The Jitterbug

Serkk-it 4811A
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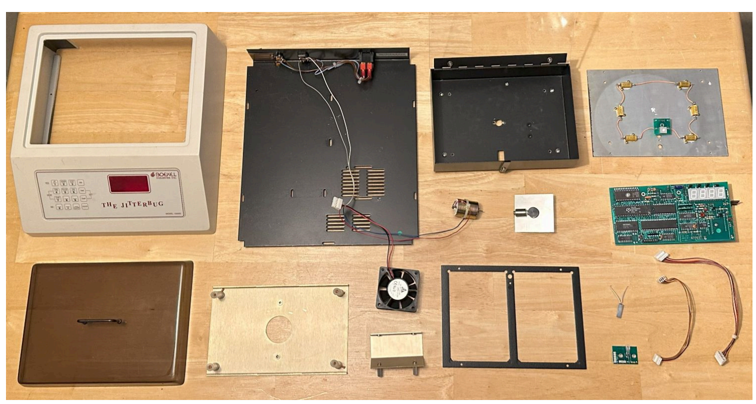
Andover, Massachusetts



Contents

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

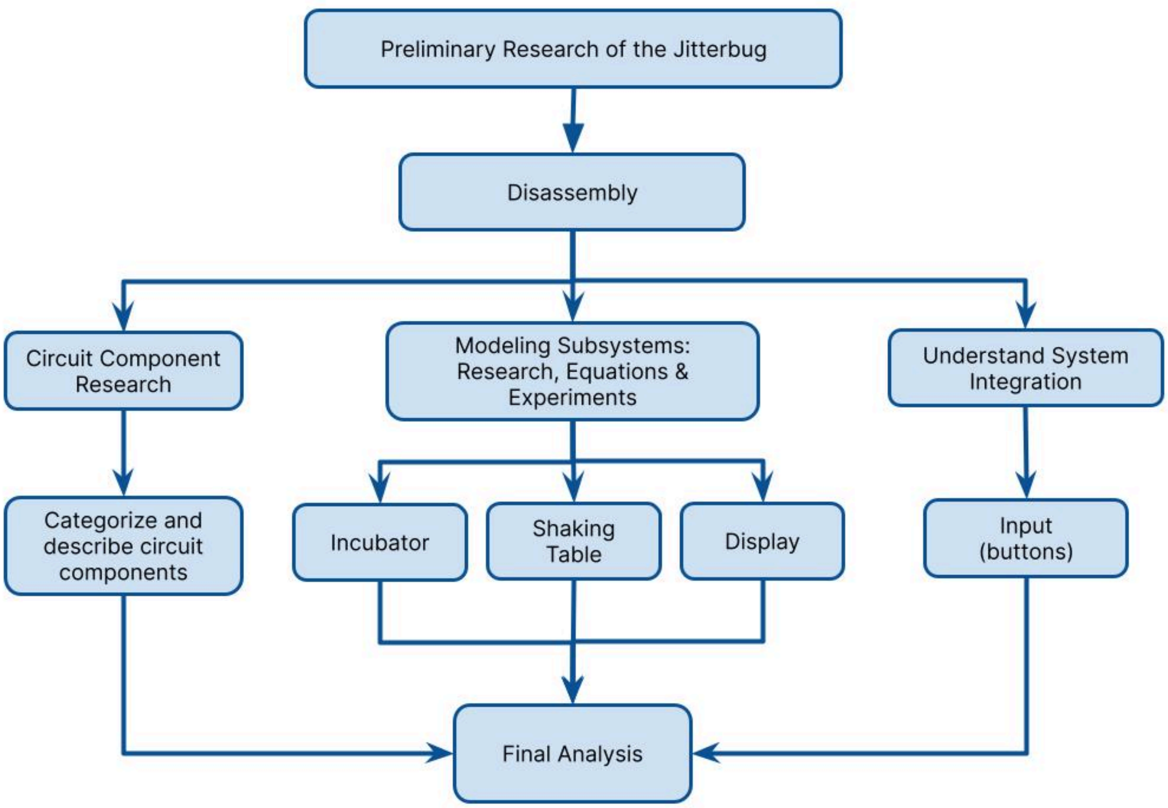


Figure 1: Plan of Action

3. Equipment

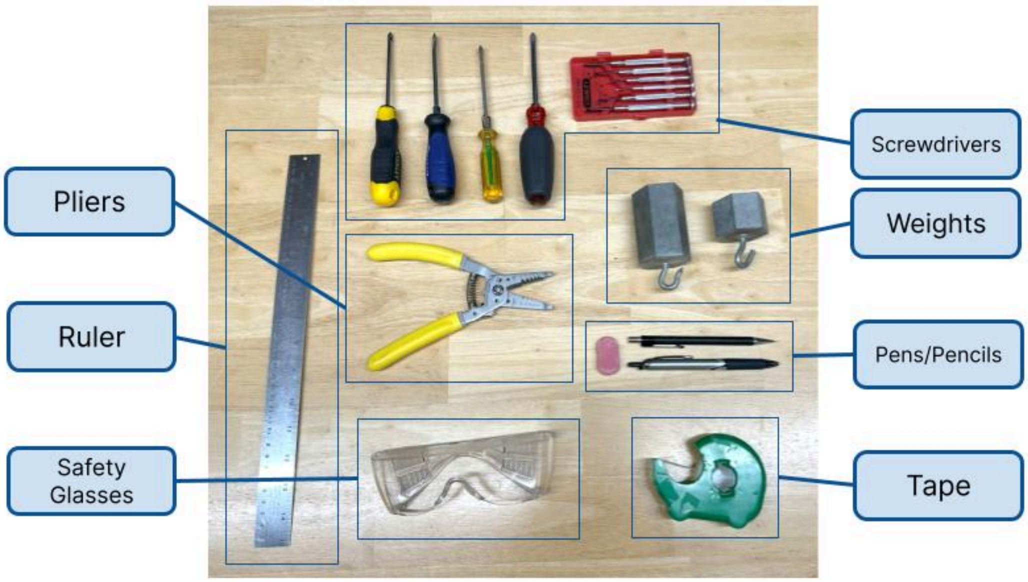


Figure 2: Labeled equipment

Figure 3: Labeled equipment used with descriptions

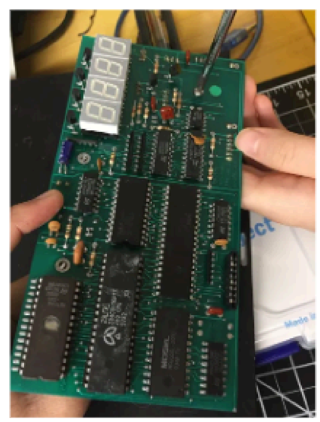
4. Disassembly

Front of Jitterbug

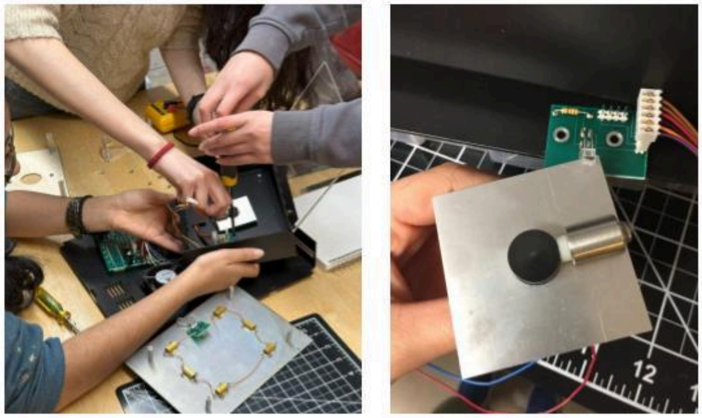
Bottom of Jitterbug

Step 1: Removed the exterior casing

Step 2: Removed the incubation chamber



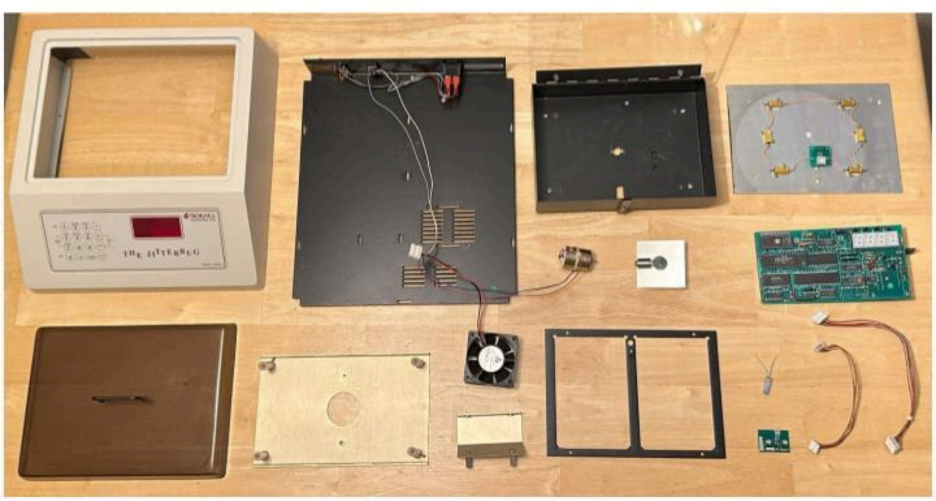
Step 3: Removed the main circuit board



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

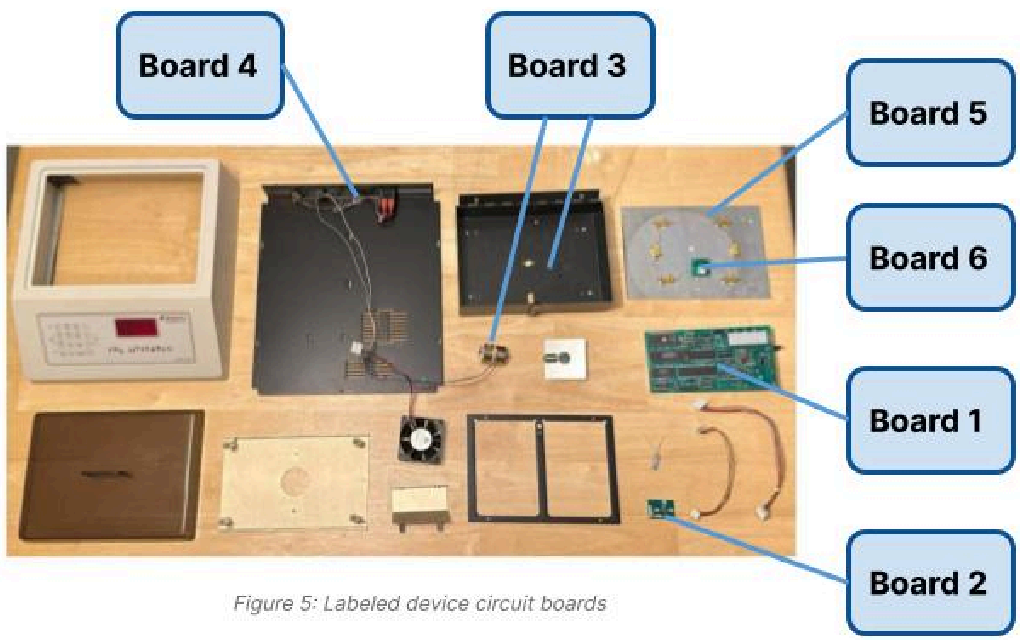
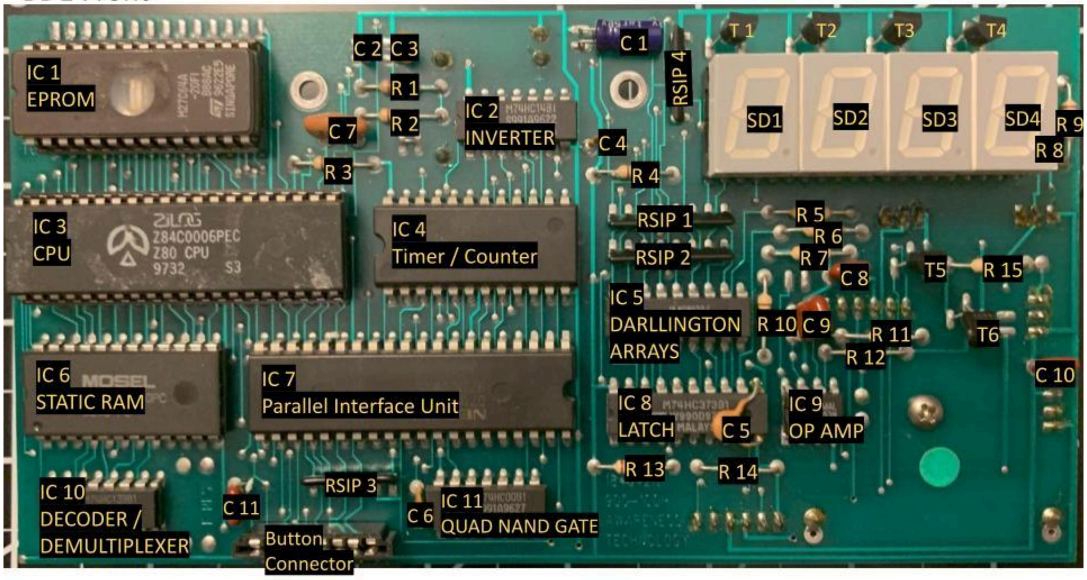
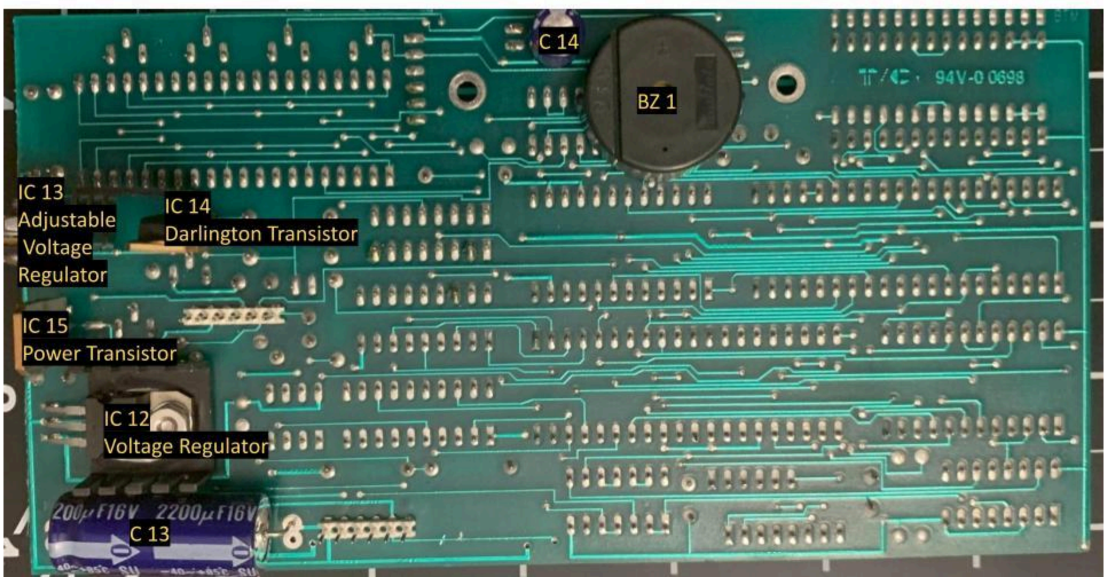


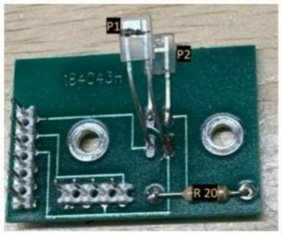
Figure 5: Labeled device circuit boards

BD1 Front

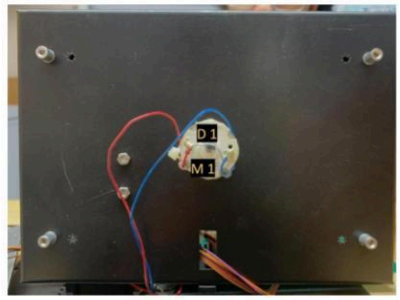


BD1 Back

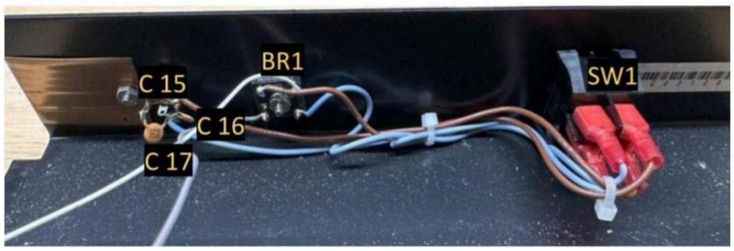




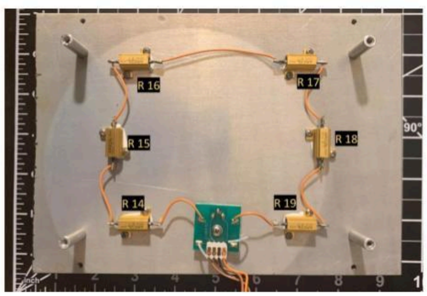
BD2



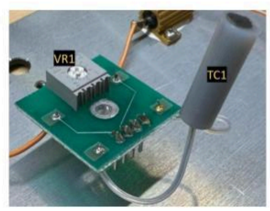
BD3



BD4

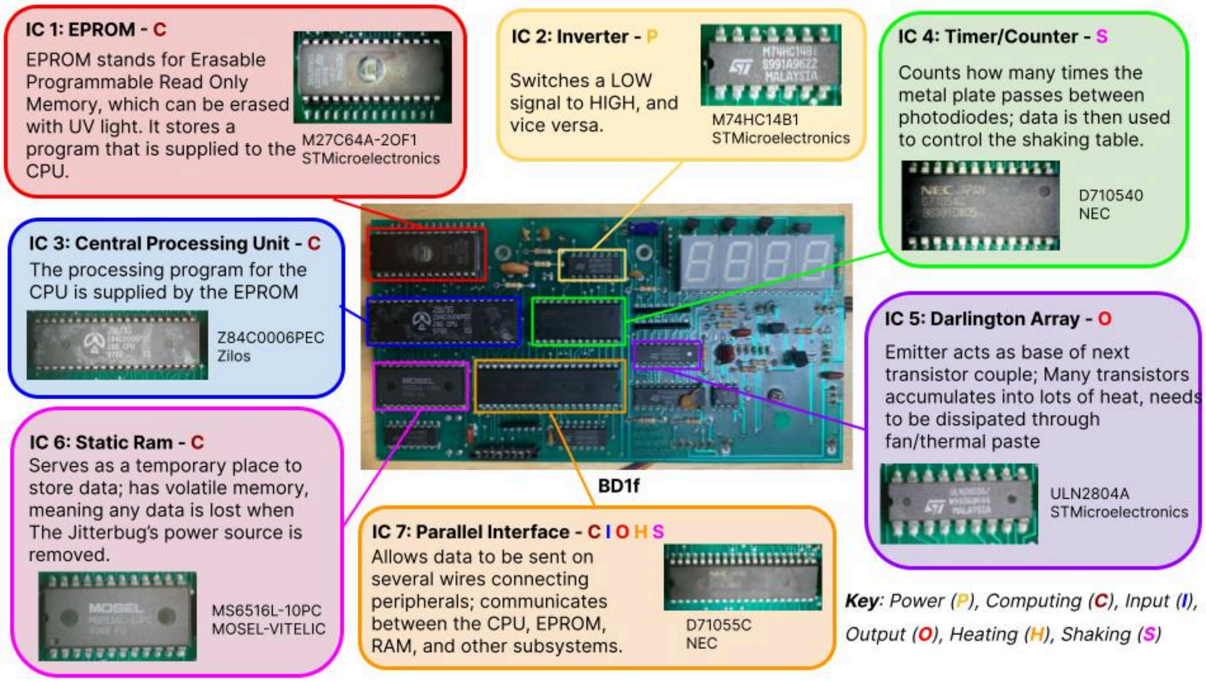


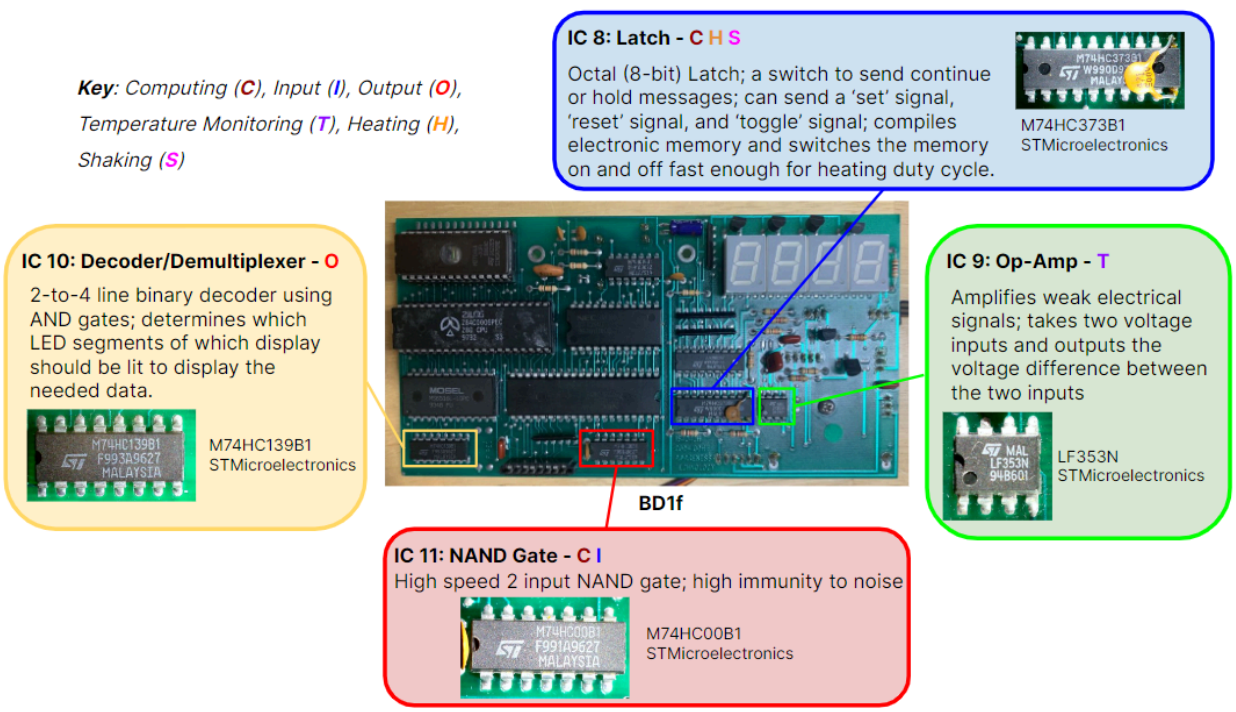
BD5



BD6

5.2.2. Components





IC 13: Voltage Regulator - P

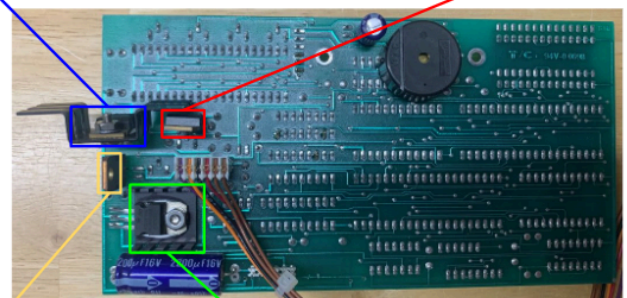
Positive adjustable voltage regulator; converts uneven DC to a more smooth, usable current; attached to a large metal piece to dissipate generated heat.

LM317T
STMicroelectronics

IC 14: Transistor - S

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

TIP112
STMicroelectronics



BD1b

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

IC 15: Transistor - H

Used as a switch in subsystem circuitry.

TIP32C
STMicroelectronics

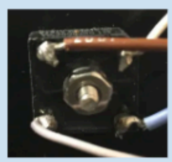
IC 12: Voltage Regulator - P

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

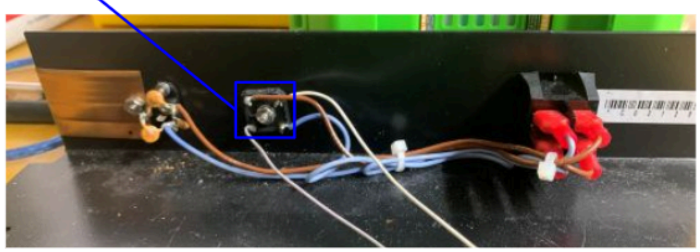
L78S05CV
STMicroelectronics

BR 1: Bridge Rectifier - P *(Power)*

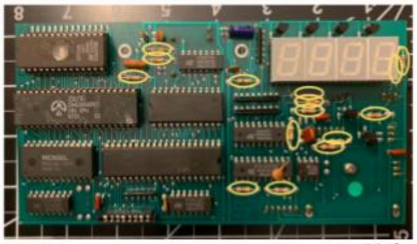
4 diode single phase bridge rectifier; converts AC current to DC current; mounted to a metal casing with a screw to keep generated heat and high AC voltage away from the rest of the circuitry.



GBPC602
VISHAY

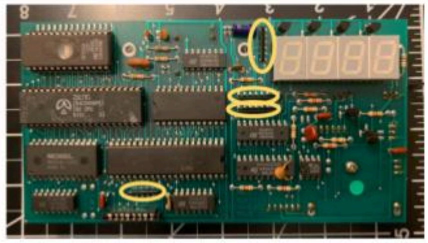


BD4



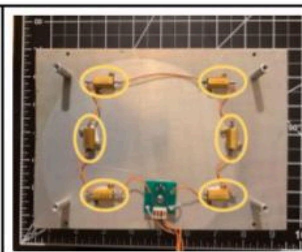
BD1f

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



BD1f

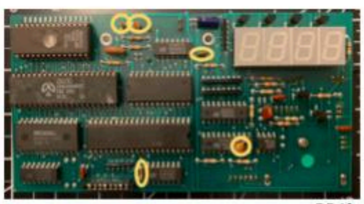
Desc.	**Variable Resistor** Have several 'output' pins; depending on which pin is connected, a different resistance is applied.
Image	
IDs	RSIP1, RSIP2, RSIP3, RSIP4



BD5

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

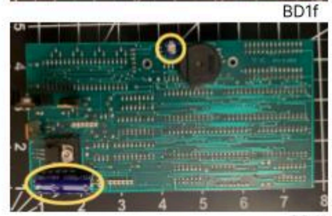
BD4

Desc.	**Ceramic Capacitors** Have a fixed value; ceramic acts as a dielectric.
Image	
IDs	C2, C3, C4, C5, C6, C15, C16, C17

BD1f

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

BD1f



BD1b

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

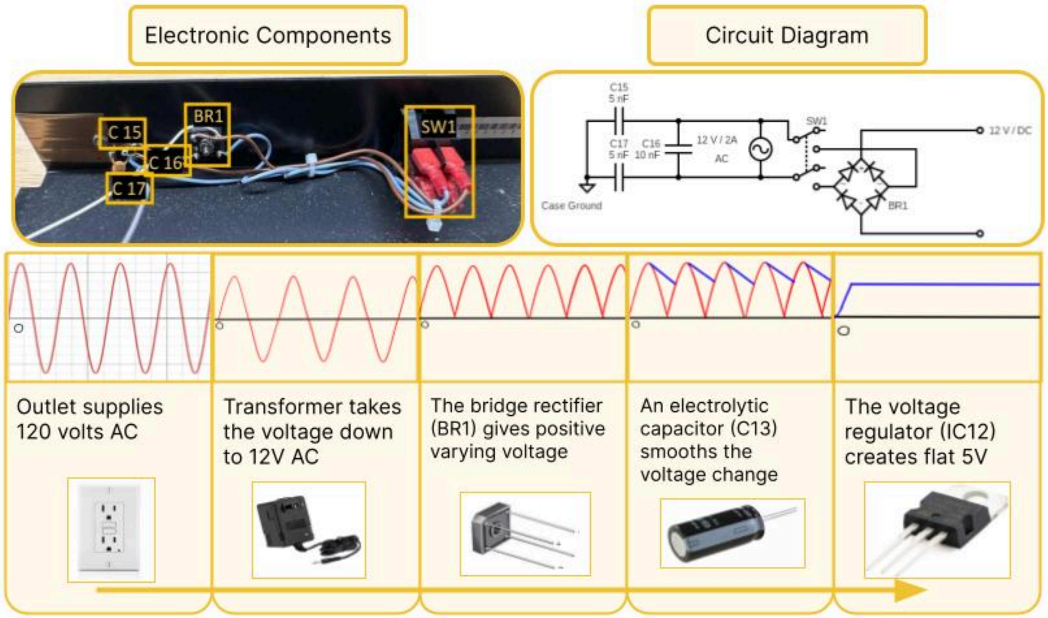


Figure 9: The Jitterbug electronics require DC at 5V. The bridge rectifier is mounted to the outer metal casing to keep generated heat and high AC voltage away from the rest of the circuitry.

6.2. Computing

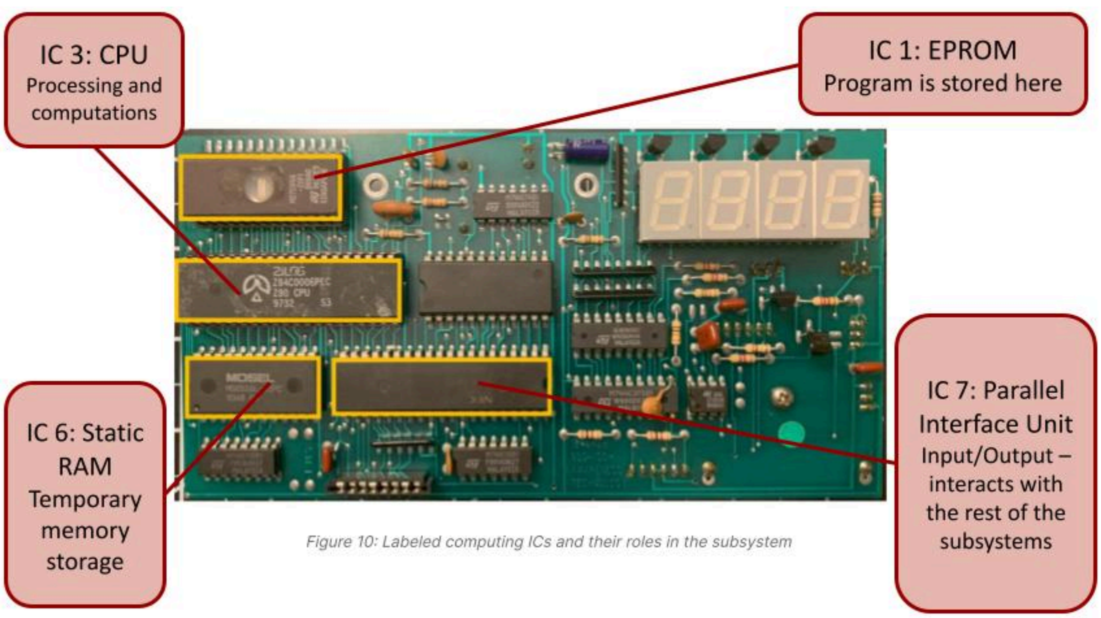


Figure 10: Labeled computing ICs and their roles in the subsystem

6.3. Input

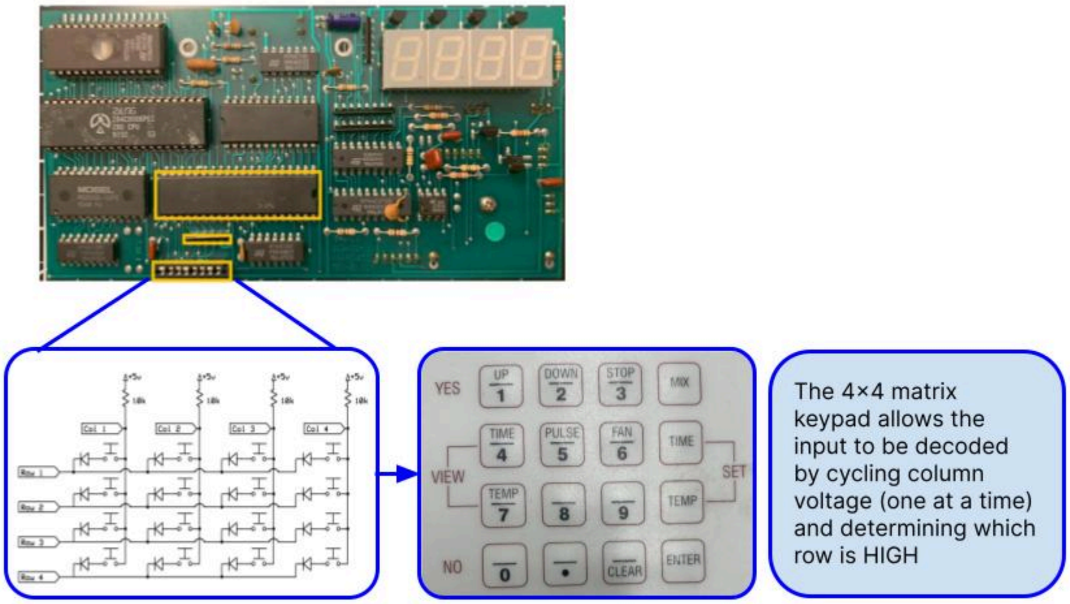


Figure 11: Keypad Operation

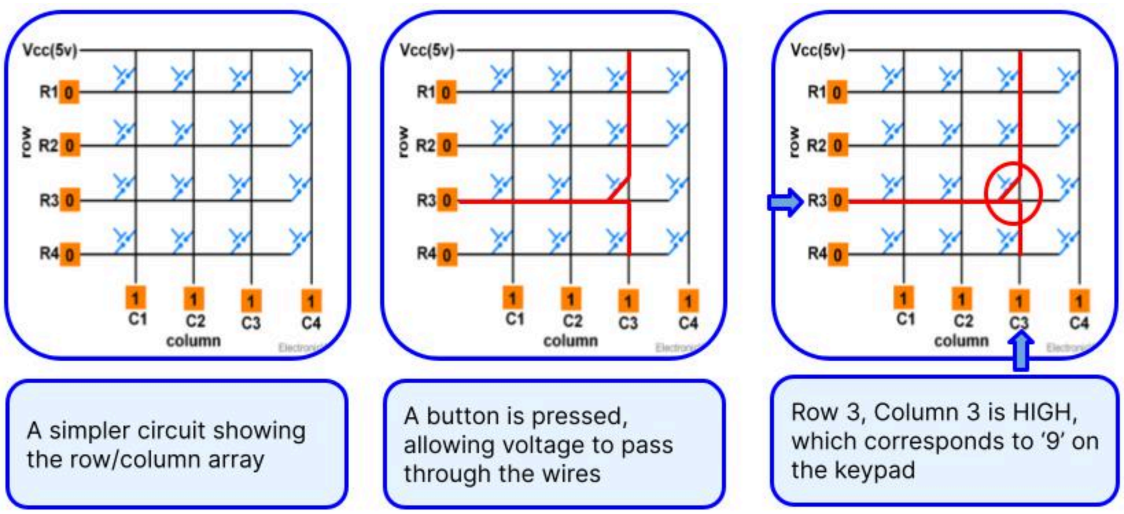


Figure 12: Theory of how buttons are pressed

6.4. Display

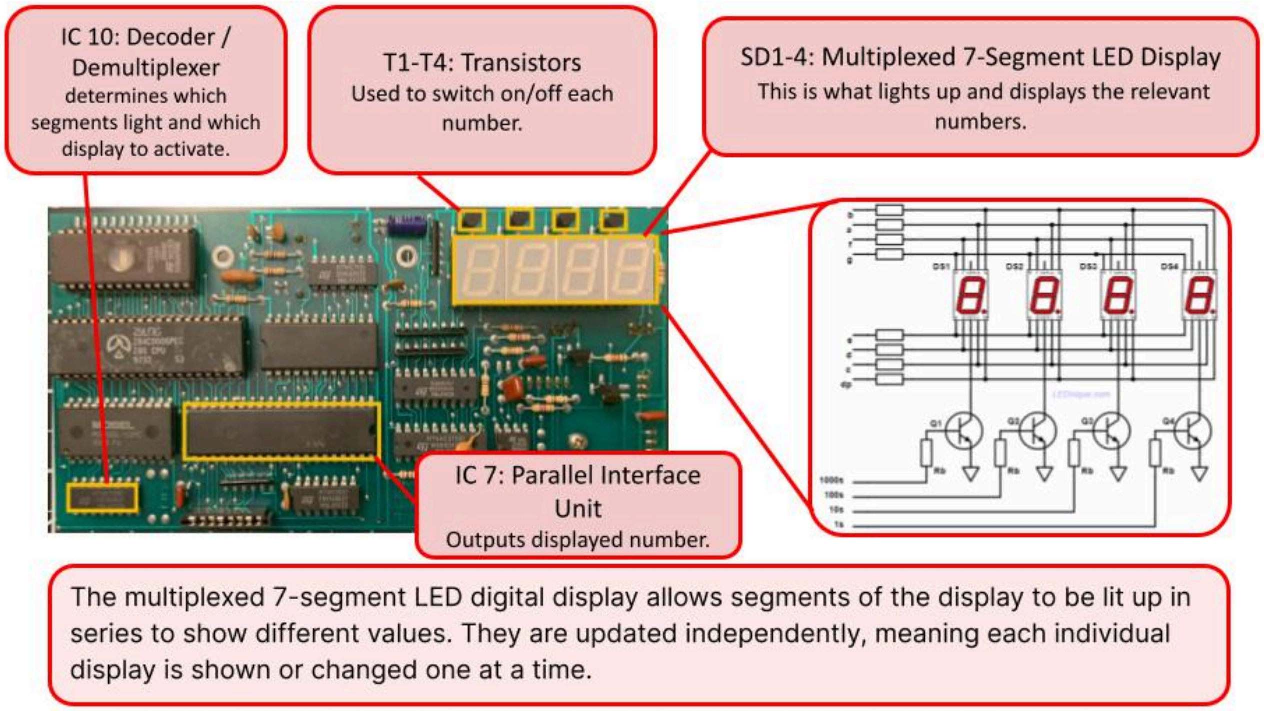


Figure 13: Labeled display ICs and their roles in the subsystem

LED Digital Display

Figure 14: The Jitterbug's LED digital display

Operating Single Display

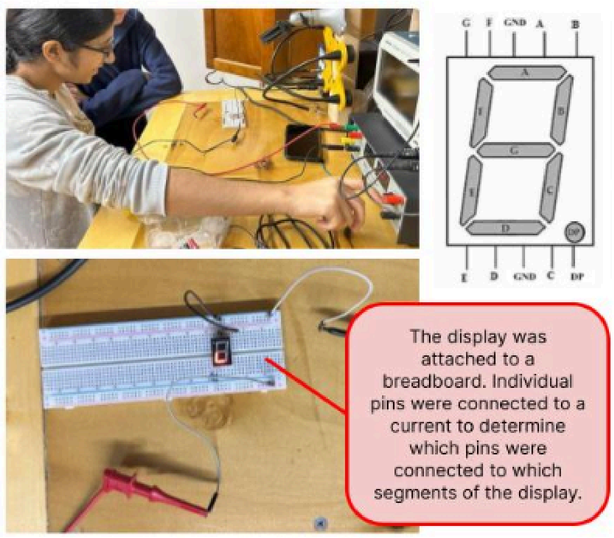


Figure 15: Turning on single display segments

6.5. Temperature Monitoring

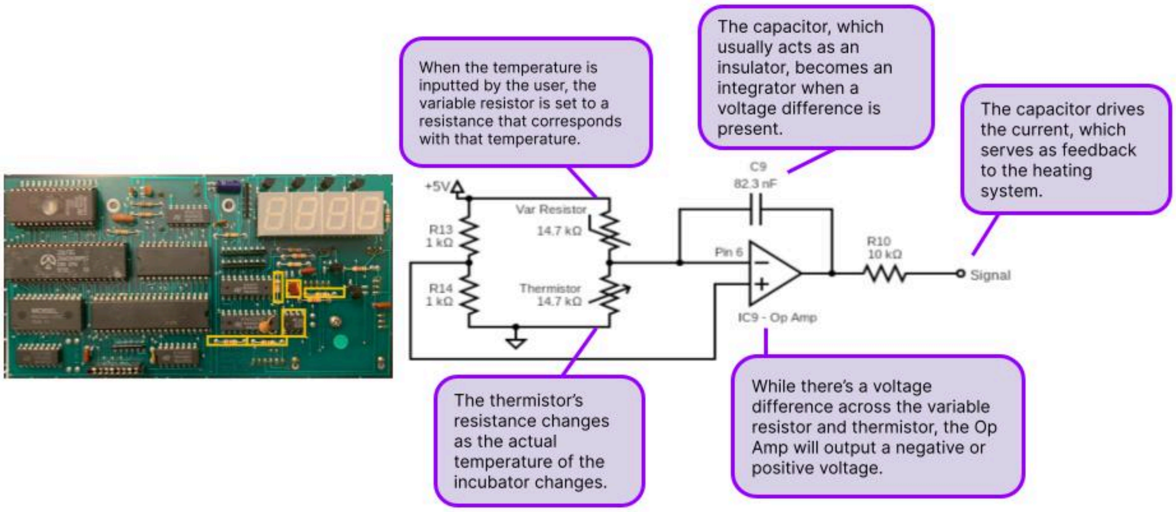
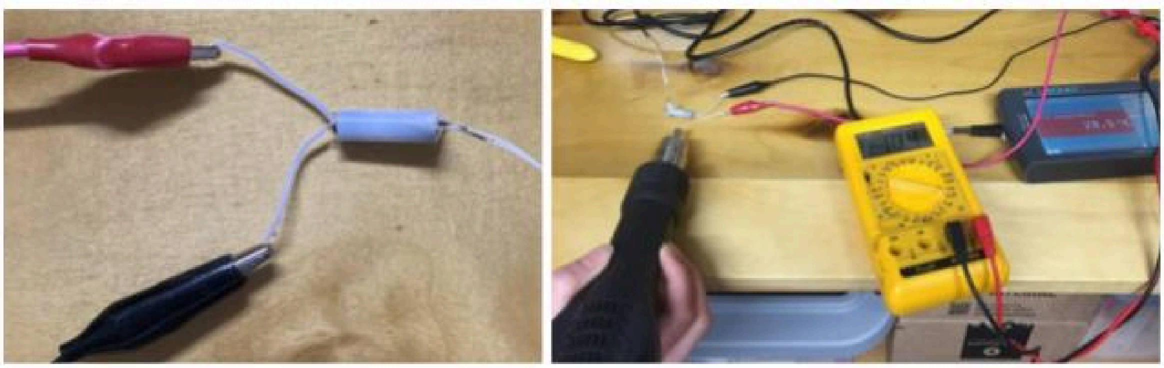


Figure 16: Circuit diagram of temperature monitoring subsystem

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

Data

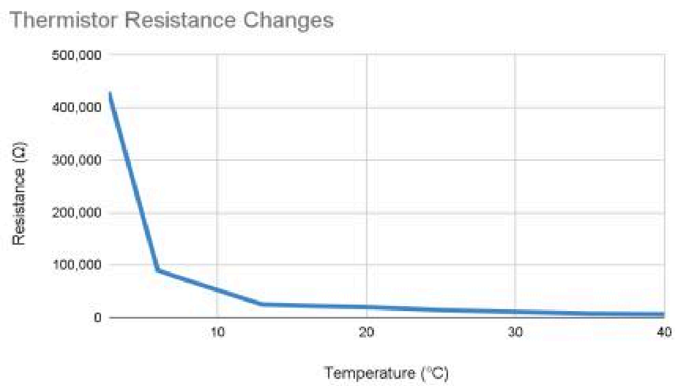


Figure 18: The resistance decreases with increasing temperature

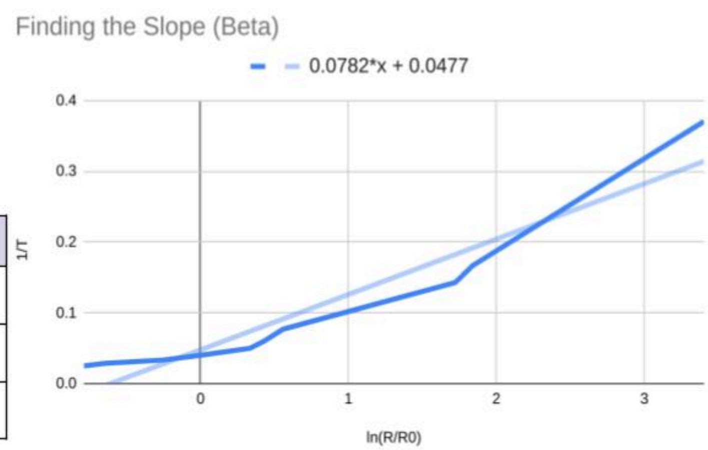
Calibration

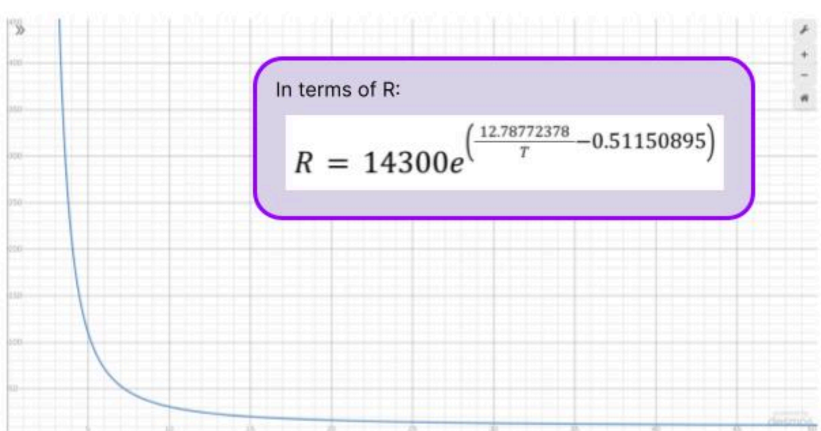
Steinhart-Hart equation for thermistor resistance:

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

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/(slope of the best fit line)





In terms of R:

$$R = 14300e^{\left(\frac{12.78772378}{T} - 0.51150895\right)}$$

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

6.6. Heating

6.6.1. Electronics

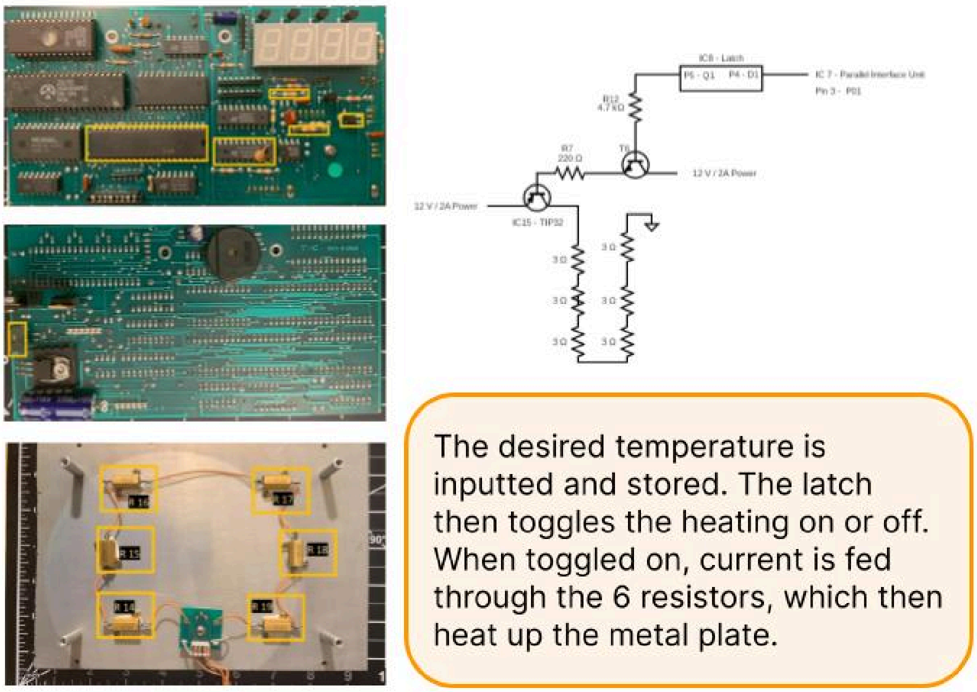


Figure 20: Circuit diagram of heating subsystem

6.6.2. Heating Plate

Determining Material

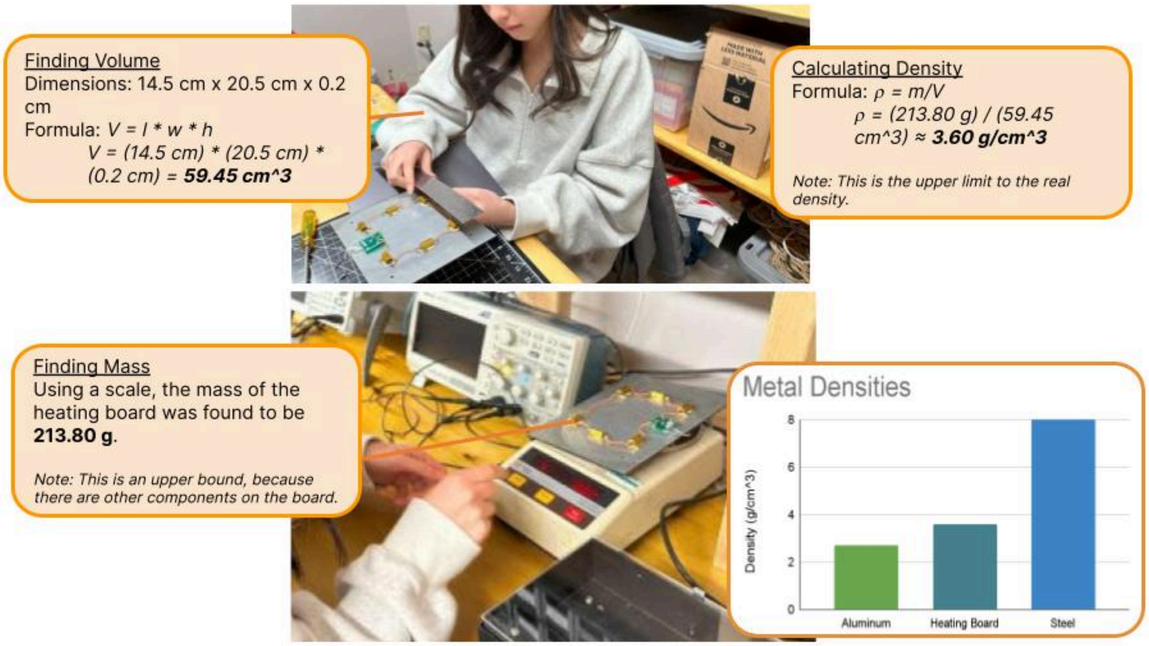
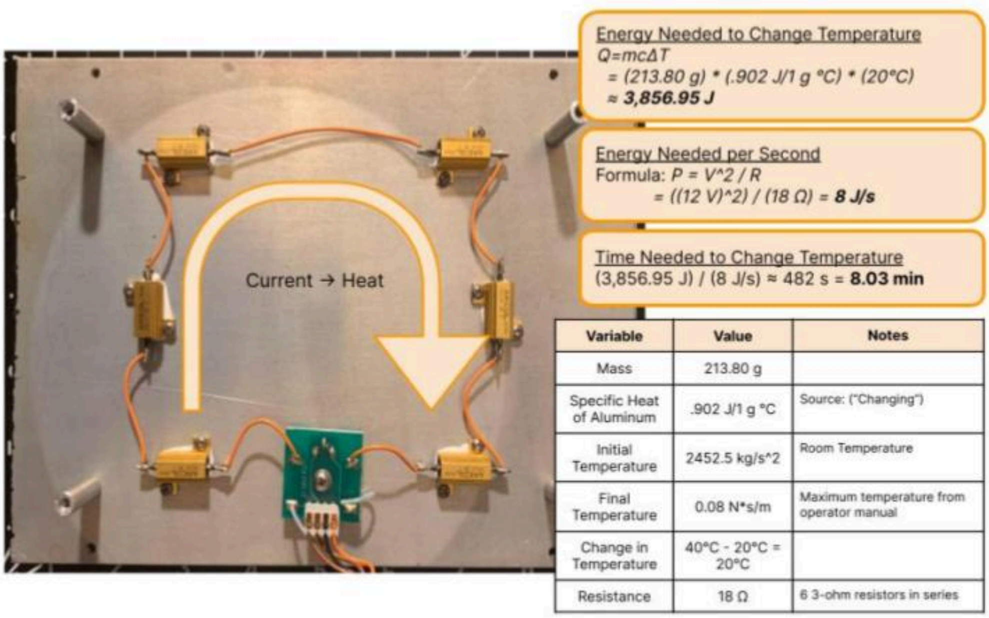


Figure 21: Determined the plate is made of Aluminum

Theoretical Calculations



Variable	Value	Notes
Mass	213.80 g	
Specific Heat of Aluminum	.902 J/1 g °C	Source: ("Changing")
Initial Temperature	2452.5 kg/s^2	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

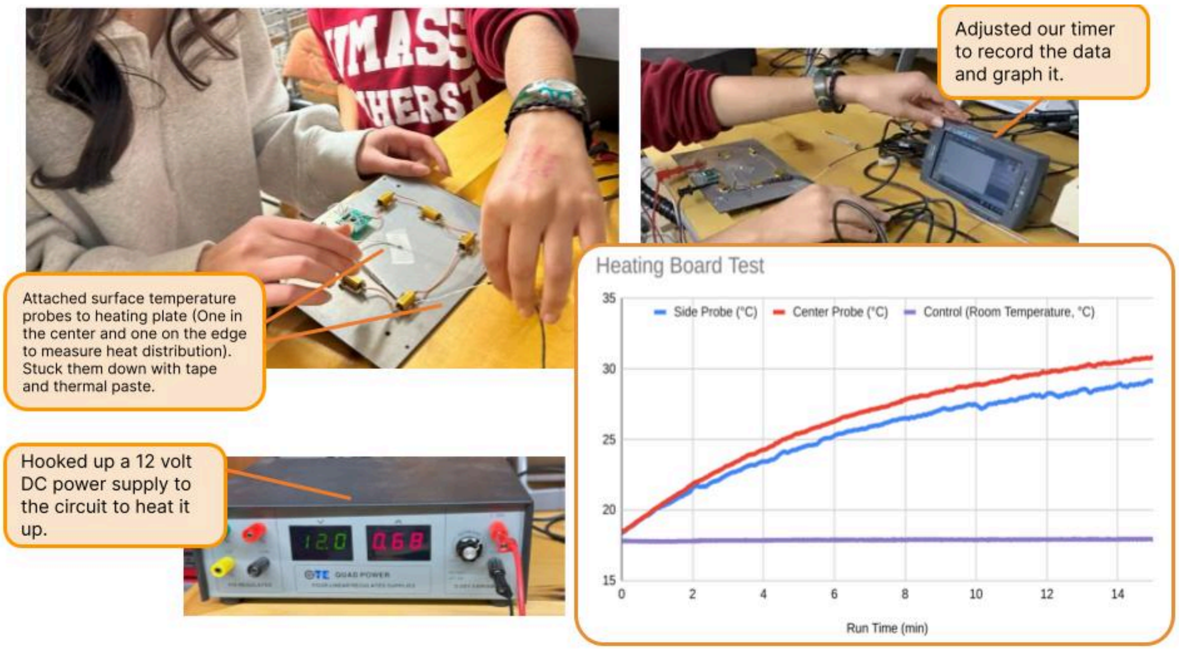
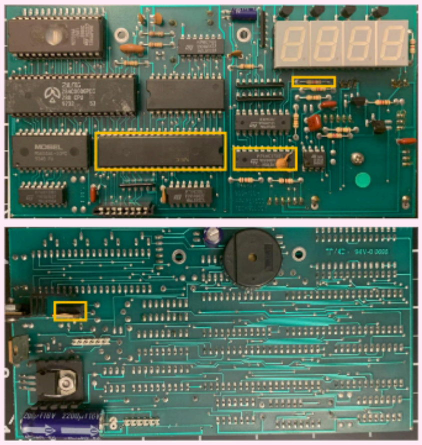
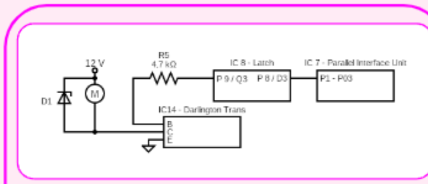


Figure 23: To test these calculations, we ran a physical experiment with the heating board

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.

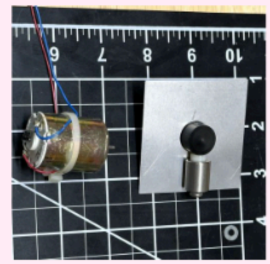
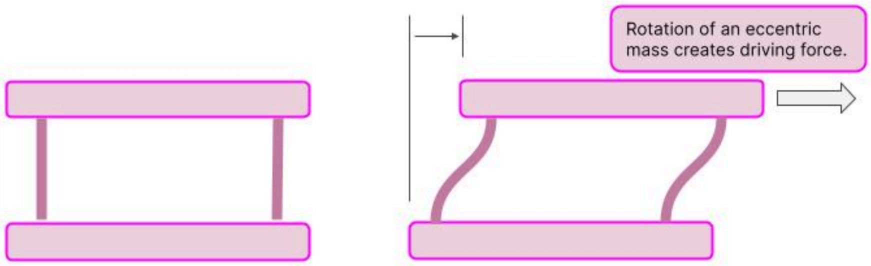


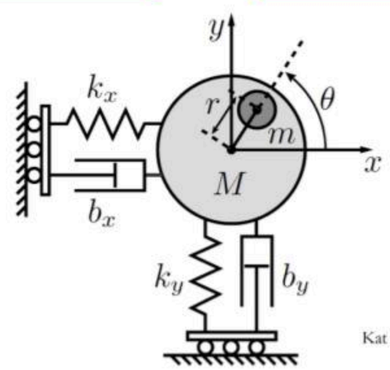
Figure 24: Circuit diagram for shaking table subsystem

The shaking table is best understood as damped spring system where the legs are springs.



The movement of the shaking table can be modeled as a **sinusoidally driven oscillation**, with:

- a **spring force** (bending of table legs)
- a **damping force** (from friction in rubber legs)
- a **driving force** (from the rotation of the mass)



The oscillations can be split into an **x-component** and **y-component**.
This system includes:

- two **spring forces**
- two **damping forces**
- the mass provides a **driving force** in the x and y directions that can be described using sinusoidal functions

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:

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

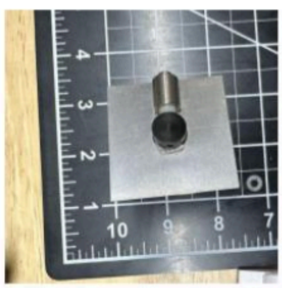
The steady-state solution remains after the unsteady vibrations have died down, and is the most relevant in describing the motion of the shaking table.

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



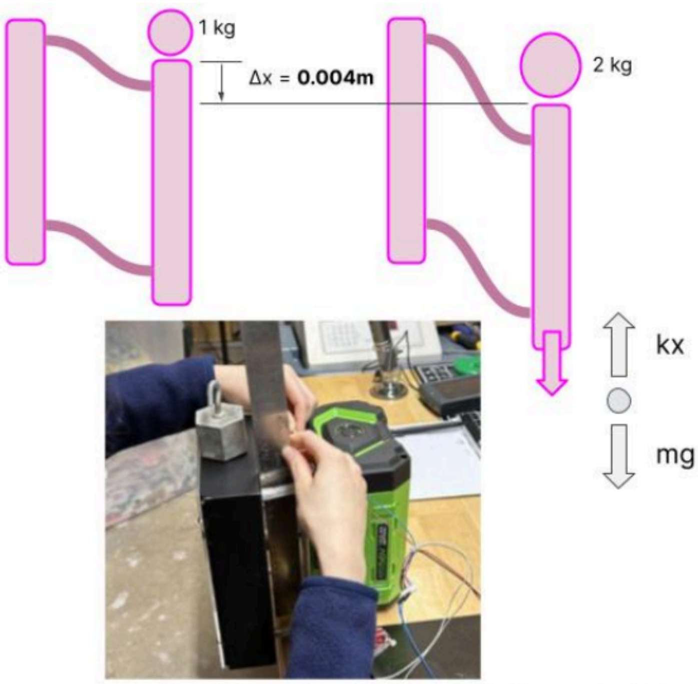
Eccentric Mass

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:

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

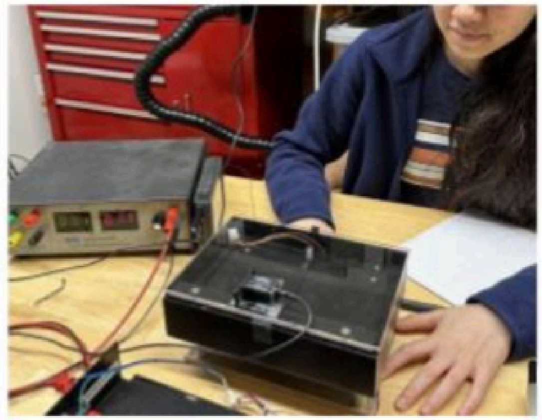
(at rest), therefore:

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

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

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

Damping Coefficient



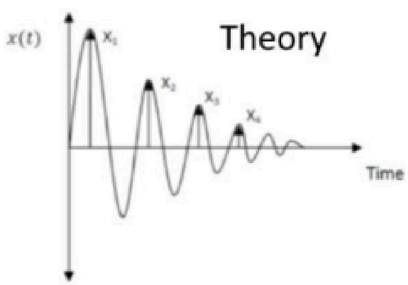
Accelerometer

Accelerometer attached to vibrating shaking table

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

Logarithmic Decrement Method

Theory



Logarithmic decrement method

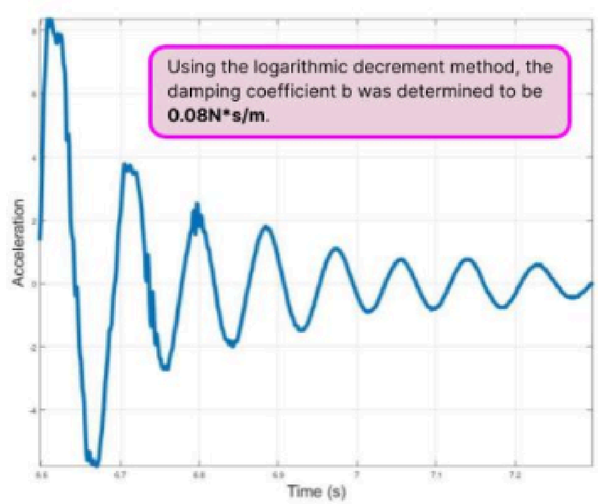
$$\delta = \frac{1}{n} \ln \left| \frac{x_1}{x_{n+1}} \right|$$

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

("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

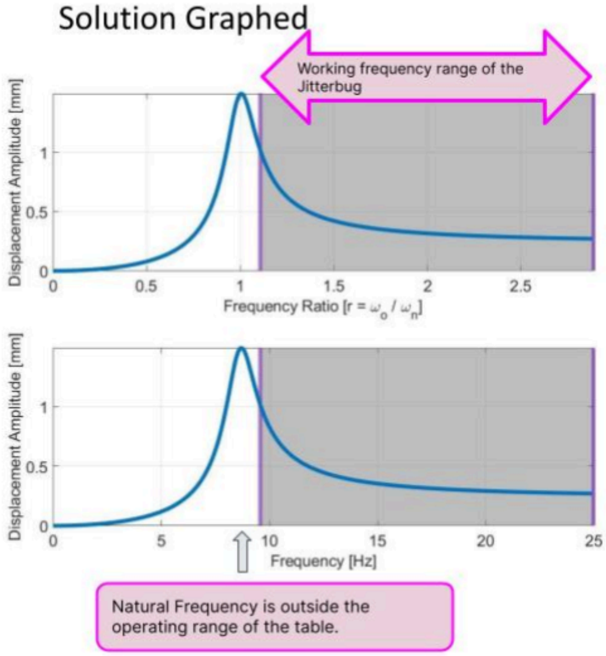


Using the logarithmic decrement method, the damping coefficient b was determined to be **0.08N*s/m**.

Figure 30: Calculating the damping coefficient.

Theoretical Frequency Response Curve

Solution Graphed



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_0	*Depends on desired oscillation frequency*	Magnitude of the driving force

Figure 31: Oscillation amplitude.

6.7.5. Photodiode

Circuit Board

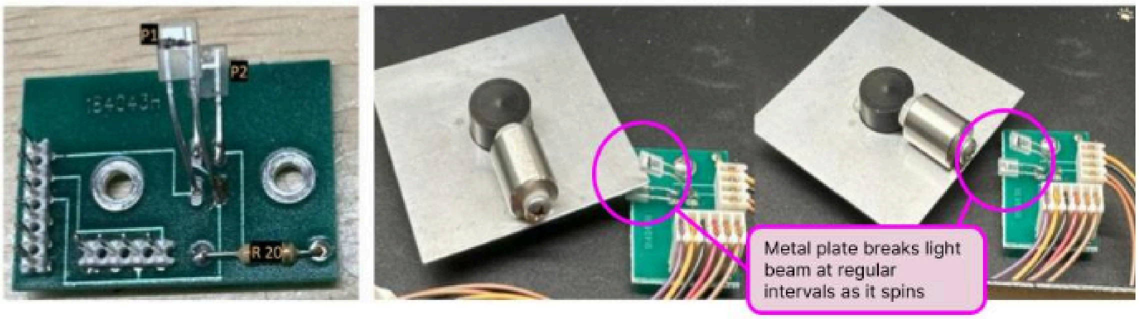
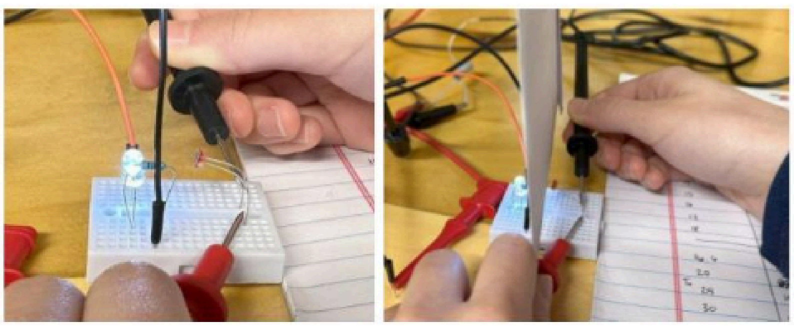


*Figure 32: An **infrared laser (P1)** is directly above a **photodiode (P2)**.*

Model



Measuring resistance of Photodiode with light source

Measuring resistance of Photodiode without light source

Light Intensity	Resistance
Light	4.15 kΩ
No light	14.5 kΩ

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

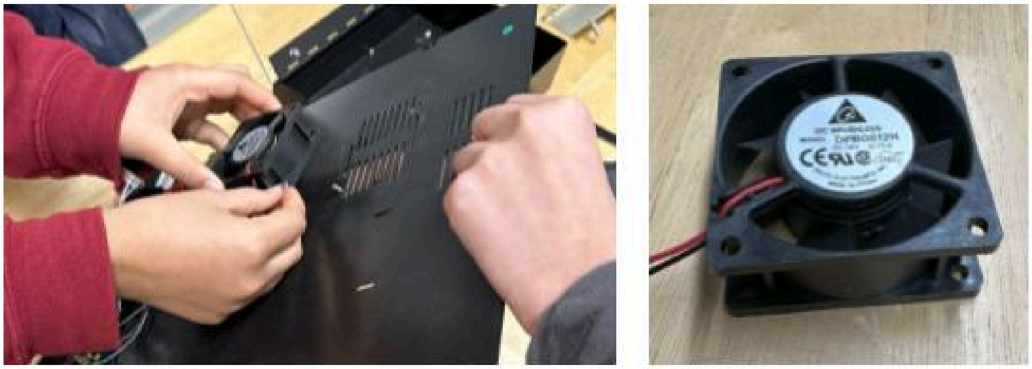


Figure 34: The fan takes heat out of the casing and prevents condensation, allowing the Jitterbug to function well even when incubating at high temperatures or running for a long time.

6.9. System Integration

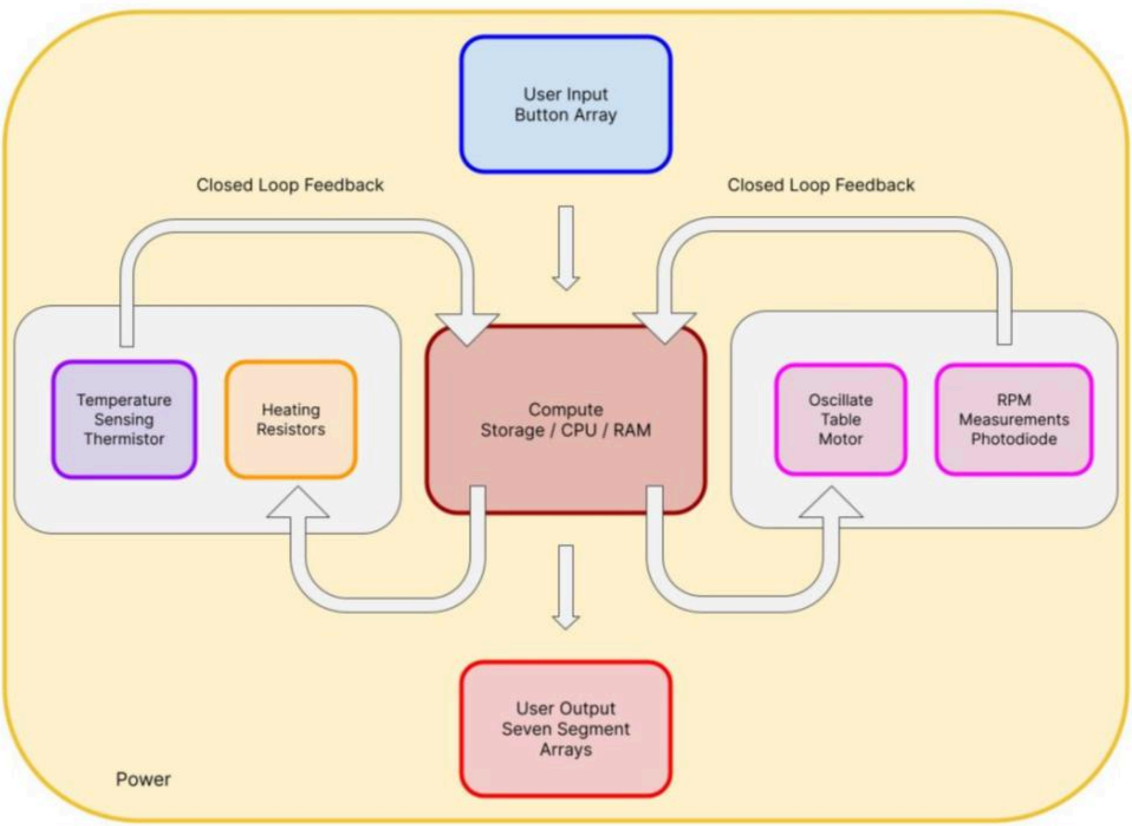


Figure 35: How subsystems are connected

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