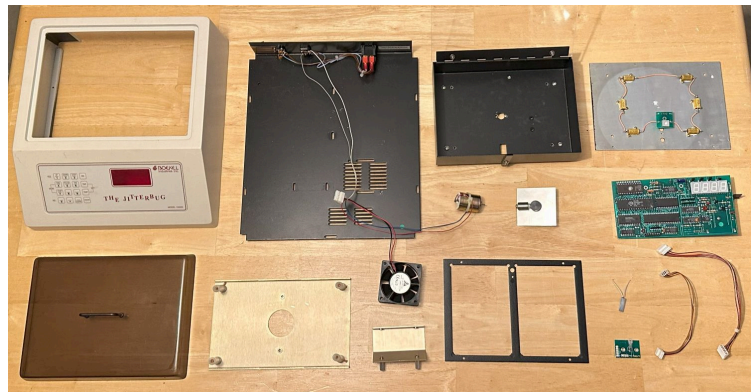


The Jitterbug



Serkk-it 4811A
Emma, Sharayu & Kaila
Andover, Massachusetts



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1. Introduction

Have you ever used an incubator or shaking table during a biology lab? We've used these devices in classes, bio-related clubs, and even research labs to facilitate the growth and cultivation of cells, microorganisms, and enzymes. We've always wondered how machines like the Jitterbug combine heating and shaking of petri dishes at a precise level, providing the perfect growth environment. Luckily, we had an old model of The Jitterbug. We knew this would be the perfect device to reverse engineer, as it would give us the opportunity to explore The Jitterbug's many functions, including a shaking table, incubation, and a display.

2. Approach

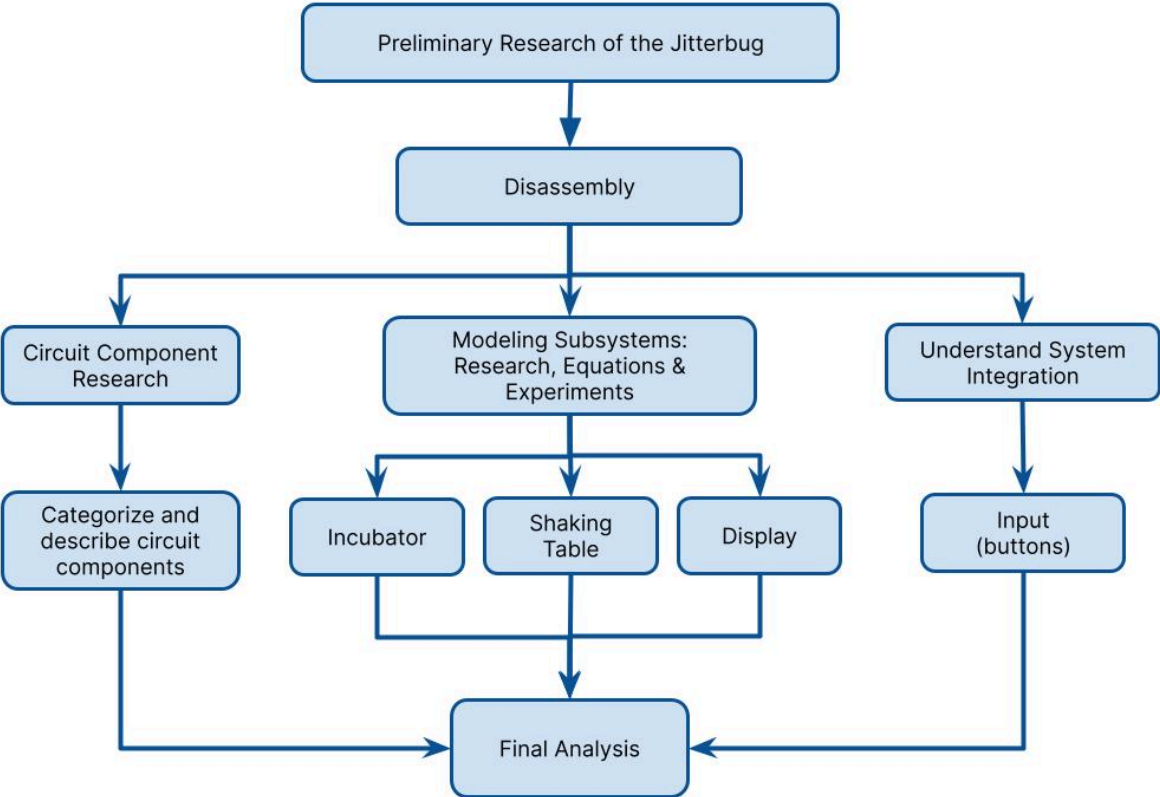


Figure 1: Plan of Action

3. Equipment

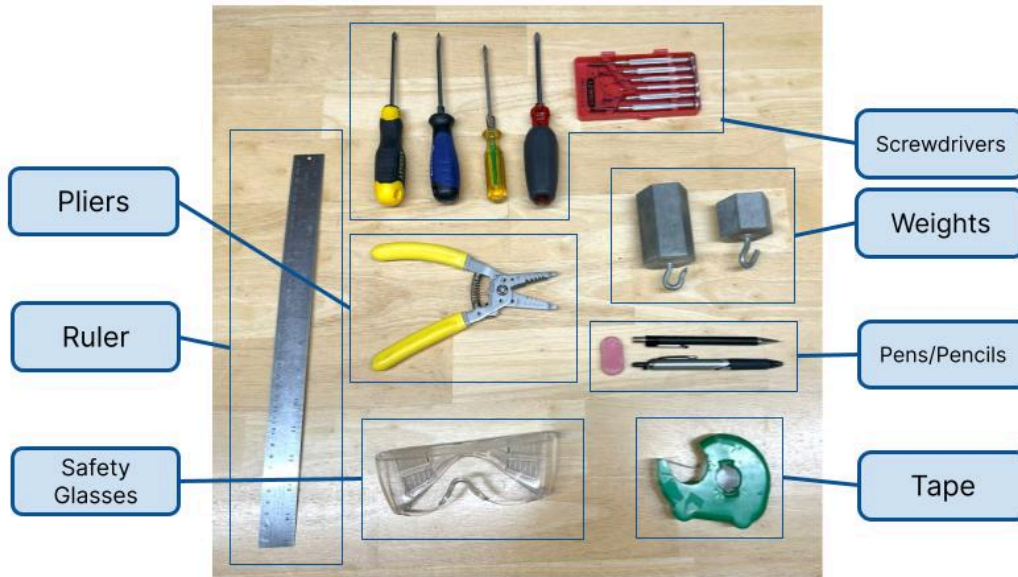


Figure 2: Labeled equipment



Figure 3: Labeled equipment used with descriptions

4. Disassembly



Front of Jitterbug



Bottom of Jitterbug



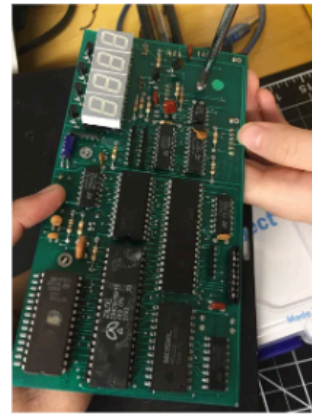
Step 1: Removed the exterior casing

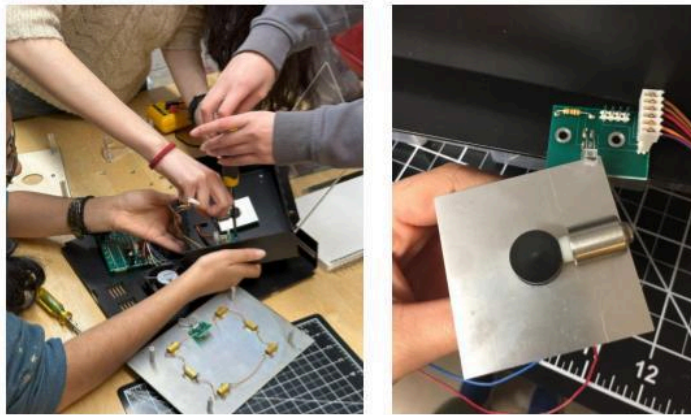


Step 2: Removed the incubation chamber



Step 3: Removed the main circuit board

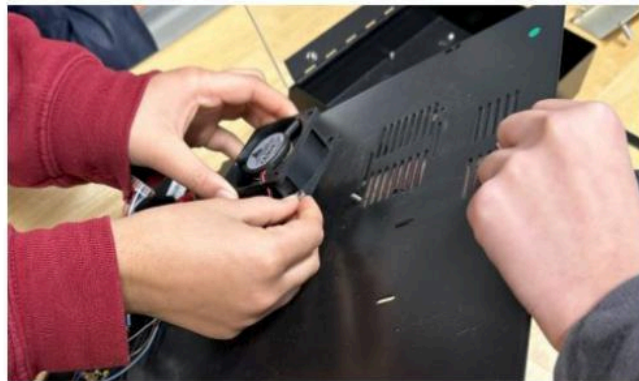




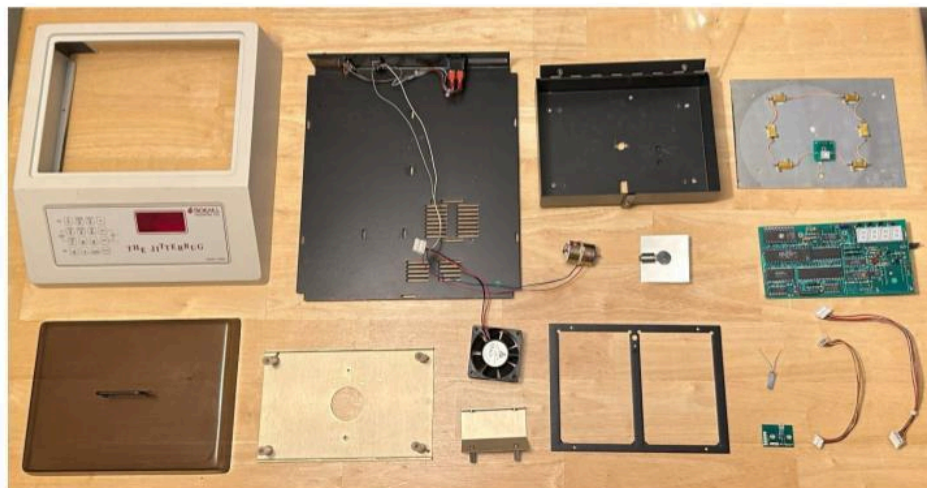
Step 4: Removed the vibration plate



Step 5: Removed the motor



Step 6: Removed the fan



Final Disassembly

5. Components

5.1. Non-Electronic



Figure 4: Labeled non-electronic components

5.2. Electronic

5.2.1. Circuit Boards

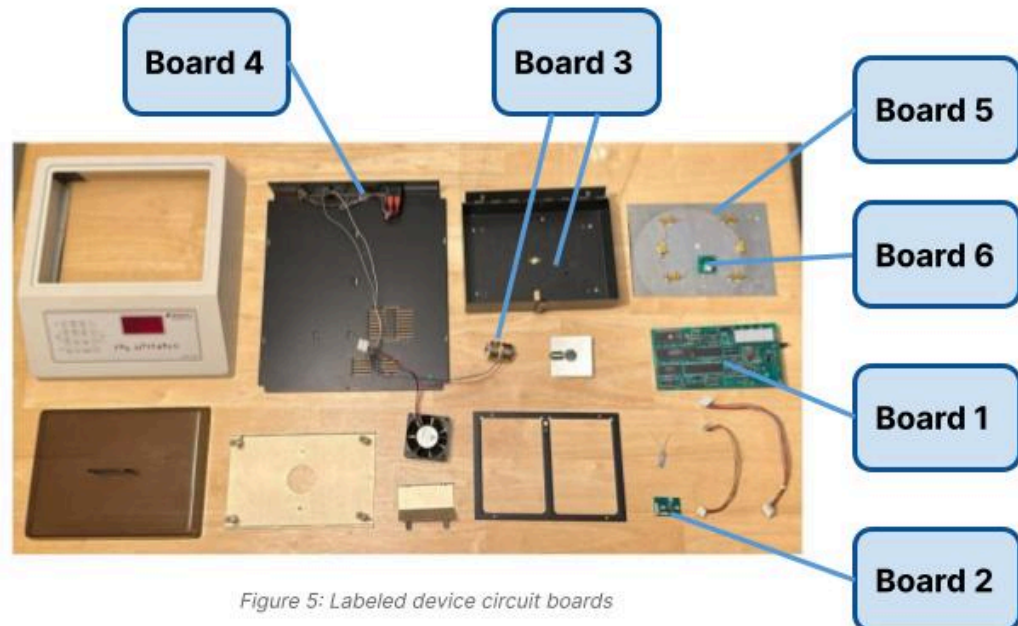
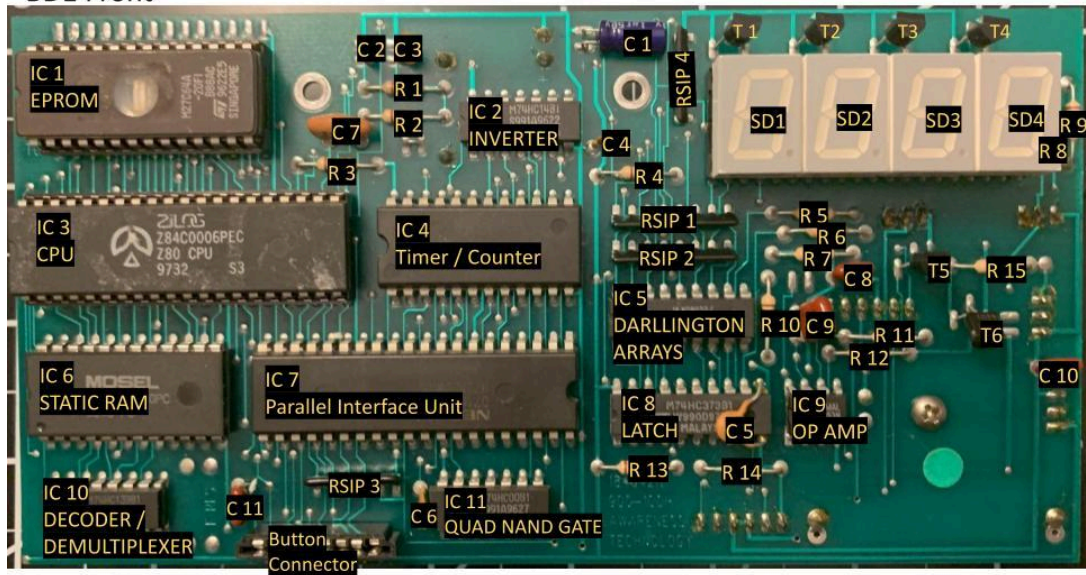
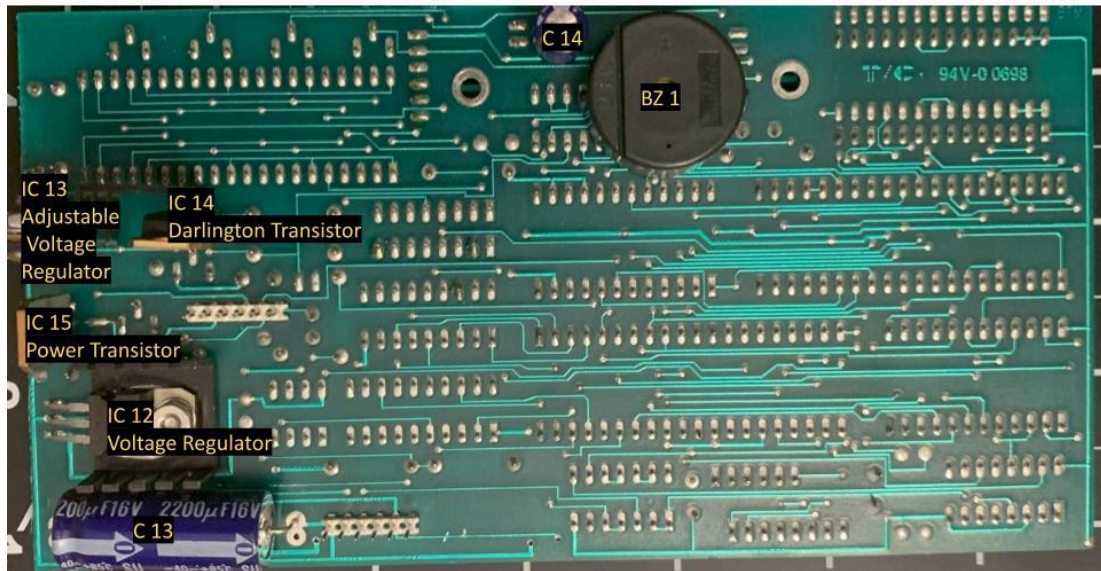


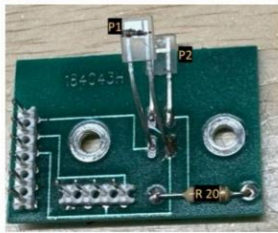
Figure 5: Labeled device circuit boards

BD1 Front

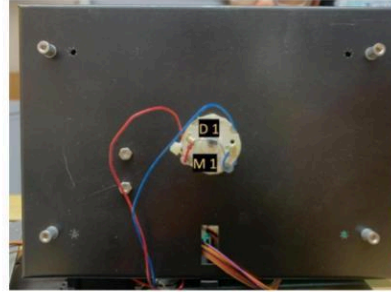


BD1 Back

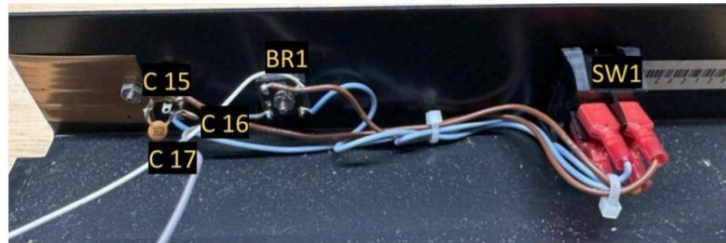




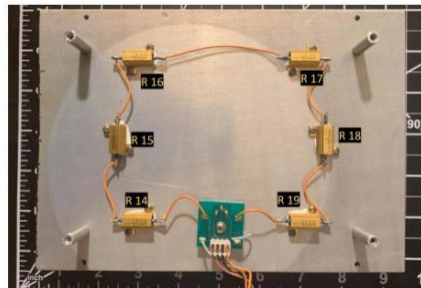
BD2



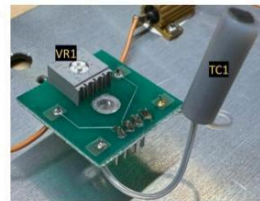
BD3



BD4



BD5



BD6

5.2.2. Components

IC 1: EPROM - C

EPROM stands for Erasable Programmable Read Only Memory, which can be erased with UV light. It stores a program that is supplied to the CPU.



M27C64A-20F1
STMicroelectronics

IC 2: Inverter - P

Switches a LOW signal to HIGH, and vice versa.



M74HC14B1
STMicroelectronics

IC 4: Timer/Counter - S

Counts how many times the metal plate passes between photodiodes; data is then used to control the shaking table.



D710540
NEC

IC 3: Central Processing Unit - C

The processing program for the CPU is supplied by the EPROM



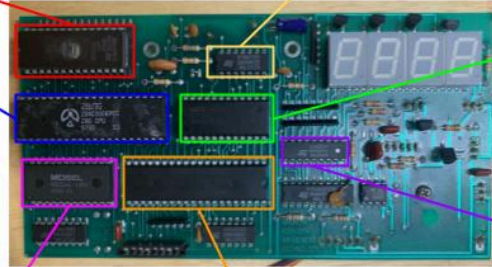
Z84C0006PEC
Zilos

IC 6: Static Ram - C

Serves as a temporary place to store data; has volatile memory, meaning any data is lost when The Jitterbug's power source is removed.



MS6516L-10PC
MOSEL-VITELIC



BD1f

IC 7: Parallel Interface - C I O H S

Allows data to be sent on several wires connecting peripherals; communicates between the CPU, EPROM, RAM, and other subsystems.



D71055C
NEC

IC 5: Darlington Array - O

Emitter acts as base of next transistor couple; Many transistors accumulates into lots of heat, needs to be dissipated through fan/thermal paste



ULN2804A
STMicroelectronics

Key: Power (P), Computing (C), Input (I), Output (O), Heating (H), Shaking (S)

Key: Computing (C), Input (I), Output (O), Temperature Monitoring (T), Heating (H), Shaking (S)

IC 8: Latch - C H S

Octal (8-bit) Latch; a switch to send continue or hold messages; can send a 'set' signal, 'reset' signal, and 'toggle' signal; compiles electronic memory and switches the memory on and off fast enough for heating duty cycle.



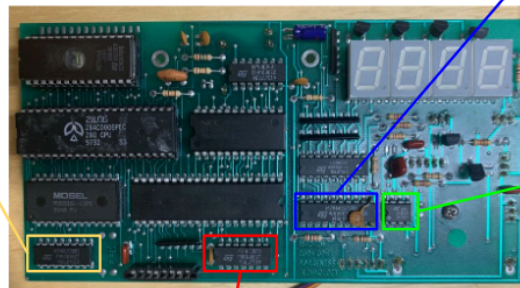
M74HC373B1
STMicroelectronics

IC 10: Decoder/Demultiplexer - O

2-to-4 line binary decoder using AND gates; determines which LED segments of which display should be lit to display the needed data.



M74HC139B1
STMicroelectronics



BD1f

IC 9: Op-Amp - T

Amplifies weak electrical signals; takes two voltage inputs and outputs the voltage difference between the two inputs



LF353N
STMicroelectronics

IC 11: NAND Gate - C I

High speed 2 input NAND gate; high immunity to noise



M74HC00B1
STMicroelectronics

IC 13: Voltage Regulator - P

Positive adjustable voltage regulator; converts uneven DC to a more smooth, usable current; attached to a large metal piece to dissipate generated heat.



LM317T
STMicroelectronics

IC 14: Transistor - S

Acts as an amplifier; low speed switching in subsystem circuitry.



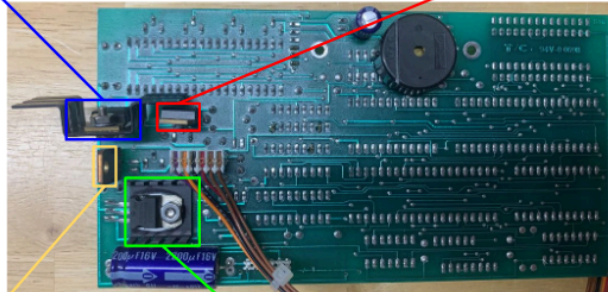
TIP112
STMicroelectronics

IC 15: Transistor - H

Used as a switch in subsystem circuitry.



TIP32C
STMicroelectronics



BD1b

Key: Power (P), Heating (H), Shaking (S)

IC 12: Voltage Regulator - P

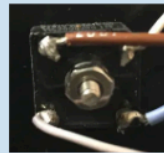
3 terminal fixed voltage regulator; helps regulate voltage to provide a smoother current to circuits.



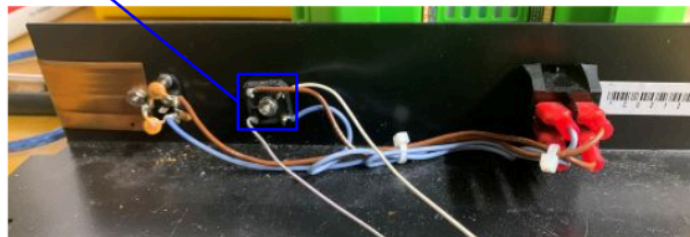
L78S05CV
STMicroelectronics

BR 1: Bridge Rectifier - P (Power)

4 diode single phase bridge rectifier; converts AC current to DC current; mounted to a metal casing with a screw to keep generated heat and high AC voltage away from the rest of the circuitry.



GBPC602
VISHAY



BD4

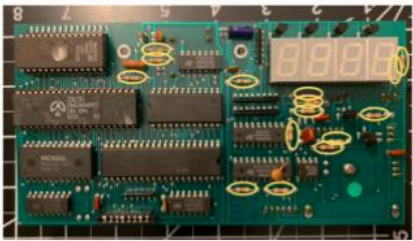
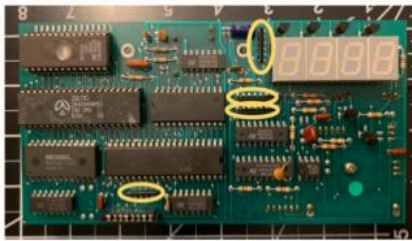
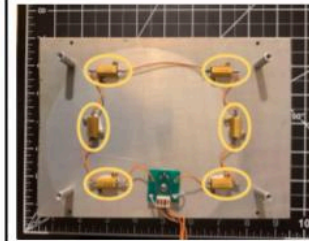









																				
BD1f	BD1f	BD5																		
<table border="1"> <tr> <td>Desc.</td> <td>Carbon Film Resistor Have very low wattage values; regulate the flow of current with a fixed resistance value.</td> </tr> <tr> <td>Images</td> <td></td> </tr> <tr> <td>IDs</td> <td>R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13</td> </tr> </table>	Desc.	Carbon Film Resistor Have very low wattage values; regulate the flow of current with a fixed resistance value.	Images		IDs	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13	<table border="1"> <tr> <td>Desc.</td> <td>Variable Resistor Have several 'output' pins; depending on which pin is connected, a different resistance is applied.</td> </tr> <tr> <td>Image</td> <td></td> </tr> <tr> <td>IDs</td> <td>RSIP1, RSIP2, RSIP3, RSIP4</td> </tr> </table>	Desc.	Variable Resistor Have several 'output' pins; depending on which pin is connected, a different resistance is applied.	Image		IDs	RSIP1, RSIP2, RSIP3, RSIP4	<table border="1"> <tr> <td>Desc.</td> <td>Wire-Wound Resistor Has a conductive wire wrapped in coils around a non-conductive core; designed for heat dissipation; often mounted on a metal plate.</td> </tr> <tr> <td>Image</td> <td></td> </tr> <tr> <td>IDs</td> <td>R14, R15, R16, R17, R18, R19</td> </tr> </table>	Desc.	Wire-Wound Resistor Has a conductive wire wrapped in coils around a non-conductive core; designed for heat dissipation; often mounted on a metal plate.	Image		IDs	R14, R15, R16, R17, R18, R19
Desc.	Carbon Film Resistor Have very low wattage values; regulate the flow of current with a fixed resistance value.																			
Images																				
IDs	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13																			
Desc.	Variable Resistor Have several 'output' pins; depending on which pin is connected, a different resistance is applied.																			
Image																				
IDs	RSIP1, RSIP2, RSIP3, RSIP4																			
Desc.	Wire-Wound Resistor Has a conductive wire wrapped in coils around a non-conductive core; designed for heat dissipation; often mounted on a metal plate.																			
Image																				
IDs	R14, R15, R16, R17, R18, R19																			

Figure 7: Resistor table





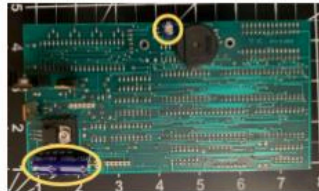









																				
BD1f	BD1f	BD1f																		
																				
BD4		BD1b																		
<table border="1"> <tr> <td>Desc.</td> <td>Ceramic Capacitors Have a fixed value; ceramic acts as a dielectric.</td> </tr> <tr> <td>Image</td> <td></td> </tr> <tr> <td>IDs</td> <td>C2, C3, C4, C5, C6, C15, C16, C17</td> </tr> </table>	Desc.	Ceramic Capacitors Have a fixed value; ceramic acts as a dielectric.	Image		IDs	C2, C3, C4, C5, C6, C15, C16, C17	<table border="1"> <tr> <td>Desc.</td> <td>Film Capacitors Have a thin film of plastic which acts as the dielectric; valued for their stability.</td> </tr> <tr> <td>Image</td> <td></td> </tr> <tr> <td>IDs</td> <td>C7, C8, C9, C10, C11</td> </tr> </table>	Desc.	Film Capacitors Have a thin film of plastic which acts as the dielectric; valued for their stability.	Image		IDs	C7, C8, C9, C10, C11	<table border="1"> <tr> <td>Desc.</td> <td>Electrolytic capacitors Store high amounts of voltage; typically used for filtering power supply or low-frequency signals.</td> </tr> <tr> <td>Image</td> <td></td> </tr> <tr> <td>IDs</td> <td>C1, C13, C14</td> </tr> </table>	Desc.	Electrolytic capacitors Store high amounts of voltage; typically used for filtering power supply or low-frequency signals.	Image		IDs	C1, C13, C14
Desc.	Ceramic Capacitors Have a fixed value; ceramic acts as a dielectric.																			
Image																				
IDs	C2, C3, C4, C5, C6, C15, C16, C17																			
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Image																				
IDs	C7, C8, C9, C10, C11																			
Desc.	Electrolytic capacitors Store high amounts of voltage; typically used for filtering power supply or low-frequency signals.																			
Image																				
IDs	C1, C13, C14																			

Figure 8: Capacitor table

6. Systems

6.1. Power

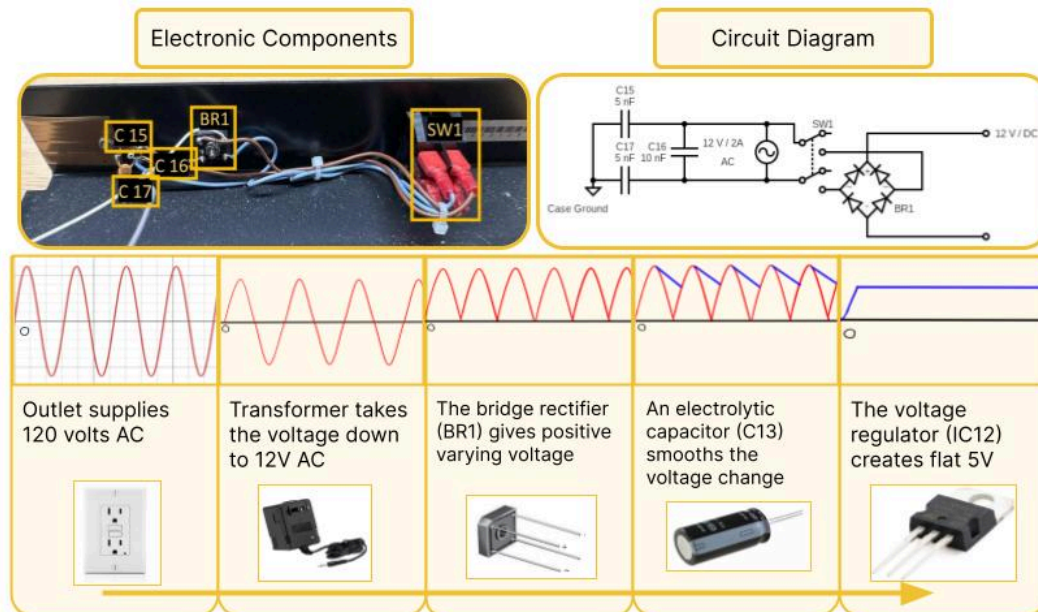


Figure 9: The Jitterbug electronics require DC at 5V. The bridge rectifier is mounted to the outer metal casing to keep generated heat and high AC voltage away from the rest of the circuitry.

6.2. Computing

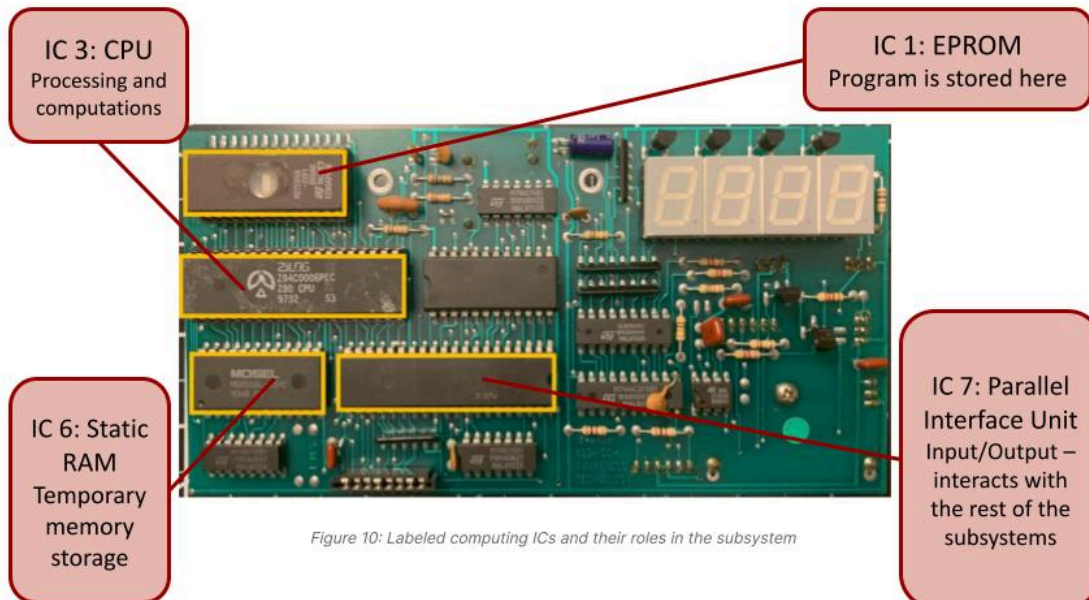
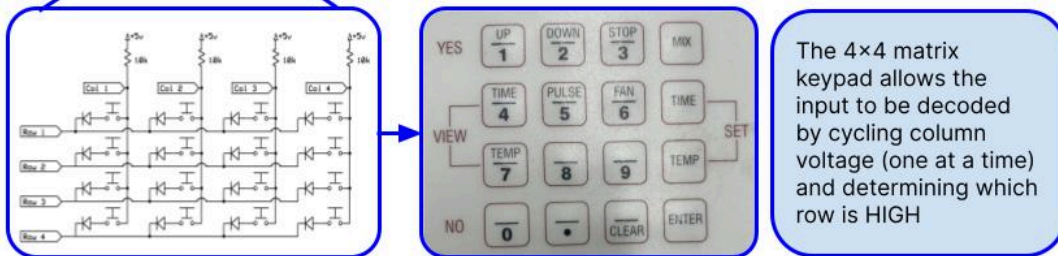


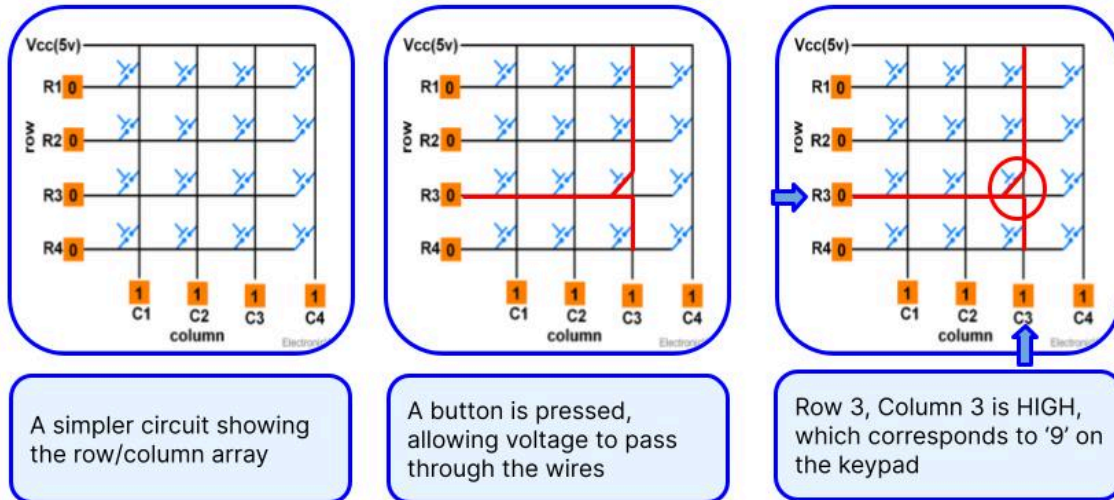
Figure 10: Labeled computing ICs and their roles in the subsystem

6.3. Input



The 4x4 matrix keypad allows the input to be decoded by cycling column voltage (one at a time) and determining which row is HIGH

Figure 11: Keypad Operation



A simpler circuit showing the row/column array

A button is pressed, allowing voltage to pass through the wires

Row 3, Column 3 is HIGH, which corresponds to '9' on the keypad

Figure 12: Theory of how buttons are pressed

6.4. Display

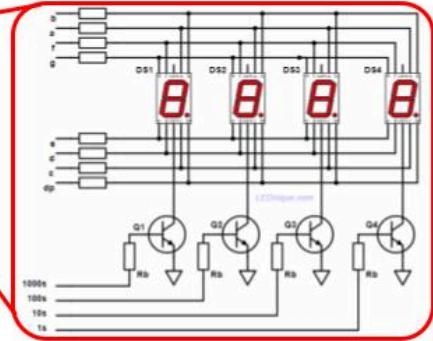
IC 10: Decoder / Demultiplexer determines which segments light and which display to activate.

T1-T4: Transistors Used to switch on/off each number.

SD1-4: Multiplexed 7-Segment LED Display This is what lights up and displays the relevant numbers.



IC 7: Parallel Interface Unit Outputs displayed number.



The multiplexed 7-segment LED digital display allows segments of the display to be lit up in series to show different values. They are updated independently, meaning each individual display is shown or changed one at a time.

Figure 13: Labeled display ICs and their roles in the subsystem

LED Digital Display

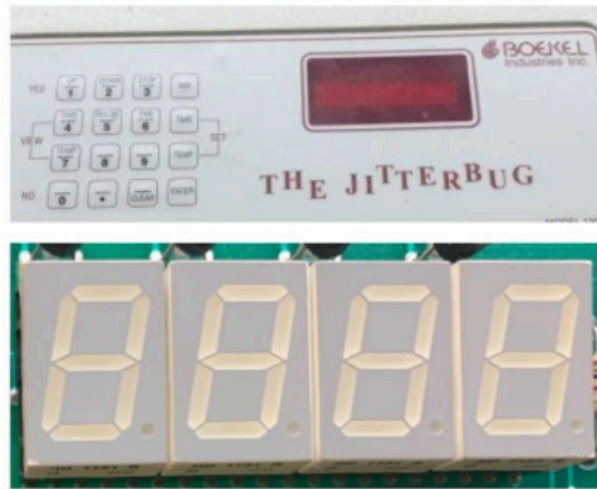


Figure 14: The Jitterbug's LED digital display

Operating Single Display

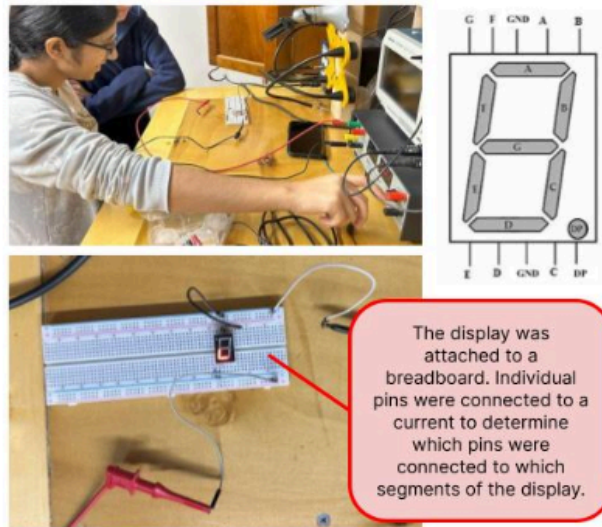


Figure 15: Turning on single display segments

6.5. Temperature Monitoring

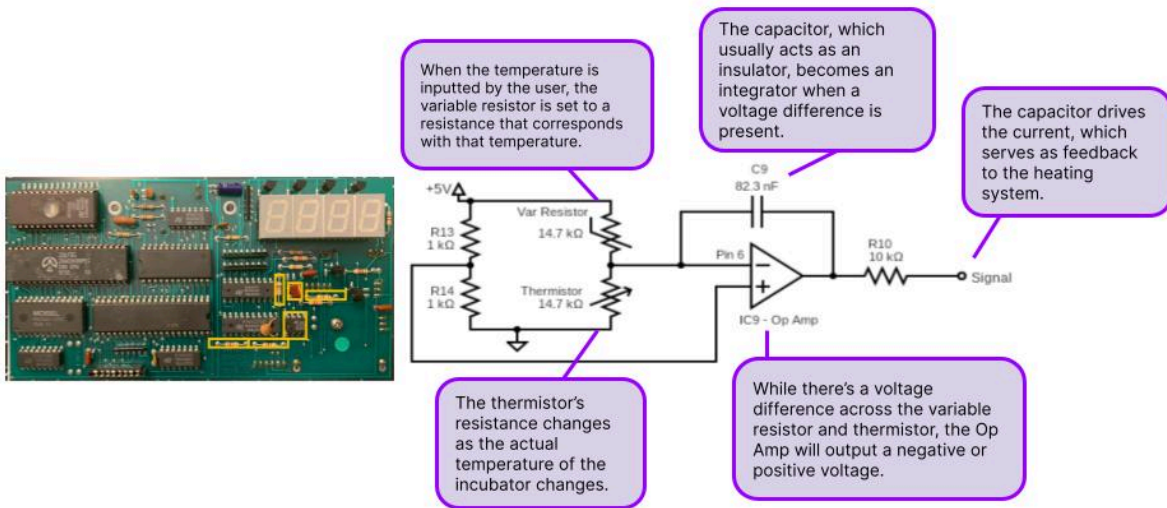


Figure 16: Circuit diagram of temperature monitoring subsystem

Thermistor

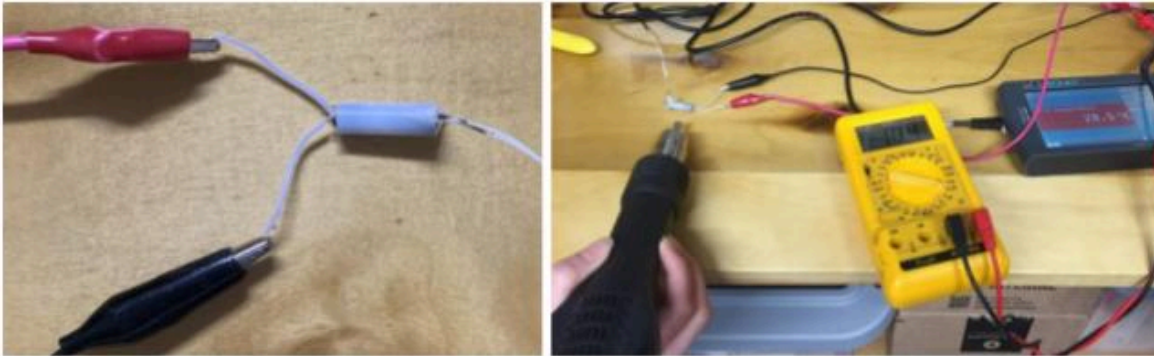


Figure 17: Using Ice and a heat gun, we measured the resistance as a function of the temperature for the thermistor.

Data

Thermistor Resistance Changes

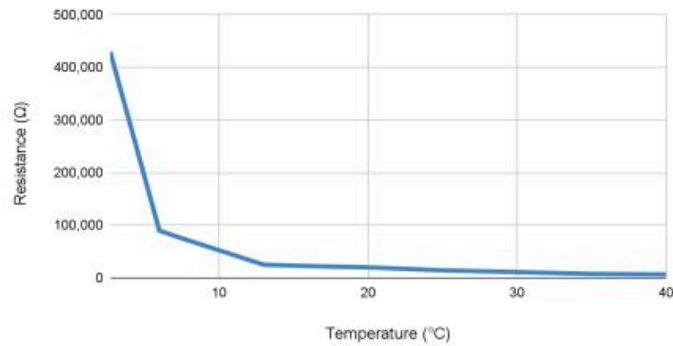


Figure 18: The resistance decreases with increasing temperature

Calibration

Steinhart-Hart equation for thermistor resistance:

$$\frac{1}{T} = \frac{1}{\text{Beta}} \ln\left(\frac{R}{R_0}\right) + \frac{1}{T_0}$$

Source: (Baierlein, 1983, p. 529)

Variable	Value	Notes
T_0	25°C	
R_0	14,300 Ω	thermistor resistance at T_0
Beta	$1/0.0782 = 12.79$	$1/(\text{slope of the best fit line})$

Finding the Slope (Beta)

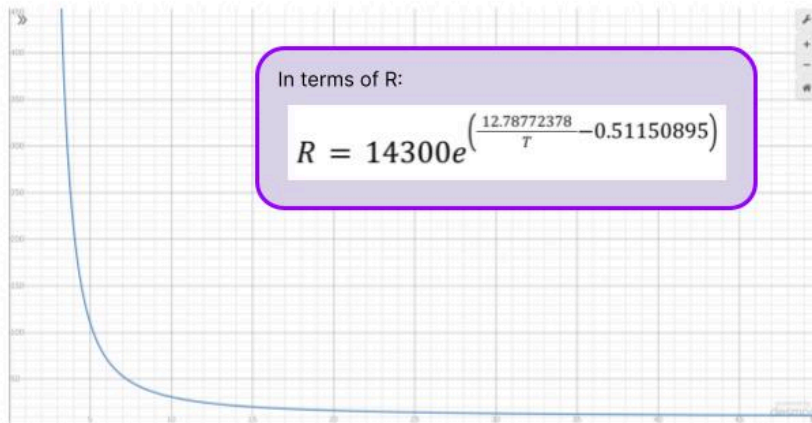
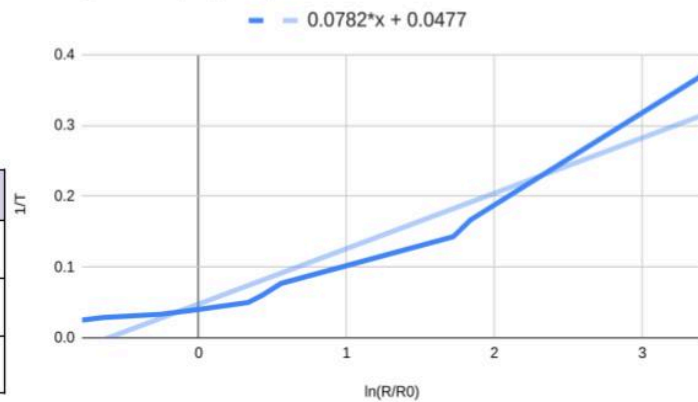
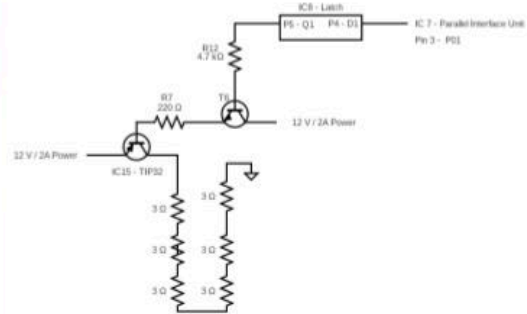
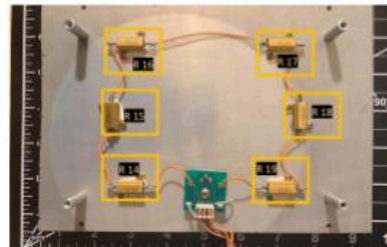


Figure 19: Equation giving resistance (kΩ) as a function of Temperature (°C) (Desmos)

6.6. Heating

6.6.1. Electronics



The desired temperature is inputted and stored. The latch then toggles the heating on or off. When toggled on, current is fed through the 6 resistors, which then heat up the metal plate.

Figure 20: Circuit diagram of heating subsystem

6.6.2. Heating Plate

Determining Material

Finding Volume

Dimensions: 14.5 cm x 20.5 cm x 0.2 cm

Formula: $V = l * w * h$

$$V = (14.5 \text{ cm}) * (20.5 \text{ cm}) * (0.2 \text{ cm}) = 59.45 \text{ cm}^3$$

Calculating Density

Formula: $\rho = m/V$

$$\rho = (213.80 \text{ g}) / (59.45 \text{ cm}^3) \approx 3.60 \text{ g/cm}^3$$

Note: This is the upper limit to the real density.

Finding Mass

Using a scale, the mass of the heating board was found to be **213.80 g**.

Note: This is an upper bound, because there are other components on the board.

Metal Densities

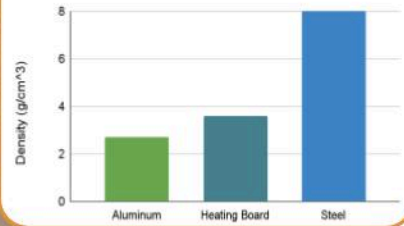
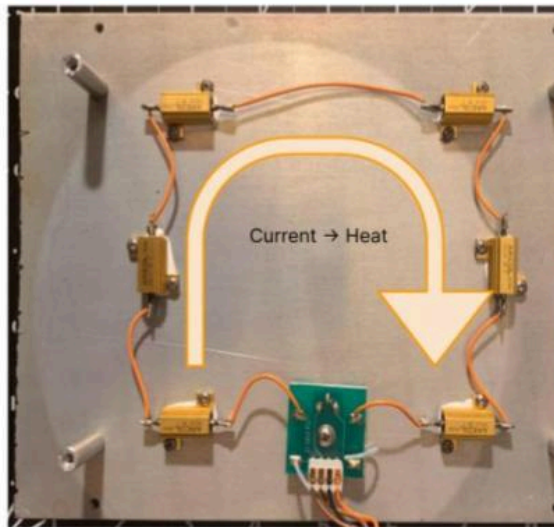


Figure 21: Determined the plate is made of Aluminum

Theoretical Calculations



Energy Needed to Change Temperature

$$Q = mc\Delta T \\ = (213.80 \text{ g}) * (.902 \text{ J/1 g } ^\circ\text{C}) * (20^\circ\text{C}) \\ \approx 3,856.95 \text{ J}$$

Energy Needed per Second

$$\text{Formula: } P = V^2 / R \\ = ((12 \text{ V})^2) / (18 \Omega) = 8 \text{ J/s}$$

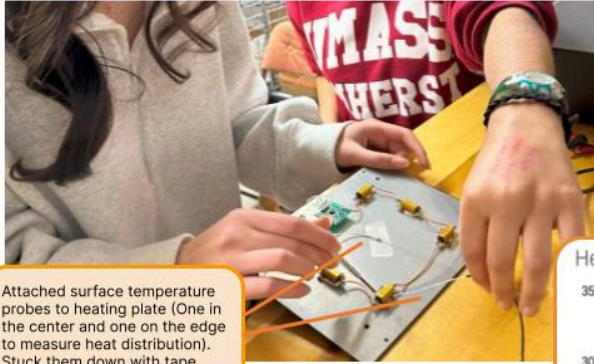
Time Needed to Change Temperature

$$(3,856.95 \text{ J}) / (8 \text{ J/s}) \approx 482 \text{ s} = 8.03 \text{ min}$$

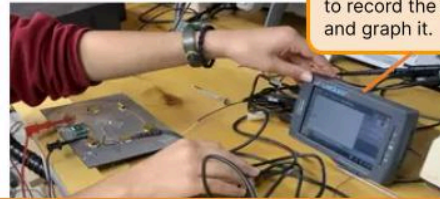
Variable	Value	Notes
Mass	213.80 g	
Specific Heat of Aluminum	.902 J/1 g °C	Source: ("Changing")
Initial Temperature	2452.5 kg/s²	Room Temperature
Final Temperature	0.08 N*s/m	Maximum temperature from operator manual
Change in Temperature	40°C - 20°C = 20°C	
Resistance	18 Ω	6 3-ohm resistors in series

Figure 22: Calculating time to change temperature using given and found values

Experiment Set-Up



Attached surface temperature probes to heating plate (One in the center and one on the edge to measure heat distribution). Stuck them down with tape and thermal paste.



Adjusted our timer to record the data and graph it.

Hooked up a 12 volt DC power supply to the circuit to heat it up.



Heating Board Test

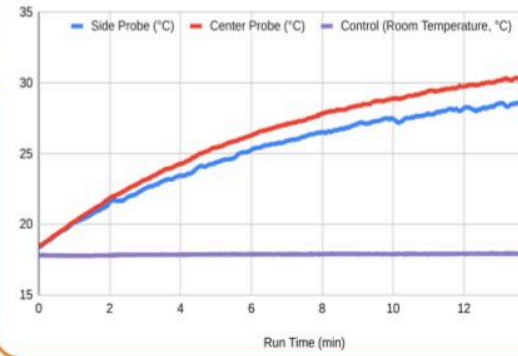
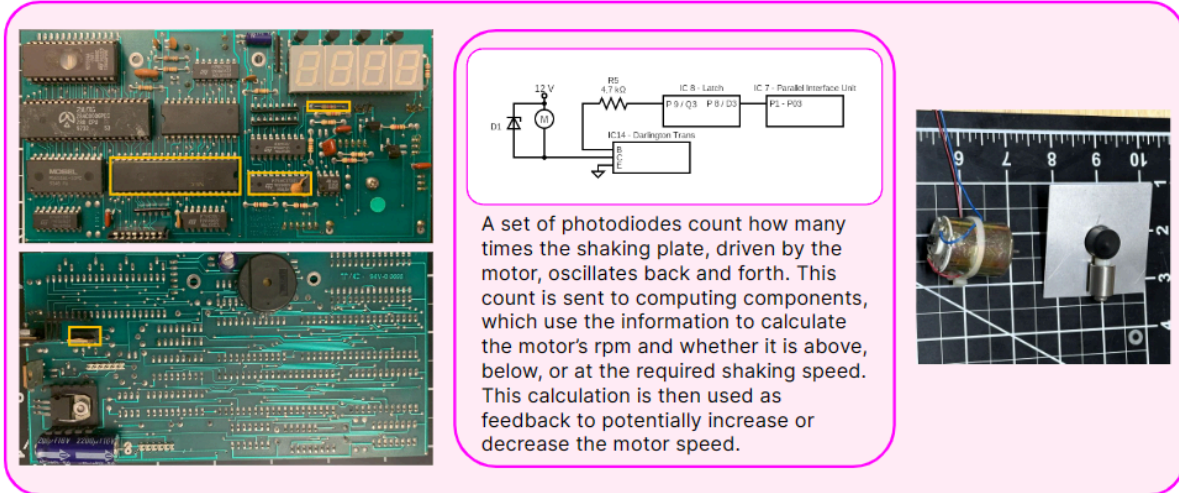


Figure 23: To test these calculations, we ran a physical experiment with the heating board

6.7. Shaking Table



A set of photodiodes count how many times the shaking plate, driven by the motor, oscillates back and forth. This count is sent to computing components, which use the information to calculate the motor's rpm and whether it is above, below, or at the required shaking speed. This calculation is then used as feedback to potentially increase or decrease the motor speed.

Figure 24: Circuit diagram for shaking table subsystem

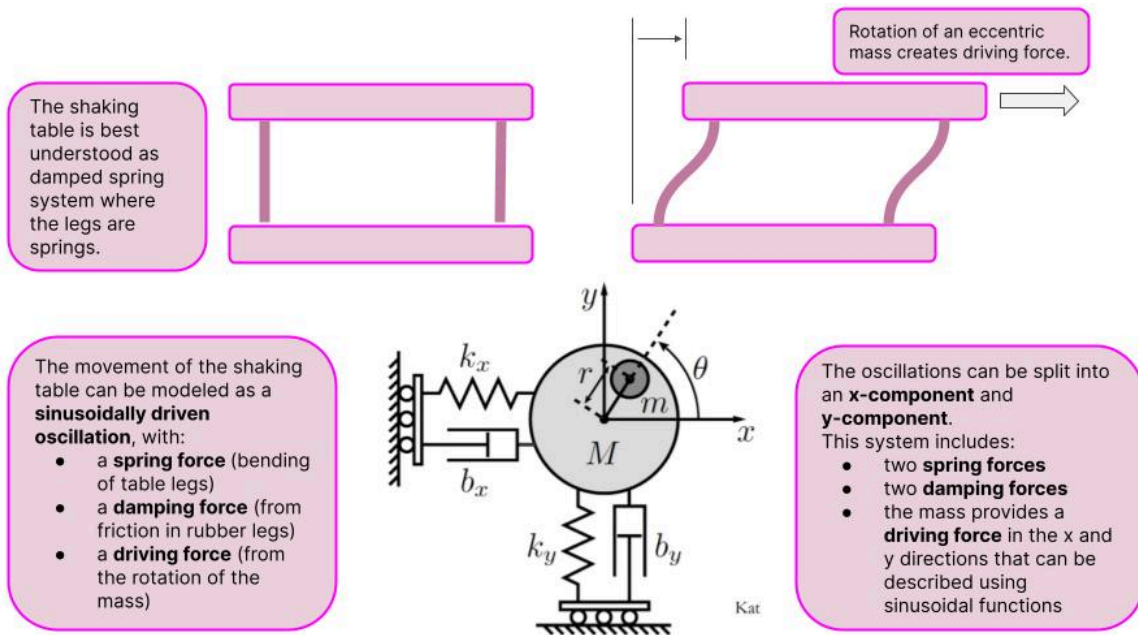


Figure 25: Idealized model of eccentric mass

Equations of motion (from Newton's Second Law):

$$(m + M)\ddot{x} = -k_x x - b_x \dot{x} + F_0 \sin \Omega t$$

$$(m + M)\ddot{y} = -k_y y - b_y \dot{y} + F_0 \cos \Omega t$$

Steady-State Solution:

$$X_0 = \frac{m\varphi^2 r/M}{\sqrt{(1-\varphi^2)^2 + (2\zeta\varphi)^2}}$$

$$\tan\theta = \frac{2\zeta\varphi}{1-\varphi^2}$$

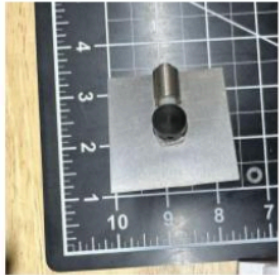
The steady-state solution remains after the unsteady vibrations have died down, and is the most relevant in describing the motion of the shaking table.

Variable	Description
m	Mass of the eccentric mass
M	Mass of the shaking table
k _x and k _y	Spring constants (k _x and k _y equal)
b _x and b _y	Damping coefficients (b _x and b _y are equal)
F ₀	Magnitude of the driving force
r	The distance between the center of mass of the shaking table and the center of mass of the eccentric mass
ζ	Defined as $\zeta = \frac{c}{2\sqrt{km}}$
φ	Defined as $\varphi = \Omega\sqrt{\frac{m}{k}}$


Figure 26: Equations of motion and steady-state solution

6.7.3. Finding Parameters


Masses



Eccentric Mass



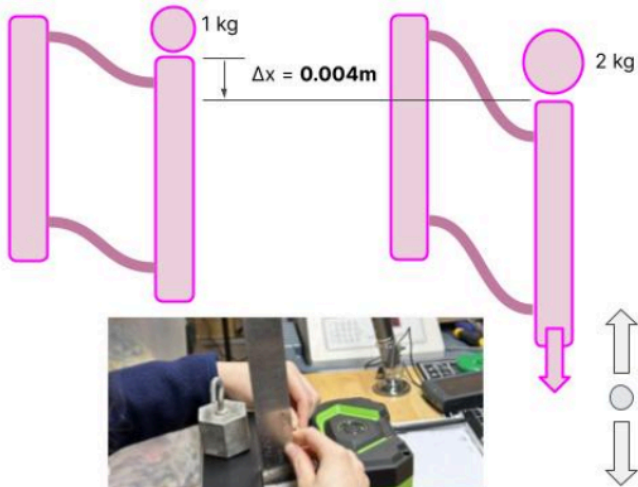
Shaking Table



Object	Mass
Eccentric Mass	0.0198 kg
Shaking Table	0.83 kg

Figure 27: The eccentric mass and the shaking table were found using a scale.

Spring Constant



Newton's Second Law:

$$m\ddot{x} = -kx + mg$$

(at rest), therefore:

$$k = mg/x = \frac{(2-1\text{kg}) \cdot 9.81 \frac{\text{m}}{\text{s}^2}}{0.004\text{m}}$$

$$k = 2452.5 \frac{\text{kg}}{\text{s}^2}$$

Figure 28: The spring constant was calculated by measuring displacement as a function of mass.

Damping Coefficient



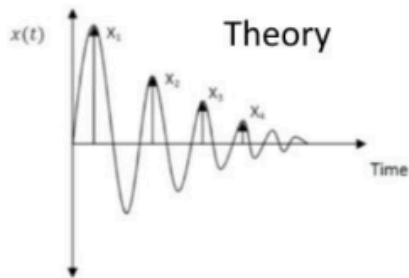
Accelerometer



Accelerometer attached to vibrating shaking table

Figure 29: An accelerometer was attached to the shaking table to determine the damping coefficient.

Logarithmic Decrement Method



Logarithmic decrement method

$$\delta = \frac{1}{n} \ln \left| \frac{x_n}{x_{n+1}} \right|$$

$$\text{Damping} = \zeta = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}}$$

("Damping")

The **logarithmic decrement method** can be used to determine the damping coefficient for an underdamped system such as our shaking table from a graph.

Experimental

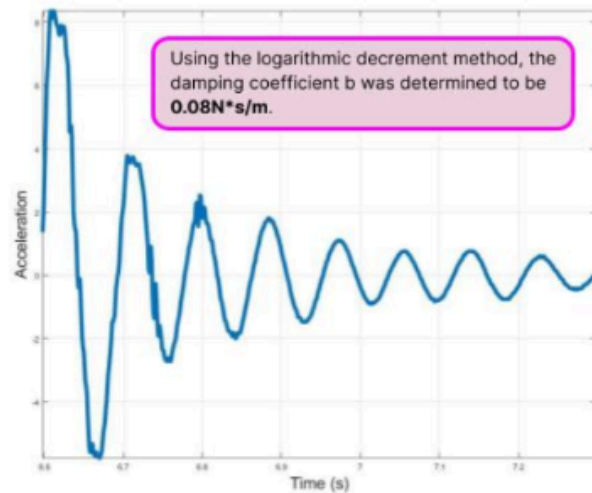
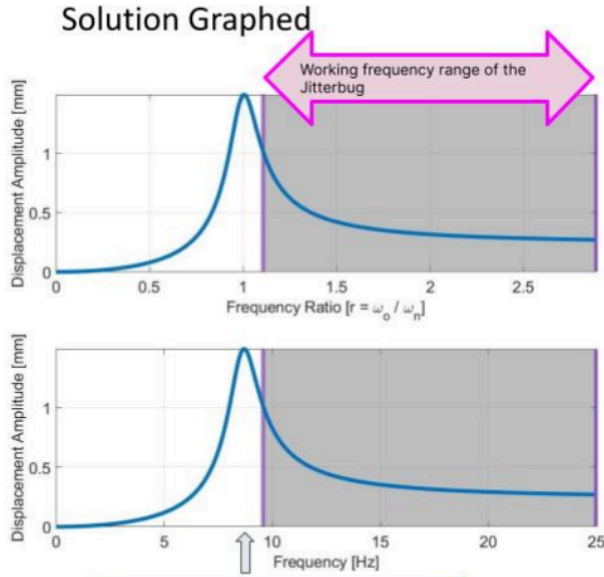


Figure 30: Calculating the damping coefficient.

Theoretical Frequency Response Curve



Natural Frequency is outside the operating range of the table.

Solution Parameters

Variable	Value	Description
m	0.0198 kg	Mass of the eccentric mass
M	0.83 kg	Mass of the shaking table
k_x and k_y	2452.5 kg/s ²	Spring constants (k_x and k_y equal)
b_x and b_y	0.08 N*s/m	Damping coefficients (b_x and b_y are equal)
F_o	<i>Depends on desired oscillation frequency</i>	Magnitude of the driving force

Figure 31: Oscillation amplitude.

6.7.5. Photodiode

Circuit Board

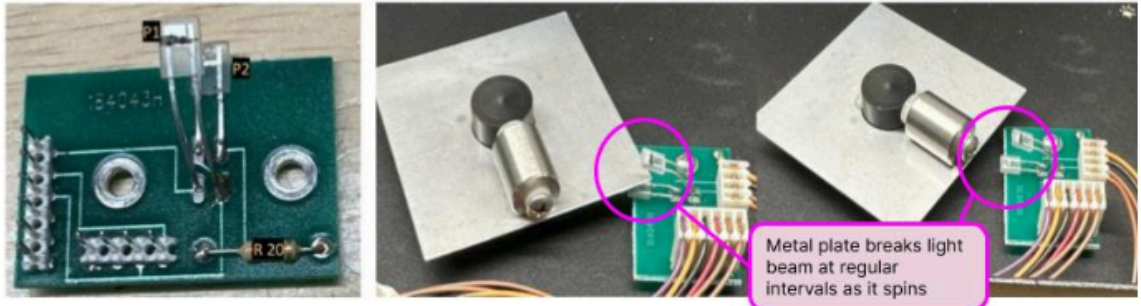
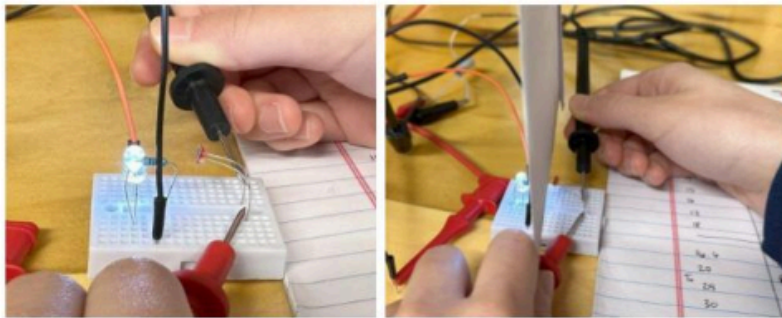


Figure 32: An infrared laser (P1) is directly above a photodiode (P2).

Model



Measuring resistance of Photodiode with light source

Measuring resistance of Photodiode without light source

Light Intensity	Resistance
Light	4.15 k Ω
No light	14.5 k Ω

A lit LED was used as the light source for the photodiode, and the resistance across the photodiode was measured with and without light.

Figure 33: Photodiode experiment

6.8. Fan

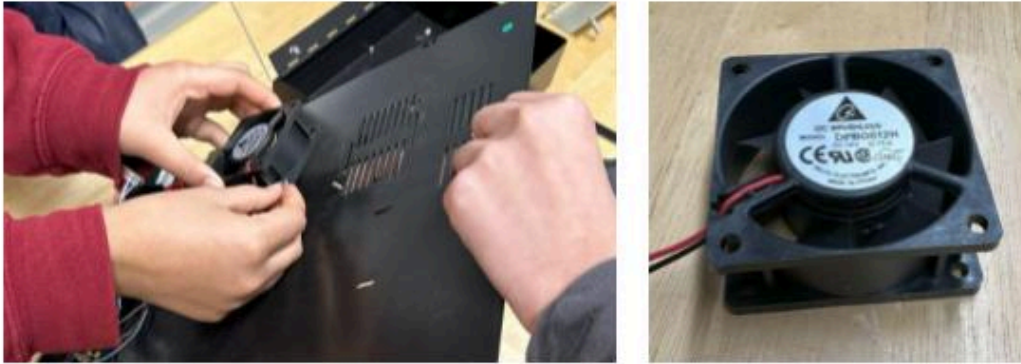


Figure 34: The fan takes heat out of the casing and prevents condensation, allowing the Jitterbug to function well even when incubating at high temperatures or running for a long time.

6.9. System Integration

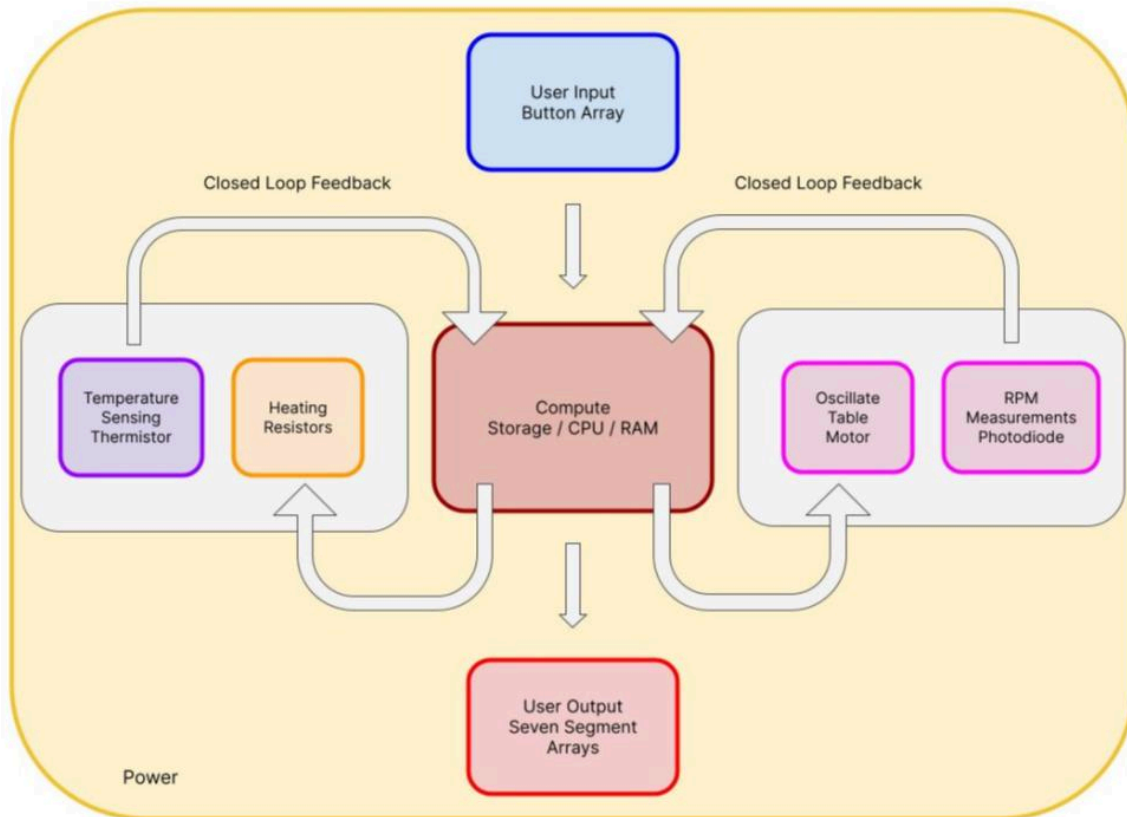


Figure 35: How subsystems are connected

7. Summary, Findings, and Lessons Learned

Through this project, we learned about the roles of the individual components within the system:

- The CPU, EPROM, RAM, and parallel interface control information, storing programs and sending signals to individual systems and driving system integration
- Transformers, capacitors, regulators, and the bridge rectifier work together to convert 120V of AC to 5V of usable DC
- The input system uses an array to translate pressed buttons into signals which the Parallel Interface sends to other subsystems as necessary
- The multiplexed, 7-segment LED display updates output data in real-time, displaying time, temperature, and the speed of the shaking table
- Wire-wound resistors heat The Jitterbug and the thermistor monitors incubation temperatures in a feedback loop
- The motor oscillates the shaking table and the photodiode measures the motor's rpm in a feedback loop
- The fan works as a heat exhaust, preventing condensation and cooling electronics

We also learned a lot during the reverse engineering process:

- Different components and subsystems communicate and work together in feedback loops to control a complicated device
- Current and power conversion turns outlet voltage into current that can be used by digital electronics
- How LED circuits function and update outputted data in real-time
- How to design and execute reliable experiments with valid results, which can be used to find measurable coefficients in physical models
- How to model and understand rotation of eccentric masses
- How feedback loops allow devices to monitor important variables—in this case, temperature or shaking speed

We're excited to apply our improved understanding of electronics to the devices found all around us.

8. References

[References Link](#)