Reverse Engineering Online Challenge 2022

Disassembly and Analysis of the Nintendo Entertainment System

Team 11588E

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1.0 Summary Report

Released on October 18, 1985, the Nintendo Entertainment System (NES) was made as a simple, cheap console that ran games stored on cartridges. The NES was one of the best-selling game systems of its time and it helped strengthen the gaming industry after the video game crash of 1983. Selling over 60 million units, this system brought the joy of arcade games to families all across the globe. Nearly one-third of all the houses in the US and Japan owned a NES. We, a team of video game-loving students, decided to disassemble the NES, to find out how it works and to find out why the NES was such a great feat in the video game industry.

Once a game cartridge, consisting of a video RAM chip, a ROM chip, an 8-bit shift register chip, an OR logic chip, and a CIC lockout chip, is inserted into the 72-pin connector of the console, the system can then be turned on. The game logic and character data in the ROM chip is then read by the CPU to obtain the game program data and process it. The CPU also obtains user input from the controllers. It sends the processed data to other components on the motherboard, such as the APU and PPU. The PPU uses the data on the ROM chip to produce an image on the TV, while audio is generated by APU. Even though the motherboard already has a video RAM on it, some game cartridges contain a video RAM chip. This is extra RAM to augment the RAM on the motherboard for more complicated games. The CIC lockout chip is used for security purposes to prevent piracy, and the motherboard also has a CIC lockout chip.

Aside from the knowledge we gained by reading countless articles and documents, we also learned about the passionate retro hardware community, whose goal is to preserve the significance of retro hardware, such as the NES. We used information created by the community to support our research and learning. Due to its great simplicity and popularity, the NES is perhaps the most emulated console with many different emulators. Emulators are programs that allow you to run games or applications that are not designed for the host computer. Emulators are used to help preserve the history of NES and its great engineering feat. The NES only ran at 1.79 MHz in comparison to modern-day gaming consoles which can run at 3.5 Gigahertz, almost 3 orders of magnitude more in speed capability! By using little resources, such as a low memory and a slow CPU, the designers were able to run many groundbreaking, fun games like Mario, Zelda, Metroid, Castlevania.

The success of the 8-bit NES eventually ushered in another era of gaming, inspiring the design of 16-bit gaming consoles, such as the SNES and Genesis. The NES laid the groundwork for many future generations of gaming consoles. The team had fun researching the NES and experiencing the fun of 8-bit gaming. **(Word Count: 499)**

2.0 Architecture Diagram

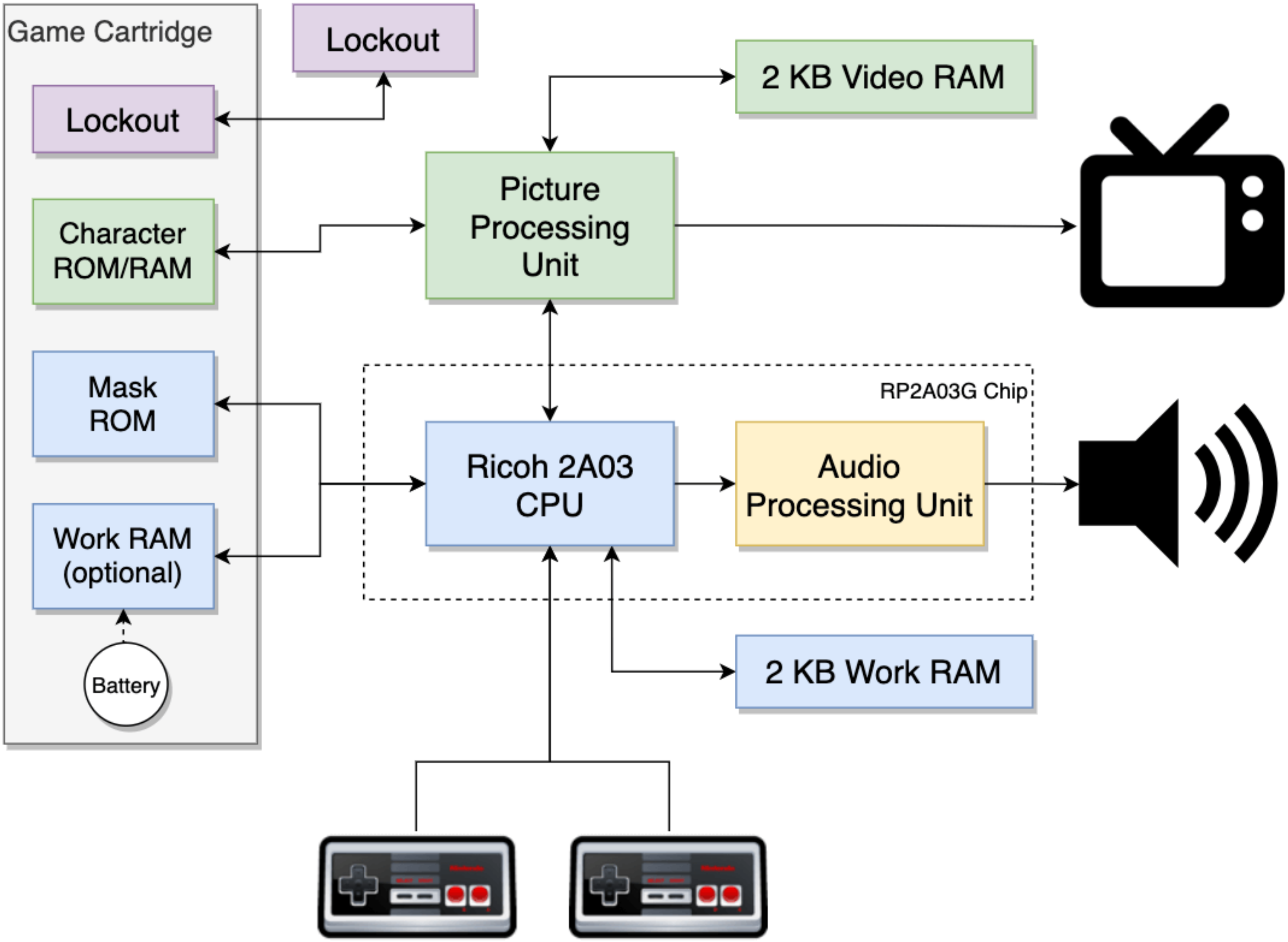


Figure 1: Architecture Diagram of Nintendo Wii Console

This diagram shows how the parts of the NES interact with each other to create a successful system. We used this diagram to help identify and understand components for the NES.

3.0 External Anatomy of the Nintendo Entertainment System

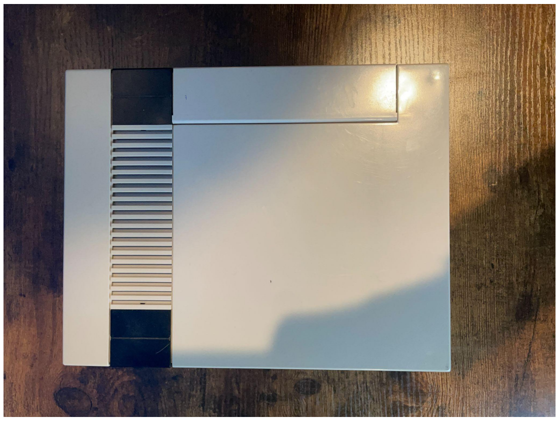


Figure 2.1: Top View

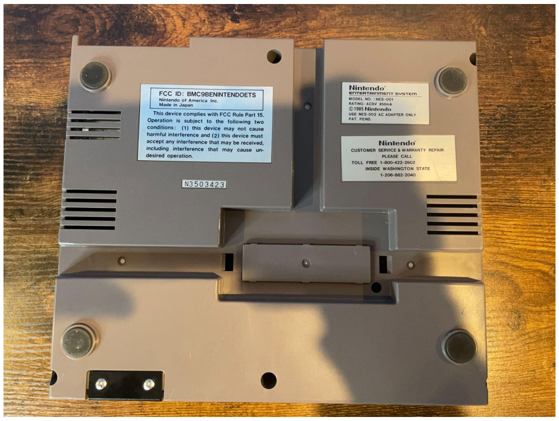

FCC ID: BMC9BENINTENDOETS
Nintendo of America Inc.
Made in Japan
This device complies with FCC Rule Part 15. Operation is subject to the following two conditions: (1) this device may not cause harmful interference and (2) this device must accept any interference that may be received, including interference that may cause undesired operation.
N3503423
Nintendo
ENTERTAINMENT SYSTEM
MODEL NO. :NES-001
RATING: AC9V 850mA
©1985 Nintendo
USE NES-002 AC ADAPTER ONLY
PAT. PEND.
Nintendo
CUSTOMER SERVICE & WARRANTY REPAIR
PLEASE CALL
TOLL FREE 1-800-422-2602
INSIDE WASHINGTON STATE
1-206-882-2040

Figure 2.2: Bottom View

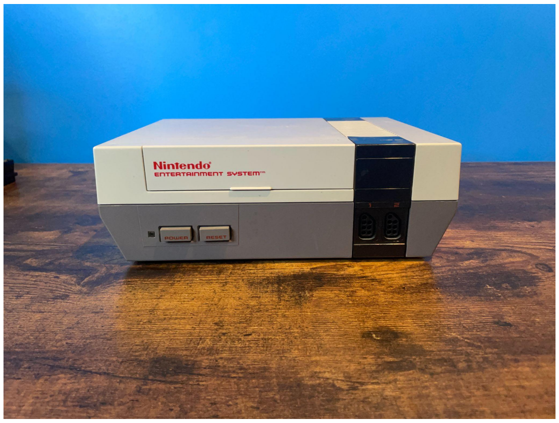


Figure 2.3: Front View

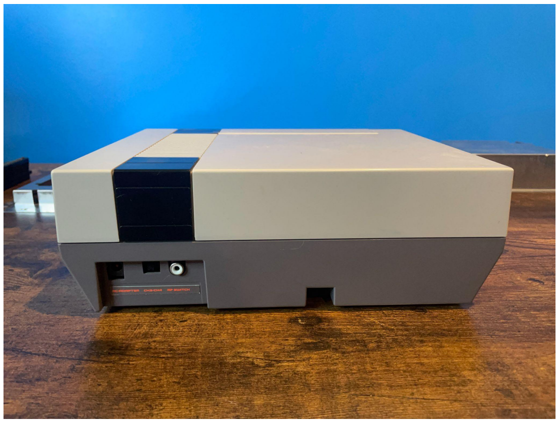


Figure 2.4: Back View

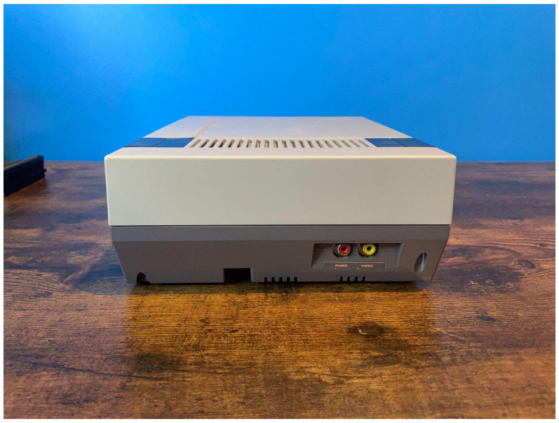


Figure 2.5: Right Side View

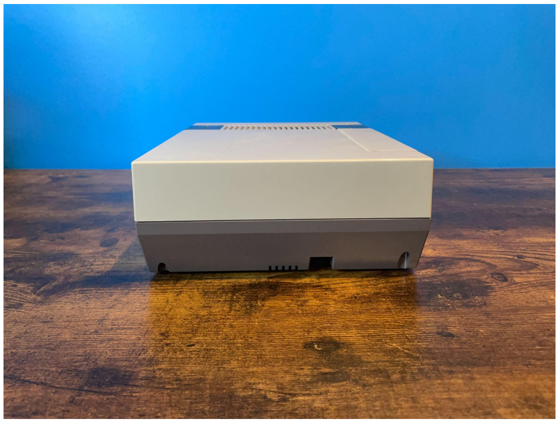


Figure 2.6: Left Side View

4.0 Disassembly Process

Preparation: **Wear safety equipment such as safety goggles and gloves to ensure the safety of you and team members**. To disassemble the NES, you will need a Philips #2 Screwdriver and a Flathead Screwdriver (2.5 mm or 3/32”). Remember to keep the loose screws organized.

Step 1: Remove the Top Housing

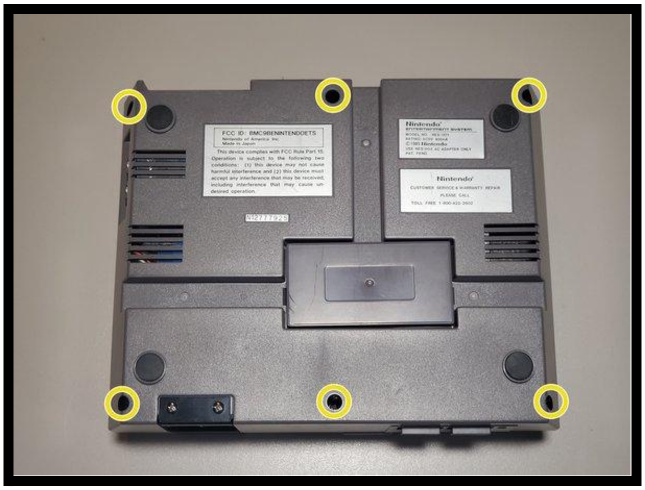


Figure 3.1.1: Remove the 6 screws shown

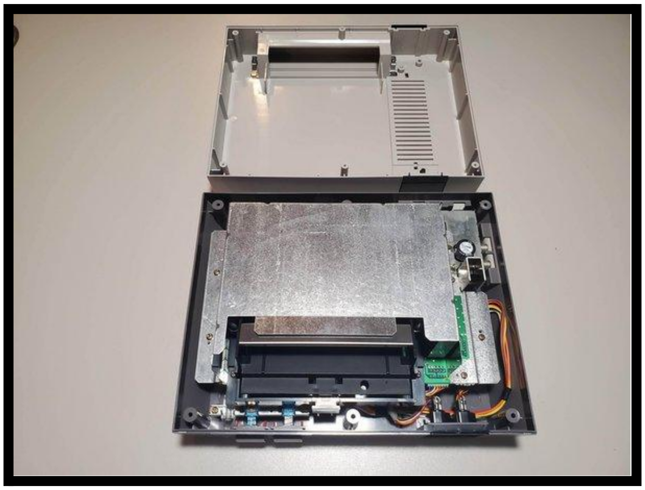


Figure 3.1.2: Take the top housing off the bottom of the system

Step 2: Remove the Top Radio Frequency Shield

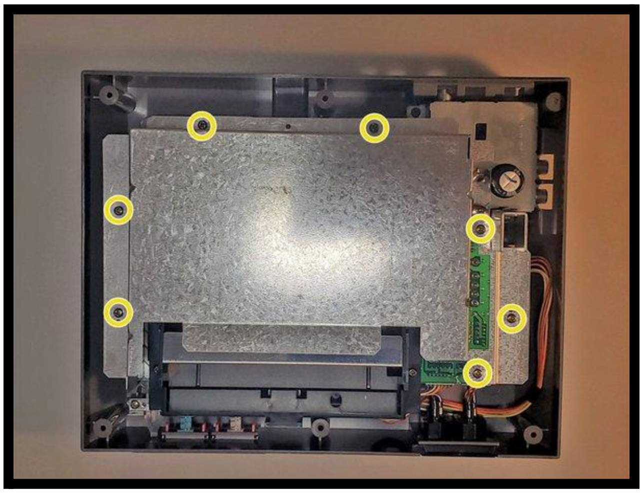


Figure 3.2.1: Remove the 7 screws shown

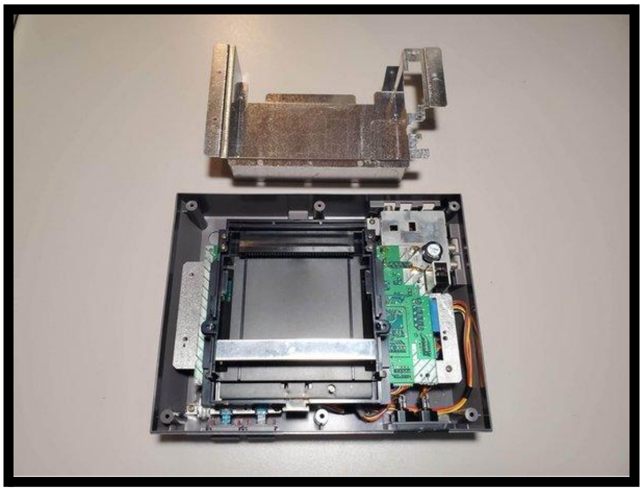


Figure 3.2.2: Lift the RF shield and place it to the side

Step 3: Remove the Cartridge Tray

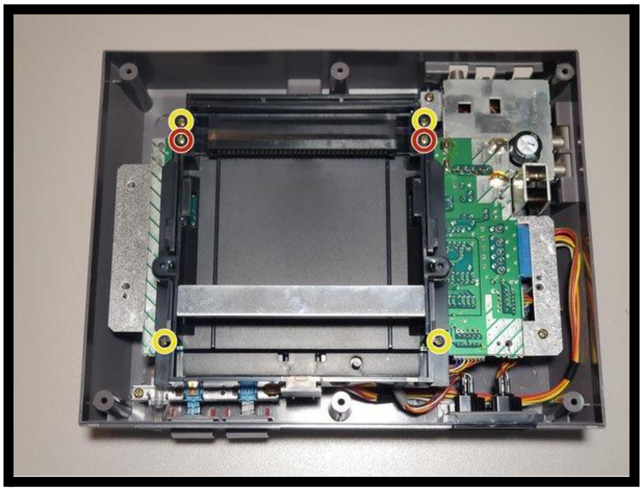


Figure 3.3.1: Remove the 6 screws shown

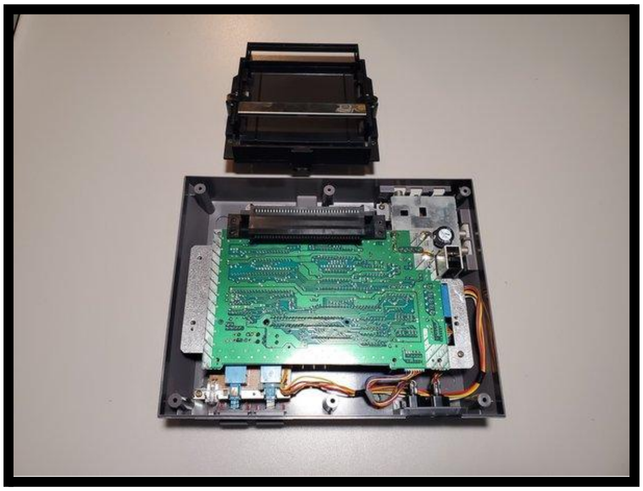


Figure 3.3.2: Remove the cartridge tray by sliding it towards the front of the system

Step 4: Remove the Motherboard Part 1

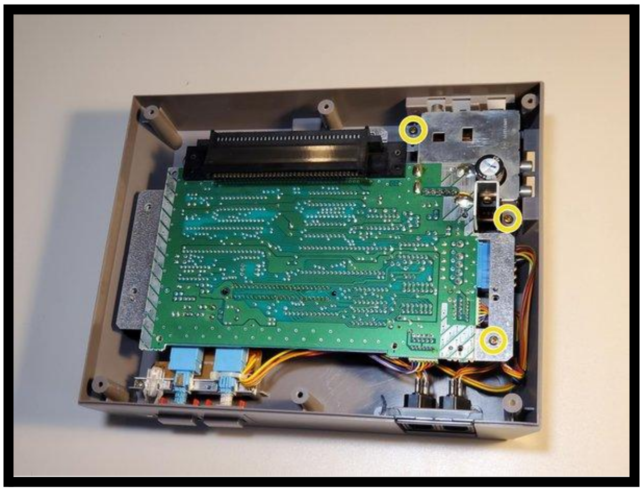


Figure 3.4.1: Remove the three screws shown

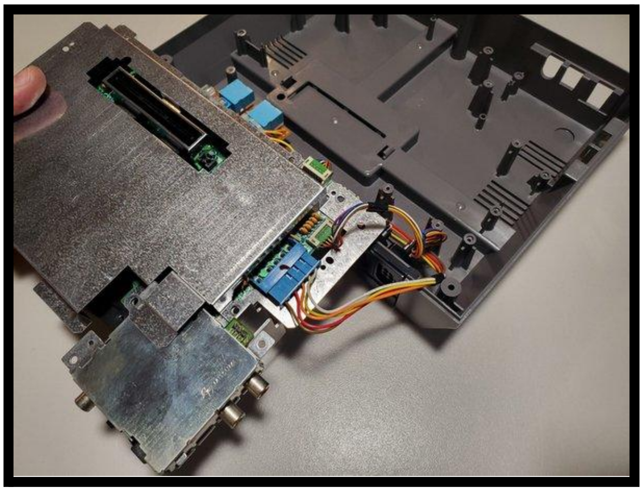


Figure 3.4.2: Lift the motherboard and turn it over for the next step

Step 5: Remove the Motherboard Part 2

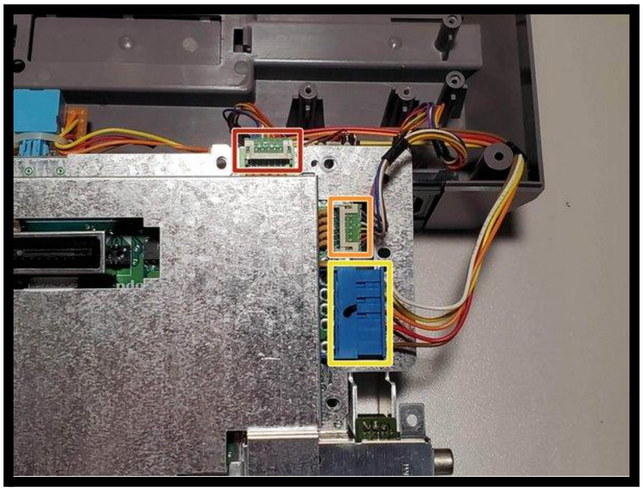


Figure 3.5.1: Disconnect the 3 wires

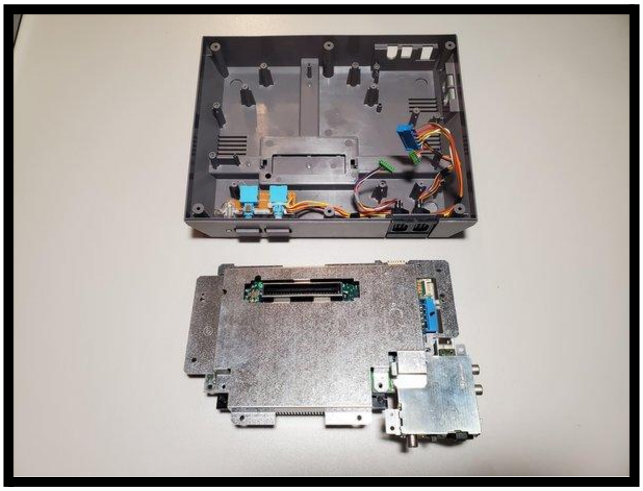


Figure 3.5.2: Remove the motherboard

Step 6: Remove the Bottom Radio Frequency Shield

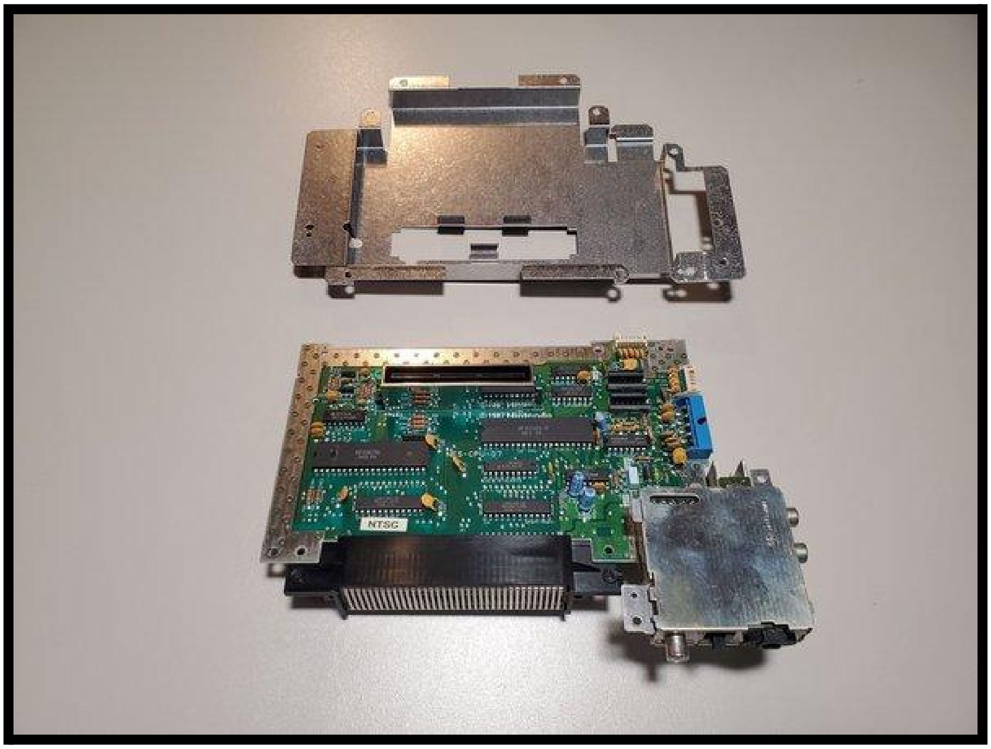


Figure 3.6.1: The shield is not held by screws. Remove the shield from the motherboard.

Step 7: Remove the 72-Pin Connector

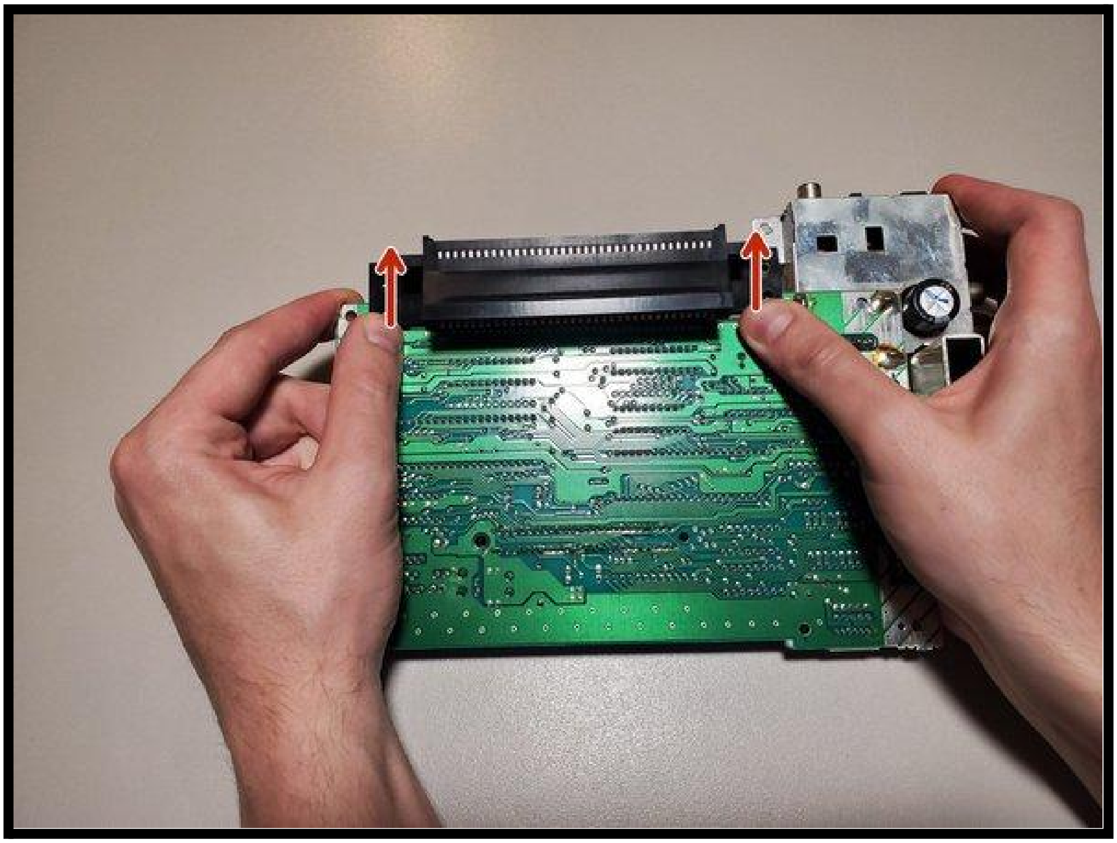


Figure 3.7.1: Push the 72 Pin connector off the motherboard as shown

Step 8: Remove Power/Rest Buttons

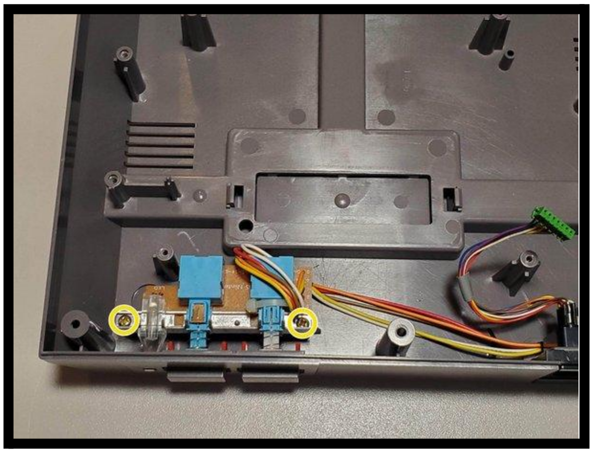


Figure 3.8.1: Remove the 2 screws

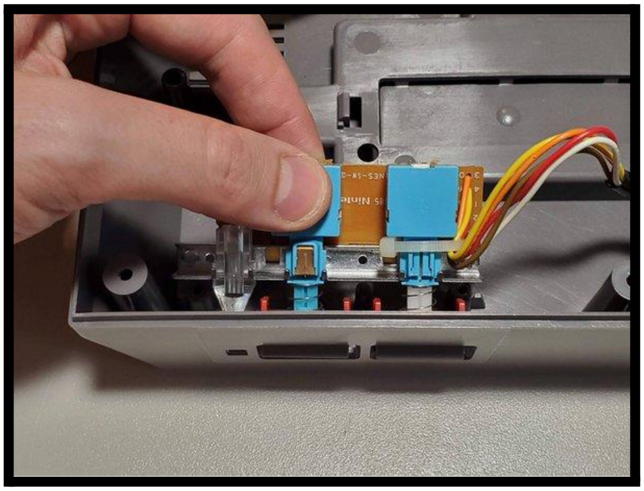


Figure 3.8.2: Remove the buttons from the housing

Step 9: Remove Controller Ports

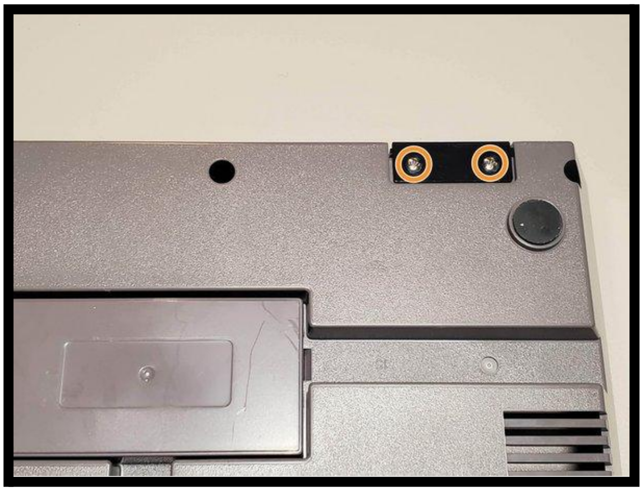


Figure 3.9.1: Remove the 2 screws

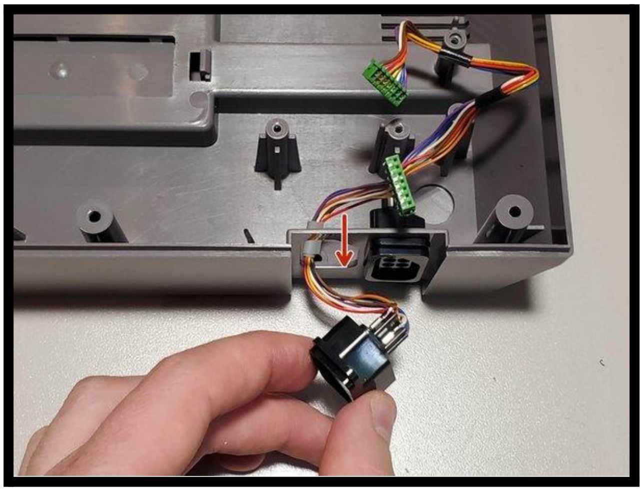


Figure 3.9.2:Remove the controller ports

Step 11: Disassembly Complete!

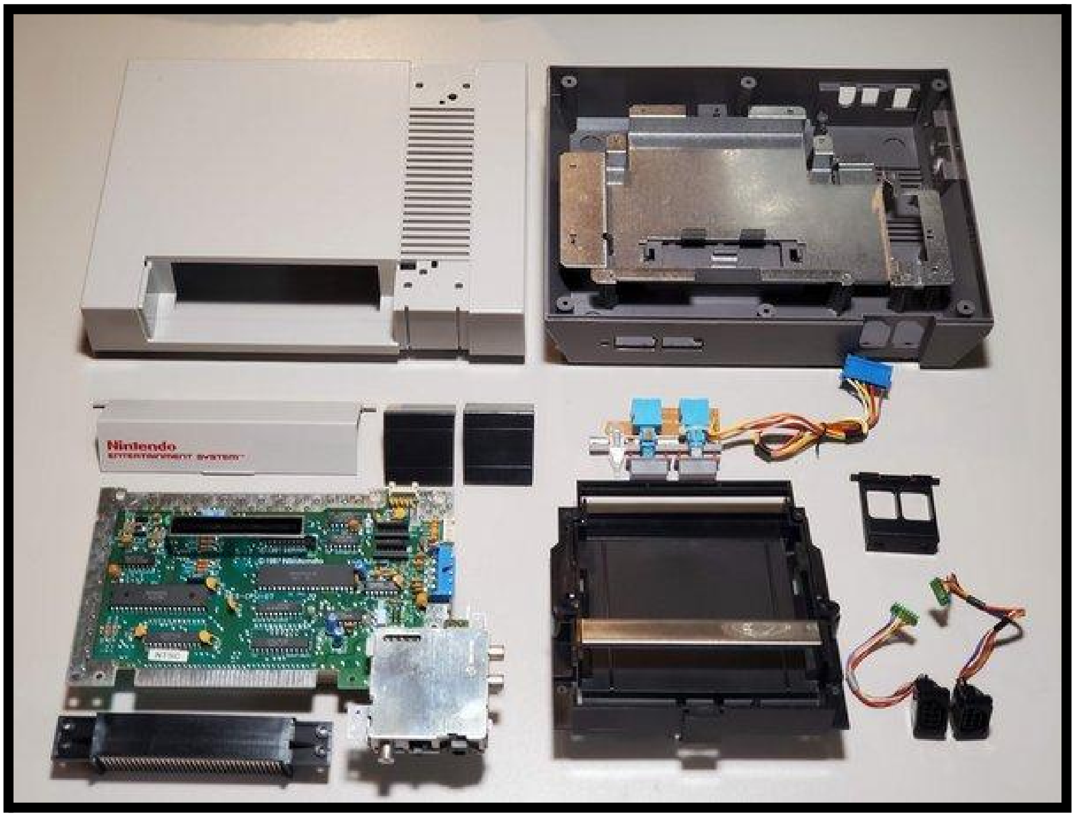
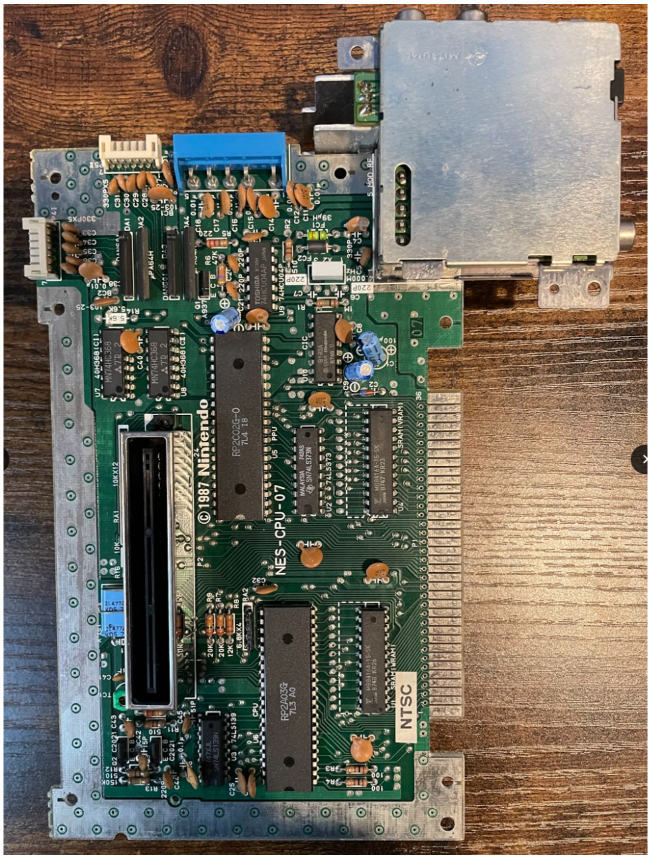


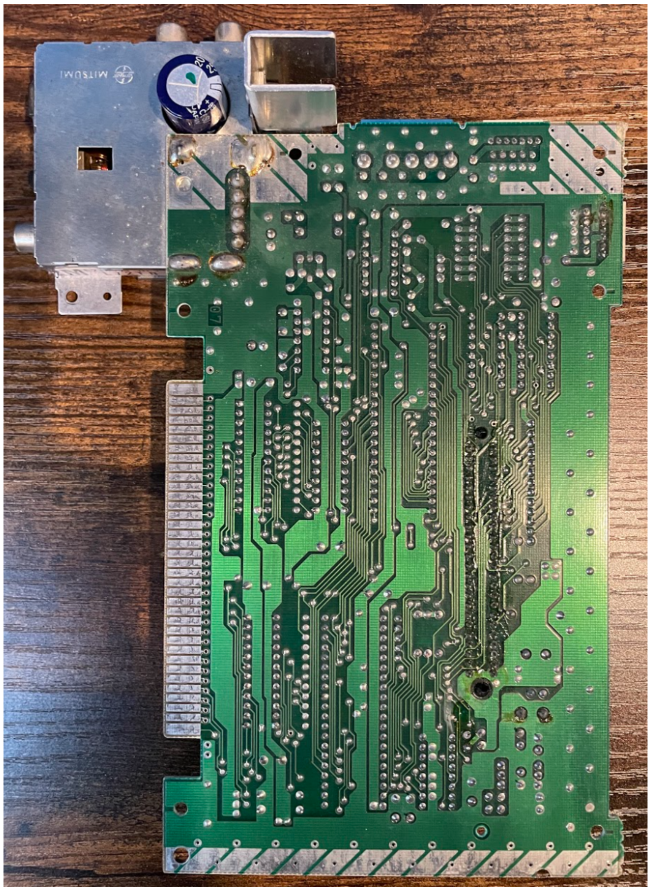
Figure 3.10.1: Disassembly Complete!

5.0 Analysis Process

Plan to identify each chip on the NES motherboard and research its purpose.

5.1: Motherboard





5.1.1: Labeled Images of the Motherboard

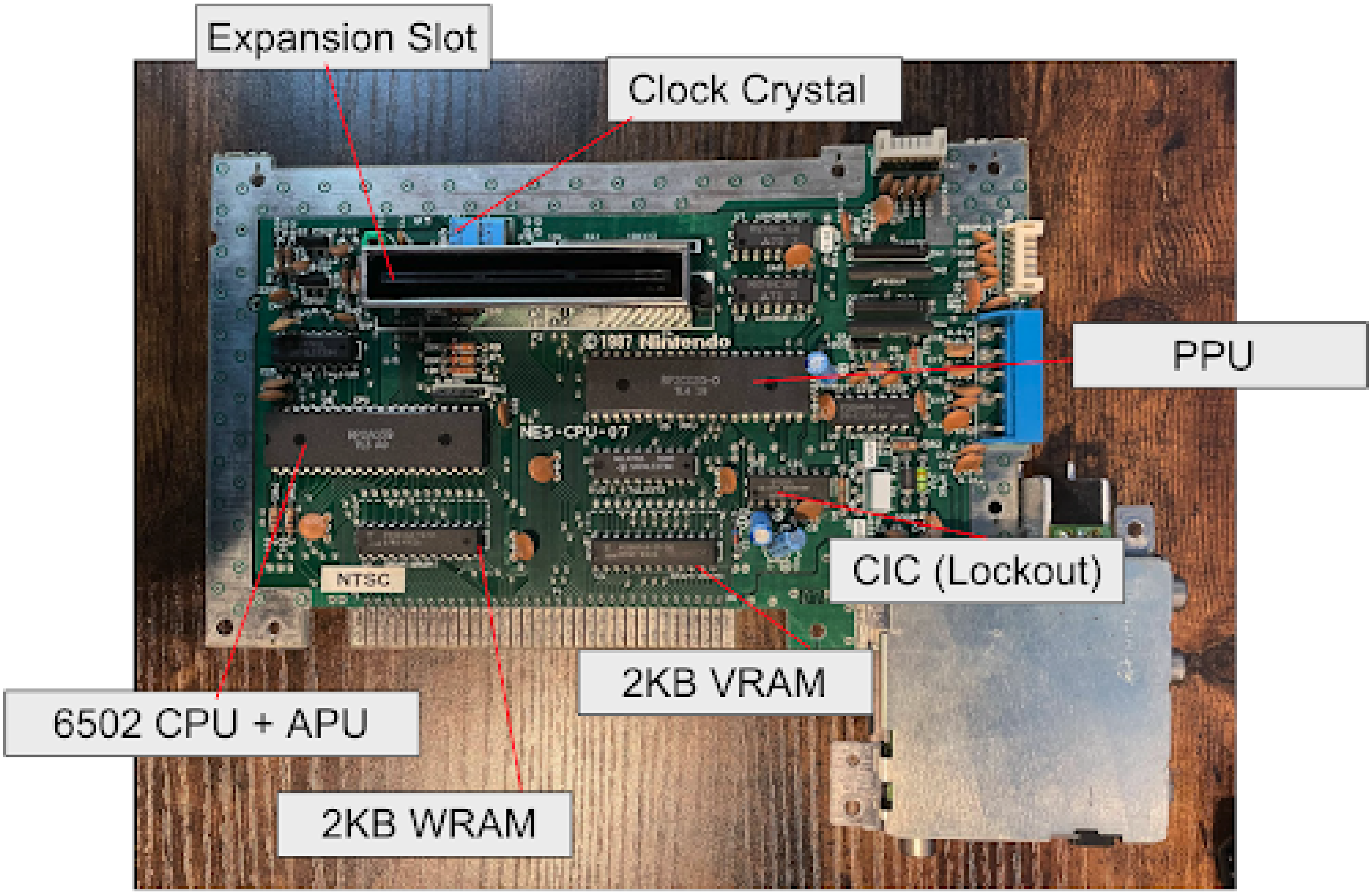
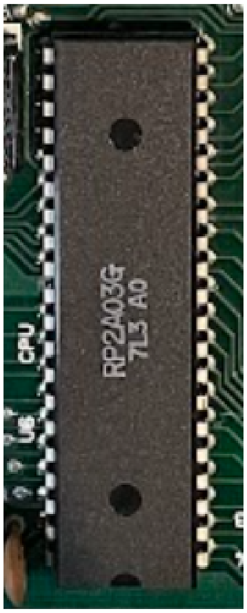
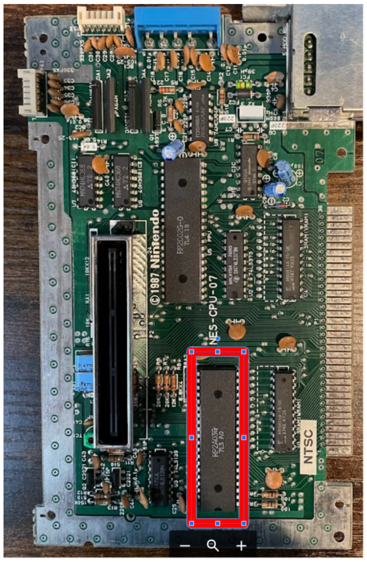


Figure 4.2: Labeled Image of the Motherboard

5.1.2: Motherboard Components Analysis

<table>
<tr><th>Part and Description</th><th>Image</th><th>Location</th></tr>
<tr>
<td><b>Ricoh RP2A03G CPU Chip =
6502 Central Processing Unit (CPU) +
Audio Processing Unit (APU)</b>

Functions to process data and run game program stored in each cartridge.</td>
<td> </td>
<td> </td>
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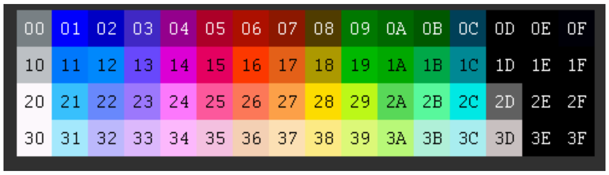
<tr>
<td><b>Picture Processing Unit Chip (PPU)
RP2C02G-0</b>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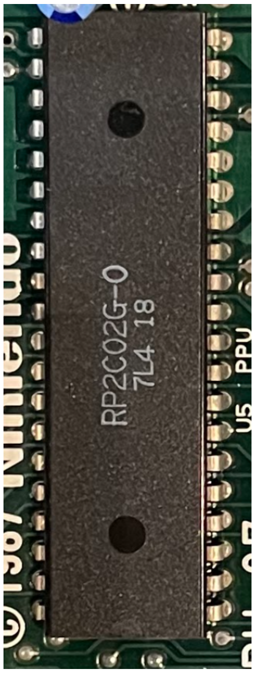
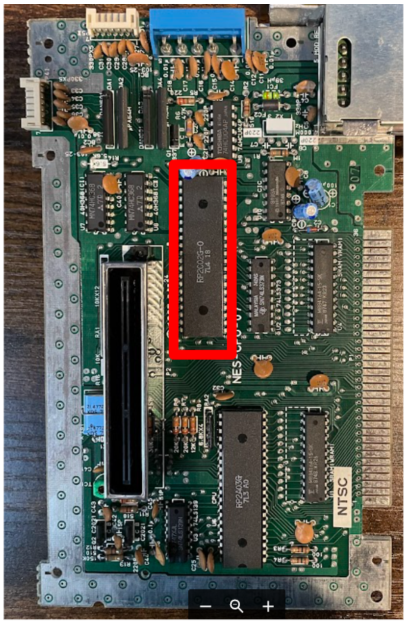
<tr><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>1A</td><td>1B</td><td>1C</td><td>1D</td><td>1E</td><td>1F</td></tr>
<tr><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>2A</td><td>2B</td><td>2C</td><td>2D</td><td>2E</td><td>2F</td></tr>
<tr><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td><td>38</td><td>39</td><td>3A</td><td>3B</td><td>3C</td><td>3D</td><td>3E</td><td>3F</td></tr>
</table>
<i>Figure 5.1.1 PPU Color Palette</i>

Functions to generate image to output to a TV</td>
<td> </td>
<td> </td>
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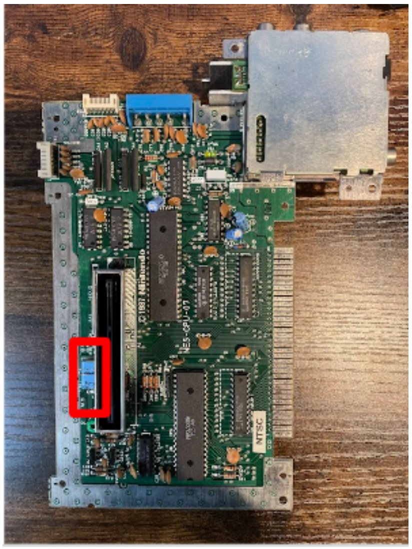
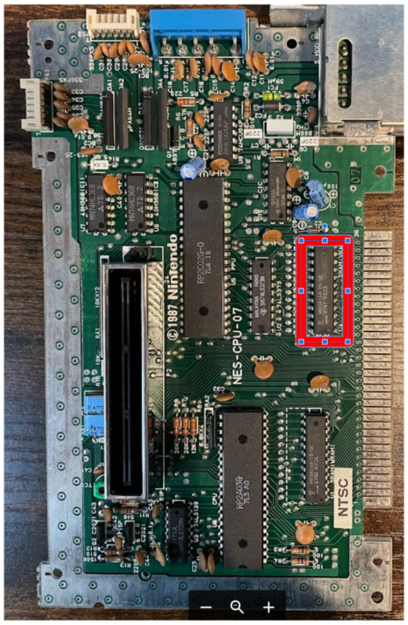
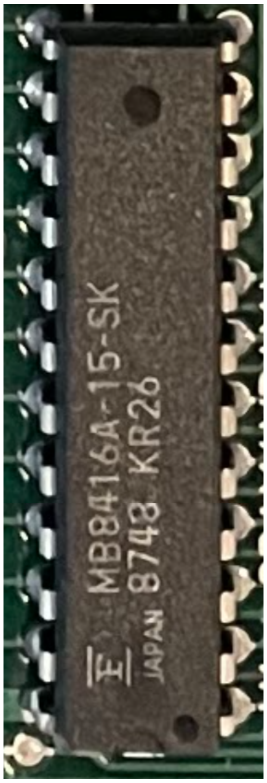
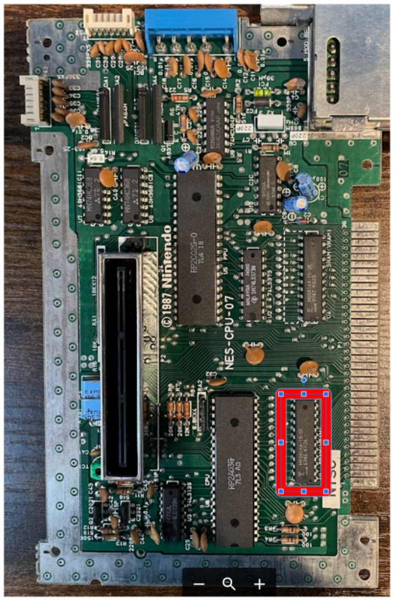
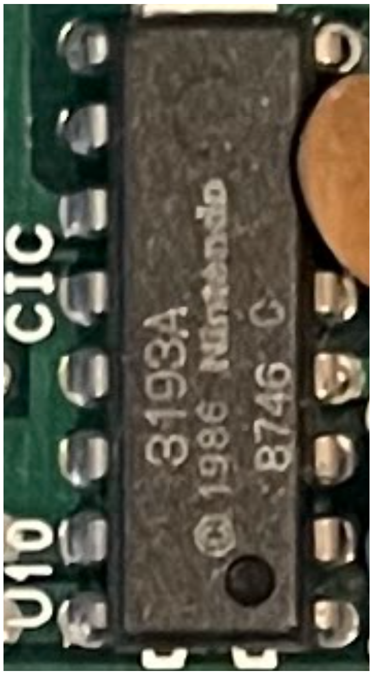
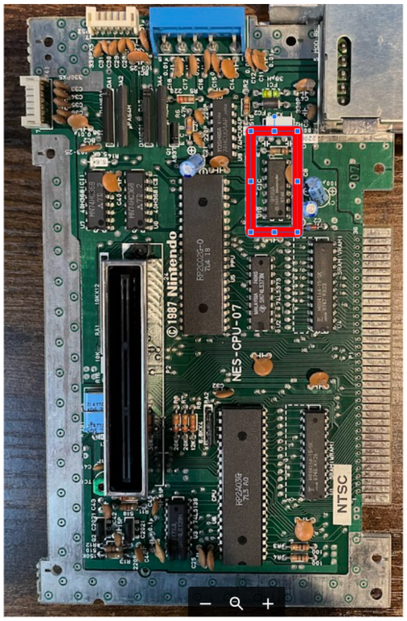
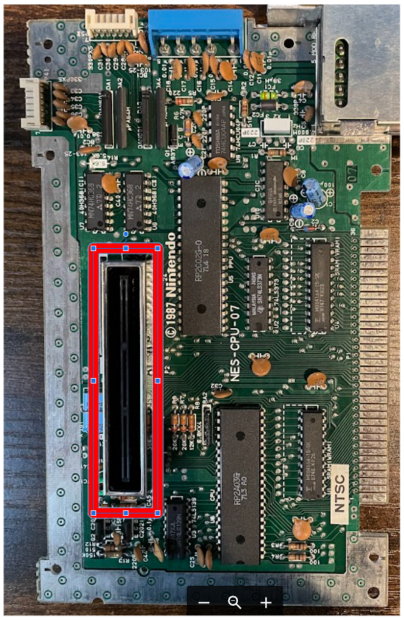
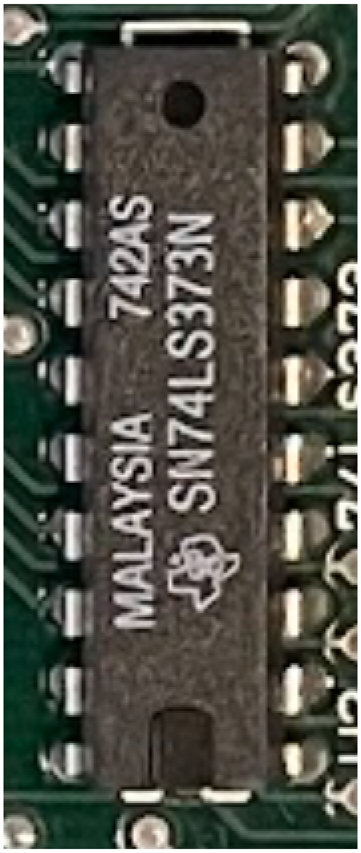
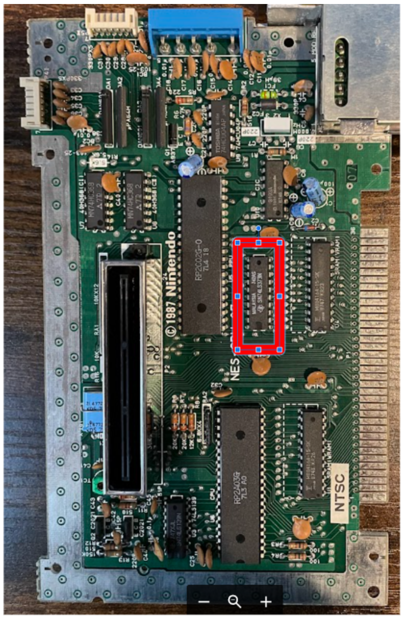
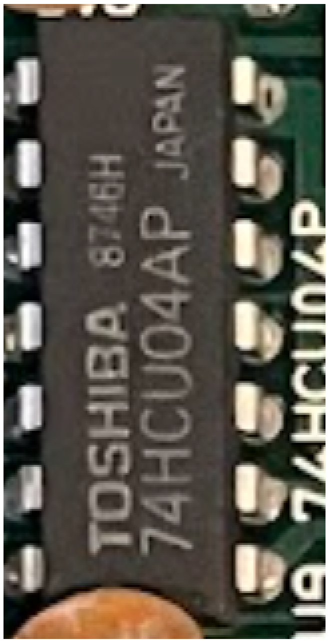
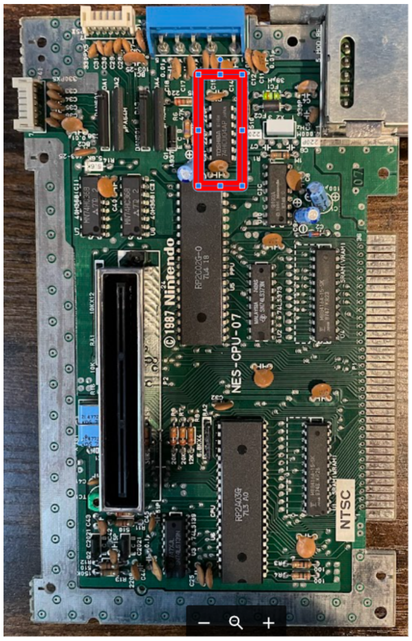
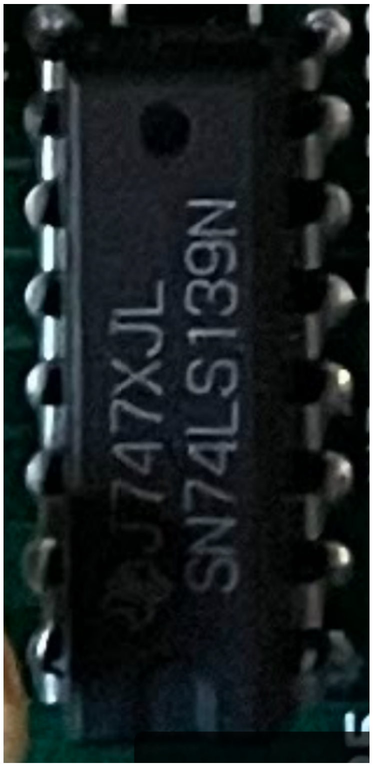
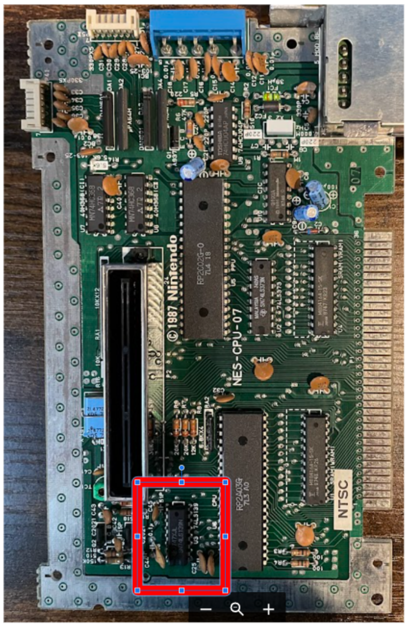
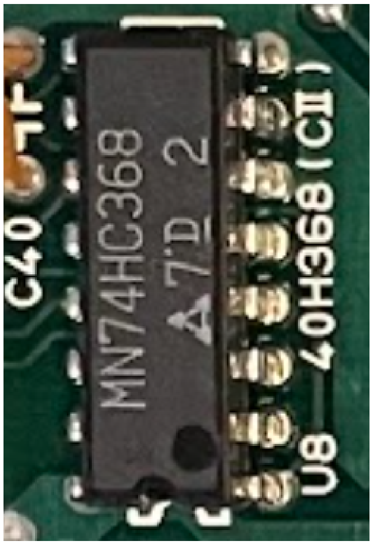
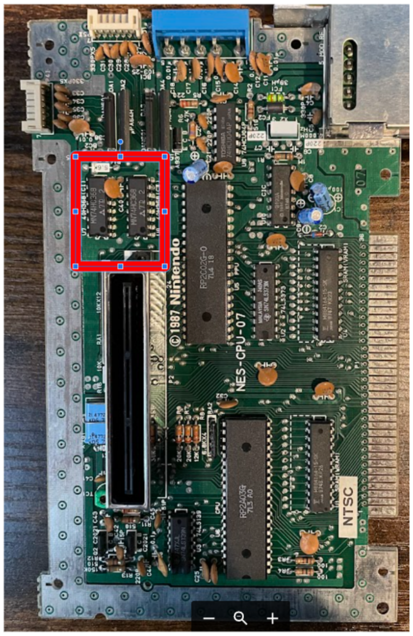
Clock Crystal Functions to generates 1.79MHz to run the NES CPU	 	
2KB Video Random Access Memory Chip (VRAM) Stores interim processed video data for the CPU	 	

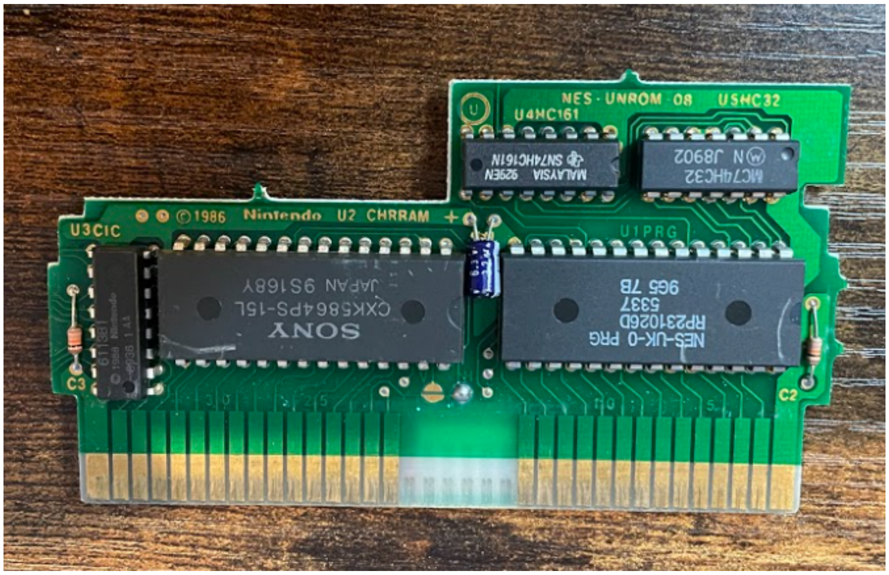
2KB Work Random Access Memory Chip (WRAM) Stores interim game state data for the CPU	 	
CIC Lockout Chip Piracy Prevention	 	

Expansion Slot Extend NES Hardware - for future add-ons		
Texas Instrument Latches Chip Essentially functions in the NES as a small storage device		

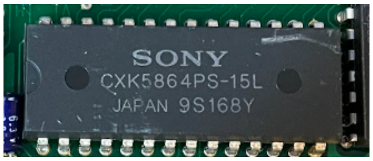
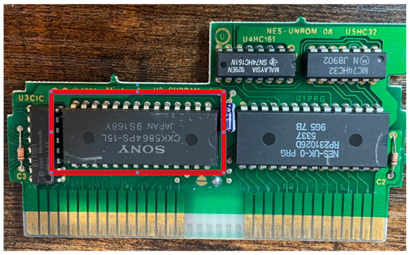
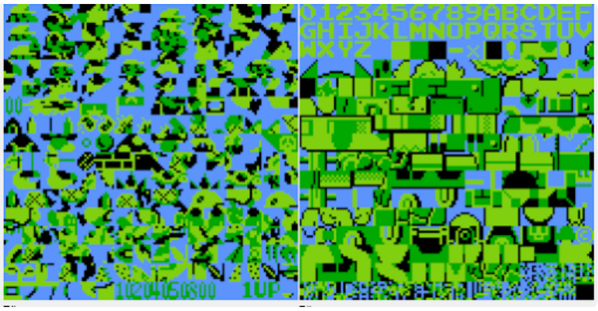
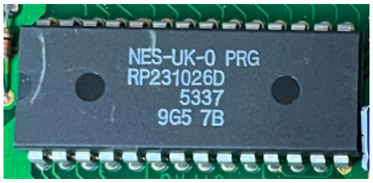
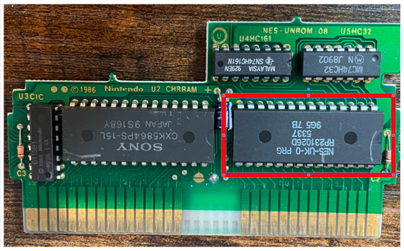
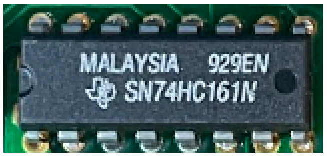
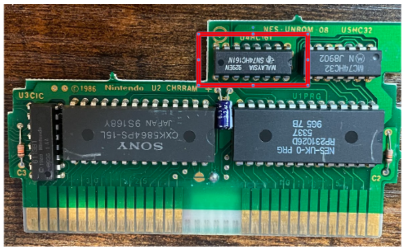
Hex Inverters Chip Takes input of value 1 and outputs a value 0 and vice versa Used by the controller ports to interface with the CPU		
Texas Instrument Data Decoder Chip Used by CPU to decode data from the cartridge		

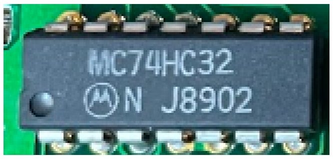
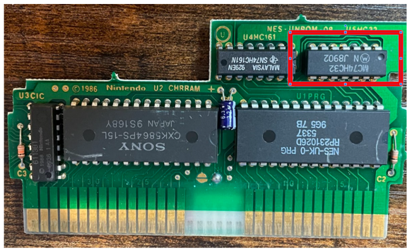
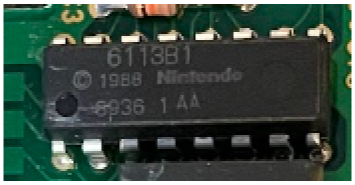
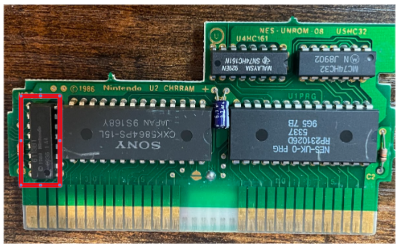
Panasonic Data Converter Chip Used with the PPU to help generate image to the TV		

5.2 Cartridge

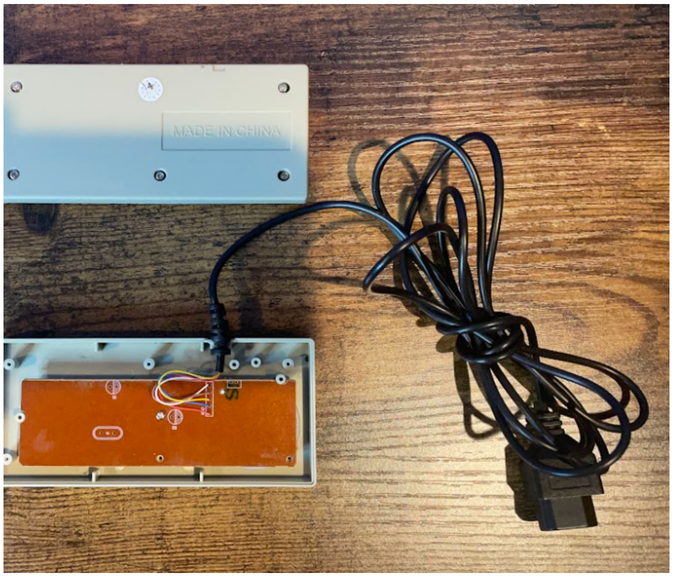


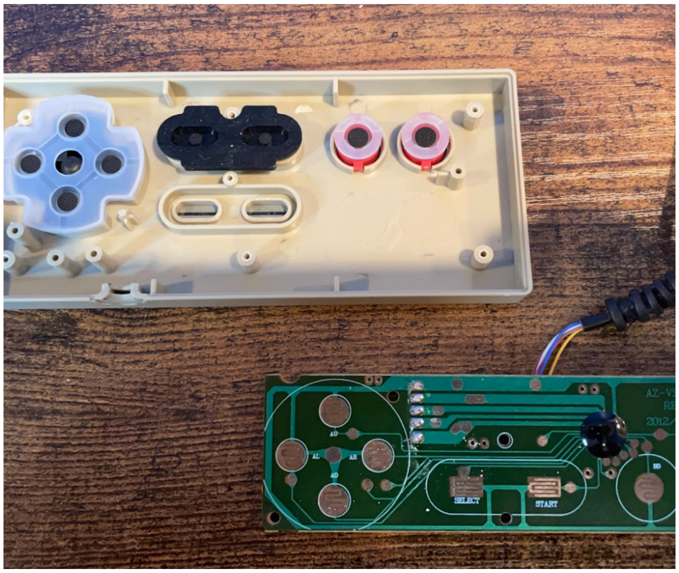
5.2.1: Cartridge Components Analysis

Part and Description	Image	Location
Video RAM Chip Extra video random access memory - to augment RAM found on motherboard		
ROM Chip Read Only Memory - where game logic and character data are stored Example character sprites stored on the ROM chip  *Image above was captured from an NES emulator*		
8 bit shift register chip Moves 8 bits of data along a sequence to be read by the CPU		

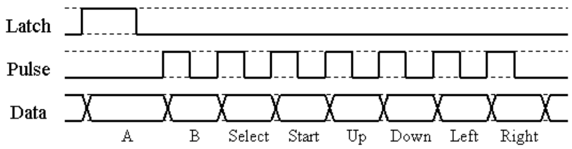
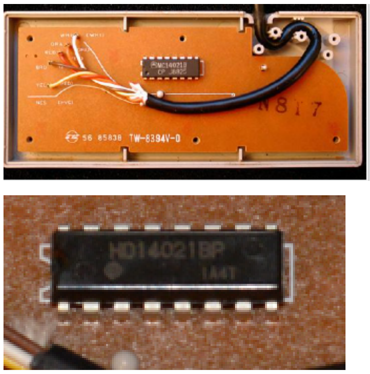
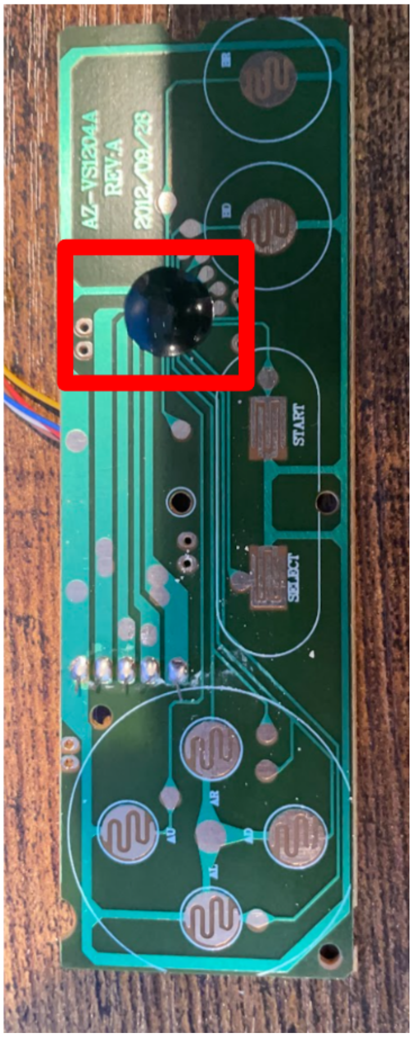
OR Logic Chip Takes 2 inputs of value and outputs its OR value Example: 1 OR 0 = 1 Used to decode data from the cartridge to the CPU		
CIC Lockout Chip Piracy Prevention		

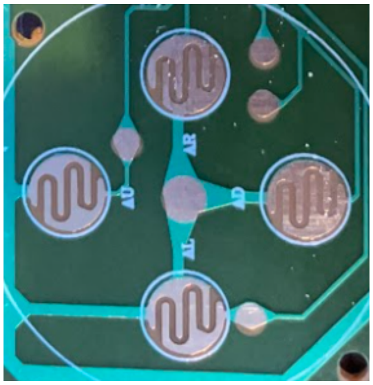
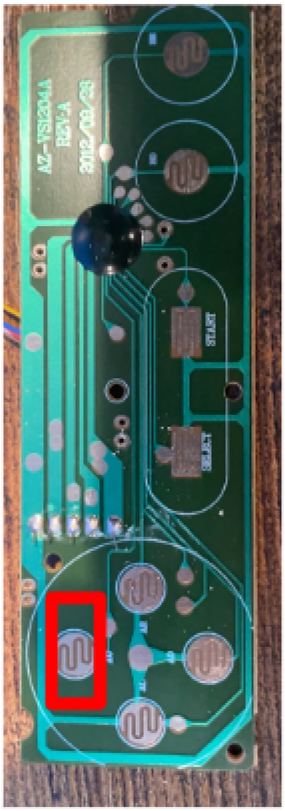
5.3 Controller



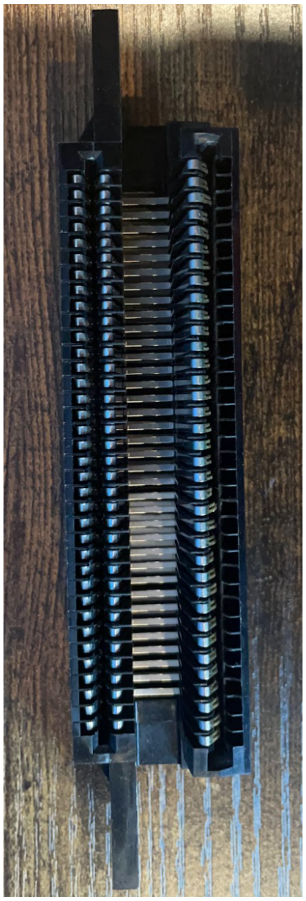
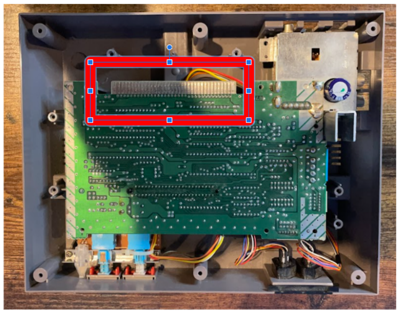
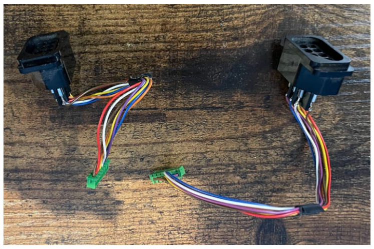
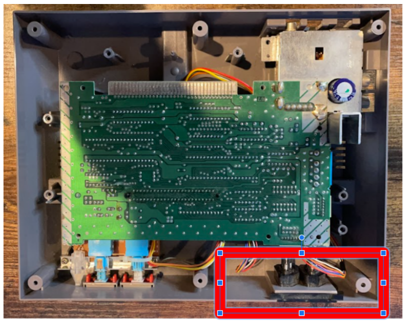


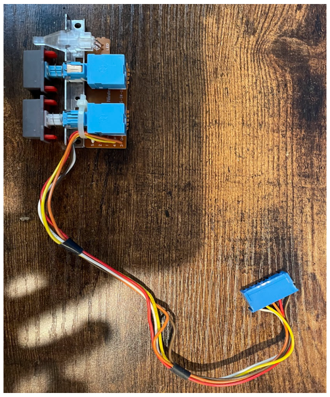
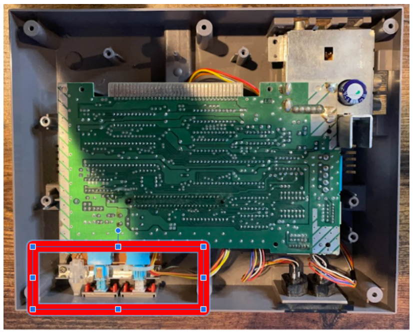
5.3.1: Controller Components Analysis

Part and Description	Image	Location
Shift Register Chip Takes controller input and moves data to CPU using the following protocol:  Latch Pulse Data A B Select Start Up Down Left Right	 *Figure 5.3.1* Image shown is a controller with the actual chip, while the location image shown is the same chip without the plastic packaging. Instead the chip is epoxied to the controller PCB (Printed circuit board)	

Conductive Pads When the button gets pressed, it completes a circuit connection, sending a signal to the shift register chip on the controller pcb.	 	

5.4 Other Parts/Components

Part and Description	Image	Location
72 pin connector Connects the Cartridge to the Motherboard		
Controller Ports Connects the controllers to the motherboard		

Power & Reset Buttons (Turn on, off, and reset the NES)		

6.0 References

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   https://www.copetti.org/writings/consoles/nes/

2. https://forums.nesdev.org/viewtopic.php?t=20685

3. Figure 3.1.1 - 3.10.1:
   https://www.ifixit.com/Guide/Nintendo+Entertainment+System+Disassembly/143046

4. Figure 5.1.1:
   https://nesdoug.com/2018/09/05/05-palettes/

5. https://forums.nesdev.org/viewtopic.php?t=20685

6. Figure 5.3.1:
   https://electro-music.com/forum/topic-44303-0.html&postdays=0&postorder=asc&highlight=

7. https://en.wikipedia.org/wiki/CIC_(Nintendo)

8. https://8bitworkshop.com/docs/platforms/nes/

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11. http://web.mit.edu/6.111/www/s2004/PROJECTS/2/game.htm