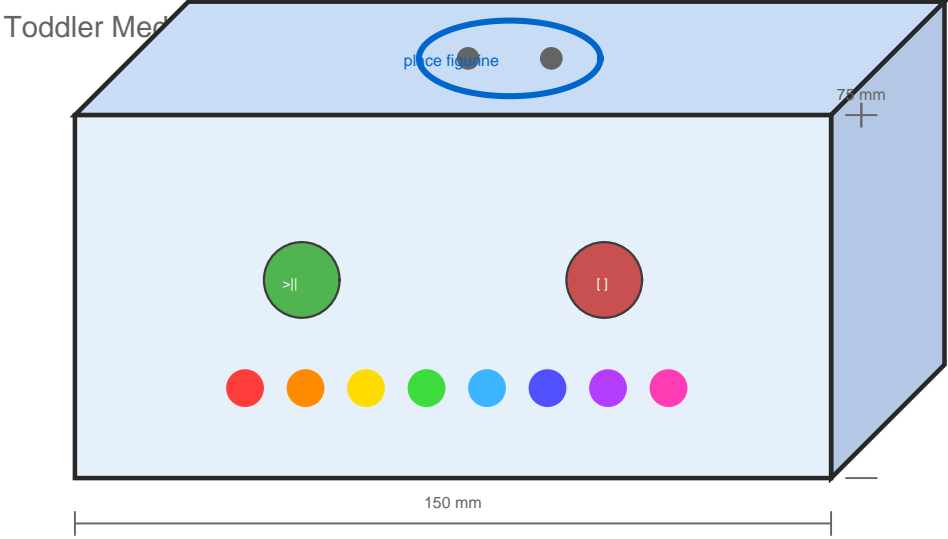


BabyBox

Assembly Guide



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1. Bill of Materials

Everything you need to build a BabyBox. Most electronic components come from a standard sensor kit. The total cost is approximately \$51 if you already own a Bluetooth speaker.

Component	Qty	Source	Est. Cost
Raspberry Pi Zero 2 W	1	Purchase	~\$15
MicroSD card (32 GB+)	1	Purchase	~\$8
MFRC522 RFID Module	1	Sensor kit	--
RFID coin stickers (25mm, 13.56 MHz)	10	Purchase	~\$5
Neodymium magnets (6x3mm disc)	20+	Purchase	~\$5
Bluetooth speaker	1	Already owned	~\$0-20
WS2812 RGB 8-LED strip	1	Sensor kit	--
Passive buzzer	1	Sensor kit	--
Tactile buttons (6x6mm)	2	Sensor kit	--
Resistors / wires / breadboard	1	Sensor kit	--
5 V 3 A micro-USB power supply	1	Purchase	~\$8
Mini-HDMI to HDMI cable	1	Purchase	~\$5
3D-printed enclosure + figurines	1	Bambu Lab P2S	~\$5 filament

NOTE: Magnets must be 6 x 3 mm neodymium discs. Larger magnets will not fit the printed pockets. Buy extras -- you need at least 4 per figurine (2 for the figurine base + 2 for the lid) plus spares for polarity mistakes.

2. GPIO Wiring Reference

All connections use the Raspberry Pi Zero 2 W 40-pin header. SPI must be enabled in raspi-config for the MFRC522. Buttons use internal pull-ups (active low).

Signal	Pin	Notes
MFRC522 SDA	GPIO 8	SPI0 CE0
MFRC522 SCK	GPIO 11	SPI0 SCLK
MFRC522 MOSI	GPIO 10	SPI0 MOSI
MFRC522 MISO	GPIO 9	SPI0 MISO
MFRC522 RST	GPIO 25	General GPIO
MFRC522 3.3 V	3.3 V	Pin 1 or 17
MFRC522 GND	GND	Pin 6, 9, 14, 20, 25, 30, 34, 39
WS2812 DIN	GPIO 18	PWM0
WS2812 5 V	5 V	Pin 2 or 4
WS2812 GND	GND	Any GND pin
Play/Pause btn	GPIO 17	Internal pull-up
Stop button	GPIO 27	Internal pull-up
Buzzer signal	GPIO 12	PWM1
Buzzer GND	GND	Any GND pin

Pin Diagram (color-coded by function)



3. 3D Printing

The BabyBox has three printed parts: the enclosure body, the lid, and figurine bases. All parts are designed in OpenSCAD and printed on a Bambu Lab P2S (or any FDM printer with a 256 x 256 mm bed).

Recommended Print Settings

Parameter	Value
material	PETG
nozzle	0.4 mm
layer_height	0.2 mm
infill	20 %
perimeters	3
top_layers	5
bottom_layers	4
supports	None (designed support-free)

Part A: Enclosure Body

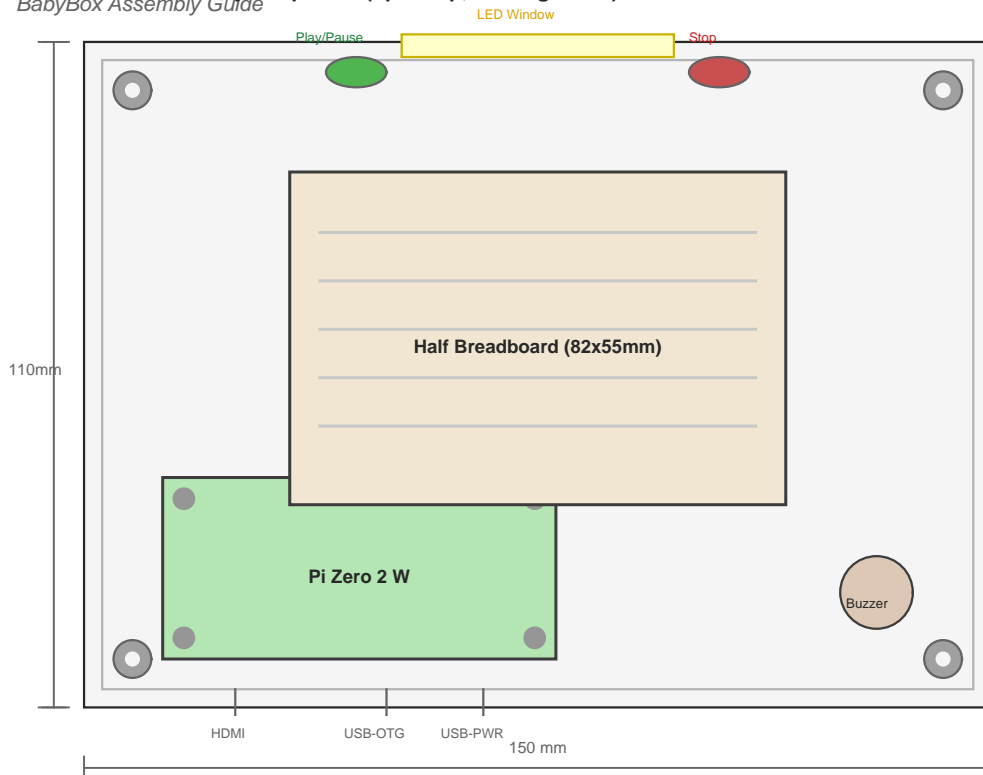
Dimensions: 150 x 110 x 63 mm (body height without lid).

Wall thickness: 3 mm. Corner radius: 5 mm.

Floor thickness: 3 mm.

- Print UPRIGHT (open top facing up). No supports needed.
- The breadboard bay is a recess in the floor -- prints as part of the body.
- Four M3 screw posts at the corners accept screws from the lid.
- Button holes (12 mm dia) and LED window (55 mm wide) are on the front wall.
- Port cutouts (mini-HDMI, 2x micro-USB, microSD) are on the back/side walls.

Enclosure Body - Top View (open top, looking down)



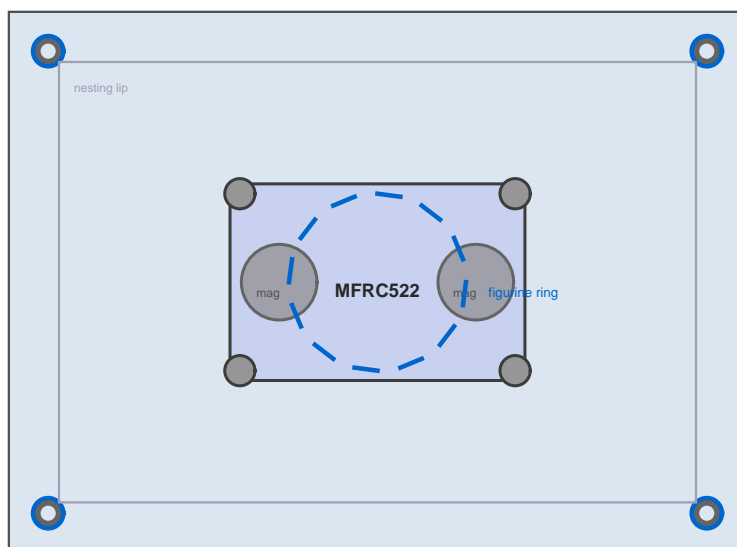
Part B: Enclosure Lid

Dimensions: 150 x 110 x 12 mm.

The lid has a 3 mm nesting lip that fits inside the body opening.

- Print UPSIDE-DOWN (top surface on the build plate for a smooth finish).
- RFID module (MFRC522) mounts on standoffs hanging from the ceiling.
- Two magnet bosses enclose the neodymium magnets (see Section 4).
- A 36 mm engraved ring on the top surface marks the figurine placement zone.
- Four M3 clearance holes at the corners align with the body screw posts.

Lid - Bottom View (looking up into the lid)



Part C: Figurine Base

Diameter: 35 mm. Height: 6 mm.

Chamfer: 0.8 mm on the bottom edge.

All figurines share the same base for consistent magnet alignment.

- Print RIGHT-SIDE UP (flat bottom on build plate).
- Two magnet pockets (6.3 mm dia, 3.2 mm deep) spaced 20 mm apart.
- Shallow RFID recess (25.5 mm dia, 0.5 mm deep) on the bottom face.
- Magnets inserted via pause-and-insert at Z = 4.2 mm (see Section 4).

4. Hidden Magnet Insertion

WARNING: Neodymium magnets are extremely dangerous if swallowed by a child. The pause-and-insert technique fully encloses each magnet inside solid plastic with no access points. NEVER leave magnets accessible. Always verify the seal layers printed correctly after resuming.

Both the lid and figurine bases use the same technique: the print is paused at a specific Z height, magnets are dropped into the open cavities, and printing resumes to seal them with solid layers above.

Pause Heights

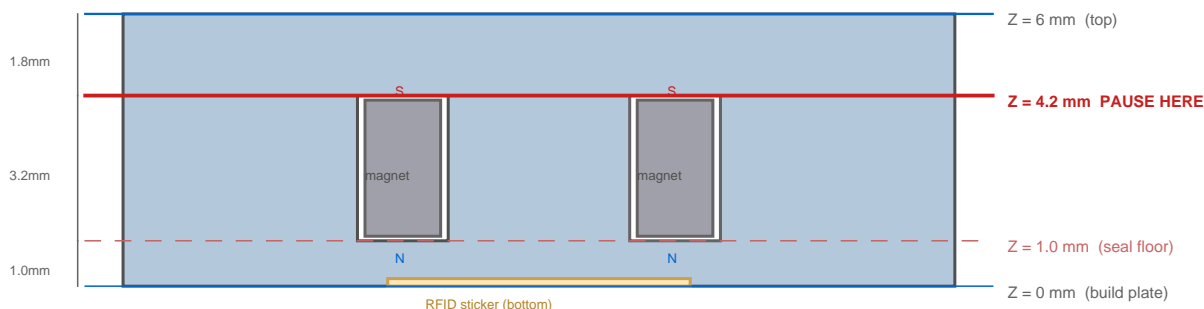
Part	Pause Z	Seal below	Cavity	Seal above
Figurine base (right-side up)	4.2 mm	1.0 mm	3.2 mm	1.799999999999998 mm
Lid (upside-down)	4.2 mm	1.0 mm	3.2 mm	~2.0 mm (top wall)

Step-by-Step Procedure

1. Slice the part in Bambu Studio and add a pause (M600) at the target Z height. For both figurine bases and the lid, pause at Z = 4.2 mm.
2. Start the print. When the printer pauses, the cavities will be open cylinders with a solid floor of 1.0 mm below.
3. Check magnet polarity BEFORE inserting! Use a reference magnet taped to the build plate with the correct pole facing up. Each new magnet must ATTRACT the reference (i.e., opposite poles face each other).
4. Drop one magnet into each cavity. It should sit flush or slightly below the rim. If it sticks up, the pocket depth is wrong -- do not continue.
5. Resume the print. The printer will lay solid layers over the magnets, permanently sealing them inside.
6. After the print completes, verify the top surface is smooth and fully sealed. Try to feel or pry out the magnets -- you should not be able to.

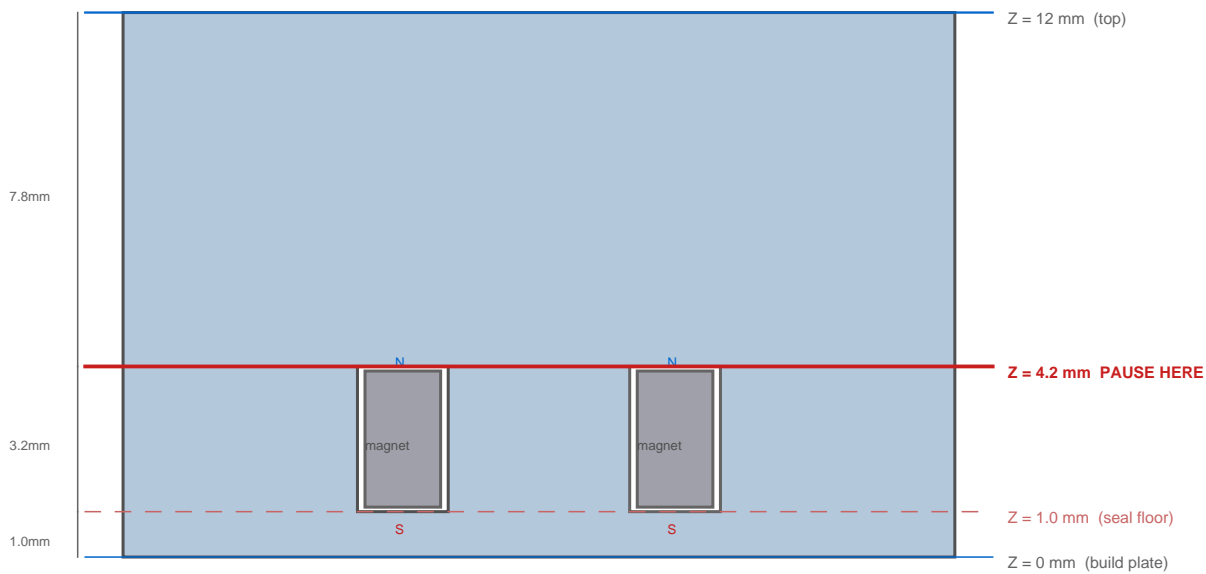
Figurine Base Cross-Section

Figurine Base Cross-Section



Lid Cross-Section (printed upside-down)

Lid Cross-Section (printed upside-down)



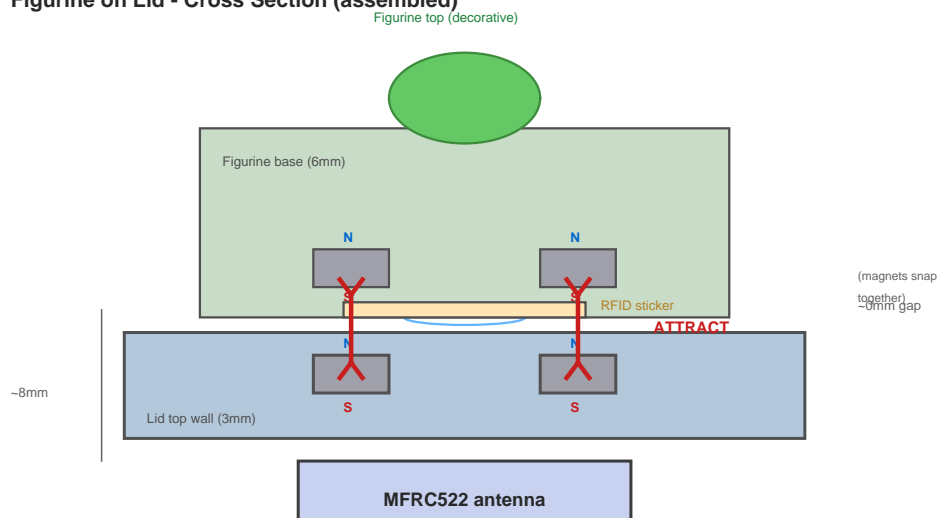
Polarity Reference

All magnets in the BabyBox must have matching polarity so figurine magnets ATTRACT the lid magnets. Use this system:

1. Mark one magnet with a dot of paint on its NORTH face. This is your reference.
2. When inserting magnets into the LID (printed upside-down), place them with the NORTH (dotted) face UP (toward you, away from the build plate).
3. When inserting magnets into FIGURINE BASES, place them with the SOUTH (un-dotted) face UP.
4. Test: after both parts are printed, place the figurine on the lid. The magnets should snap together firmly.

Assembled View: Figurine on Lid

Figurine on Lid - Cross Section (assembled)



5. Electronics Mounting

Raspberry Pi Zero 2 W

The Pi mounts on four M2.5 standoffs (5 mm tall) near the back-left corner of the enclosure body. Use M2.5 x 6 mm screws from above.

- Ports face the back wall: mini-HDMI, 2x micro-USB (OTG + power).
- The microSD slot faces the left side wall.
- Ensure the Pi sits level and does not contact the floor (standoffs provide clearance).
- Flash Raspberry Pi OS Lite to the SD card before mounting.

MFRC522 RFID Module

The MFRC522 mounts on four M2 standoffs hanging from the lid ceiling, centered on the lid. The antenna faces upward toward the figurine placement zone.

- Module dimensions: 60 x 40 x 4 mm (8 mm with header pins).
- Mounting holes: M2, spaced 56 x 36 mm.
- Use M2 x 8 mm screws from below (through the standoffs into the module).
- The module must sit as close to the lid's inner ceiling as possible for best read range.
- Total distance to figurine RFID tag: ~3 mm wall + ~5 mm figurine base = ~8 mm (well within the 30 mm read range).

Half Breadboard

A half-size breadboard (82 x 55 mm) sits in a recessed bay in the enclosure floor. This provides a prototyping area for wiring the MFRC522, buttons, buzzer, and LED strip without soldering.

- The bay is 83 x 56 mm (with 0.5 mm tolerance per side).
- The breadboard sits flush with the floor surface.
- Peel off the adhesive backing and press into the bay, or leave it friction-fit.

Buttons

Two 6x6 mm tactile buttons mount through 12 mm holes in the front wall. Use button caps (12 mm round) for a toddler-friendly surface.

- Left button (Play/Pause): GPIO 17, with internal pull-up.
- Right button (Stop): GPIO 27, with internal pull-up.
- Buttons are spaced 60 mm apart, centered on the front wall.
- Wire one leg to the GPIO pin and the opposite leg to GND.

WS2812 LED Strip

An 8-LED WS2812 strip (51 x 10 mm) mounts behind the LED window on the front wall. The LEDs shine outward through the window slot.

- Window dimensions: 55 mm wide x 12 mm tall.
- A 5 mm deep channel behind the window holds the strip.

- Adhere the strip with its self-adhesive backing, LEDs facing outward.
- DIN connects to GPIO 18 (PWM0). 5V and GND to the Pi header.

Passive Buzzer

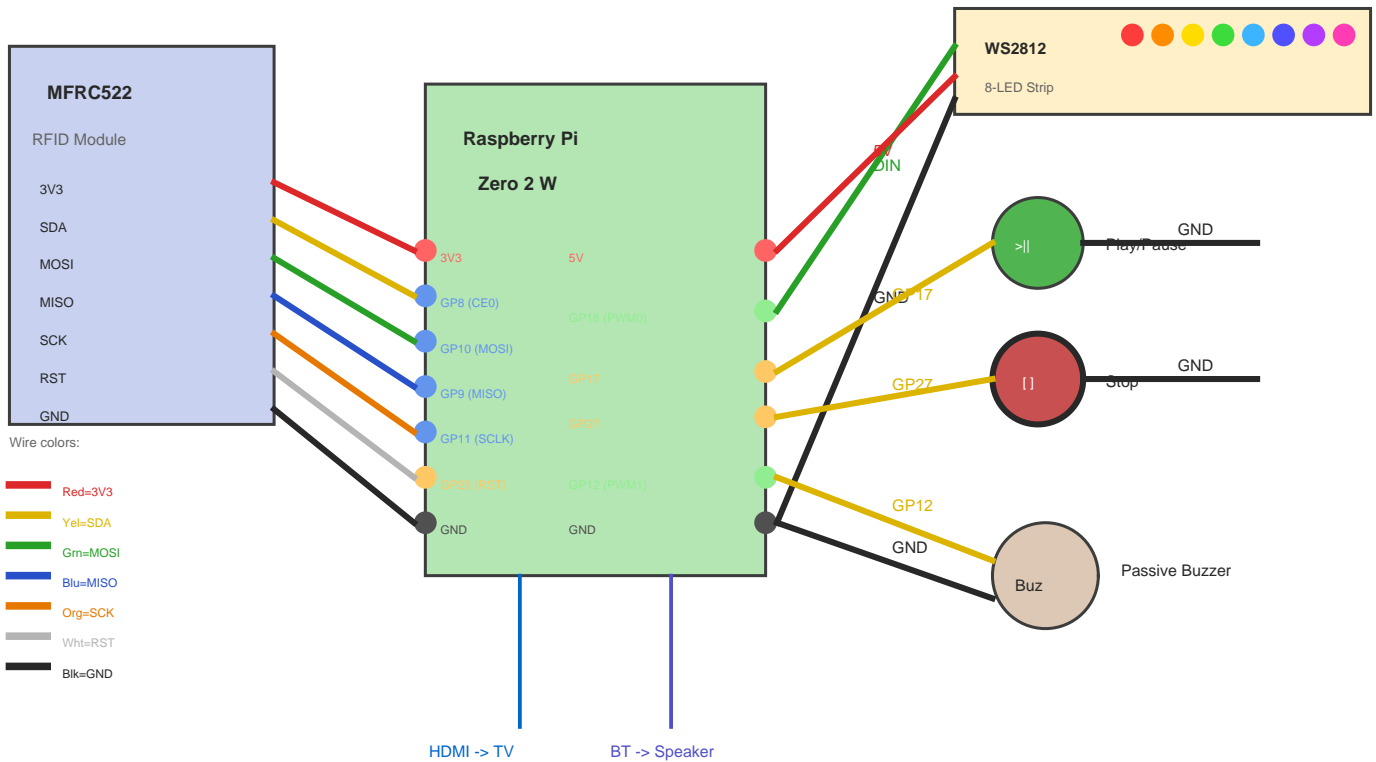
A 12 mm passive buzzer sits in a ring cradle in the back-right corner of the floor.

- Cradle outer diameter: 15 mm, inner: 12.4 mm.
- Signal pin connects to GPIO 12 (PWM1). GND to any ground pin.
- Passive buzzers require a PWM signal to produce tones (unlike active buzzers).

6. Wiring Guide

All wiring goes through the half breadboard. Use jumper wires (male-to-female for the Pi header, male-to-male for the breadboard).

Wiring Overview



MFRC522 RFID Module (7 wires)

MFRC522 Pin	Wire Color (suggested)	Pi Header Pin
SDA	Yellow	GPIO 8 (Pin 24, CE0)
SCK	Orange	GPIO 11 (Pin 23, SCLK)
MOSI	Green	GPIO 10 (Pin 19, MOSI)
MISO	Blue	GPIO 9 (Pin 21, MISO)
RST	White	GPIO 25 (Pin 22)
3.3V	Red	3.3 V (Pin 1 or 17)
GND	Black	GND (Pin 6)

WARNING: The MFRC522 operates at 3.3 V. NEVER connect it to 5 V -- this will permanently damage the module.

WS2812 LED Strip (3 wires)

LED Pin	Wire Color	Pi Header Pin
DIN	Green	GPIO 18 (Pin 12, PWM0)
5V	Red	5 V (Pin 2 or 4)
GND	Black	GND (Pin 9)

Buttons (4 wires total)

Button	Leg A	Leg B
Play/Pause	GPIO 17 (Pin 11)	GND (Pin 14)
Stop	GPIO 27 (Pin 13)	GND (Pin 14 or 20)

No external pull-up resistors needed -- the software enables internal pull-ups.

Passive Buzzer (2 wires)

Buzzer Pin	Wire Color	Pi Header Pin
Signal (+)	Yellow	GPIO 12 (Pin 32, PWM1)
GND (-)	Black	GND (Pin 34)

NOTE: Route wires neatly and keep them away from the RFID antenna area in the lid. Loose wires near the MFRC522 can cause interference and reduce read range.

7. Figurine Construction

Base Printing

All figurines share a standard base: 35 mm diameter, 6 mm tall. The base has two magnet pockets (6.3 mm dia, 3.2 mm deep) spaced 20 mm apart, and a shallow RFID recess (25.5 mm dia) on the bottom.

1. Open hardware/figurines/base-template.scad in OpenSCAD.
2. Set render_part = "base" and press F6 to render.
3. Export as STL. Import into Bambu Studio.
4. Use PETG, 0.2 mm layer height, 20% infill.
5. Add a pause at Z = 4.2 mm for magnet insertion.
6. Print right-side up (flat bottom on bed).

Magnet Insertion

Follow the procedure in Section 4 (Hidden Magnet Insertion). Insert magnets at the pause, with the correct polarity (SOUTH face up for bases).

RFID Sticker Application

1. Take a 25 mm MIFARE 13.56 MHz coin sticker.
2. Peel off the backing to expose the adhesive.
3. Center the sticker on the BOTTOM face of the figurine base, inside the shallow recess (25.5 mm dia).
4. Press firmly. The sticker should sit flush in the recess.
5. Test: hold the base near the MFRC522 module. The tag UID should be read successfully at up to ~25 mm distance.

Figurine Top (Decorative Shell)

The top part of each figurine is the decorative character or object that the child interacts with. There are two approaches:

Option A: AI-Generated (Meshy AI + Blender)

1. Go to meshy.ai and generate a 3D model from a text prompt (e.g., "cute cartoon dinosaur, low poly, smooth").
2. Download the model as OBJ or GLB.
3. Open Blender. Import the Meshy model and the figurine base STL.
4. Position the decorative top on top of the base. Boolean-union them together.
5. Verify the magnet pockets and RFID recess are not obstructed.
6. Export as STL. Slice in Bambu Studio and print.

Option B: Simple Geometric Shape (OpenSCAD)

For simpler figurines, you can add a geometric top directly in OpenSCAD (cylinder, sphere, cone, etc.) on top of the base template.

Figurine Design Guidelines

- Total height: 40-60 mm (base + top). Easy for toddler hands.
- Base diameter: 35 mm (standardized for magnet alignment).
- No small detachable parts. Everything is one solid piece after assembly.
- Bright colors. Multi-color prints possible with Bambu AMS.
- Minimal overhangs to avoid supports.
- Test each figurine on the box before giving to the child.

8. Final Assembly Sequence

Follow these steps in order to assemble a complete BabyBox from printed parts and electronics.

1. Print the enclosure BODY (Part A). Inspect for clean button holes, LED window, port cutouts, and screw posts.
2. Print the enclosure LID (Part B) upside-down. Pause at Z = 4.2 mm and insert 2x magnets (NORTH face up). Resume and let it complete.
3. Print at least 2 figurine BASES (Part C). Pause at Z = 4.2 mm and insert 2x magnets per base (SOUTH face up). Resume and complete.
4. Test magnet polarity: place a figurine base on the lid. The magnets should snap together firmly and align the base over the engraved ring.
5. Mount the Raspberry Pi Zero 2 W on its standoffs in the body using 4x M2.5 screws. Ports face the back wall.
6. Mount the MFRC522 RFID module on its standoffs under the lid ceiling using 4x M2 screws. Antenna faces upward.
7. Place the half breadboard in the floor recess. Press down to seat it.
8. Wire the MFRC522 to the Pi header (7 wires: SDA, SCK, MOSI, MISO, RST, 3.3V, GND). Route wires through the breadboard.
9. Wire the WS2812 LED strip (DIN to GPIO 18, 5V, GND). Adhere the strip behind the LED window with LEDs facing outward.
10. Wire the two buttons (Play/Pause to GPIO 17 + GND, Stop to GPIO 27 + GND). Mount buttons through the front wall holes with caps.
11. Wire the passive buzzer (signal to GPIO 12, GND). Seat it in the back-right cradle.
12. Flash Raspberry Pi OS Lite to the microSD card. Insert it into the Pi.
13. Connect a 5V 3A micro-USB power supply to the Pi's power port (the one further from the HDMI port). Verify the Pi boots.
14. Place the lid on the body. Align the nesting lip and screw posts. Secure with 4x M3 screws at the corners.
15. Attach RFID stickers to figurine bases (centered in the bottom recess). Glue or attach decorative tops to the bases.
16. Test: place a figurine on the lid. The RFID tag should be read, the LEDs should animate, and media should play. Connect a Bluetooth speaker and verify audio routing.

9. Safety Notes

WARNING: This device is intended for toddlers (ages 1-4). Safety is paramount. Review all points below before allowing a child to use the BabyBox.

Magnet Safety

- ALL magnets MUST be fully enclosed inside 3D-printed plastic using the pause-and-insert technique. No magnets should be accessible.
- After printing, verify the seal: the top surface should be smooth and continuous with no visible cavities or holes.
- If a print fails mid-seal (power outage, filament runout), DISCARD the part. Do not use it with exposed magnets.
- Neodymium magnets are extremely dangerous if swallowed. Two magnets swallowed separately can attract through intestinal walls, causing perforation, obstruction, or death.
- Keep loose magnets locked away during assembly.

Electrical Safety

- Use only a regulated 5V power supply. Never exceed 5V.
- The MFRC522 operates at 3.3V. Never connect it to 5V.
- Keep all wiring inside the enclosed box. No exposed connections.
- The enclosure should be fully closed (lid screwed on) during use.
- Do not use the device near water or liquids.
- Unplug the power supply when not in use or when opening the enclosure.

Volume and Hearing

- All audio goes to an external Bluetooth speaker.
- Set the speaker volume to a safe level BEFORE giving it to the child.
- The American Academy of Pediatrics recommends keeping volume below 75 dB for extended listening.
- Place the speaker at least 1 meter from the child when possible.

Screen Time

- The BabyBox has a built-in daily video limit system.
- Set appropriate limits in the web UI (Settings page).
- Audio content is unlimited; only video counts against the daily limit.
- The box provides LED + buzzer feedback when the video limit is reached.
- Supervise screen time for children under 2 (AAP recommendation).

Physical Safety

- All enclosure corners are rounded (5 mm radius).
- Walls are 3 mm thick PETG -- sturdy enough for toddler handling.
- Figurines should be inspected regularly for cracks. If a crack exposes a magnet, remove the figurine immediately.

- The device is not a toy -- supervise initial use sessions.
- Keep small parts (screws, wire scraps) away from children during assembly.