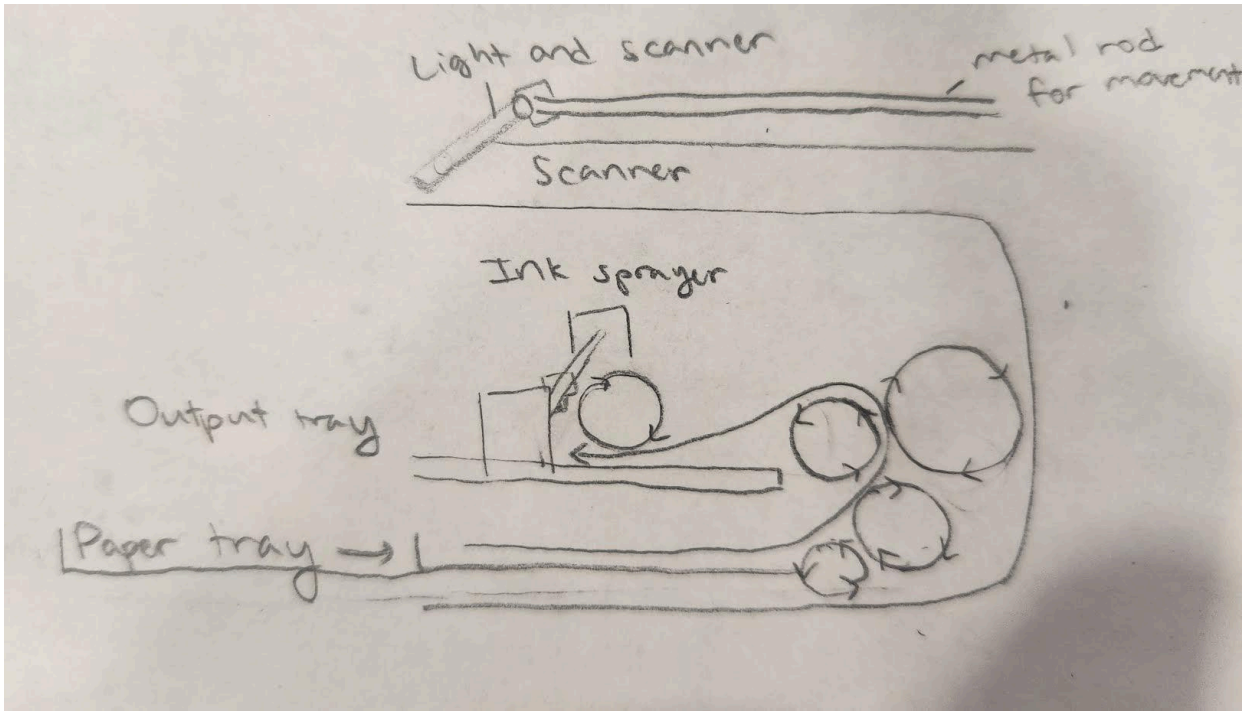


Figure 3.1. Initial hypothesis for mechanisms behind the printer and the scanner.

Before disassembling, we also examined the history of printers and how they evolved.

Timeline:

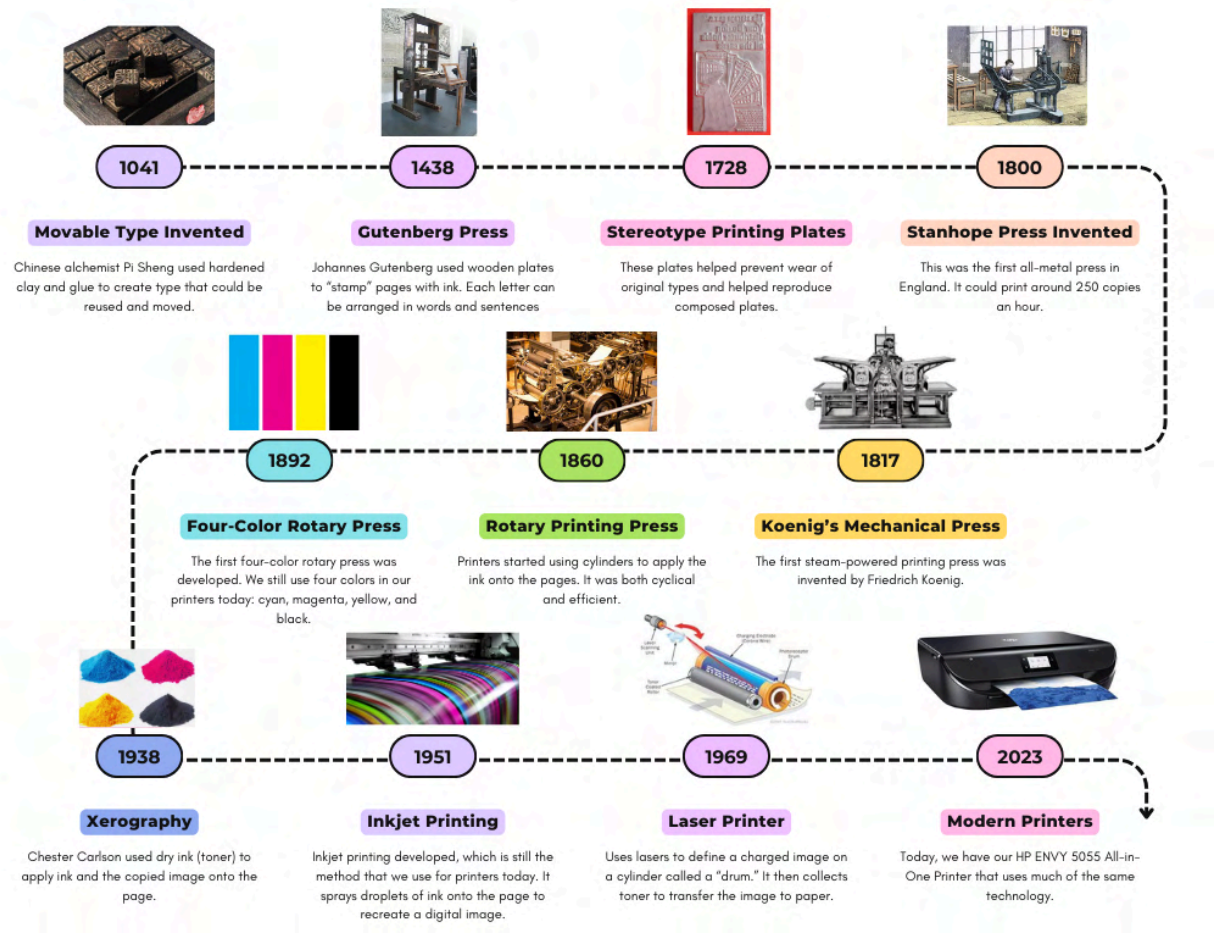


Figure 3.2. Evolution of printing technologies over time. See cited sources in Citations. Timeline created using Canva.

4. Disassembly

Pre-Disassembly Questions:

1. How does the printer coordinate the inking process with the paper-feeding process?
2. How do the placements of the rollers and sensors help with detecting errors?
3. How are the components in the printer able to fit in such a compact shell?

Tools needed:

- T10 Screwdriver
- Safety Goggles
- Flathead Screwdriver
- Flashlight (from phone)
- Camera (phone)
- Digital Caliper

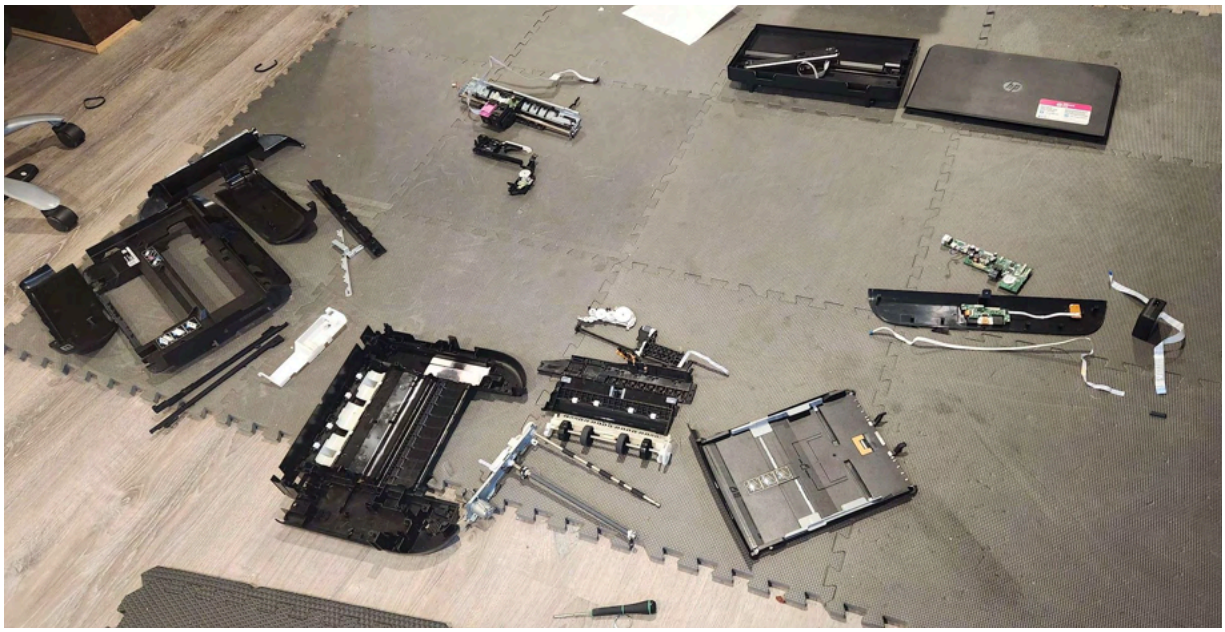


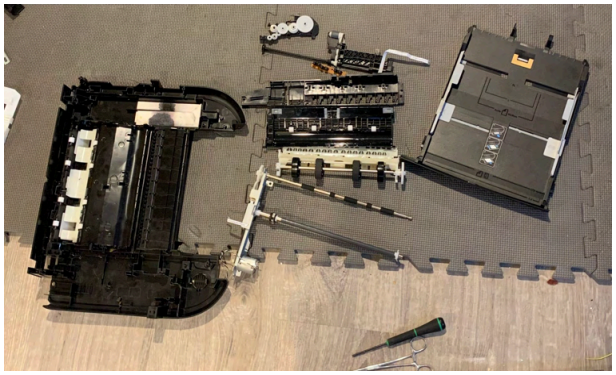
Figure 4.1. How to disassemble the printer and analyze components. View it here.

5. Component Analysis

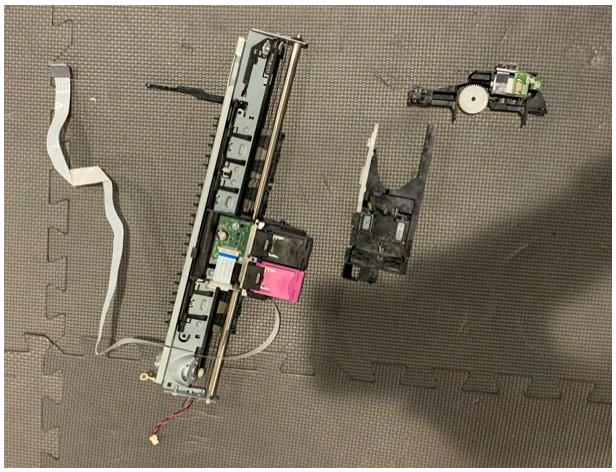
After disassembling our printer, we chose to group the components into several subsystems.

1. **Scanner**

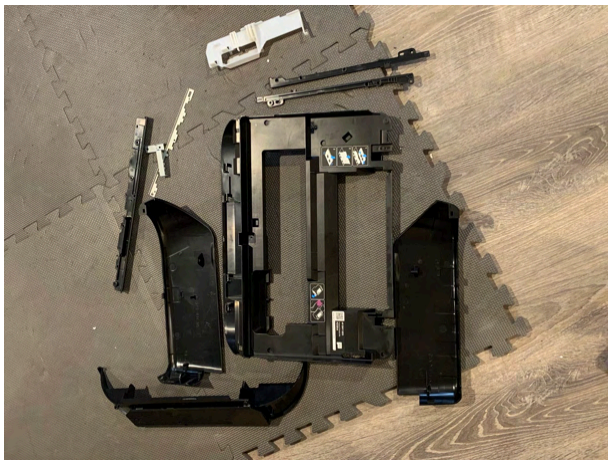
2. **Paper indexing**



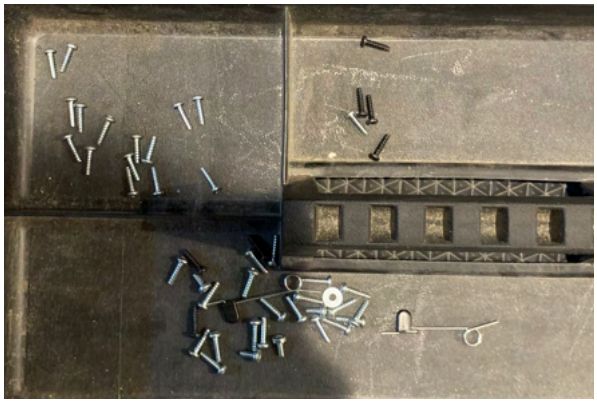
3. **Ink Spray System**



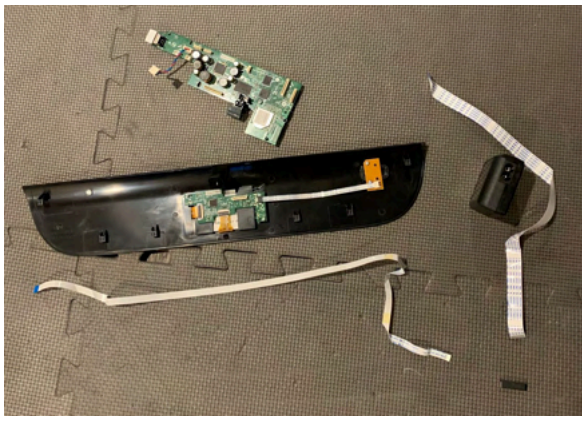
4. **Structure**



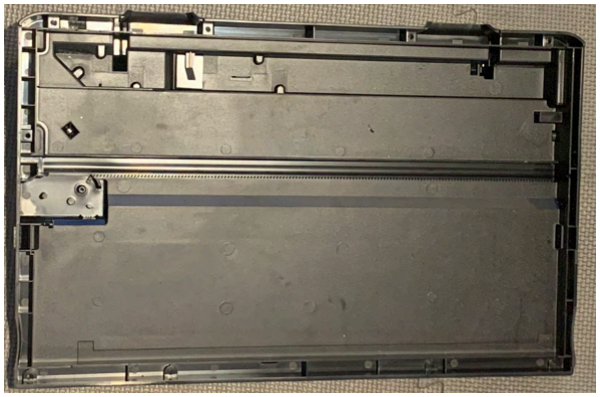
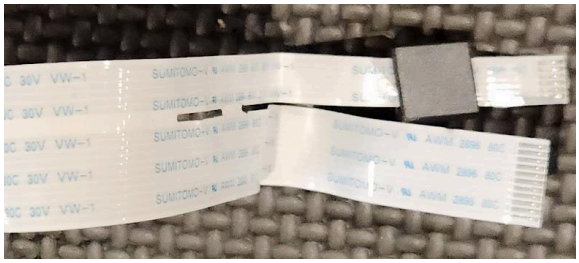
5. **Hardware**



6. **Misc Electronics**



5.1 Parts Lists: Scanner

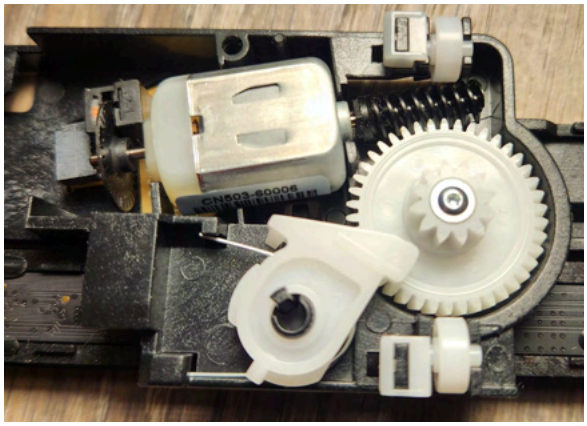
Component and Description	Image
Scanner Case 17.5”x11”x1” Contains the scanner Has a gear rack in the middle to let the scanner move around Has a ferrite core for where the wire goes	
Scanner Wire Ribbon Cable: • Reduces space usage • Easy to use 2 Wires in one cable • Wire on top connects to motor • Wire on right connects to scanner • Has ferrite core to reduce damage from static	

Scanner Linear Movement System
Uses Motor (described in next box)

Has 2 wheels to glide

Worm gear powers gear in the middle which rotates along rack gear → allows the scanner to move linearly side to side

Cam on spring clamps on to rail in case to make sure it doesn't slide off rack

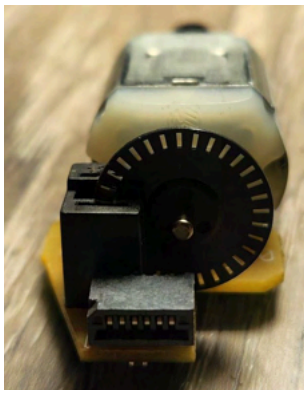


Scanner Linear Movement Motor
Motor is connected to worm gear

PCB attached to motor can control motor speed

- Has an encoder disc with holes to read the rotation more accurately
- Has an encoder sensor to read speed of disc
- Has a wire port to transmit power and data from the motor to the motherboard

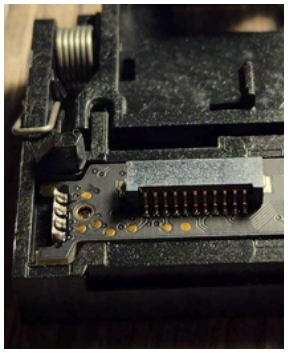
https://www.ebay.com/itm/204141256350



Scanner
White bar at the top shines a light and scans the paper

Port sends the data of the paper that is scanned is sent through the ribbon cable to the motherboard

Has spring on the joint to make sure the scanner is constantly pressing down onto the glass in front of the paper that it is scanning



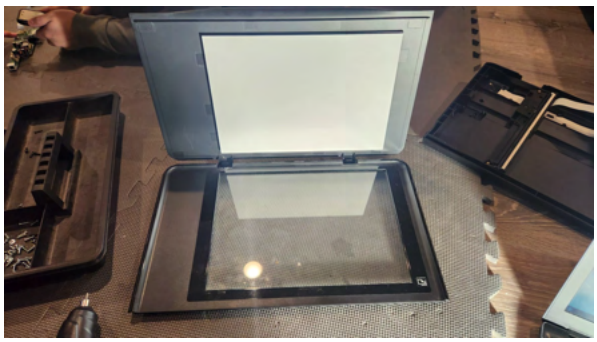
Scanner Paper Holder
17.5”x11”x1”

Acts as printer lid

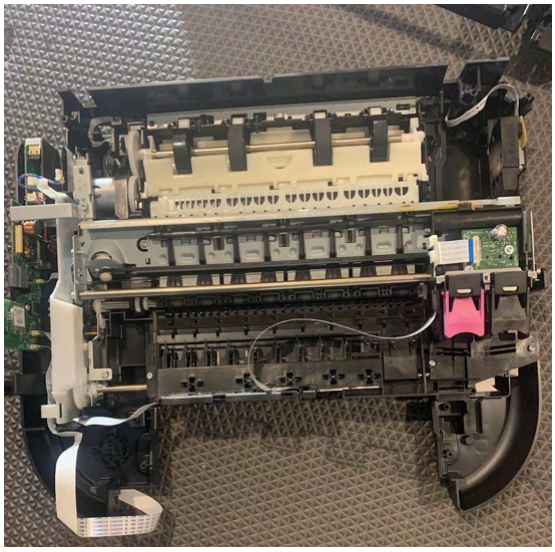
Has a white foam piece to press the paper into the glass and removes any background light.

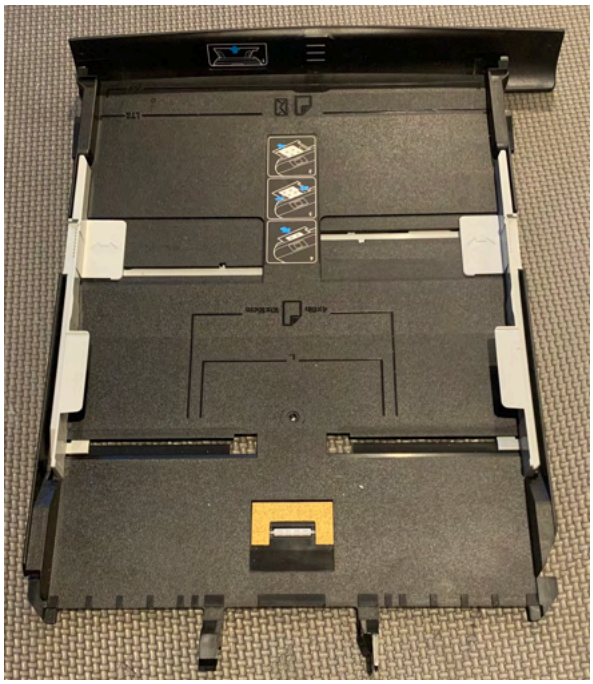
Paper rests on glass piece, while scanner scans the paper from under the glass

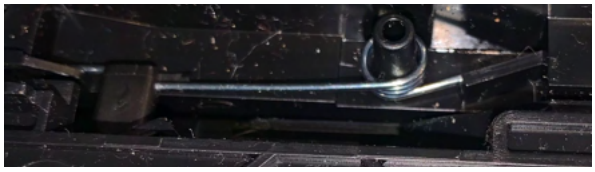
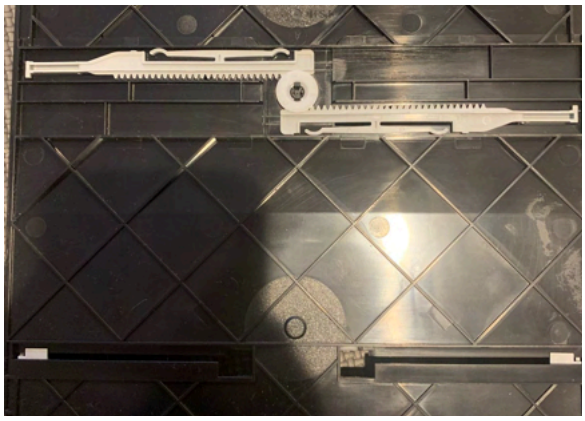
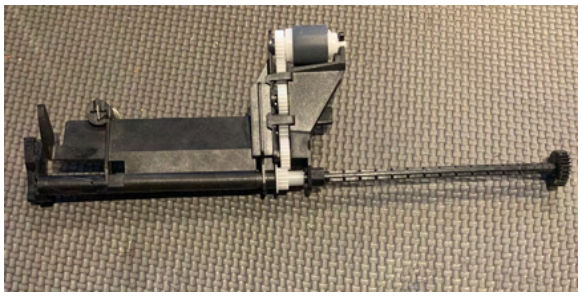
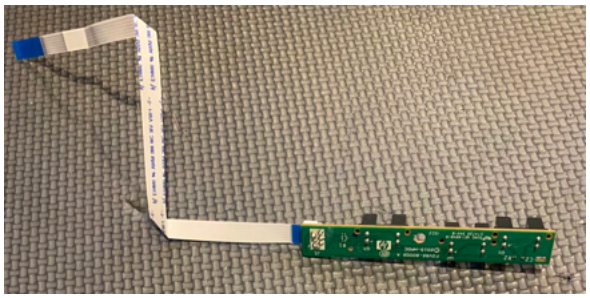
Hooks into the scanner case to become the entire scanner assembly

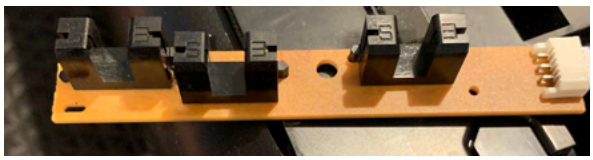


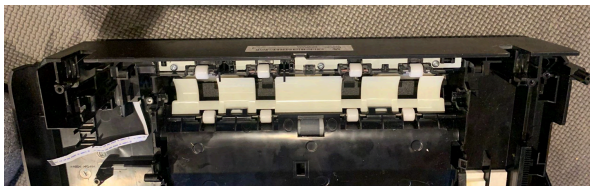
5.2 Parts Lists: Paper Indexing



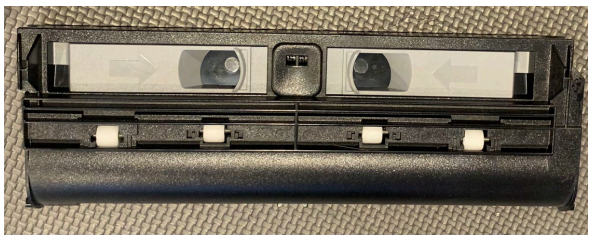
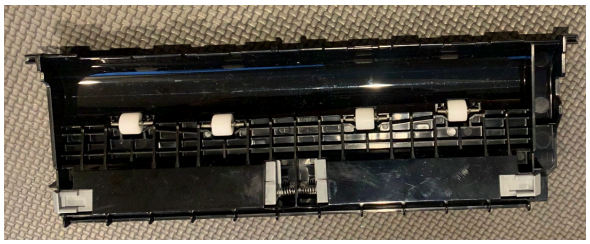
Component and Description	Image
Paper Tray 12.5”x9”x1” Holds the Paper Has 2 ramps at back to allow it to go into rollers Sits on the Paper Tray Rails under the Printer base Is held in by paper tray springs	

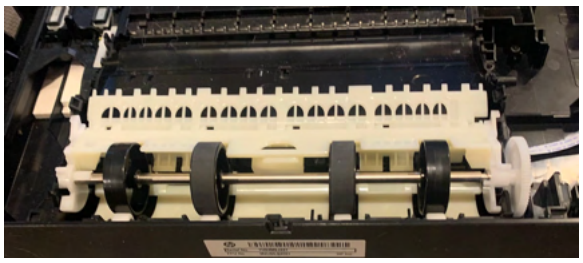
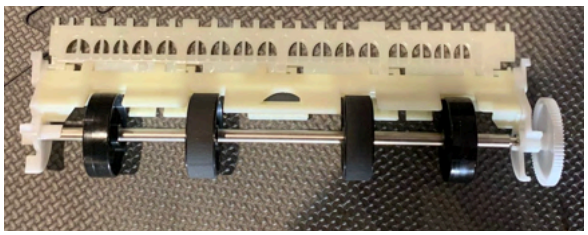
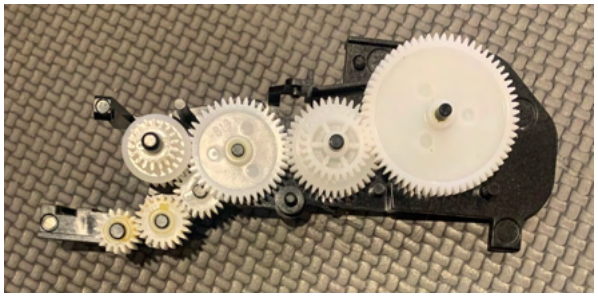
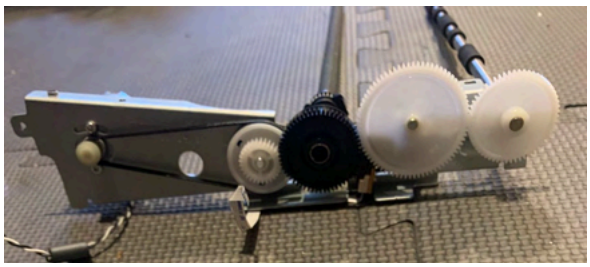
Paper Tray Springs (x2) Applies friction to paper tray so it won't fall out	 
Paper Railings Inside the paper tray Can adjust size using rack gears and idler gear to maintain size and direction of paper	
Paper Feeder Sits under the printer base and has a spring pushing it down Is spun by the feeder motor through the black gear on the right Is extended when Paper tray is in and when ink is being used Has rubber on roller for more grip	
Main Error Detector PCB with 3 sensors and a wire port Wire port connects and sends data to the motherboard through ribbon cable 3 sensors: • Sensors on left and right detect if a paper has entered from the paper	

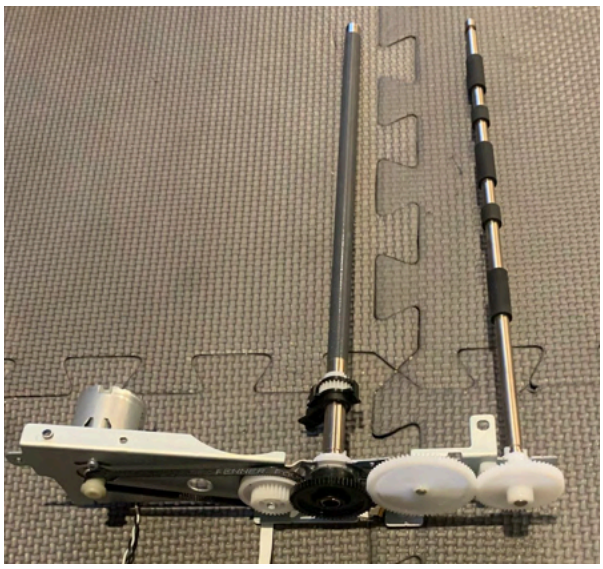
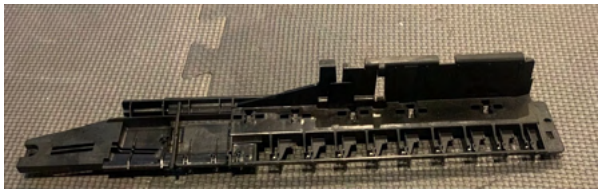
<table>
<tr>
<td>tray by the paper feeder (has 2 for smaller pieces of paper)
• Sensor in the middle detects if the paper tray is fully inside the printer</td>
<td> 
  </td>
</tr>
<tr>
<td>Bottom of Main Paper Hood
Paper from the Feeder roller rides up on the ramps of the paper tray and goes underneath the hood to rotate perpendicular to the ground

Many unpowered rollers to minimize chances of jamming</td>
<td>  </td>
</tr>
<tr>
<td>Top of Main Paper Hood (Anti-Jam Tray)
9.5”x3.5”x1”

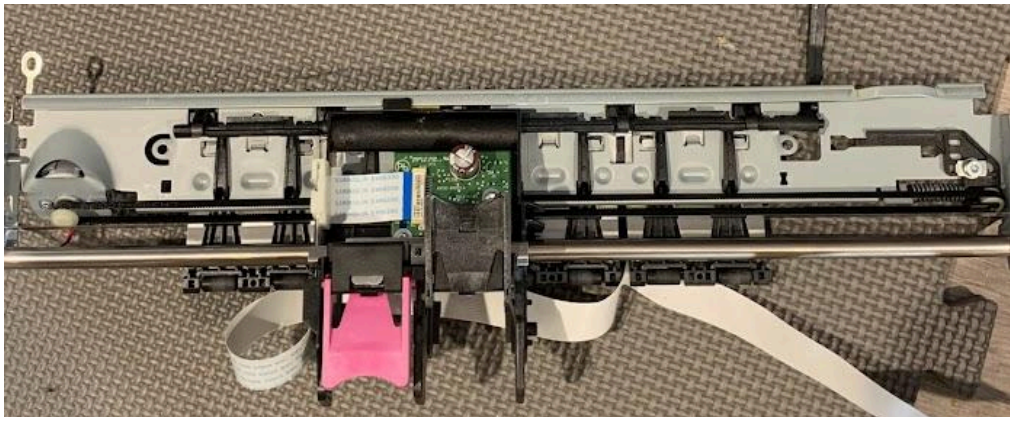
Designed to be able to come off without unscrewing any screws to fix if any papers are jammed

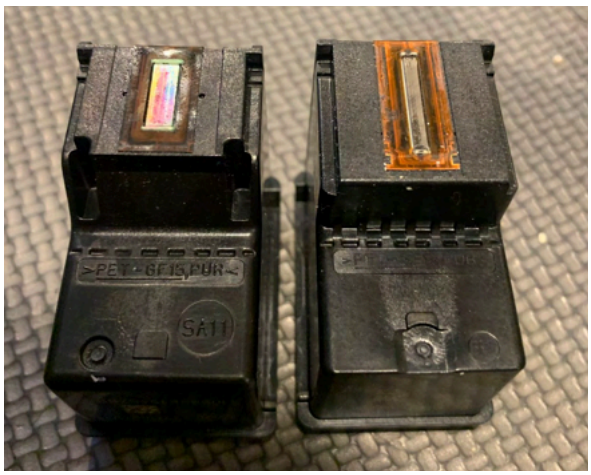
Top half of the hood allows the paper from the bottom half of the paper hood to go from 90 deg to 180 deg and into the inking area</td>
<td> 
  </td>
</tr>
</table>

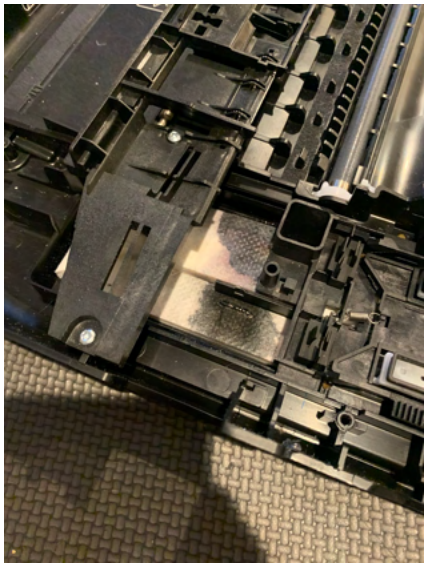
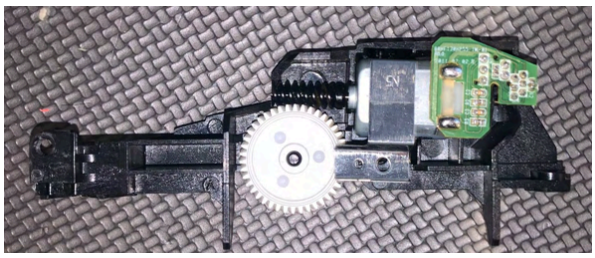
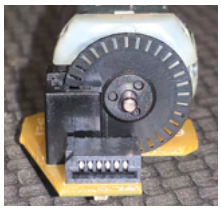
Main Paper Hood Roller Is powered by roller motor through white gear on the right Can pivot to prevent jamming Has rubber on wheels to have more grip Only spins one way	 
Gearbox for Bottom Rollers Connects the Main Paper Hood roller and the Paper Feeder to the output rollers	
Main Gearbox Encoder disc allows for extremely accurate readings of speed Gearbox connects the output rollers to the motor Belt drive	 

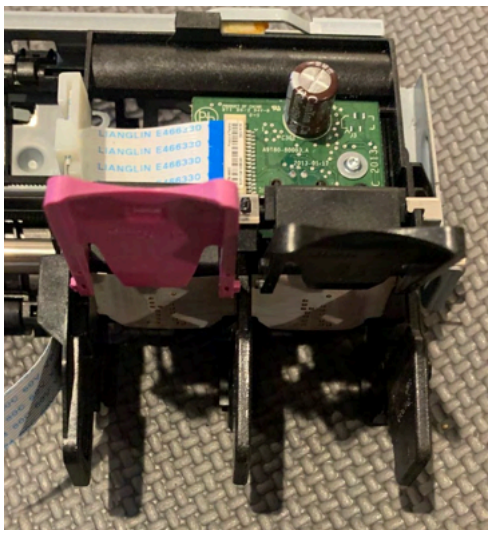
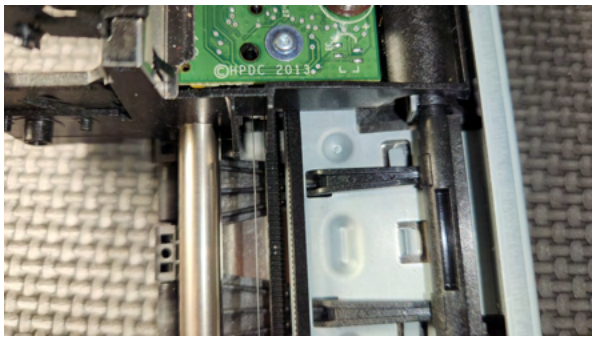
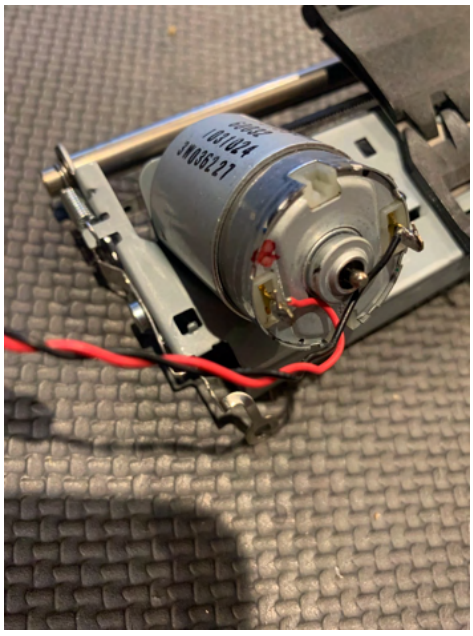
Bottom Output Rollers Spits the paper out onto the output tray The gear box in the middle of the left output roller shifts between 2 gears in the Gearbox for Bottom Rollers • Depends on the direction it is spinning to make sure the Paper Feeder and the Main Hood Roller are only spinning in 1 direction	
Top Output Rollers Are unpowered Prevents jamming and presses the paper into the Bottom Output Rollers	

5.3 Parts Lists: Ink Spray System



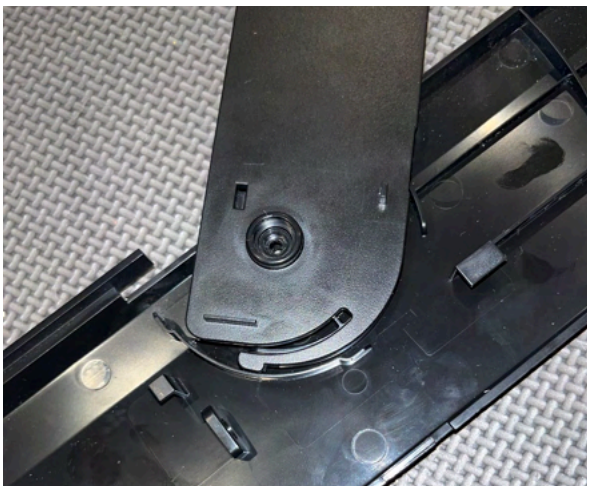
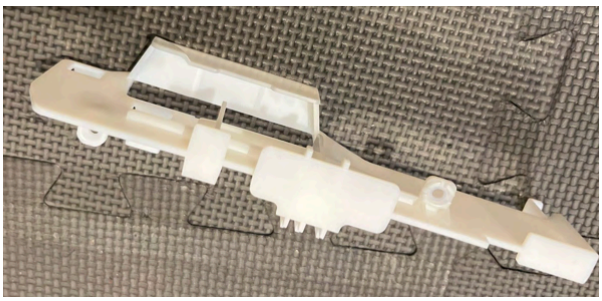
Component and Description	Image
Cartridge 2”x2”x1.25” Releases the ink from the bottom onto the paper Is held in the cartridge holder Uses CMYK printer color theory	 

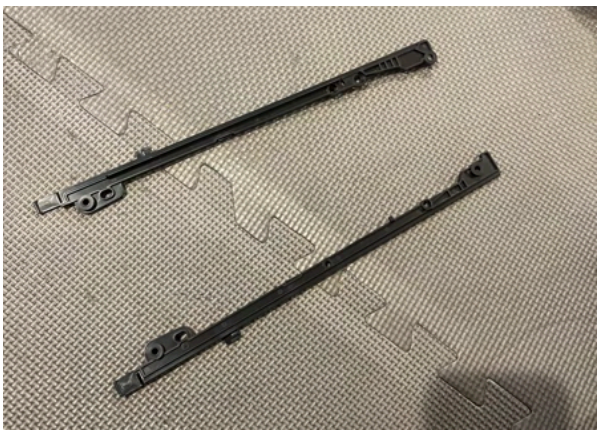
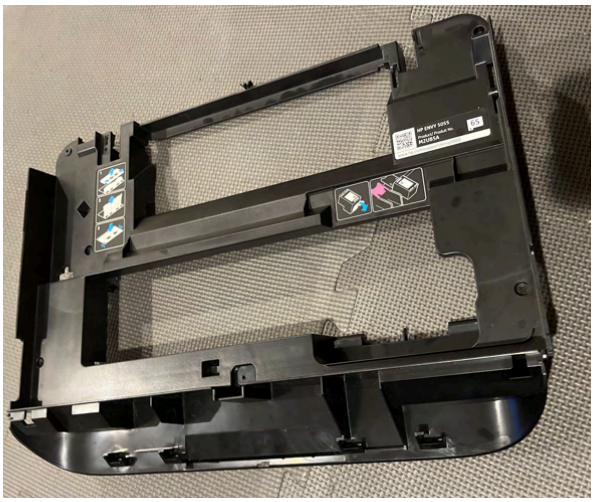
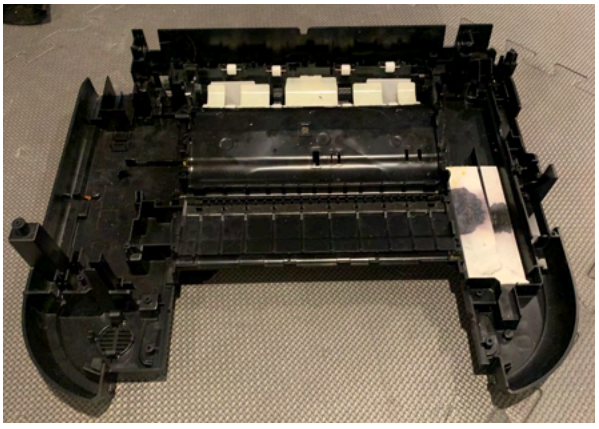
Cartridge sealer Seals cartridges when the ink is not being used Also keeps the Feeder roller up when ink not used Has a rack gear to move linearly using a motor Locks the cartridge holder in place and stops it from moving	
Cloth Absorbs leakage from the cartridges	
Cartridge sealer motor Motor powers worm gear which powers the gear attached to the rack gear → moves the tray linearly Attaches to the printer base Motor has encoder disc and encoder to keep track of speed and distance Has a wire port to connect to motherboard	 

Cartridge Holder Holds onto the cartridges and has metal dots to detect if correct cartridge is in place PCB in back controls the cartridges and detects linear movement along a strip of plastic with many lines (linear encoder) Has a capacitor (330 mF & 25V) Sits on metal rail, connected to motor through belt drive	 
Cartridge Holder motor Spins the belt which moves the cartridge holder linearly Wire has a ferrite core to reduce static damage	

5.4 Parts Lists: Structure

Component and Description	Image
Output Tray 14.5”x17.5”x3.5” Place where printed paper comes out	
Output Tray Extender Flips out horizontally to support the outputted paper	

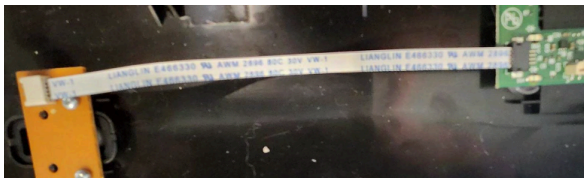
Output Tray Extender Lock Uses springy plastic to push into a divot in the wall to lock Can also slide out easily	
Right Side Plastic 4.5”x14”x2.5” Keeps structure from falling apart from the right side	
Left Side Plastic 4.5”x14”x2.5” Keeps structure from falling apart on the left side	
Gear Box 0.5”x7”x2” Keeps gear for paper indexing together and protected Provides support for the motherboard	

Paper Tray Rails 11.5”x0.5”x0.25” Guide rails for paper tray: left and right side	
Main Printer Structure 17.5”x12.5”x2” Middle part of printer Attaches to screen Sits on top of printer base Has hinges that attach to the scanner	
Printer Base 17”x14”x3” Contains and acts as the main structure for the motherboard, power source, paper tray, paper indexing, and ink cartridges	
Bottom Corner Panel 1”x8”x1” Protects sensors and paper ramps	

5.5 Parts Lists: Hardware

Component and Description	Image
36x Torx 10 Button Head Screw 0.5 in	
4x Torx 10 Pan Screw .275 in	
7x black Torx 10 Button Head Screw 0.5 in	
1x Metal Washer: THK .04 in, OD .35 in, ID: .14 in	

5.6 Parts Lists: Miscellaneous Electronics

Screen 50mm wide, 30mm tall Functions: • Displays information for the user • Receives inputs from user (touchscreen)	
Power Button Turns printer on/off Connected to screen PCB via a ribbon wire	 

Screen PCB Wires • 2 connected to screen • 1 connected to power button • 1 connected to motherboard PCB behind screen with 2 wires going into the screen and one wire connecting to power button and one wire connecting to rest of printer Contains a microcontroller chip	
Infineon Technologies CY8C4024AZI-S413 Microcontroller System microcontroller • Likely processes and sends commands to the screen Datasheet	
HP Officejet 4650 Power Supply Adapter F0v63-60012 Changes current from 100-240 VAC (alternating current voltage) to +32/+12 V (direct current voltage)	 

5.6.1 Parts Lists: Motherboard

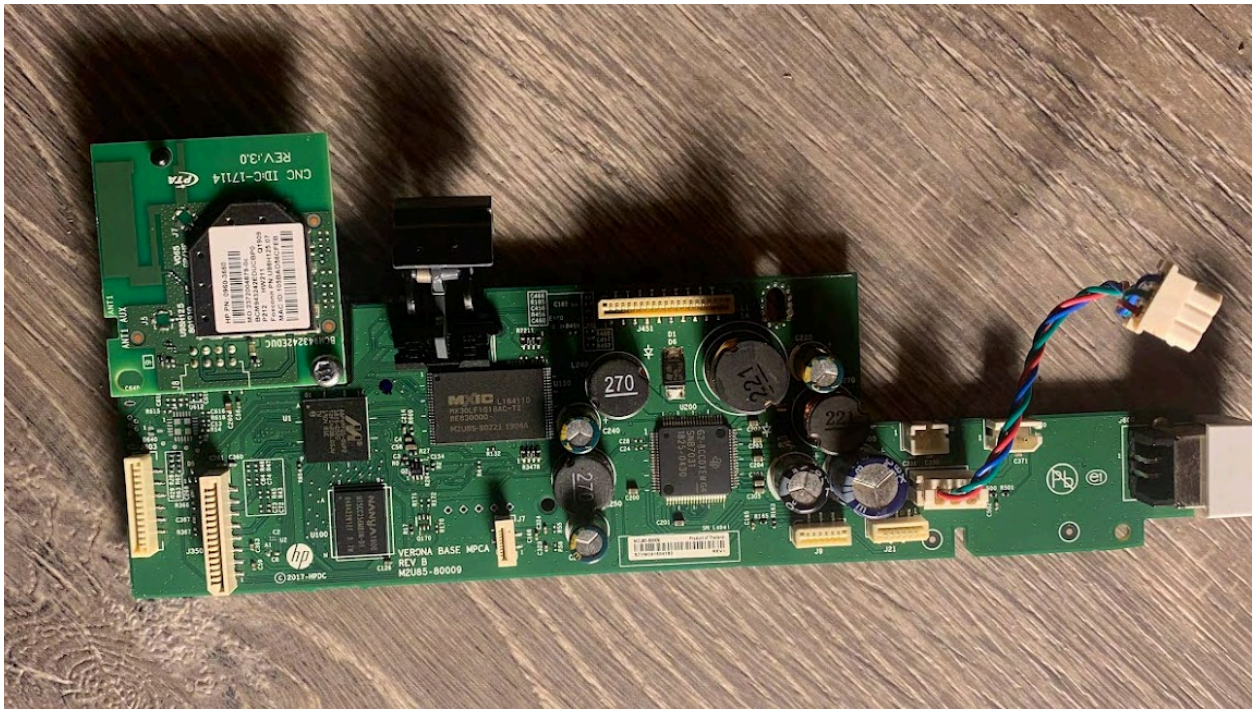


Figure 5.6.1.1 Front side of the motherboard.

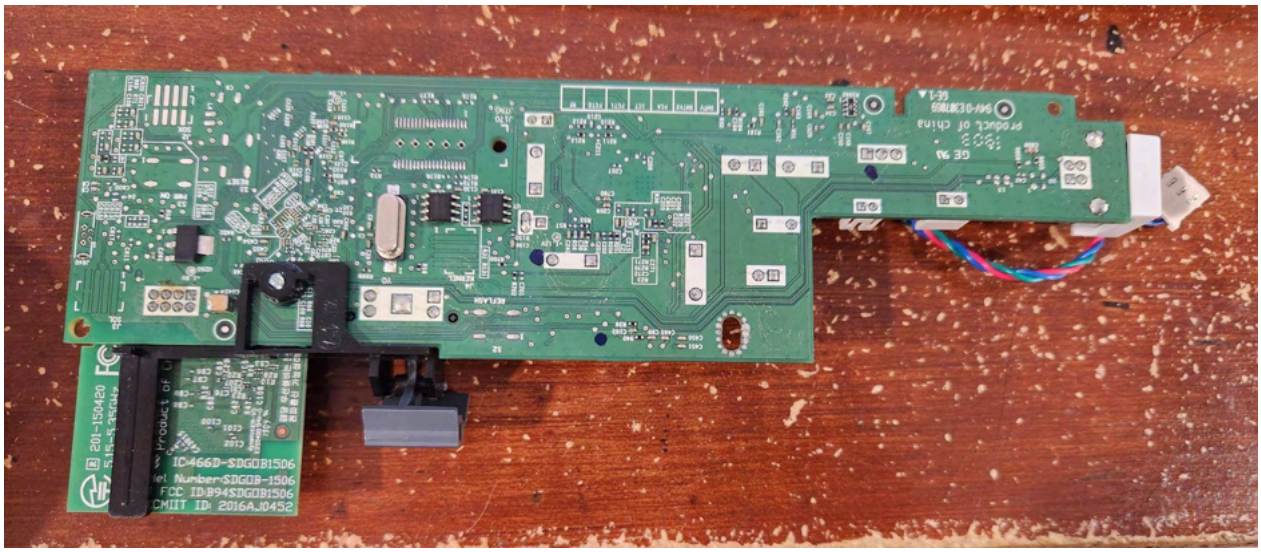


Figure 5.6.1.2 Back side of the motherboard.

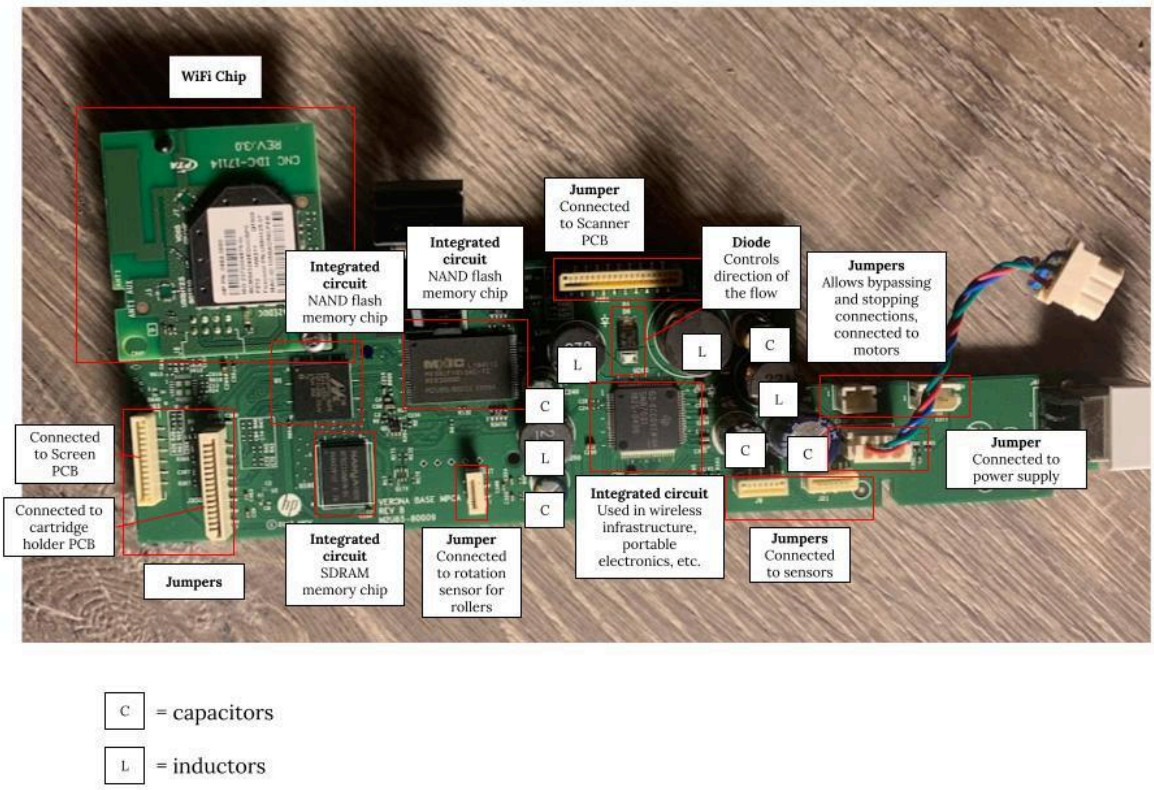


Figure 5.6.1.3 Front side of the motherboard components. View it here.

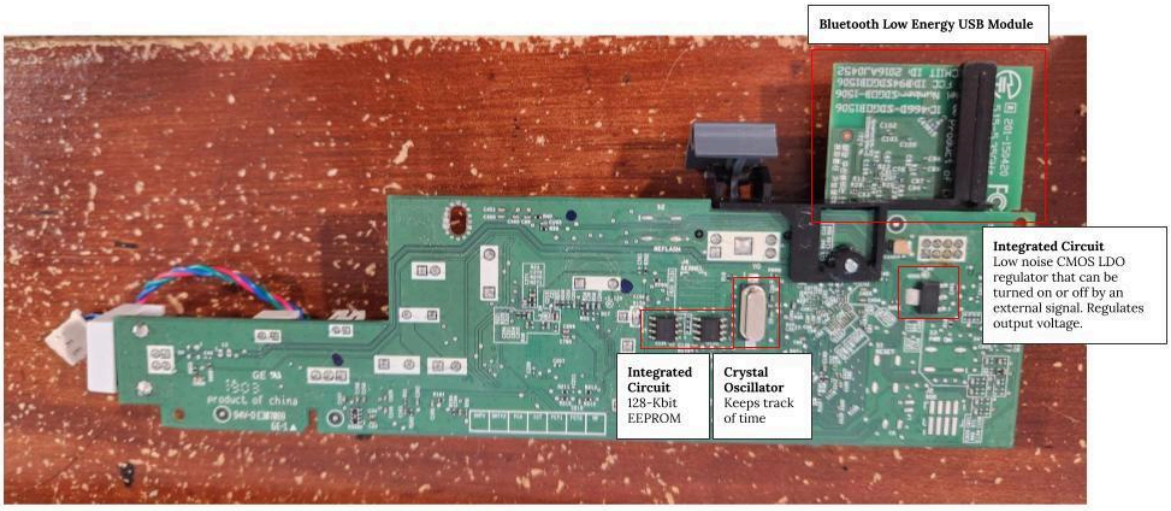
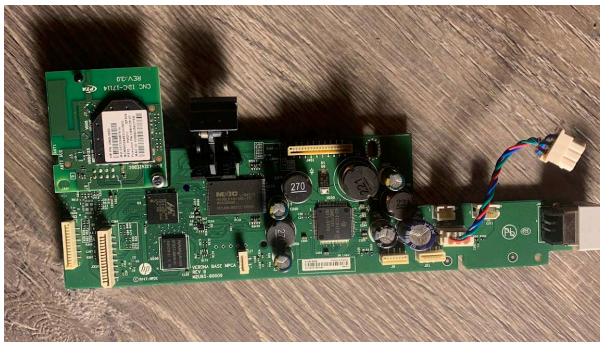
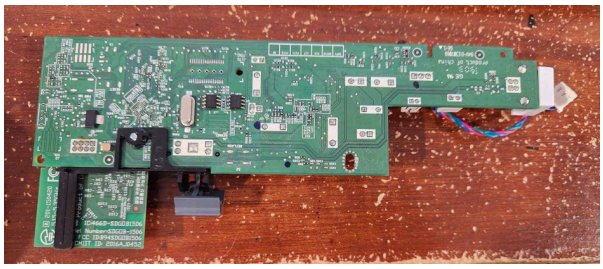
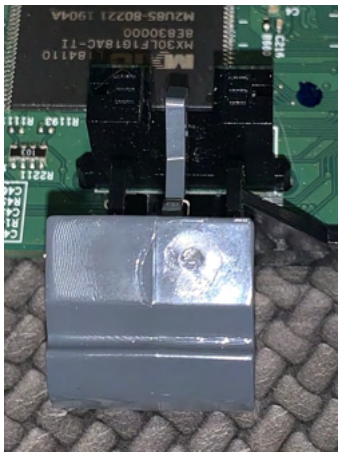
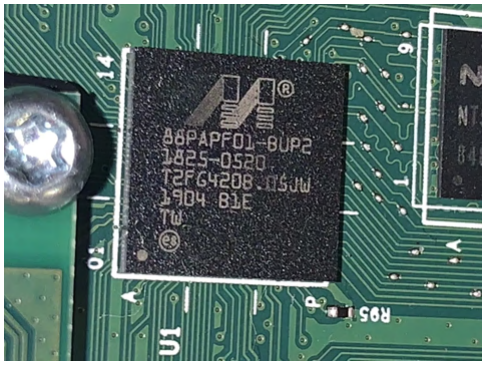
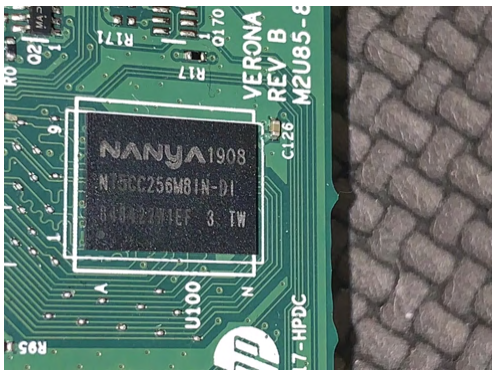


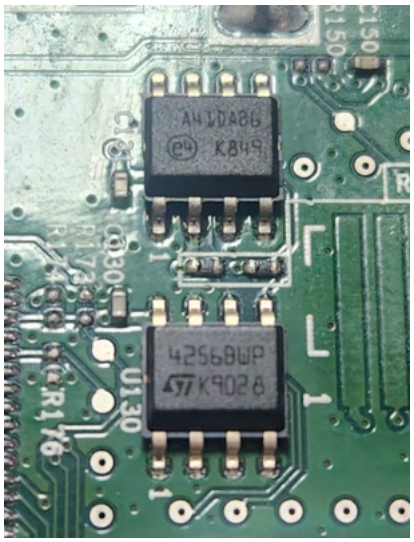
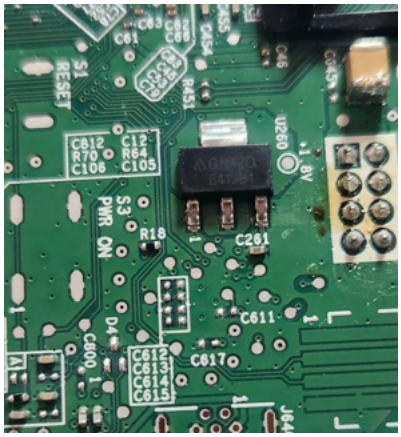
Figure 5.6.1.4 Back side of the motherboard components. View it here.

5.6.1 Parts Lists: Motherboard Components

Motherboard Connects to all other electronic components of printer Connects to WiFi	 Front  Back
WiFi Chip Connects to local networks, allowing the printer to receive data from other devices connected to the same network Includes Bluetooth Low Energy USB Module	 Front  Back

Lid Sensor Detects if the lid is opened, exposing the printer's moving parts Prevents printer from operating while lid is open due to prevent harm to the user	
USB Type B Port Connects to other devices, allowing the printer to establish a direct connection with them	
Marvell 1825-0520 Integrated Circuit Helps store and transmit data to and from WiFi chip Datasheet not found - it is a specialized IC	

Nanya NT5CC256M8IN-DI 2Gb SDRAM chip • Synchronous Dynamic Random Access Memory • RAM can be freely read and changed • Data in SDRAM decays quickly and needs to be periodically rewritten • SDRAM is synchronized to clock inputs, which allows for greater efficiency through command pipelining ○ The next instruction can be received before the previous is finished Acts as short term data storage for the printer, and likely temporarily stores the document to be printed Datasheet	
Macronix MX30LF1G18AC-TI NAND flash memory chip • Can store memory even after power is turned off • Likely plays a role in storing preprogrammed instructions for the printer Datasheet	
Texas Instruments SNB7031 A versatile integrated circuit with many capabilities - could play many roles in the function of the printer Datasheet not found - most probably a specialized or custom-made integrated circuit	

Crystal Oscillator Frequency unknown Keeps track of time - by counting the vibrations of the quartz crystal inside, the motherboard is able to measure time	
128K Bit Serial I^2C Bus EEPROM M24128-BW Electrically erasable programmable read-only memory (EEPROM) • Often used in computers smart cards, and remote keyless systems • Can store information even after power is removed • Can be programmed and erased in-circuit Datasheet	
Low Noise CMOS LDO Regulator With Enable GH12D Regulates linear voltage Uses the complementary metal-oxide-semiconductor (CMOS) technology for low power consumption and low noise Can be turned on and off by an external signal Datasheet	

Other electronic components

- 2x 220µH inductor
- 3x 330µF 6.3V capacitor
- 1x 330µF 25V capacitor
- 1x 330µF 50V capacitor
- 2x 27µH inductor

6. Findings

After analyzing each component and researching online, we established flow charts for the printer, scanner, and power supply.

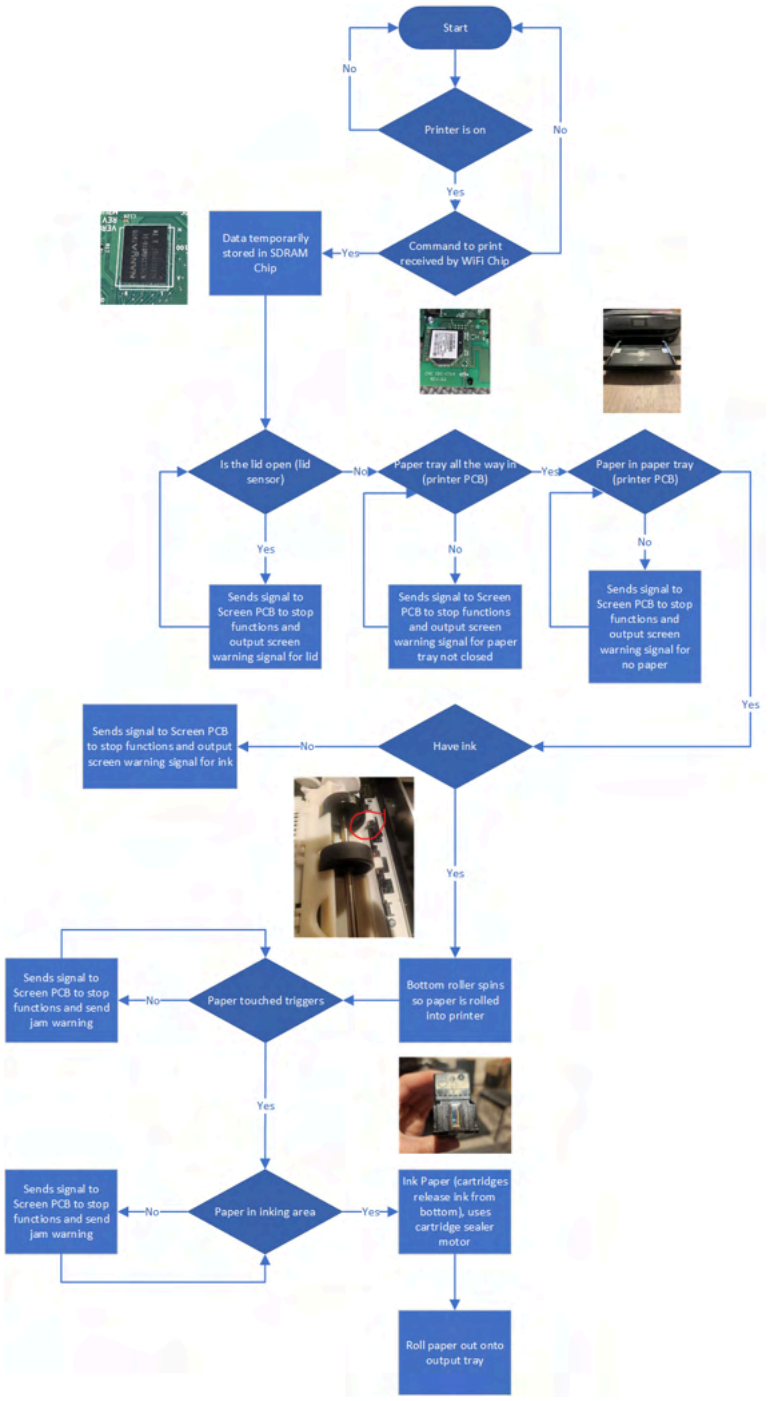


Figure 6.1. Printer Control Flow Chart. View it here.

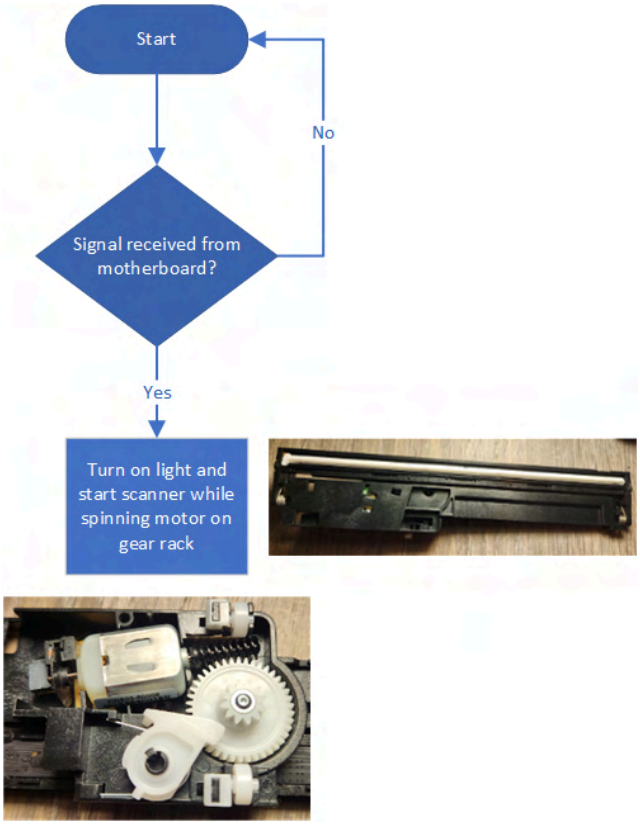


Figure 6.2. Scanner Control Flow Chart. View it here.

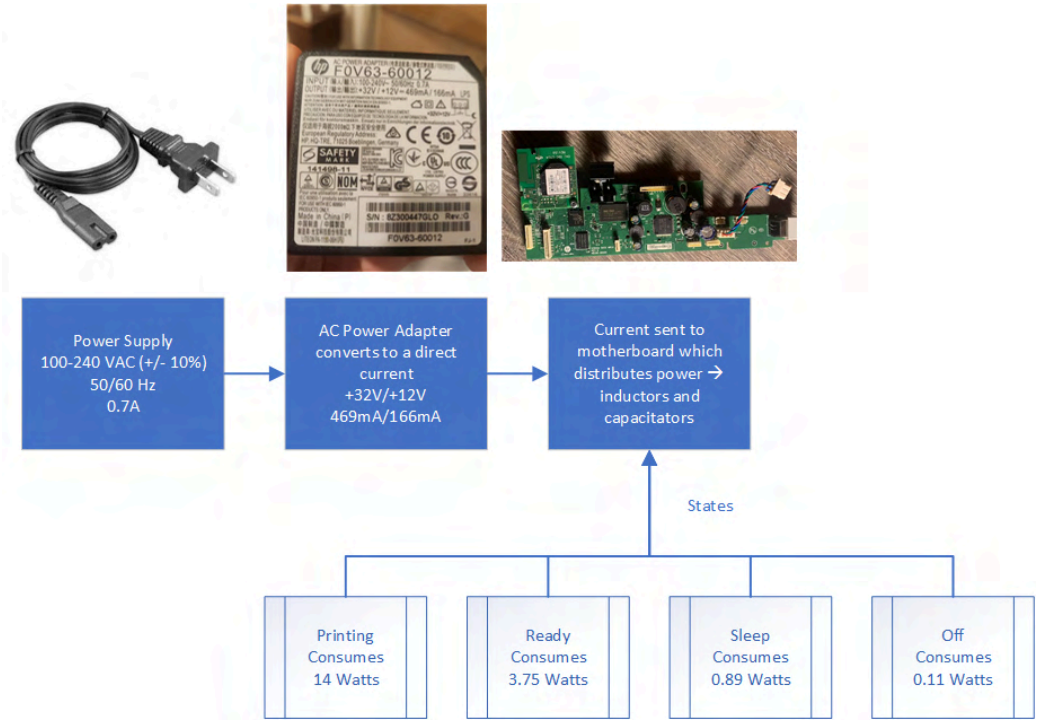


Figure 6.3. Power Supply Flow Chart. View it here.

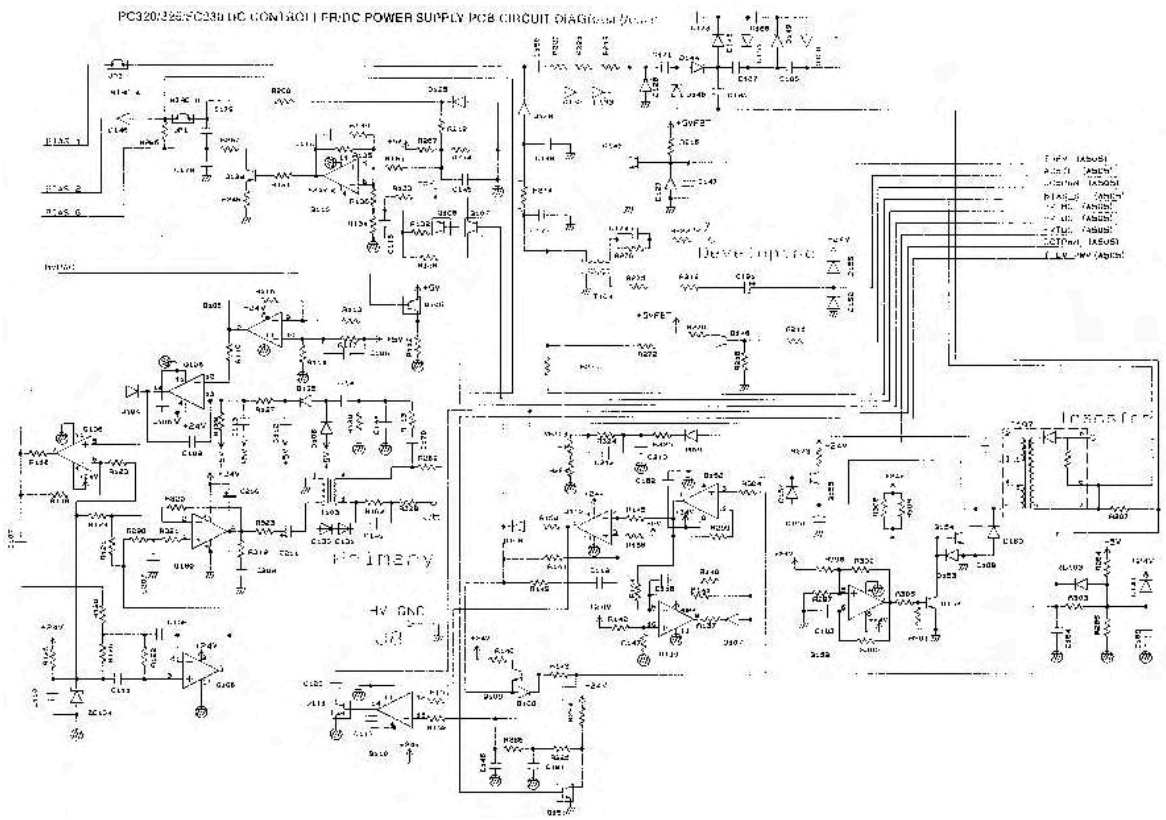


Figure 6.4. Power Supply PCB Circuit of an HP Printer.

We also researched the hidden or microscopic components of the colors and cartridges.

Figure 6.4. The insides of the ink cartridges (black on the left and cyan, magenta, and yellow on the right). Each cartridge has separate compartments for sponges filled with ink of each

color. They contain an integrated circuit chip to determine how much ink has been used. Credit to [Felladaw](#).

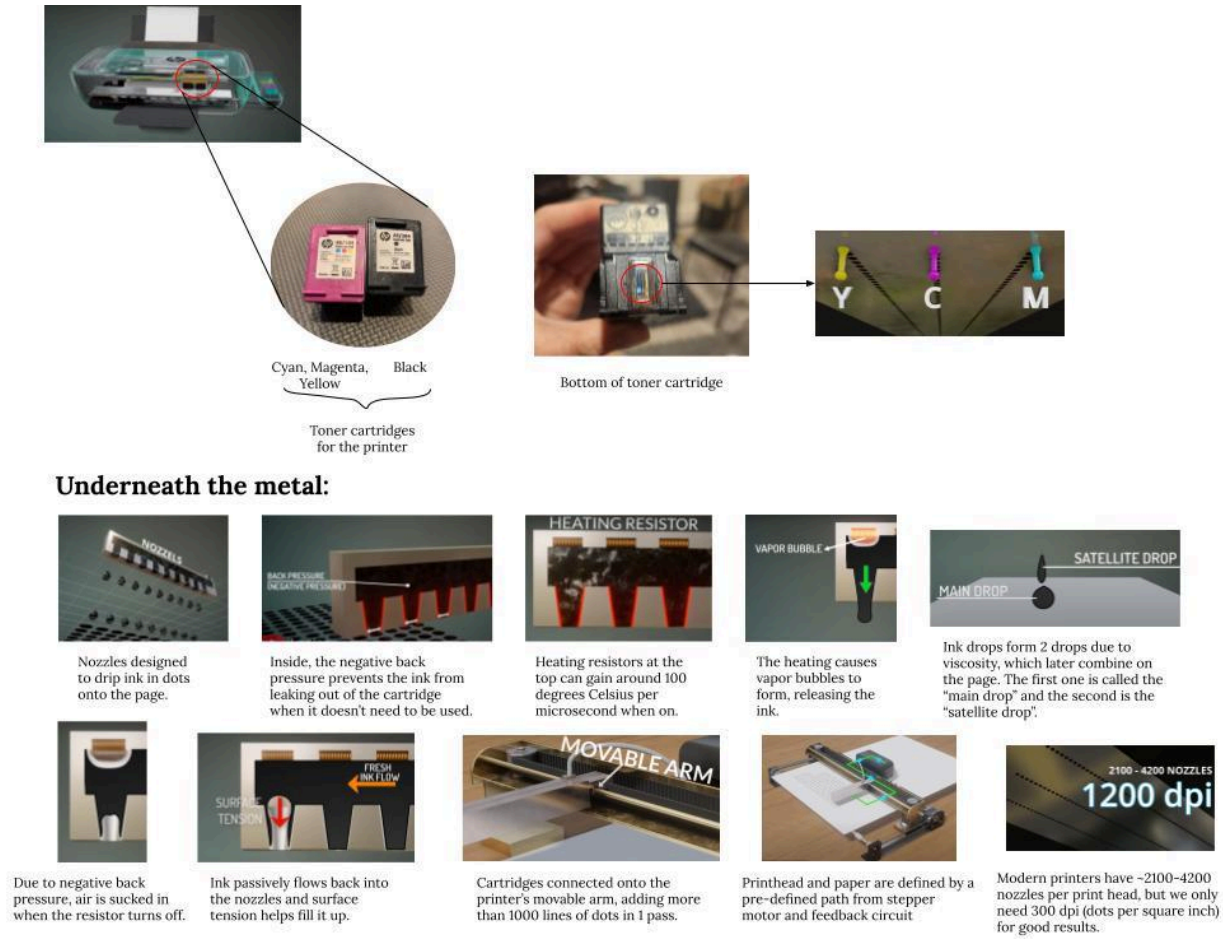
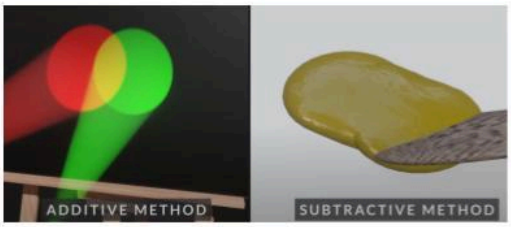
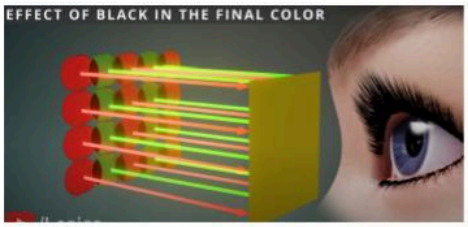


Figure 6.5. Components of the thermal inkjet printing mechanism. Credit to [Lesics](#). View it [here](#).

Why do we use magenta, cyan, and yellow?

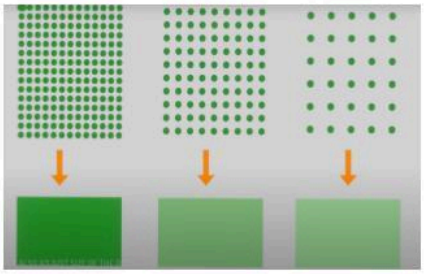


Normally, we see light using the additive method (it is directly reflected from the object into our eyes). But, we need the printer to reflect the color from the ink, so we need to use the subtractive method.

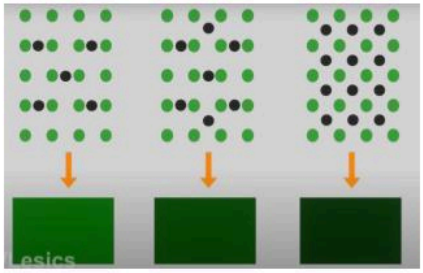


In this example, we consider layers of red and green ink molecules. When we look at the ink, the green molecules reflect green light and the red molecules reflect red light. But, in different layers, red light reflected by red molecules will be absorbed by the green molecules and cause a black spot. This changes the colors we see. So, we need to use the inverse of red, green, and blue to get cyan, magenta, and yellow.

How do printers print lighter shades and darker shades?



Decreased spacing allows us to perceive a "lighter color."



For darker colors, we add in black in between our drops of our original color. We decrease the spacing of black droplets to make the shade darker.

Figure 6.6. The theory behind printing colors. Credit to Lesics. View it here.

6. Conclusions

Throughout our investigation, we learned many new skills of teamwork, disassembly, and research that will greatly help us on our robotics journey. By analyzing each component, we learned the value of the mechanical and electrical systems that form the electronic devices we see today. We deepened our understanding of the Engineering Design Process after analyzing the history behind inkjet printers and seeing firsthand the many fail-safe mechanisms there are on the HP Envy 5055. By analyzing how electronics and hardware work together to perform such a precise task as printing, we furthered our knowledge for creating integrated systems to perform certain tasks. Above all, we learned both the developmental and physical capabilities of technology to adapt and how concepts from simple mechanisms like block printing are used to construct devices that are in use daily around the world.

Lessons Learned:

1. **Team research, communication, and project planning skills**
2. **History and revisions of inkjet printers**
3. **Color printing theory and ink sprayer details - use of science for passive processes**
4. **Optimization of space and structure**
5. **Analyzing components of PCB boards**
6. **Possible applications to robot (reliability and traction or rollers and screw joints for structure and movement)**

7. Citations and References

All other sources are cited with links.

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