BUGG v2 Handover Report

August 5, 2021

Contents

1 Context

Building upon previous work, the main goal of the design presented herein is to produce a device that can constantly stream audio over the Internet to a remote server, is easily produced en masse, in quantities of 1000 or more, is easy to install and use by lay people, and is durable enough to withstand long periods deployed outdoors in rainforest conditions.

Monad Gottfried Ltd. divided the work into three work packages; delivering prototype and production Printed Circuit Board Assemblies (PCBA's), and an injection moulded enclosure design. The final output was a batch of 70 assembled units.

2 Scope

This document provides information necessary to replicate the build given the data in the following Design Pack.

3 Specification

See Appendix A for detail of the product specification as issued and as delivered. Various details changed as the project evolved, including input from the client team.

4 Design Pack

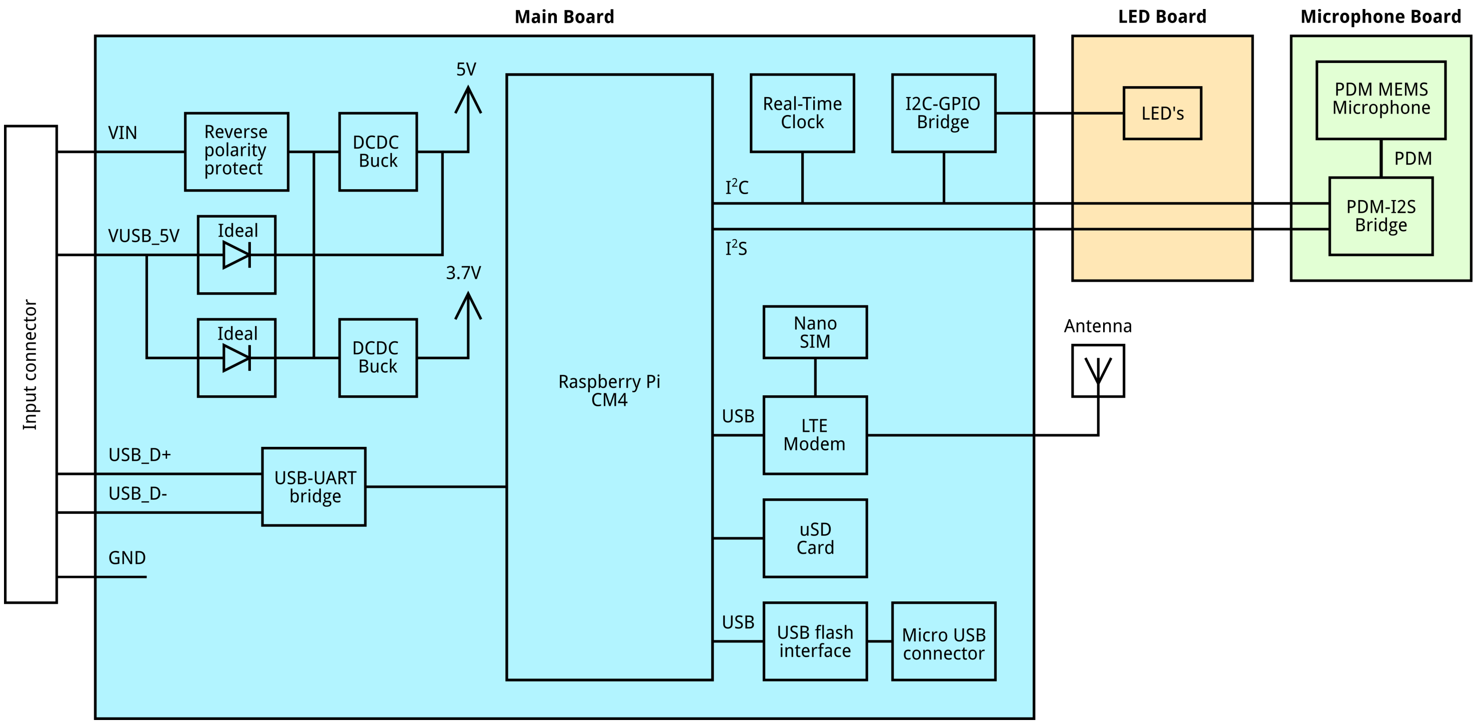
The completed design materials are issued with this companion document as a set of Git repositories.

Repository name	**Description**	**Tool**
sp-hardware-main	Main board design and manufacturing data	KiCad
sp-hardware-led	LED board design and manufacturing data	KiCad
sp-hardware-mic	Microphone board design and manufacturing data	KiCad
sp-hardware-panel	Three boards comined into one sub-panel.	KiCad
	BoM data for whole project, mechanical and electronic.	LibreOffice/ Excel
bugg-enclosure	Mechanical design of the enclosure, including PCBA models, fasteners, connectors, etc.	FreeCAD
bugg-mech-tooling	Tools to aid assembly of the enclosure	STEP/STL interchange
rpi-eco-monitoring-v3	Firmware running on the Raspberry Pi Compute Module	Any Python code editor
bugg-handover	This document.	LyX

Note: the project was renamed from "SafeProject" to "BUGG" mid way through, so files have both "bugg-" and "sp-" prefixes.

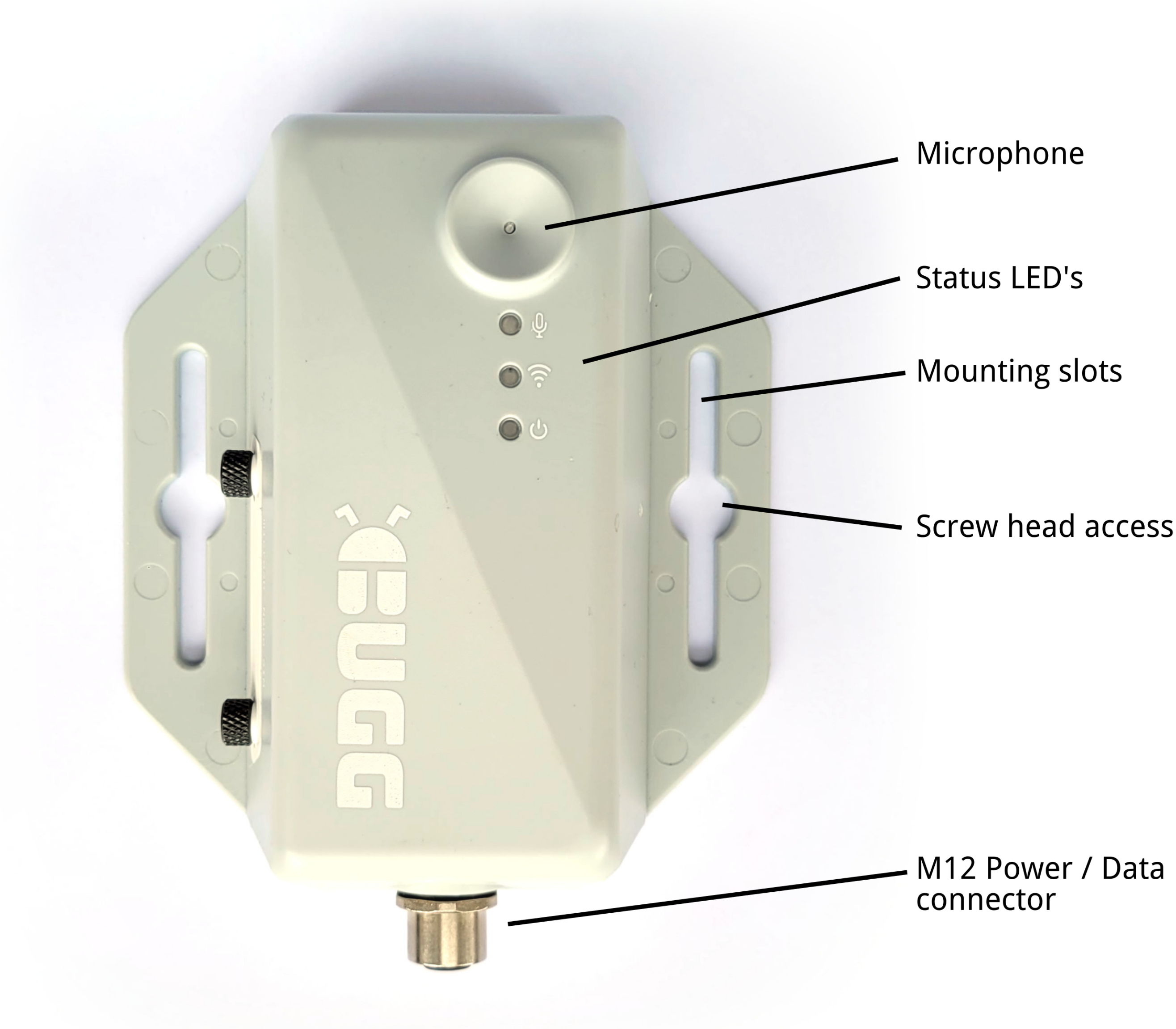
5 Device Overview

5.1 System diagram

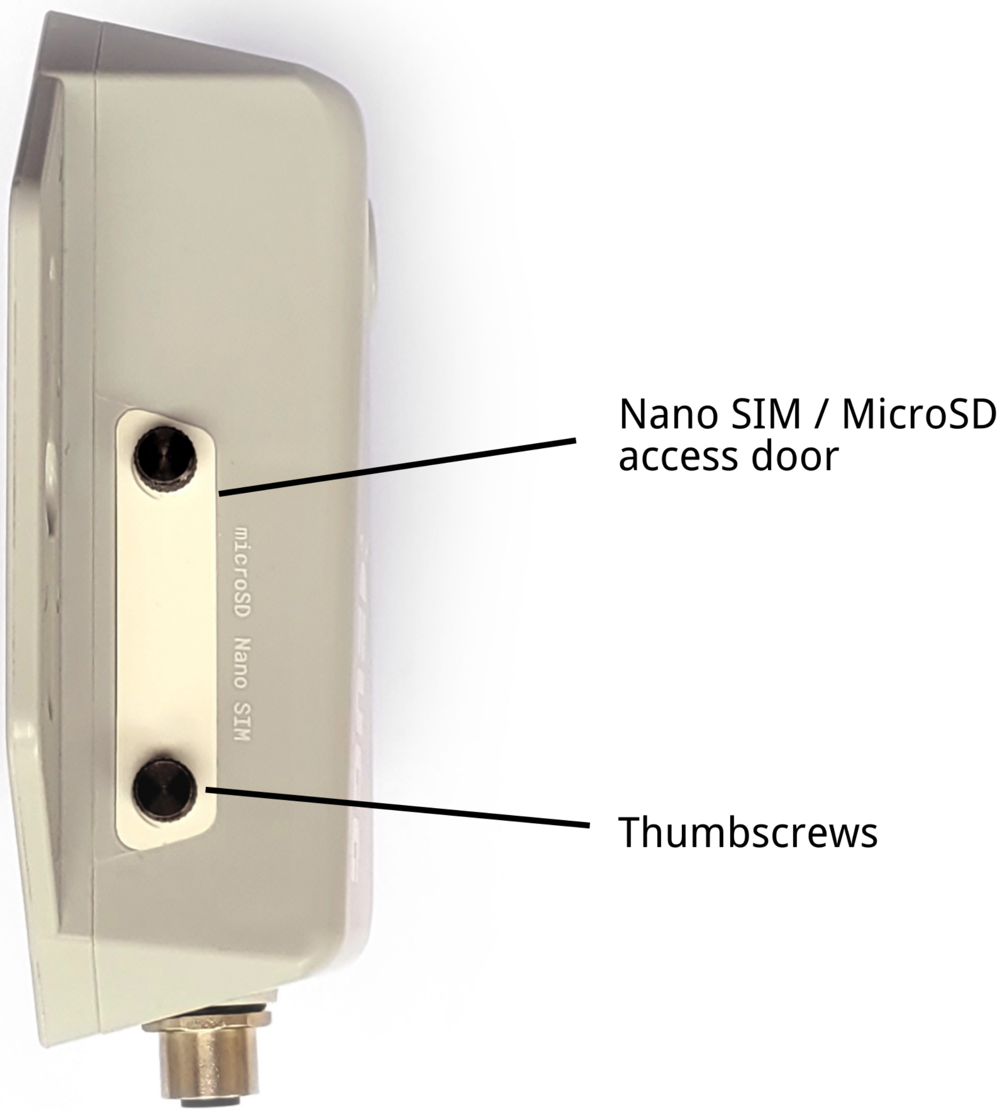


This system diagram indicates how the various parts are distributed over the three boards (indicated in colour) and how the boards are connected.

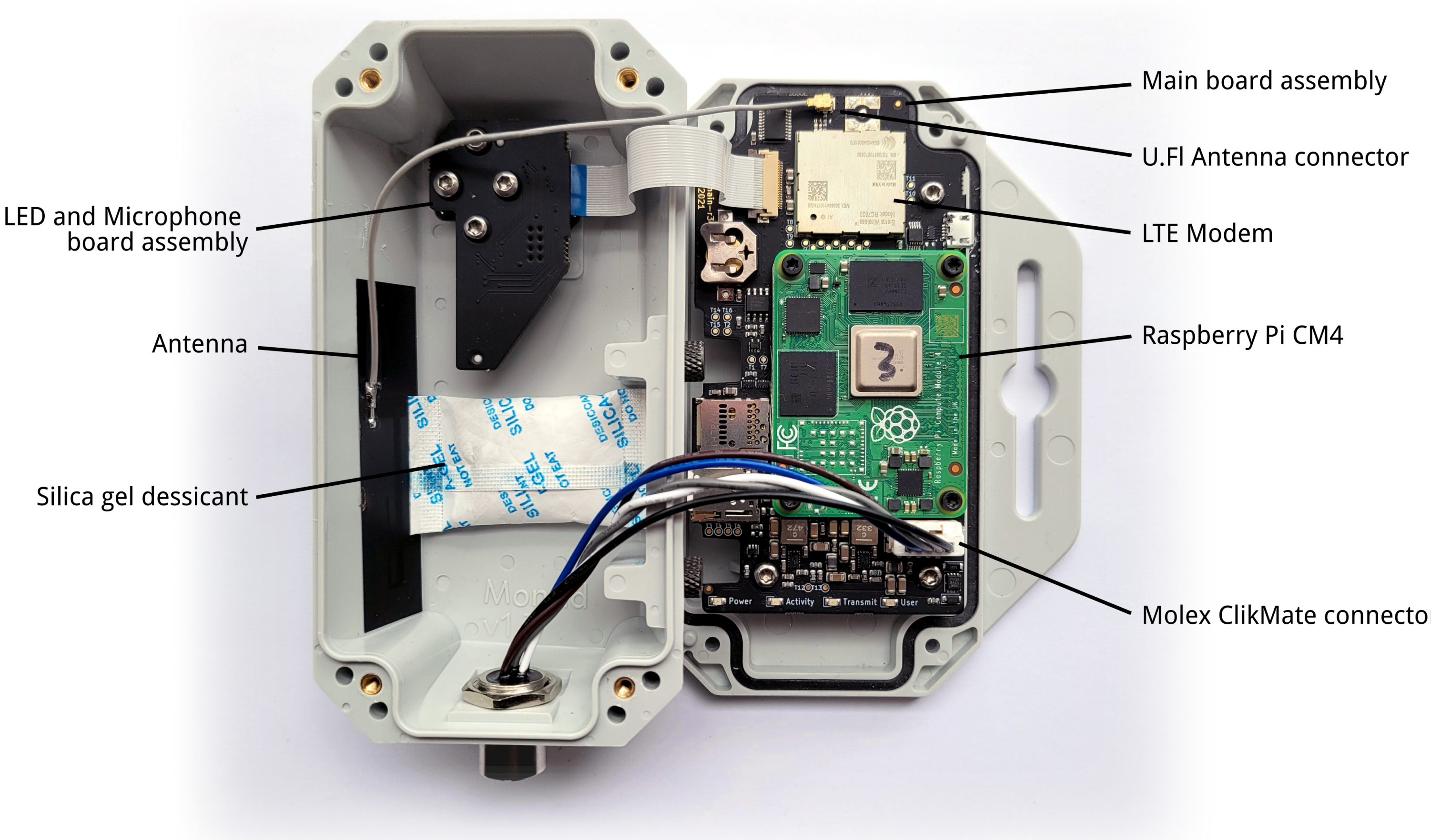
5.2 Front view



5.3 Side view



5.4 Inside view



6 PCBA's Design and Manufacture

6.1 ECAD Software

The three boards were designed in Kicad, an open source tool. I used the nightly build, 5.99. It is recommended to use the nightly version if you wish to edit the files. The latest stable release is sufficient for viewing the files. The complete schematics for the three PCBA's are also available in PDF format in the hardware repositories.

6.2 PCBA Manufacture - Fabrication and Assembly

The BUGG product contains three custom PCBA's, called the *Main Board, LED Board* and the *Microphone Board.* To minimise assembly cost, these three boards are grouped into one sub-panel, linked together with breakaway mouse-bites. This grouping allows all of the boards to be assembled in one go with a single paste stencil and Pick-and Place program. Further cost savings were achieved by designing all boards as single-sided loads. Multiple sub-panels can be combined into a production panel to optimise bare board cost and assembly through-put. For this production run, our assembly and fabrication providers recommended combining four sub-panels into one production panel. Ordering 20 production panels therefore provided us with enough sub-panels for 80 finished BUGG units. One assembled production panel can be seen in Figure 1.

In larger production runs it would likely make economic sense to make larger production panels with more sub-panels. At some scale, it would become cheaper to replace the sub-panel approach with run separate panel designs for each PCBA, to make more efficient use of panel area.

6.3 Manual Assembly Steps

After the panels have been assembled, some manual work must be done on the boards to prepare them for installation in the enclosure.

6.3.1 Preparation

The use of anti-static assembly gloves or finger cots is recommended to prevent skin oils coating the boards, and reduce risk of anti-static damage. A full anti-static environment is not required, but is an advantage if available.

6.3.2 Vacuum pick-up pads

There are a number of orange Kapton film stickers and solid black plastic vacuum pick-up pads covering various components on the board. These are required for the pick-and-place machine to lift parts with uneven surfaces. Remove and discard them before proceeding.

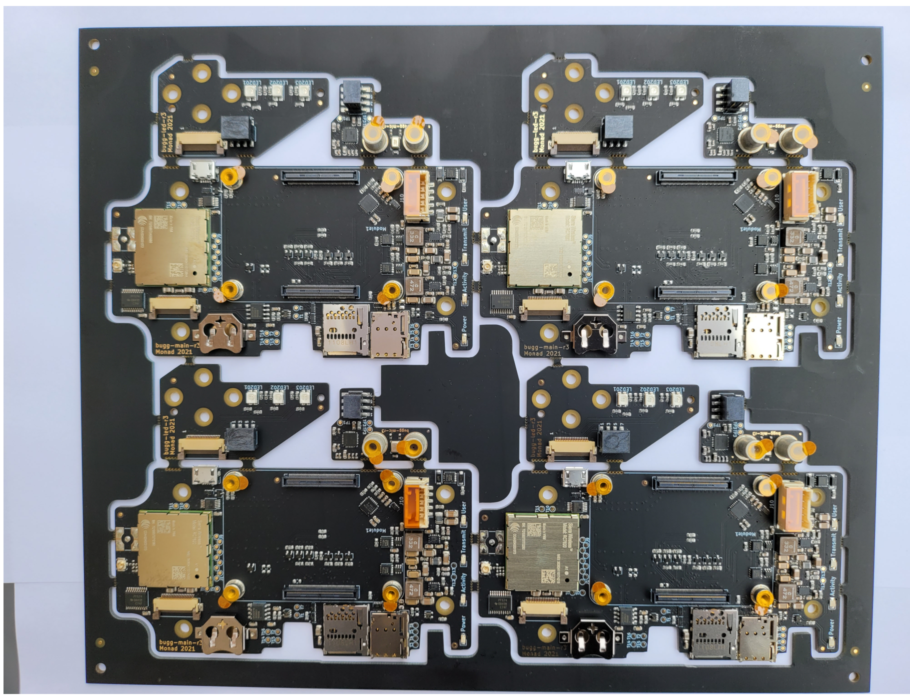


Figure 1: Production panel including four sub-panels

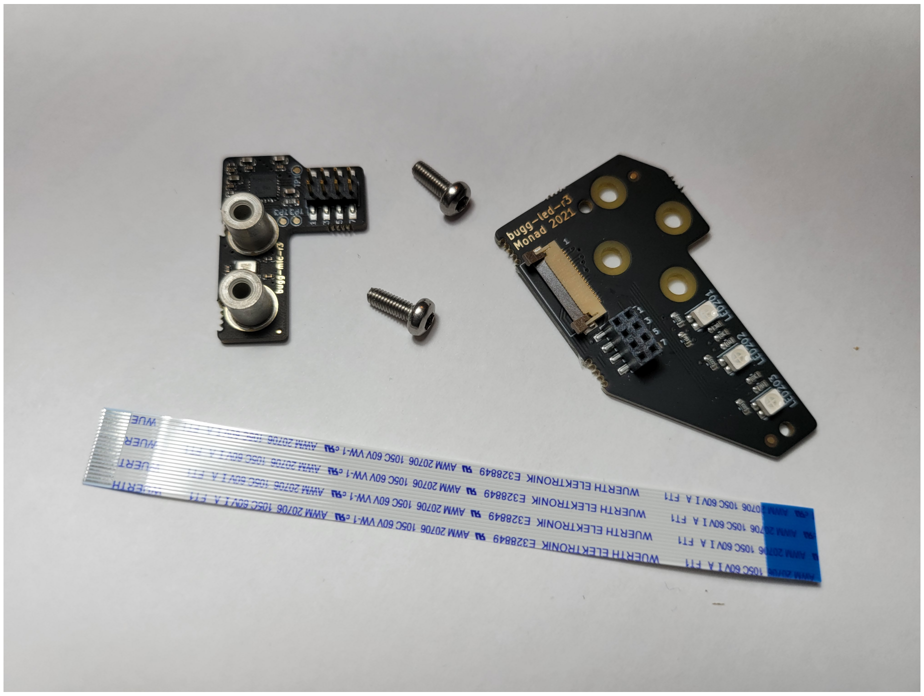


Figure 2: Parts for the LED-Microphone assembly

6.3.3 Depanel

1. Break each PCB out of the panel. This can be done by hand, or with the assistance of a nibbler. Take care not to flex each board more than necessary, but don't be afraid of using some force.

2. Remove all of the small spanning tabs that join the mouse-bites, leaving each board with a continuous, smooth outline. This can be done by gripping them with a pair of pliers and bending them away until they come apart at the line of small holes.

6.3.4 LED - Microphone assembly

Figure 2 shows the parts required for the LED-Microphone board assembly.

1. Ensure the brown locking bar on the LED board FFC connector is raised approximately 45°.

2. Insert the FFC cable into the connector, above the locking bar, with the blue side facing downwards. Ensure the cable is square to the board edge.

3. Ensure that the FFC cable is pushed in fully. Press down the locking bar from both ends to lock it in place.

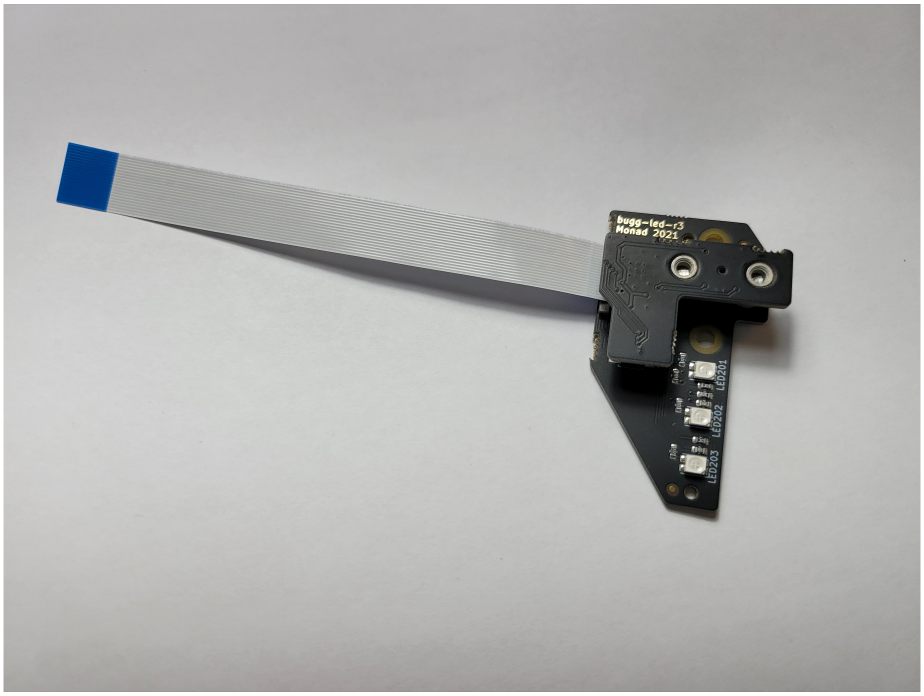


Figure 3: Completed LED-Microphone assembly

4. Mate the LED and microphone boards at the 8-way board-to-board connector. The holes in the LED boards should line up with the spacers on the microphone board.

5. Screw in the two M3 machine screws with a T10 Torx driver.

The completed assembly should be as pictured in Figure 3

6.3.5 Main board assembly

1. Mate the Raspberry Pi CM4 into place on the mezzanine connectors on the main board. Ensure that the connectors are aligned before applying force. Apply force on top of the connectors. Expect to apply a fair amount of force, probably up to a few kg, but if you experience difficulty, stop and check the alignment is correct.

2. Ensure the CM4 is completely seated, in contact with the threaded bosses at each corner.

3. Screw in the four M2.5x4 machine screws with a TX8 Torx driver to retain the CM4. This step may seem unnecessary as the retention force of the mezzanine connectors is high, but it guaratees that every board is perfectly mated.

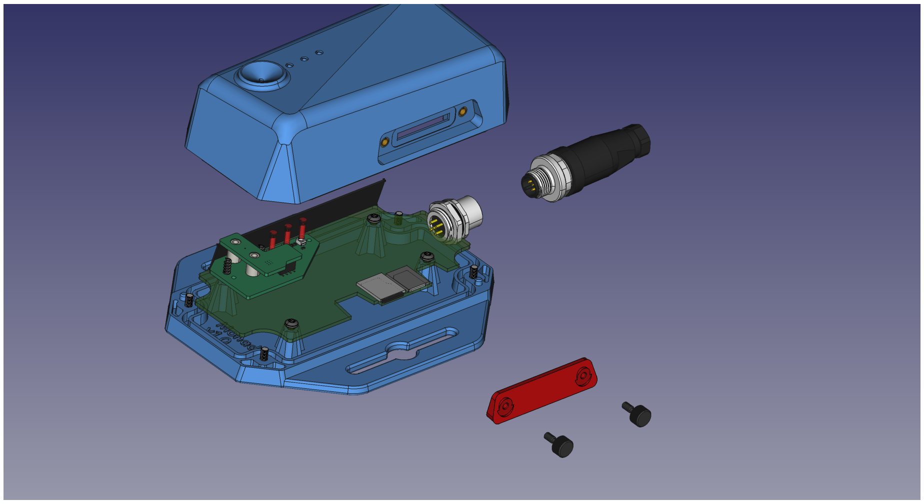


Figure 4: Simplified exploded view of the BUGGv2 unit

4. Insert the CR1220 coin cell. This keeps the RTC running when the unit is not powered.

7 Enclosure Design and Manufacture

7.1 MCAD software

The enclosure was designed in FreeCAD, an open source mechanical modelling tool. I used the nightly build versions up to 2021.615. It is recommended to use the nightly build if you wish to modify the model. The latest stable release is sufficient for viewing the files.

7.2 Enclosure components - Mouldings and features

The enclosure consists of three injection moulded ABS parts - the *Lid, Base* and *Door*. A simplified, exploded view of the unit can be seen in Figure 4. Polylac PA-727 was selected as the resin, coloured RAL 7035 (Light Grey) for the lid and base and RAL 9003 (Signal White) for the door. The injection moulding tools were manufactured in Aluminium, for a good trade-off of tooling cost and cycle life.

7.2.1 Lid

The Lid (Figure 4, blue, top) is a moulding which provides most of the storage volume. There are threaded inserts to provide clamping force to the Base and Door. There are screw bosses for self tapping screws that retain the LED-Microphone Assembly. There is an access panel on one side that allows access

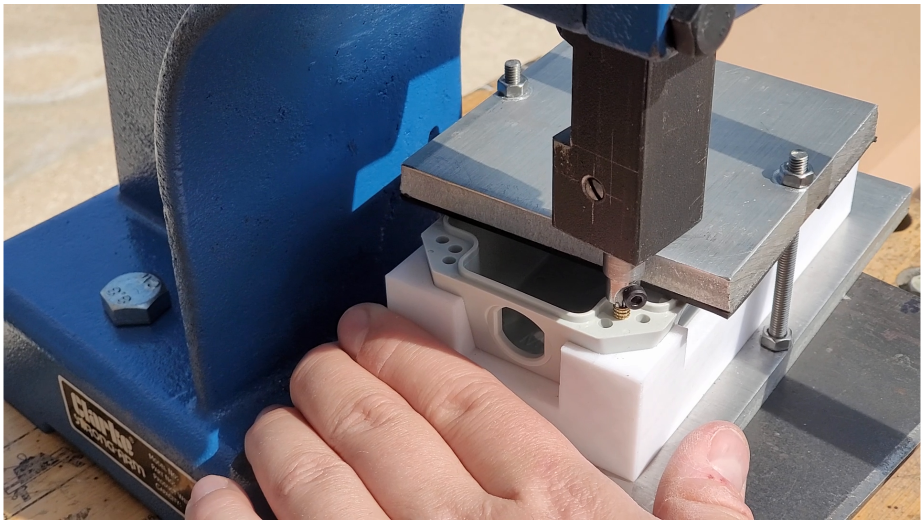


Figure 5: Pressing the threaded inserts into the lower surface of the lid

to the microSD card and Nano SIM slots. There is a hole at one end for the M12 connector. A sealing lip mates onto the foamed polyurethane gasket of the Base.

Branding and notices are applied to the Lid, after injection moulding, via a pad printing process.

7.2.2 Base

The Base (Figure 4, blue, bottom) has screw bosses to retain the Main Board, "wings" with keyhole-shaped mounting features for webbing/screw mounting. There is a Form-in-Place Foam Gasket (FIPFG) applied in a groove, after injection moulding, by a secondary process by a specialist manufacturer.

7.2.3 Door

The Door (Figure 4, red, side) features a FIPFG to seal against the Lid, and two holes and lands for thumbscrews to provide the clamping force.

7.3 Manual Assembly Steps - Lid

After the enclosure parts have been moulded, FIPFG's applied and pad printing completed, a number of manual steps must be completed.

7.3.1 Threaded inserts - lower surface

Four threaded inserts must be inserted into the lower surface of the Lid. See Figure 5.

Figure 6: Pressing the threaded inserts into the door recess

1. Load the insert guide into the arbour press ram, lock in place with the grub screw.
2. Load a threaded insert onto the nose of the guide
3. Load the base into the FDM 3D printed fixture and tighten the nuts on the clamping plate
4. Locate the insert into its hole, and push it home with the press. Make sure to press it far enough that it is recessed below the surface.

7.3.2 Threaded inserts - door recess

Two threaded inserts must be inserted into the door recess of the Lid. See Figure 6.

1. Load the insert guide into the arbour press ram, lock in place with the grub screw.
2. Load a threaded insert onto the nose of the guide
3. Load the base into the FDM 3D printed fixture. Snap it into place.
4. Locate the insert into its hole, and push it home with the press. Make sure to press it far enough that it is recessed below the surface.

Figure 7: Antenna mounted

Signal	Description	Wire colour	ClikMate pin	M12 pin
V+	5-36V power in	Brown	1	1
V_{BUS}	5V USB power in	Blue	2	3
D+	USB 2.0 D+	Grey	3	5
D-	USB 2.0 D-	White	4	2
GND	ground	Black	5	4

Table 1: Power/Data cable wiring

7.3.3 Antenna mounting

Note: bugg-mainboard-r3 USB flashing connector and CM4 board edge can foul on antenna. See Section 9.1.1 for a workaround.

1. Remove backing film from the antenna.
2. Mount the antenna as shown in Figure 7. Beware that the adhesive is extremely strong and bonds instantly on contact. Take care to positon the antennna accurately before allowing the adhesive to make contact. See Section 9.1.1 for an errata notice regarding antenna position.

7.3.4 Light Pipes

Note: Revision 1.3 lids need lead-ins to be cut before light pipes will fit. See Section 9.2.1 for a workaround.

1. Load the acetal light pipe press tool into the arbour press ram, lock in place with grub screw.
2. Insert a light pipe into the hole. With light pressure applied, move the lid left-right-fore-aft until the light pipe is vertical
3. Push the light pipe home. See Figure 8. Feel for a light detent force as the ridged portion of the light pipe seats into the ABS. Be careful not to push the pipe too deep.

Figure 9 shows the light pipes correctly installed.

7.3.5 M12 Power/Data cable assembly

Power and data enter the unit via a 5-way panel mount TE M12 connector. Hermetically potted 22AWG wires lead from the back of the connector to a Molex ClikMate wire-to-board connector which plugs into the Main Board. Figure 10 illustrates a completed assembly.

1. Take the panel mount M12 connector and remove the retaining nut. Retain it for later use.

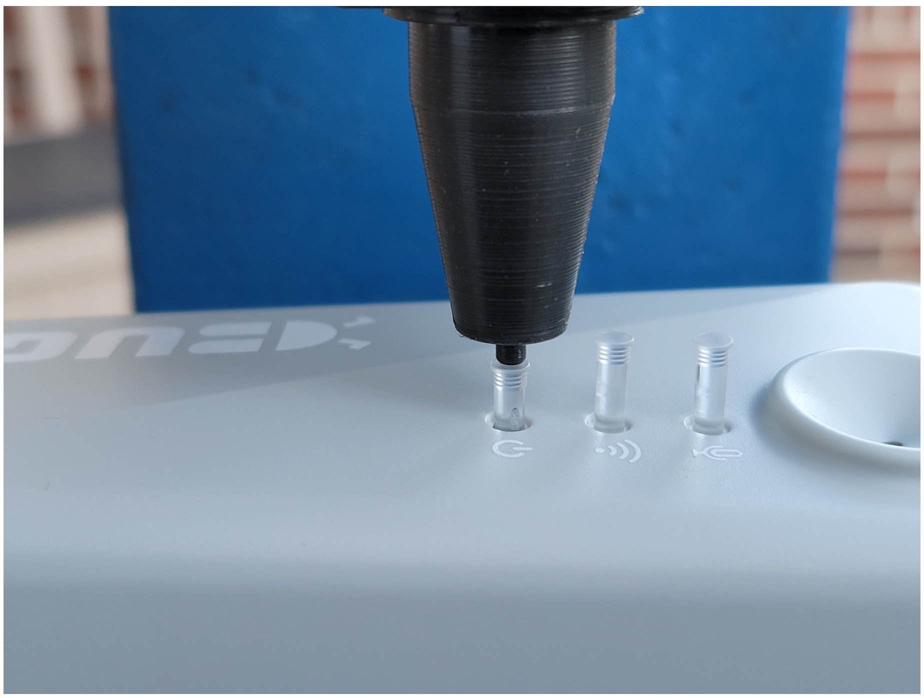


Figure 8: Pressing light pipes into place

Figure 9: Light pipes correctly installed

Figure 10: M12-ClikMate cable assembly

Figure 11: Crimping the terminals in place

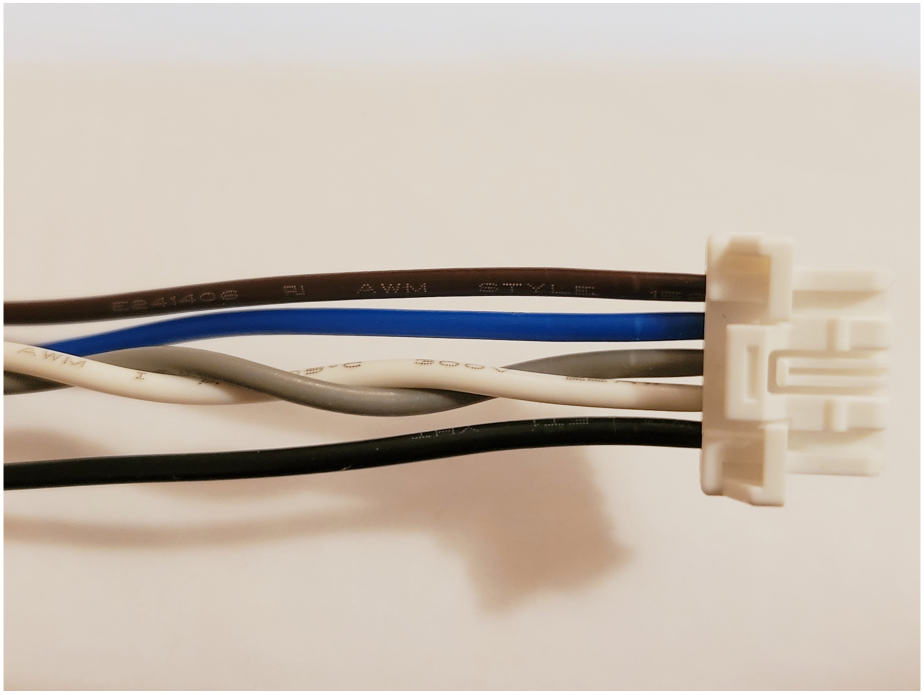


Figure 12: Close view of the ClikMate pinout. Note the locking tab facing the camera lens.

2. Cut the five wires to length. They should measure 120mm from the black potted surface.
3. Strip insulation back approximately 2.5mm. Do not twist the strands together.
4. Use Mouser crimping tool 63819-2800 to crimp terminal 502438-0100 onto each wire using the 22AWG opening. Follow the tool's instructions. See Figure 11. Take extreme care to insert the wire fully into the terminal, and to make sure no strands are free of the terminal.
5. Twist the USB D+/D- wires together with approximately five twists.
6. Insert the crimped D+/D- wires into the ClikMate connector housing 502439-0500. Follow the wiring guide in Table 1.
7. Insert the remaining wires without twisting them.
8. Confirm connections against Figure 12

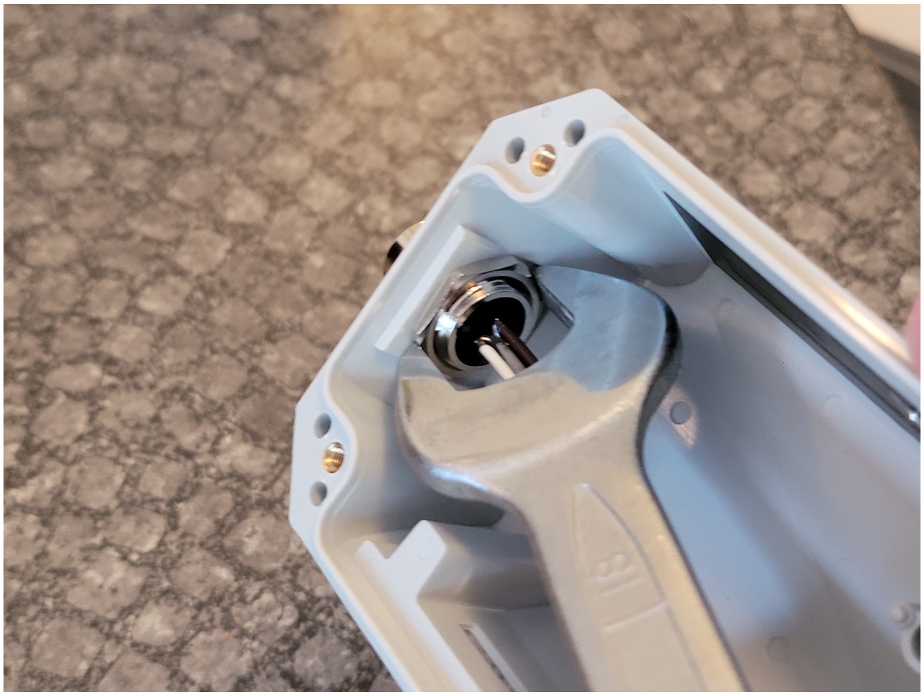


Figure 13: Tightening the M12 connector

7.3.6 M12 Power/Data cable installation

1. Thread the cable through the hole in the Lid.
2. Thread the ClikMate connector through the nut. It is a tight fit - gently bend the wires to one side to clear the nut. Do not apply excessive force - with proper technique the nut slides over the connector quite easily.
3. Tighten the nut against the inside of the Lid using an 18mm spanner, as shown in Figure 13.

7.3.7 Acoustic membrane

1. Carefully peel the membrane off its cover film. Be careful to make the minimum possible contact with the adhesive layer, and never touch the adhesive with bare fingers. These steps will ensure the strongest bond. One method is to use the end of a fine-tipped tweezer to lift the membrane by one edge, being careful to extend it under the edge of the membrane by less than 1mm. See Figure 14.
2. Gently position the membrane into its position in the lid. Use the circular guide mark to centre it over the hole.

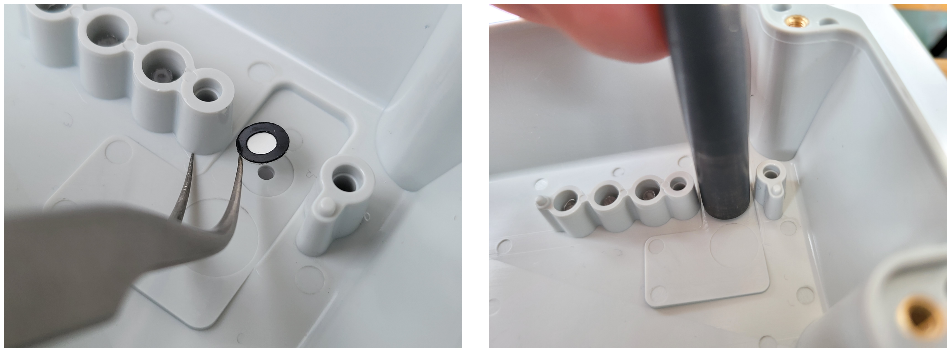


Figure 14: Positioning and seating the acoustic membrane

3. Use a flat-ended tool, e.g. the shank of a drill bit, to push down on the adhesive to make it bond fully.

7.3.8 LED-Microphone subassembly mounting

1. Take the Led-Microhone subassembly from Section 6.3.4
2. Position it on the moulded mounting pins in the Lid.
3. Fix the subassembly in place with two 3x8mm self tapping screws using a T10 Torx driver.

7.4 Manual assembly steps - Base

1. Stick a silica gel sachet to the floor of the Base moulding using a double-sided tape disk.
2. Fix the Main Board in place with four 3x8mm self tapping screws using a T10 Torx driver.
3. Plug in the ClikMate connector. Listen for a click sound when it is fully mated.
4. Plug the FFC into the connector on the main board as per the procedure in Section 6.3.4.
5. Plug in the u.FL antenna connector. Take care to properly locate the connector before applying mating force. You may wish to use a square ended tool, such as the shank of a drill bit, to apply vertical, controllable force.

Note: Now the Lid and Base are connected by three cables, care must be taken to avoid placing stess on the connections by pulling the two assemblies apart. Particular care must be taken with the antenna cable as it is termintaed with a solder joint and no strain relief and, as the shortest connection, reaches full loading first. Given this situation it is best not to leave the housing open for long periods.

7.5 Manual assembly steps - Door

Note - Revision 1.0 lids need to be drilled out for M3 thumbscrews. See Section 9.2.2.

1. Locate thumbscrew in hole.
2. Screw locking washer over the threaded region into the reduced-shank region.

7.6 Closing the enclosure

Due to errata 9.1.1 and 9.1.2 it is a little more fiddly to close the enclosure than anticipated.

1. With the M12 connector facing downwards, locate the Main PCBA tongue at the bottom left, with the microSD and Nano SIM slots. Locate the tongue into the opening in the door aperture in the Lid. Remove the door for a clear view of the position of the PCB edge in the door opening.
2. Seat the left edge of the Lid and Base mouldings together on the left edge, like the spine of a book, so there is no gap and the right side of the housing is still open a little. You may need to apply force to compress the gasket to keep the gap closed on the left side. You should feel the PCB edge locate in the door opening.
3. Check there are no wires in the way of the closing gap.
4. Swing the lid closed, keeping pressure on the left edge, then apply pressure along the closing edge, particularly towards the bottom right corner.
5. Apply even pressure to both sides, and you'll hear a sharp "Snap!" as everything everything seats into place. The enclosure should stay closed when pressure is removed, though it is not a requirement. If you find yourself applying high forces, stop and evaluate the situation.
6. Insert four M3 machine screws and tighten with a T10 Torx driver.

7.7 Opening the enclosure

1. Remove the four screws
2. With the M12 connector facing downwards, slide a plectrum, plastic pry-bar or finger nail into parting line towards the top right corner of the unit. Gently apply pressure until a click is heard and the device opens. You may need to work around the edge if it doesn't open immediately. If you find yourself applying high forces, stop and evaluate the situation.

8 Flashing the OS image

The firmware for the device is in rpi-eco-monitoring-v3. The README file details the contents of the firmware, and instructions for building a full OS image from a stock Raspberry Pi OS Lite image as a starting point. A pre-built OS image “2021-06-21-norway-release-1-0.img” is provided for immediate deployment of the firmware to a Bugg device.

Plugging a cable into the Micro USB conector automatically places the CM4 bootloader into firmware update mode, allowing the OS image to be downloaded to the eMMC storage. It is recommended to use the *rpiboot* tool for this purpose. See `https://www.raspberrypi.org/documentation/hardware/computemodule/cm-emmc-flashing.md` for more information. Note that while the flashing cable is plugged in, the modem will be disconnected from the CM4.

9 Errata

9.1 Electronics

9.1.1 bugg-main-r3: microUSB connector fouls on antenna

- Description: On board revision bugg-main-r3, the microUSB connector protrudes approximately 1.5mm too far from the board edge. It can foul on the antenna, damaging its surface or solder connection.
- Workaround: It is recommended to work around this problem by positioning the antenna lower down the wall of the Lid, until it wraps around onto the ceiling by a couple of mm. This workaround is not anticipated to cause any degradation of RF performance.
- Fix: Move the connector in-board on the next PCBA revision.

9.1.2 bugg-main-r3: CM4 fouls on inner plastic

- Description: On board revision bugg-main-r3, the CM4 protrudes around 1mm too far, grazing the inside of the Lid, making it difficult to close.
- Workaround: None, just follow recommended lid closure procedure.
- Fix: Move the CM4 in-board on the next PCBA revision.

9.2 Mouldings

9.2.1 Lid: light pipe holes need lead-in

- Description: The light pipe holes moulded into the lid are slightly too small for the light pipe to stay in place before pressing.

Figure 15: Drilling lead-in for light pipes

- Workaround: Carefully drill out the first approx 1-2mm with a 2.5mm bit. This can be done carefully with a bit held in the fingers, as shown in Figure 15, or with a drill press with a depth stop.
- Fix: A conical lead in feature will be added in a future mould revision.

9.2.2 Door: captive thumbscrews

- Description: Door v1.0 was designed to hold thumbscrews captive by means of a simple, undersized hole and a thumbscrew with a narrow thread-free shank designed for the purpose. Unfortunately this system does not work well - the door tends to get stuck in its recess and the screws tend to back out through the friction-formed threads cut in the ABS when originally installed.
- Workaround: Drill the holes out to 3mm. using a drill press to create neat, vertical holes. Retain the thumbscrew with a special machined, threaded washer designed for the purpose. Even they are not perfect, as there is still nothing to completely prevent the screw backing out, but they were the best of several alternative methods tested.
- Fix: Not identified at this time, but a future mould revision should provide an opportunity to solve the problem

A Specification

A.1 Electronic features Specified and Delivered

Specified	**Delivered**
Powered by DC 4-20V approx	Two inputs; 5V designed for USB connection, 5-36V flexible input for field deployment. Seamless cross-over.
Raspberry Pi Compute SoM (CM3+) with eMMC for OS	Raspberry Pi CM4 with eMMC
SD slot for external storage (config scripts + experiment data)	as specified
Reliable 3G/LTE connectivity	as specified
20Hz-20kHz microphone input, ported through housing	Extended bandwidth to 20Hz-80kHz to record bats, etc.
USB-connected audio ADC integrated onto PCBA	I2S bus used instead with I2S-PDM bridge IC to digital MEMS mic
Robust brownout detect & recovery	Raspberry Pi's reset circuit is sufficient
On-board 3G/LTE module, SIM slot	selected Sierra Wireless RC7620
Status LED's	as specified
Everything designed for eventual scalable production - 100's to 1000's	as specified - manual assembly steps simplified and minimised
Designed for operation at elevated temperature and humidity - >40°C, 100% humidity	as specified - mating surfaces gasketed, ePTFE micrphone membrane, silica gel sachet
Piezo buzzer for general debug	omitted
External antenna via waterproof SMA connector	Internal antenna - more robust and similar performance

A.2 Enclosure Features Specified and Delivered

Specified	Delivered
To meet IP66 with informal testing	IP66 not tested, due to unsuitable equipment. Failed IP67 (harsher) testing - after 60 min immersion at 1m, approx 1ml of water leaked. Rain (IP2-4) should be no problem.
Tough, high-impact polymer - PC / PC-ABS.	ABS Polylac PA-727; better moulding performance, 3mm nominal wall
Must withstand harsh environments - tropical rainforest etc. for up to 1 year.	Untested - not deployed yet
Waterproof, pressure-equalising microphone port (Goretex or similar).	Selected custom part from Voir. Goretex did not want to work with us
Opaque single colour, low visibility	Selected light grey RAL 7035
Easy installation - mounting to tree with durable straps.	Keyhole slots for webbing straps or screws for versatile installation
Deliver IM tool for full-custom injection moulded parts for scaled production	Aluminium tools stored at ProtoLabs - durable enough for thousands of parts
Visually appealing	Diagonal split-line over top surface defines product identity
SD and SIM access without special tools	SIM/uSD door retained by stainless steel thumb screws
LED's visible from outside - [partially] transparent housing / lightpipes	Press-fit light pipes selected. LED brightness selected for low visual impact in dark environment
Durable panel-mount power connector,	Selected robust, hermetically sealed, M12 panel-mount connector. Carries power and USB data.
Everything designed for scalable production - 100's to 1000's of units.	Post-moulding manual operations: fitting light pipes, M12 connector and fastening PCBA's into place.

B Suppliers

Part	Supplier	URL
PCBA's - bare boards	Screenbond Ltd.	https://www.screenbond.co.uk/
PCBA's - assembly	Holmes Circuit Designs Ltd. (HCD)	https://hcd-electronics.co.uk/
Injection moulding	Protolabs Ltd.	https://www.protolabs.co.uk/
Form-in-place gasketing	Robafoam, Ceracon Ltd.	https://www.robafoam.com/