



Project 1: Improving thermal performance of high-density amplification and audio processing.

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BSEE Electrical / Electronic Engineering

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BENG / Product Design (Honours)

Introduction and reasons for research

One of the greatest challenges faced while creating a product line that is both powerful and compact is heat dissipation. The Amp Master contains 720 watts of amplifier power within a 1.3 litre (1300 cubic cm) metal container, and while those amplifiers are extremely efficient class-D topography, in a confined space with tightly packed circuitry, the heat generated by those amps, along with the preamp circuitry and power supply circuitry is not insignificant.

The market itself is full of me-too amplifiers and processors. Usually, these amps are only 2 channels, and often in a larger package or a lower power rating than may be desired. It was extremely important to us to have something compact and powerful, as this has been a gap in the market for some time, and home-audio users have less and less space for good quality audio componentry. We are bridging the gap between audiophiles and the consumer market, so keeping our desired small-as-possible form factor was paramount.

The Amp Master was generating external heat to a point where touching with a bare finger was causing discomfort beyond what may be reasonably expected by a customer. Regardless of warnings in documentation, and in spite of being within what could be considered a medically safe temperature range this could still pose a significant issue for children who don't know any better, particularly as the product is designed to be compact enough to fit in whatever available space the consumer has, i.e. shelves, tables, desks, under a television etc, all places that are readily accessible. The products also have a visual appeal that lend themselves to being on display.

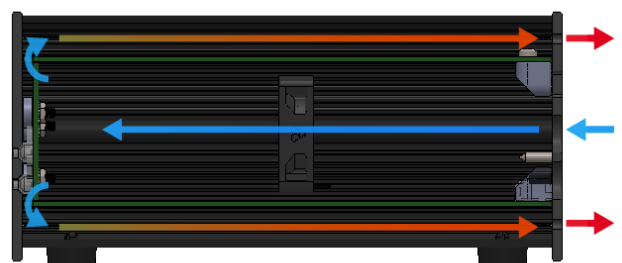
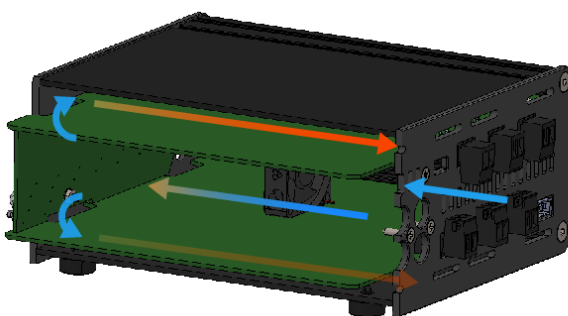
The original case design was an off-the-shelf extrusion with custom-made end plates. This was originally thought to be more than adequate for heat dispersion but time and testing showed otherwise.

Explored Solutions

- New case design:
 - Thicker metal for better overall heat dispersion
 - Thicker end-plates
- Case size increased slightly for SMV3, and moderately for the Amp Master.
 - Challenge was to maintain the form factor and cohesion between products while improving airflow and thermal performance
 - Thicker case material
 - Better and more consistent interface between case and endcaps
 - Creating two sizes of half-extrusion that interlock seamlessly while allowing for a mix / match of parts to give a small, medium and larger sized case with a consistent product identity allowed us to better control the thermal requirements for the different products.
- Amp master was given the largest possible case from the new extrusion. This allowed for more air around the hottest components in the case
- Rear plate designed with vents for warm air to escape (pictures here)

Other changes for thermal consideration:

- All PCBs were redesigned to give a continuous airflow path past all components and interface with the vents in the rear plate (Pictures here)
- Allowance was made for the option of a small fan to be installed in the Amp Master to provide the addition of forced convection. This was intended as a last resort as most small fans, even at their lowest speed, create motor noise and air turbulence that will generate noise as it passes through vents.
- Having vents created an acoustic resonance in the box, further exacerbating any potential fan noise.
- After testing, it was found forced convection was not required, but the option has been retained for potential future design updates.



Airflow Path with forced convection

Outcomes for mechanical design

Case:

After significant revisions and concepts, we landed on the design philosophy of having two extrusions halves that could interlock, with two different sizes. This would allow us to have up to three different size configurations (small+small, small+large, large+large), giving us a range of sizes for current and potential products that would allow adapting for different thermal profile requirements, while still retaining a coherent design philosophy across all products. This also gave us other advantages, including the ability to customise the internal structure of the cases to maximise the reliability of the fitment between the electronics and the mechanics, and the airflow, as well as other smaller benefits such as more reliable case feet. The initial case had self-adhesive feet, and the heat generated from those units was enough to melt the glue and cause the feet to shift around on the base.



Original case (Off the shelf extrusion, low quality control) – This case was used for both the Surround Master and the Amp master initially.

PCBs:

The outcomes for the PCB designs were mostly mechanical in order to facilitate the airflow past the boards around the case. However, the positioning of the components on the front board of the SMV3 was mostly fixed, as it forms the user interface on the front of the SMV3. This made the changes somewhat difficult, with tight tolerances to adhere to. The amp boards were relatively easy to modify, but still required extensive part position changes on two high-power boards with a lot of signals to be re-routed. It also slightly reduced the amount of copper in the ground planes for heatsinking, but this was relatively small in comparison to the gains in airflow and case surface area. In total, 5 of the 6 PCBs over the two products required design changes.

Testing method:

Equipment:

- Surround Master (Old case)
- Surround Master (New case)
- Amp Master (Old Case)
- Amp Master (New Case)
- Thermal Imaging camera (Hti HT-18)

Locations:

Small / Confined room:

2.5m x 2.6m

Low airflow, single window to outside

Single door out

Large room:

3.5m x 4m

High roof, suspended ceiling

Large windows on two walls, one to outside, one to open-plan office with door

Two plasterboard walls to open plan offices

Test Matrix:

Confined room:

Old version units stacked vs New version units stacked

Old version units separate vs New version units separated

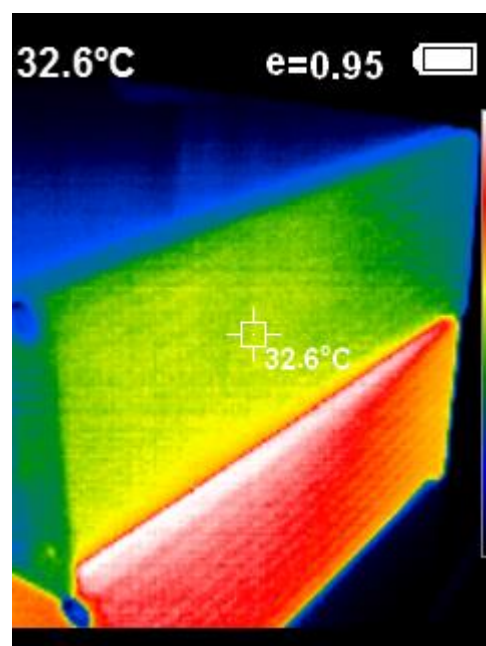
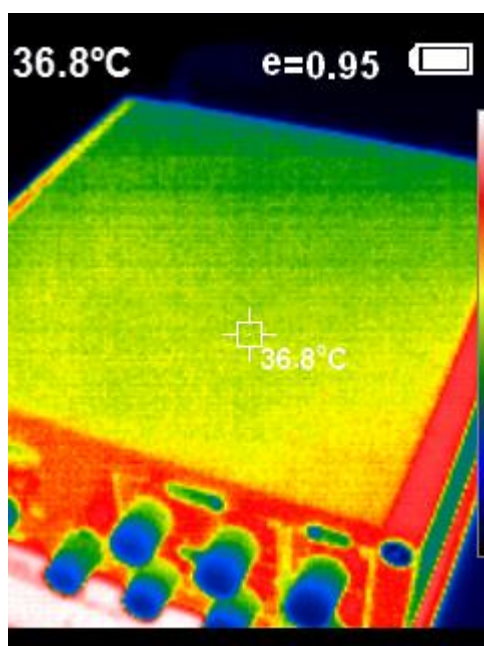
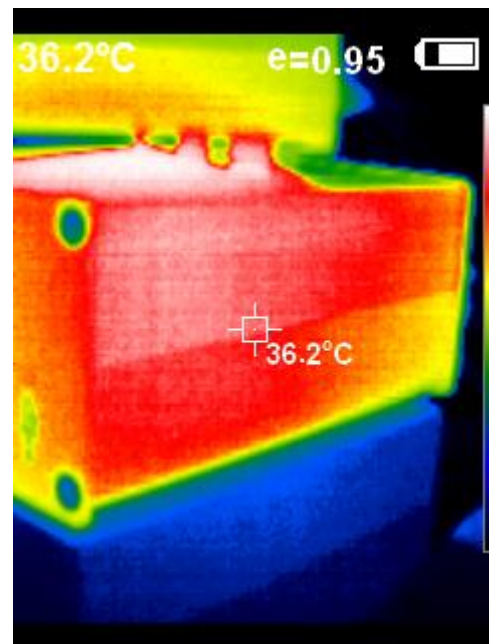
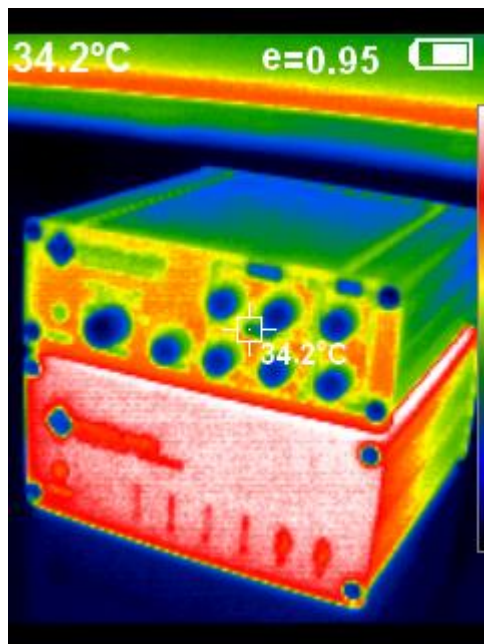
Large room:

Old version units stacked vs New version units stacked

Old version units separate vs New version units separated

Data and Results

Measurements were made using an industrial thermal camera with real-time temperature tracking.



The data is fairly extensive, a sample of the data is shown here:

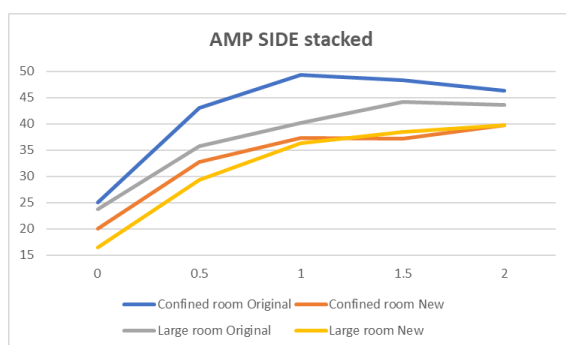
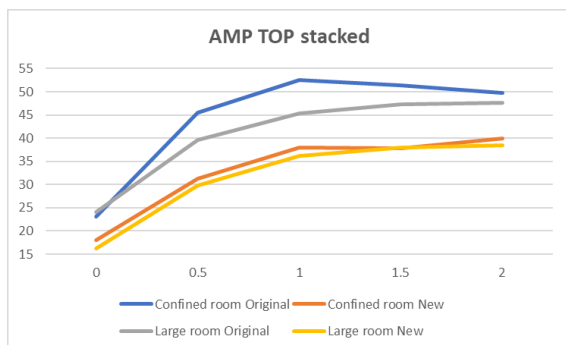
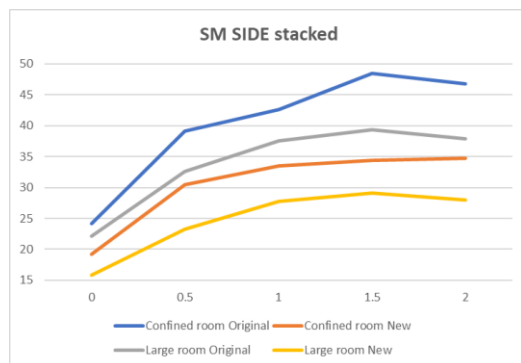
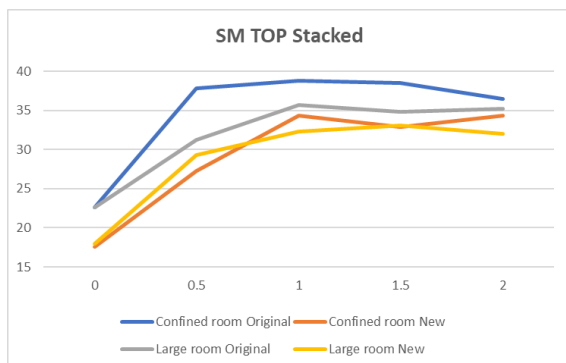
Confined Room						
Small stack						
Time (Hours)	Ambient: 1	SM Top	SM Side	Amp top	Amp Side	
0	17	19.6	21.2	20.1	22	
0.5	17	34.8	36.1	42.5	40	
1	18	36.8	40.6	50.5	47.3	
1.5	20	38.5	48.5	51.3	48.4	
2	22	38.5	48.8	51.7	48.4	
Confined room						
Large Stack						
Time (Hours)	Ambient: 1	SM Top	SM Side	Amp top	Amp Side	
0	22	19.6	21.2	20.1	22	
0.5	24	31.3	34.5	35.2	36.7	
1	24	38.3	37.5	42	41.3	
1.5	26	38.9	40.4	43.8	43.2	
2	26	40.3	40.7	46	45.7	
Confined Room						
Large separated						
Time (Hours)	Ambient: 1	SM Top	SM Side	Amp top	Amp Side	
0	21	17.1	17.3	16.7	16.9	
0.5	22	28.7	30	31.8	30.5	
1	26	34	35.4	38.1	38.4	
1.5	26	36.9	37.9	41.2	42.3	
2	27	37	39.2	41.4	42.8	

Not shown above: the data was normalised to ambient temperature.

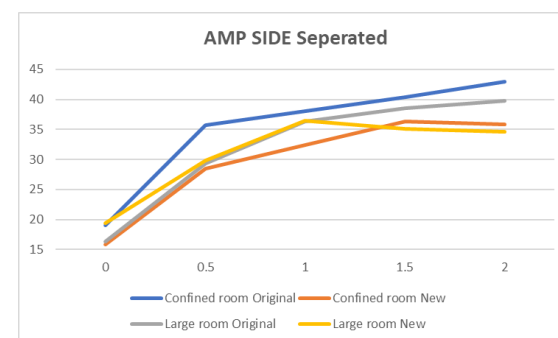
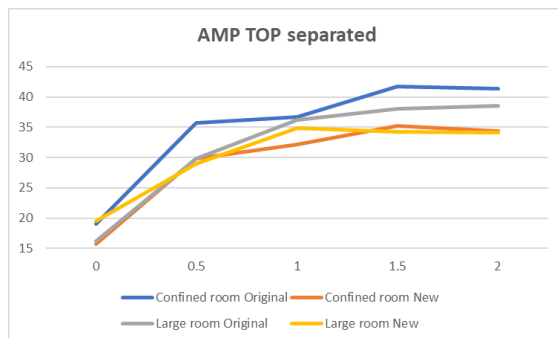
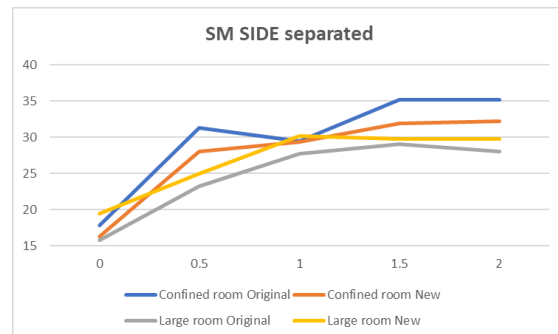
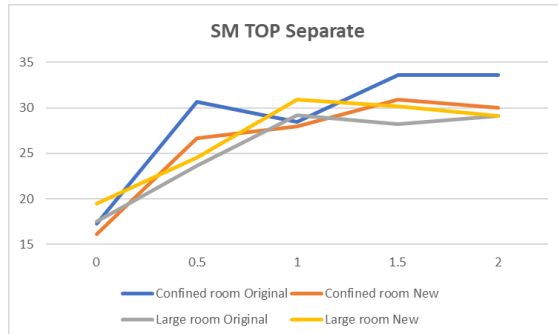
Graphed results

The graph results of the test matrix show a fairly clear trend, regardless of the location or physical configuration. The temperatures are in degrees Celsius and the time scale is in hours.

Stacked configuration (SMV3 sitting on top of Amp)



Separate configuration (SMV3 sitting next to but not close to Amp):



Regardless of physical configuration the new case is giving an overall drop of around 5 degrees Celsius on the SM and up to 10 degrees Celsius on the amp.

The amp does have the added benefit of having had the boards redesigned to allow an airflow path around the boards, and the rear of the new amp case has slotting for better air venting as well. It is also a larger case. However, it is also generating a lot more heat, so the difference in the drop in temperature shows a clear benefit of all the changes made to that unit.

Timeline:

- Both the Surround Master and the Amp Master were physically observed to be getting too warm in certain situations and locations.
- Measurements done to determine temperatures (49 degrees+ or more)
- Evaluated potential causes
 - Board layout
 - Airflow within case
 - Case material
 - Thermal coupling to case
- Determined that the cases could be more thermally efficient.
- Case is redesigned.
- Explored options for PCB and endplate modification for airflow and venting
- Endplate redesigned
- Three amplified PCBs redesigned to fit new case and new proposed airflow
- SMV3 PCBs redesigned to fit new case
- Endplates redesigned for new case – Amp back plate significantly changed for airflow, including a new method of fastening the boards to the back plate for better structural integrity and predictability
- Revised end-plates prototyped using 3D printing technology
- Revised case designs sent for tooling and prototype
- Revised PCB designs sent for prototyping
- Revised end-caps sent for manufacture
- Revised cases arrived, assembled and tested for mechanical fitment
- Revised PCBs arrived, tested for functionality
- Revised endcaps arrived, tested for mechanical fitment
- Full prototype products assembled, thermal testing to begin
- Thermal testing
 - Metrics:
 - Cool environment vs warm environment
 - Alone vs part of stack with SMV3
 - Powered but not loaded
 - Loaded for several hours



The two new extrusions, small (top) and large (bottom)



New Extruded case – SMV3 configuration (2x small extrusions)



New Extruded case – AMP configuration (2 x large extrusions)

Conclusions:

The steps taken to reduce the heat in these dense, compact electronics was a great success. When stacked together, even in a confined room with low airflow there are marked improvements of up to 10 degrees Celsius; even with a 5-degree drop, the discomfort associated with touching the case is significantly reduced. While the original temperature profiles were not enough to cause actual burns, it was still a necessary project to undertake both to extend the life of the electronics and also to improve customer perception of safety and quality.

In this compact form factor, heat is always going to be an issue, and the units will run warmer than comparable units that are much larger, but the convenience of the size is worth the additional heat, and it is now more manageable in a wider variety of consumer setups.

Future steps:

There is room to improve further on the amplifier particularly, as provision was made to include a fan to provide forced convection through the unit. Future testing will be around this.

Additionally, there may be some merit in creating venting outlets on the rear plate of the Surround Master.

Hours spent:

David Alexandrou:

Research time:

- Thermal principles: 2 weeks (76 hours)

PCB design / rework:

- Amp Front board: 1 week (38 hours)
- Amp Bottom board: 1 week (38 hours)
- Amp Top board: 1 week (38 hours)
- SMV3 front board: 3 days (24 hours)

Implementation and testing:

- General admin (parts, setup etc): 16 hours
- Build: 2 days (16 hours)
- Power and reliability test of new products (32 hours – 16 hours each)
- Test setup (4 hours total)
- Testing (3 hours per test, including cooldown time, 8 tests, 24 hours)
- Data processing and analysis (24 hours)
- Documentation and reporting: 1 week (38 hours)

Christopher Coller

Mechanical design / rework:

- Assembly and Extrusion Design: 38 hours
- Extrusion Manufacture and supplier liaison: 12 hours
- Extrusion Testing and Modification: 20 hours

Charles Van Dongen

Research: 2 hrs per week (94 hrs)

Production meetings, collaborative research and collaborative design

- David / Chris / Charlie: 1 hour Wednesdays from July 2022 to June 2023 (48 hours each, 144 total)

Total Hours: 676

Project 2: Electrostatic loudspeaker development – towards a “bulletproof” ESL speaker.

Charles Van Dongen – CTO Involve Audio

BSEE Electrical / Electronic

Christopher Coller - Product Design Engineer

BENG / Product Design (Honours)

Wayne Carey – *Speaker technology specialist (30 years)*

Introduction and reasons for the research

Electrostatic loudspeakers have long been the holy grail of audio reproduction. The technology itself has been around in some form since the 1940s. Involve Audio has gone a long way in trying to solve the problems traditionally associated with this type of speaker design, in order to make it more commercially viable for consumer-electronics.

Traditional roadblocks include:

- Consistency in manufacture
- Frequency response
- Dispersion
- SPL (Sound Pressure Level)
- Speaker size as relating to these previous challenge
- Power requirements

In the last 12 months, a number of additional hurdles have been identified and required research, prototyping and testing to try and elevate the technology to an even higher standard. Particularly:

- Conductive coating longevity.
- Electrical and mechanical design for robustness against situational environmental conditions such as humidity, temperature and UV radiation.

Methodology

Initial work

This line of research began when a number of units started to exhibit sonic degradation and/or mechanical failure within a year or two of being manufactured. This is far below the expected natural decline of this kind of technology. Many earlier examples of this technology build in the 1970s required refurbishment by the mid 1990s, which is a 20-25 year span. The manufacturing processes and materials of the time were extremely labour intensive, complicated and slow. This is also below the expected lifespan of previous models of Electrostatic produced by Involve Audio that have not degraded over time.

Testing method

The speaker panel voltages were measured using a standard multimeter. As the voltages being measured are usually in the range of kV, high-voltage probes were required to protect the equipment. It was also used to test continuity around the outside of the panel, conductivity across the resist coating, and to test for short circuits throughout.



A standard SPL meter was employed, measuring the SPL of the speakers at 1Khz, at 1 meter, as per industry standard. A quiet room with minimal reflections was necessary for accurate measurements.



Additionally, a humidifier was eventually implemented to simulate environments with high humidity. Much of the testing / exploration involved manual mechanical inspection.

Testing locations and methods included “clean” lab settings, and home settings indicative of consumer use, particularly settings with useful environmental exposure such as sunlight and humidity.

Challenges

- Adjusting / tweaking the coating process to improve longevity of the high SPL production from the speakers.
- Investigating alternative conductive coatings, taking advantage of advances in electro-chemical science and physics.
- Investigating current issues with manufacturing, including glue reliability and quantity, and panel flatness.
- Making the manufacturing process repeatable, more reliable and simpler.
- The way humidity affects the performance of the speaker has been underestimated.
- Component shortages and manufacturing times, particularly with relation to the impact Covid-19 has had on all associated industries
- The high number of mechanical, electrical and chemical variables in the design, manufacture and supply chain of parts that effect both the SPL production and longevity of the speaker's usefulness.

Initial Findings

The following points were discovered as a result of testing.

- 1) The conductive coating was inconsistent among previously constructed panels
- 2) The glue that holds the mylar to the panel, and the panel to the edge strips were failing
- 3) The amount of glue being used was inconsistent, leading to blooming and contamination
- 4) Many panels had been poorly constructed, and quality control was not working
- 5) Soldering technique applied to the pads and the strips was inconsistent and causing tears and electro-mechanical failure in the pads.
- 6) Some panels had bending that had been introduced during manufacture
- 7) Some panels were degrading quickly after power-up, others were degrading slowly.
- 8) The level of environmental humidity has a significant impact on the spl of the speakers
- 9) There are a number of physical attributes in construction that could be improved for better environmental tolerance and quality control and consistency, such as connector interfacing.
- 10) The physical construction of the speaker itself leaves a lot of avenues for environmental failure, particularly humidity.

1) Conductive coating consistency

It was found that in previous manufacture, there was little to no consideration given to the amount of conductive material in the coating during application. The coating is a suspension rather than a solution, and as such has the tendency to settle over time if not agitated regularly. It should have been agitated before every single application, and it was clear through observation that this was not happening. The outcome was that the impedance of the coating was not comparable between panels, and could lead to variations of up to 1kV or more as measured on existing panels. This can be attributed largely to poor process definition and a lack of care on the part of the person engaged in the process.

2) Glue failures in manufacture and 3) Consistent glue quantity and dispersion.bv

A number of panels were shown to either have too little glue applied, resulting in mechanical failure of the side-strips, or too much glue applied or applied unevenly, leading to large amounts of glue “bloom” which leaves a lot of residues behind – this is a contaminant but also has an unappealing visual component that may end up being visible to the consumer.



Example of strip lifting as a result of poor gluing processes and practices (seen at left)

Apart from manufacture quality, it was also discovered that the glue itself was not being handled or stored correctly, leading to both a reduction in the efficacy of the glue, and also the potential for biological contaminant. This came from discussion with the supplier / manufacturer of the glue itself, who also indicated that the use of the activator and the glue needed to be immediate once it had been applied. A third possibility that was explored was that the age of the glue might have been contributing to the mylar creeping on the interface surface and losing far too much tension over a shorter lifespan, leading to premature degradation.

4) Physical panel construction

It was discovered that many panels had been poorly manufactured in various processes, including the mechanical fitment of panel to frame, and the quality of the soldering. Working with high voltages meant that poor quality soldering on its own can actually reduce the SPL level, and this was confirmed in testing. Additionally, the interface between the panel and the frame was not shielded in any way. Previously, the frames were made using plastic, which had a good seal with the speaker and protected those edges and connectors well. Speakers made with this material have not had any degradation reported.

However, the change to wood introduced a path for voltage creep and more access for the environment to reach the electrical parts of the speaker. This can be seen below.



Wood frame with organic path to connector

5) Soldering consistency

The quality of the soldering was found to have been inconsistent between panels, another QC failure in the last 12 months. Working with high voltages, it was found by resoldering joints that a poorly soldered joint could lead to SPL drops of up to 10dB.

6) Panel Interface Surface Flatness and Roughness

One of the biggest mechanical constraints in the construction of the speakers is how extremely flat and smooth the panel surface needs to be. Gaps between the panels and the mylar are measured in fractions of a millimetre, so even a very slight bend or surface inconsistency can result in uneven performance across a single panel, leading to electrical failure and unwanted noise from electrical potential proximity. Many of the panels were showing signs of slight bowing and roughness. The process of mylar application was incorporated with a flattening process involving a more consistent set of weights to hold the panel on the mylar, and the process of filing surface smoother to reduce roughness. This resulted in far more consistently and repeatably flat and smooth. The outcome was that far fewer panels were failing on first test, but it did not address the degradation issues.

7) Degradation time

One of the things that made it hard to pin down the degradation source was that speakers that had been with customers for a year or more were only just starting to exhibit signs of SPL drop, whereas others tested in the factory and employee homes were failing at a much faster rate, though not always repeatable. While a certain level of subjectivity had to be taken into account where we are relying on people reporting correct sound levels without proper test equipment, we had a number of speakers returned to the factory for us to verify. After this testing and some theorising, it was considered that the only variables that couldn't be accounted for between various sites were the environmental conditions that the speakers were exposed to, and what was becoming increasingly apparent as a problem with production quality control consistency.

8) Environmental issues, including UV exposure, humidity and SPL

In testing at the house site and at the production site, a number of possibilities around the sudden reduction of SPL were investigated, including UV exposure, which was tested both in various positions in the house with various levels of sunlight and artificial light and at site by placing panels in varying light conditions and testing over multiple months. This was found to have little effect on the SPL. Following up on a theory, various configurations of conductive coating strength, and using different mediums as the dilution agent. This was tested over several months, and while there was a mild effect of UV overall regardless of the composition changes, it wasn't enough of a change to explain the larger problems. However, after consultation with an external expert, we discovered new coating technology was available that had superior resistance to UV exposure, making this research worthwhile. Environmental temperature was tested on and off-site, on hot and cold days and using artificial heat sources to warm the playback testing room to higher-than-normal levels, but this was found to have little effect on the SPL of the speakers.

9) Physical improvements and process improvement

The next step in testing involved improving and refining production of the panels themselves. Particular attention was paid to three areas:

- 1) The glue quality and process, including controlling the temperature of the manufacture environment to determine if it had an effect on overall panel quality. The hypothesis was that glue failure was causing a reduction in the tension of the mylar over time. What was found is that the glue and primer age played a significant factor in the mechanical reliability of the gluing process. However, while this was a useful area to explore, it did not have an effect on the degradation problems. The application of glue was initially just a drizzle process and clamp, but this was leading to inconsistent gluing in patches, and uneven coverage. Glue primer and brushes are now being used to create a repeatable, consistent glue interaction between the panel and the mylar. In the long term, while this doesn't have an immediate effect on the SPL, it does ensure the lifespan of the panels is longer and more consistent, with less chance of unwanted reductions in tension in the shorter term.
- 2) The soldering quality and process. Many of the panels had inconsistent soldering at the pads connecting the panels and conductive strip, and solder terminals around the panel. It was found that the quality of soldering had to be higher than what would be considered "normal" in an electrical solder joint situation. To help facilitate this, the solder pads were filed down until nearly completely flat against the plane of the speaker and strips themselves. This had the effect of improving the consistency of SPL output between speakers, however it did not have an effect on the degradation issues.

- 3) Mylar application and flatness – two additional processes were improved in ensuring flatness and quality of the mylaring process – the surface on which the mylar is initially tensioned was improved, using a surface that is less susceptible to things like micro-burrs, and the use of heavier, more consistent weights to apply a more even distribution of weight across the entire panel during gluing and drying.

Further investigations into humidity

Environmental humidity had become an obviously major factor in the problems associated with the panels. Off site at Chris' house, the SPL was observed to have dropped dramatically when high-water-content cooking was occurring in the same open-plan area as the speakers, in excess of 15dB reduction. The windows near the speakers were fogging up, indicating a large increase in air humidity. These panels were taken back to the factory and dried out using heat guns. Drying out all parts of the panel helped, with the largest effect occurring when heating the terminals, having the effect of the SPL recovering all the way to pre-humidified levels.

Investigation showed that a large surface area of the terminals was exposed to the environment, not in small part due to stand-offs that raise the connector above the PCB as shown below.



Terminal connections – exposed to open air underneath the connector.

To further confirm this, humid air was introduced directly at the terminals of known good panels, and the SPL immediately dropped. After drying, the sound level returned. Other panels that had degraded were heated in an oven at 80 degrees C for a few hours and the SPL on these previously degraded panels recovered significantly as well.

It was concluded that while humidity had not previously been considered a significant short-term factor because they were not being operated in high-humidity environments. However, even mild humidity levels present in the same environment contribute to the problem and degradation does occur, albeit far more slowly. This explains the problems presenting in panels that had been in the field for a year or more. However, previous generations of speakers did not have this problem, as they were manufactured using frames made with plastic composites rather than wood. The speaker frame material had been changed to wood from plastic for a number of reasons, including cost, repeatability, availability, aesthetics and ease of manufacture.

Outcomes of humidity research.

We have addressed these problems in the following ways:

- 1) The application of silicone-based sealant to the exposed surface of the wood. This creates a waterproof seal on the absorbent and organic fibres at the point where the speaker panel interfaces with the frame.
- 2) The application of a silicone-based sealant around the exposed edges of the speaker panel.

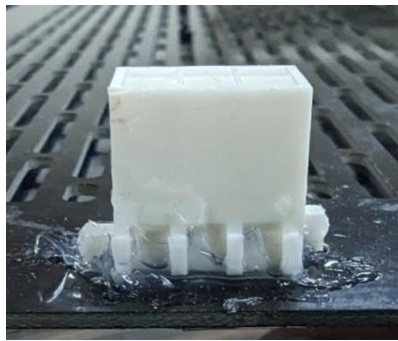


- 3) The application of high-voltage-resist tape around the edges of the speaker panel





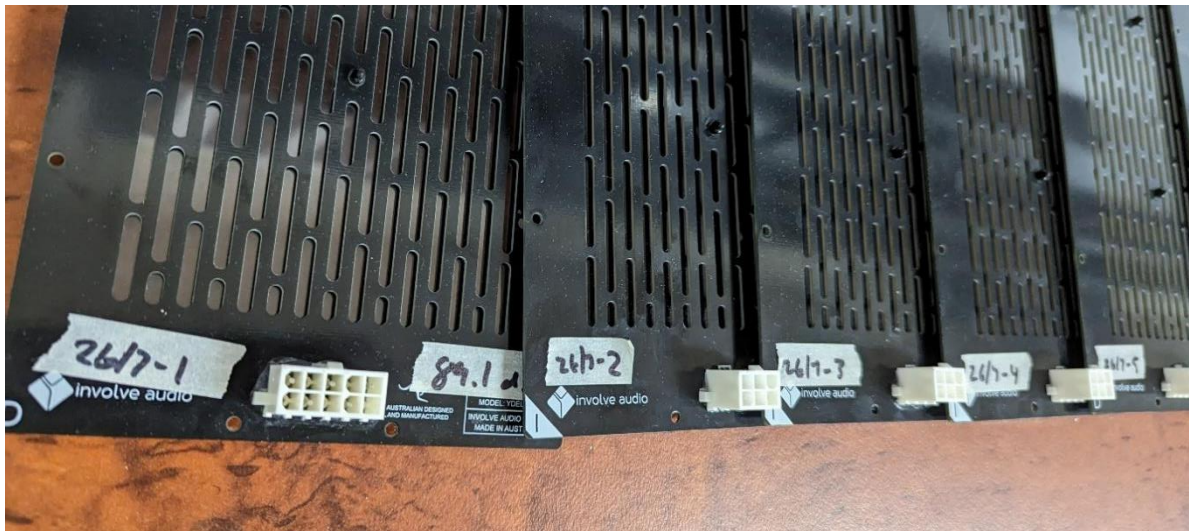
- 4) The application of silicone-based sealant around the connector interface, and:
- 5) The removal of stand-off tabs on the connector interface to reduce the exposed surface-area of the conductors.



These steps effectively create multiple electrical and environmental seals at various points in the entire panel structure, sealing the electrical interfaces of the panels from the environment.

Findings- Final thoughts

Even after all the solutions were implemented, there was still variations to the SPL output of the panels. This variation is only in the order of a few dB however. The proposed solution is to measure the capability of every manufactured panel and ensure that matched sets are created for each product so that the listening experience is as consistent as possible.



Example of panels that are marked with their SPL for matching.

Summary of findings and outcomes

Finding: Conductive coating is susceptible to degradation from UV exposure

Outcome: Replacement coating with new UV-resistant chemistry as a result of external consultation.

Finding: The conductive coating, glue and primer can all degrade and have a shorter shelf-life than is readily apparent for this application.

Outcome: All Bottles must be marked with purchase date, stored correctly and checked before use.

Finding: Conductive coating and glue are susceptible to biological contamination.

Outcome: Strict clean-production procedures, including handling, storage and usage.

Finding: Glue application can be inconsistent in free-hand.

Outcome: Brush application of glue.

Finding: Conductive coating conductivity varies depending on agitation level.

Outcome: More explicit procedure to ensure suspension is evenly dispersed in solution before application

Finding: Soldering quality plays a significant role in SPL.

Outcome: More care required, better QC implemented and better training of those performing the soldering step.

Finding: Glue procedure quality leads to mechanical failures internally.

Outcome: Stricter procedures and better training.

Finding: Mechanical consistency of strips and soldering pads affects flatness of panel.

Outcome: Additional steps such as sanding of solder pads to reduce impact of mechanical interfaces.

Finding: Panels can form mild curve, affecting SPL.

Outcome: Better equipment and procedures for mylar application and weight distribution.

Finding: Multiple environmental liabilities discovered that allow even small increases in humidity to have a huge impact on SPL over time.

Outcomes: Multiple changes to address this including sealing of all exposed wood surfaces and electrical surfaces, electrical interfaces and environmental and electrical isolation of potential high-voltage interface points, including panel edges and connector pins.

Conclusions

Involve Audio has strived for years to try to engineer out the problems traditionally associated with Electrostatic loudspeakers (ESL), and has been extremely successful. Thanks to the work done over the last 12 months, many construction and manufacture details that are easily overlooked have been examined with closer scrutiny. Conventional cone technology has come a long way in the last 5 years, but there are still major drawbacks that make ESL technology appealing. The outcomes for ESL as a result of this research are therefore significant, and will allow the company to push its already world-leading techniques to greater levels of technical excellence.

After the discovery of major issues with one of our most advanced speaker technologies, we spent the last 12 months taking a considered and methodical approach to researching all the possible causes of the short and medium-short (under two years) degradation of SPL, as well as researching innovations in the electrostatic loudspeaker space.

A large number of processes and materials were overhauled during this time, including manufacturing processes, materials handling, application of audio, thermal, mechanical and chemical engineering disciplines, and a tightening up of quality control procedures. The result of this is the improvement of an already world-leading technology, elevating it significantly beyond what was considered possible in this space.

Additionally, a fundamental shortcoming was discovered through many hours of testing and experimenting. We discovered that the combination of humidity, terminal exposure and the speaker frame composition played a much larger role in the overall quality and longevity of the technology.

While we considered our technology to already be world-leading in terms of audio reproduction and manufacturability, we are now also able to say that we are unbeatable in terms of technology lifespan. The implications are significant. By making the technology more robust, there is especially a significant impact on reducing the overall amount of waste generated by consumer and commercial electronics products.

These improvements in quality and manufacture will allow our technology to be more readily accepted for use in industries such as automotive, marine and hospitality, even airspace sectors such as commercial planes and private jets - into sectors where repeatability, quality and ease of installation are paramount, and where environmental exposure cannot be controlled to the same degree as it is in a consumer setting. In all these applications, there is a desire for the unparalleled high-end quality of the audio reproduction is highly coveted, along with efficient use of space that cannot be matched by any other technology.

Further research

We will be continuing to research this particular technology, with regard to longer and more exhaustive testing of the application of everything that was learned in the last twelve months. Doing longevity tests requires time, and while the results are more than promising, the results will bear out more fully over the next twelve months of continual testing, as well as refining some of the changes we have made as a result.

Electrically, we are beginning to explore the impact of internal connection wire length on the panels on initial SPL levels. It is possible that making them shorter and a more consistent length will improve both the sensitivity of the speakers and the consistency of SPL between panels. This level of minutia will require significant time as panels must be carefully disassembled and reassembled for each test.

Timeline of events/research

1. Noticed Panels were degrading over time, whether a few months (at house test site) or over a year (customer homes).
 - a. Various panels taken to house and found panels would degrade over time (open plan, light filled room) anywhere from between a few weeks to a few months.
 - b. Upon implementing better testing practices was found that the panel SPL consistency needed to be improved.
2. First, we thought UV may have been the issue.
 - a. UV testing conducted by placing panels in various different lighting conditions at the office and at my home test site. Required testing of panels over many months.
 - i. Tried various formulas.
 - ii. Tried various dilutions and dilutants.
 - iii. Tested these changes over a number of months.
 - b. Found UV had an effect, but not to as high a degradation as expected.
 - i. Improved formula improves longevity and SPL.
 - c. Still did not eliminate the degradation issue.
3. Second main round of tests involved manufacture consistency
 - a. Spacer Panel Soldering consistency
 - i. It was found that a higher-than-normal soldering quality is required to provide better mechanical binding between Spacers, Stators and Mylar.
 - ii. Adding additional process of filing flat improved SPL consistency.
 - b. Glue consistency
 - i. Hypothesised Mylar tension was creeping lower due to glue unbinding over time.
 - ii. Found Glue age and Primer age were a factor in SPL degradation and SPL consistency between panels.
 - iii. Still did not eliminate the degradation issue.
 - iv. Improvements in Glue stock control improved SPL consistency
4. Temperature of use
 - a. Tested whether temperature of use was an issue
 - b. Found during colder months panels would degrade quicker
 - i. More of a qualitative approach to this due to limited test locations.
 - c. Upon further testing, by heating up manufacture room this was found to not effect either degradation or consistency of SPL.
5. Humidity – on site testing
 - a. A set of test panels at Chris's house very quickly degraded. It was noticed they had started degrading slowly but one evening degraded very quickly, SPL fell dramatically.
 - i. It was noted the environment had become highly humid, windows had condensation on them, temperature was low and cooking of high water content food had occurred, raising the humidity of the open plan living space.
 - b. The speakers were taken into the office for further testing.
 - i. They had degraded a lot, over 15db
 - c. A heat gun was used to dry various areas of the panel, the main stator areas, the sides where the stator and mylar meet and the electrical terminals.

- i. It was found when heating the electrical terminals that the SPL of the panels would increase back to pre-humidified levels.
 - ii. Further humidity testing
 - 1. Humid air was introduced to high SPL panels at the terminals. SPL level immediately dropped. After drying with a heat gun the SPL returned to high levels. This was tested on multiple panels repeatedly and was found to produce consistent results.
 - 2. Previously noted panels that had degraded were put into an oven at 80°C for a couple hours. After testing SPL had increased.
 - d. To prevent humidity from effecting the terminals silicone is has been used to coat the terminals and to form a protective barrier in the entire area around the terminals. Sealing them from the environment.
 - i. Testing is currently underway to determine if this is working. Results are promising.
- 6. Baffle Material Differences
 - a. Material differences between first generation Y Speaker Baffles and current generation may have affected the humidity present at the terminals.
 - b. No degradation has been reported from first run of Y Speakers.
 - i. First run was plastic and a good seal was created between the panels and the environment, preventing higher humidity at the terminals.
 - c. Current and futures runs are made of wood, which will allow humidity into the conductor positions. This is most likely the reason this has become a noticeable issue.
 - i. Testing is planned to compare first run speakers to current run speakers.

Hours spent:

Christopher Collier:

- Panel Testing and Analysis: 4 hours per week for 6 months (104 hours)
- Off-site testing, continual: 2.5 hours weekly, 24 weeks (60 hours)

Wayne Carey:

- Panel construction, changes, mechanical updates, iteration, procedures and testing: 30% of working hours allocated to project. (590 hours)

David Alexandrou:

- PCB design support: 20 hours
- Qualitative audio testing: 2 hours weekly x 47 weeks (94 hours)

Charles van Dongen

- Advise and supervision 1 hr per week X 47 weeks (47 hours)
- Qualitative audio testing: 2 hr weekl x 47 weeks (47 hours)

Year summary

Both projects:

Total hours spent 2022/2023:

David: (384 hrs +114 hrs)@\$120 ph- \$59,760

Charlie: (94 hrs +94 hrs) @\$140 ph - \$26,320

Chris: (60 hrs+ 164 hrs)@\$100 ph - \$22,400

Wayne: 590 hrs@\$80 ph - \$47,200

Team collaborative design time 144hrs@80 ph - \$11,520

Total: \$167,200