A METHOD FOR SUPPRESSING ENCLOSURE MODE LEAKAGE FROM LOUDSPEAKER PORTS

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1 INTRODUCTION

In a surround sound system, a planned arrangement of loudspeakers surrounding an audience is designed to create an immersive audio experience. Dedicated signal processing of each channel leverages the ensemble of individual loudspeakers such that the synthesised acoustic scene dominates over the true acoustic characteristics of the loudspeakers. The plausibility of the presentation hinges on the success of making the loudspeakers as acoustically inconspicuous as possible. That is to say that anything unintended and audible that draws the attention of the listener to the loudspeaker should be suppressed. Defective behaviour may be obvious such as harmonic distortion, rattles, buzzes or more subtle aspects such as narrowband flares in directivity due to uncontrolled resonance.

Loudspeakers that utilise a full range drive unit to reproduce the entire audio band are presented with specific design challenges when incorporating a bass port. At mid frequencies, where the cabinet interior becomes modal, undesirable acoustic outputs from the port can be problematic. It is possible to mitigate this effect to some extent with considered placement of the port entrance within the enclosure and the application of internal absorbent wadding. An extension of this approach is considered in this paper.

The use case of interest is a wall mounted satellite loudspeaker incorporating a full range driver in an enclosure shared with a bass port.

2 LOUDSPEAKER PORTS IN FULL RANGE LOUDSPEAKERS

A small (approx. 2 litre) passive satellite loudspeaker is considered, with the following key design targets:

- Bass extension to 65Hz
- Flat frequency response
- Controlled directivity – progressive taper in coverage towards 20kHz
- Aestheics (determining that the bass port will be mounted to the rear)

To achieve the desired bass extension in the small form factor, a port was included and during the design some effort was put into creating a system response with controlled alignment, though as an “of the shelf driver” was selected, there were some performance limitations to overcome. To this end, the drive unit was customised with additional motor components such that the force factor increased, and thus system quality factor aligned to improve bass performance. Given this investment, it was important to retain as much of the low bass as possible.

Designing a port to extend the low frequency capability simultaneously means that over the mid-band the enclosure effectively has a hole in it, through which internal acoustic resonances can leak to the outside. These narrowband outputs may be audible, particularly if the rear-ported loudspeaker is to be used in a wall mounted setting which is common for satellites in a spatial audio application. Despite the efforts to select a transducer with controlled directivity and features of the enclosure to support this, superimposed, outputs from the port result in potentially distracting artefacts that inherit the wide dispersion characteristics of a small radiator.

To investigate this behaviour in more detail and illustrate the issue, finite and boundary element simulations were conducted.

3 DESIGN SIMULATIONS

Predictive numerical computations were conducted using the commercial software package PAFEC-FE. The vibro-acoustic model consisted of rigid piston excited with a force coupled to an internal region of acoustic finite elements into which the motor and port were incorporated. The piston was shaped representatively and its mechanical parameters prescribed using elements based on the driver's lumped parameters, which were measured. The port was extended to a surface of boundary element patches representing the enclosure's exterior, which also coupled the piston outer surface to model the infinite radiation from both acoustic entities. An arc of "microphone" points sampled the acoustic radiation ay 3m distance in the horizontal plane.

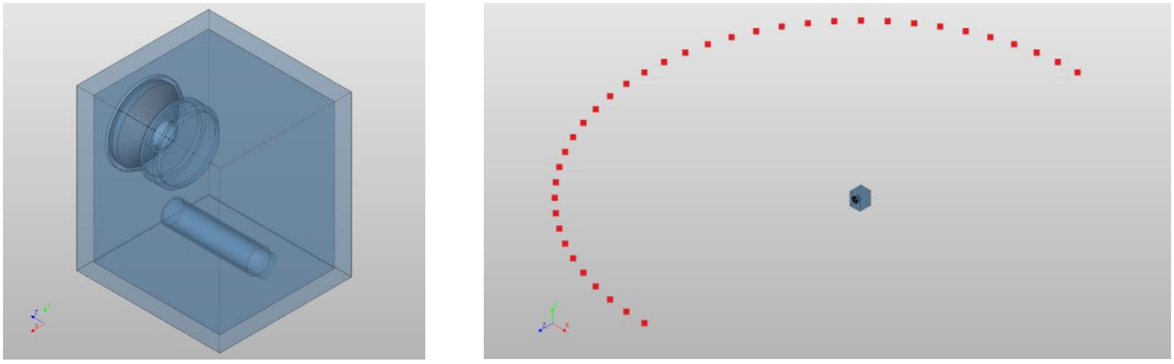


Figure 1 Simulation Model of Standard Single Port Enclosure and Mic Array at 3m Distance

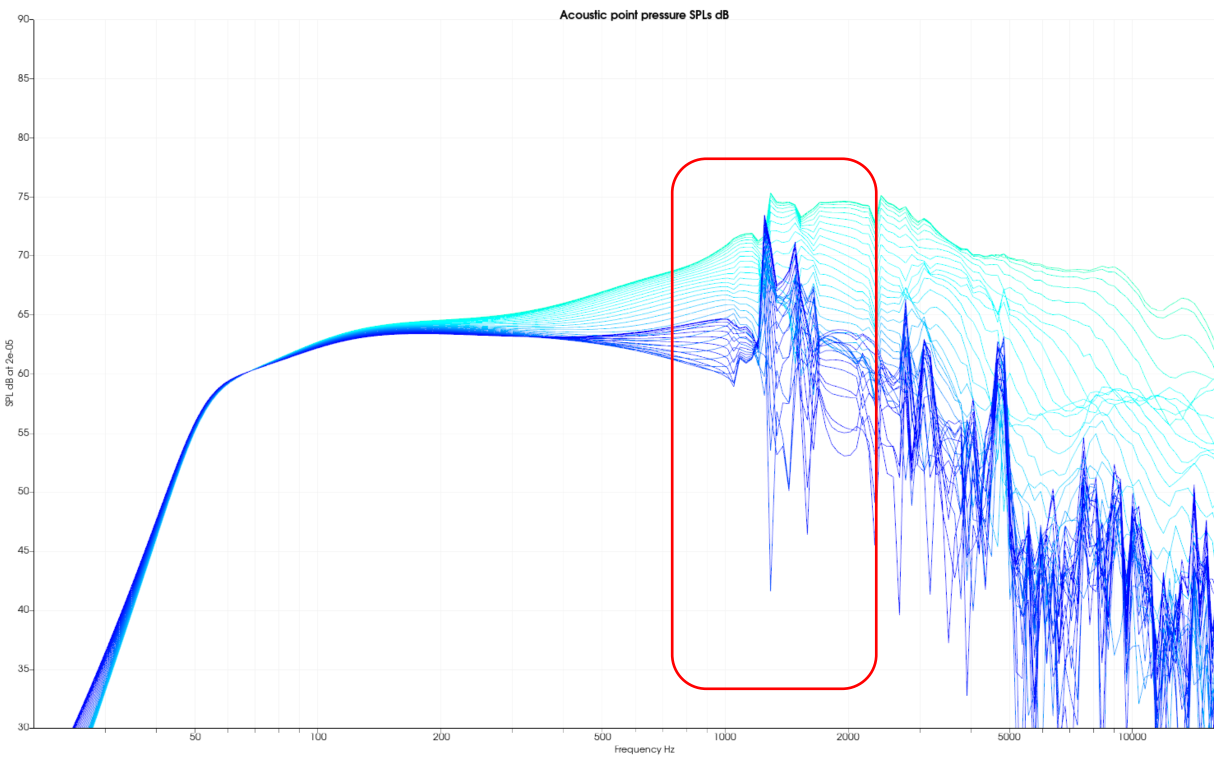


Figure 2 Simulation Model of Standard Single Port Enclosure

Note. The cyan coloured curves cover the frontal 0deg to 90deg, the darker blue are towards the rear 90deg to 180deg.

The region of initial interest is between 1 and 2kHz corresponding to axial modes of the enclosure. Here the low directivity output from the rear port is significant, competing with the axial output even in anechoic conditions.

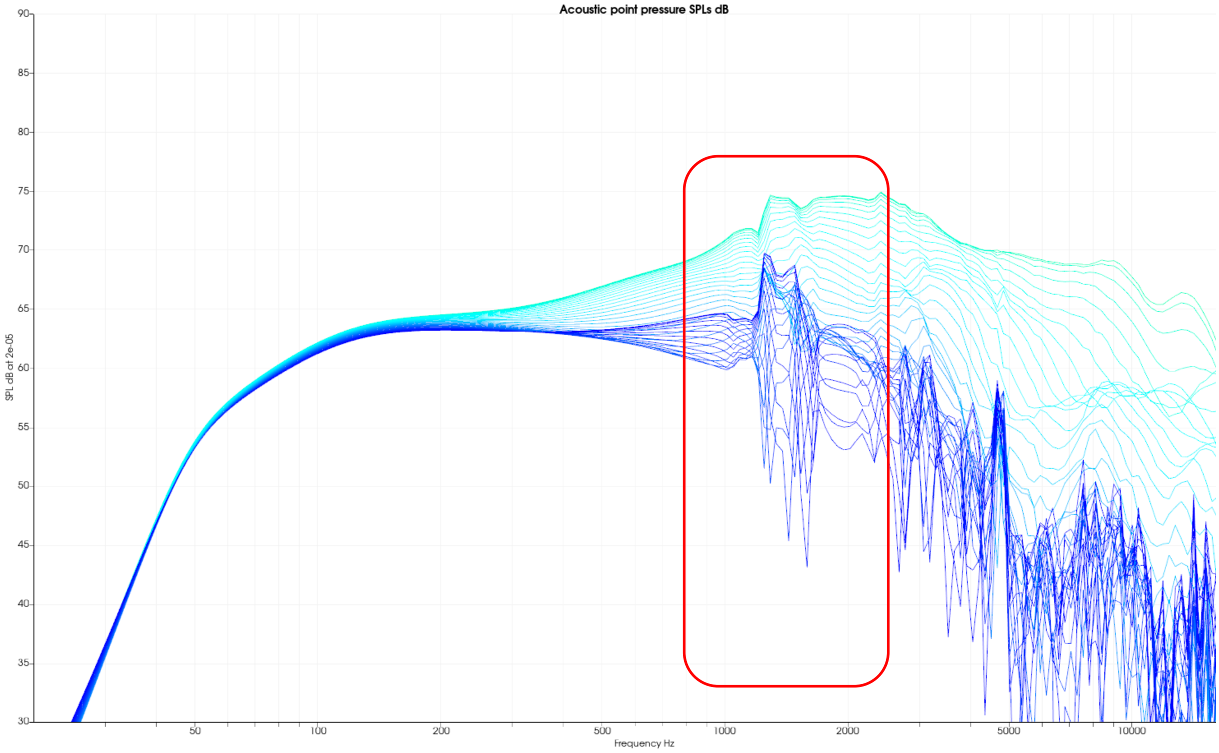


Figure 3 Simulation Model of Standard Single Port Enclosure – with Absorbency Applied (Wadding)

Adding acoustic wadding to the system suppresses these midband modes, but at the expense of low frequency performance. The task therefore is to utilise a method for controlling the port output whilst using as little absorptive wadding as possible.

DEVELOPMENT OF THE BRANCHED PORT CONCEPT

The basic idea is to reduce the transmission of internal modes to the exterior acoustic space via the port by sampling the distributed internal pressure field at different points within the enclosure, and positioning the port entrances at these locations.

An initial strategy for determining candidate positions was to define a region inside the enclosure that was within reach of a 100mm flexible port that terminated on the rear panel, and then sample the pressures using a grid of microphone points. From the complex data acquired, 3 points were selected such that their average resulted in a reduction in pressure. This reduction may result from sampling specifically at nodal locations or selecting a polarised combination where for a given mode shape, the complex combination of all 3 points reduces the pressure. Clearly this approach targets specific modes.

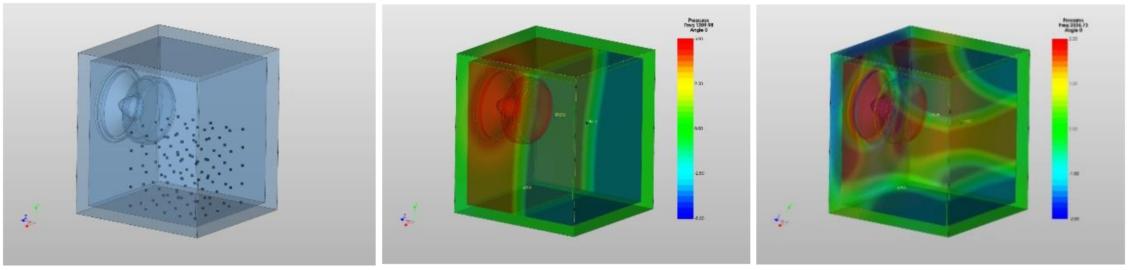


Figure 4 Modal analysis of cabinet acoustics

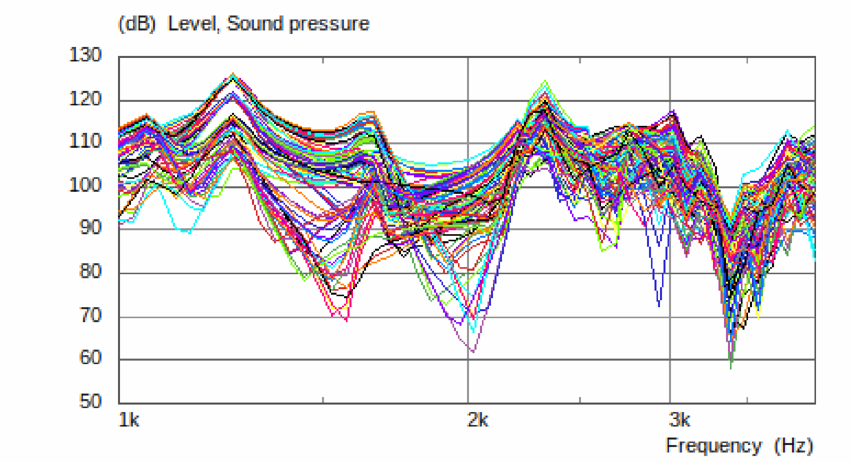


Figure 5 Complex pressures at candidate points in the box

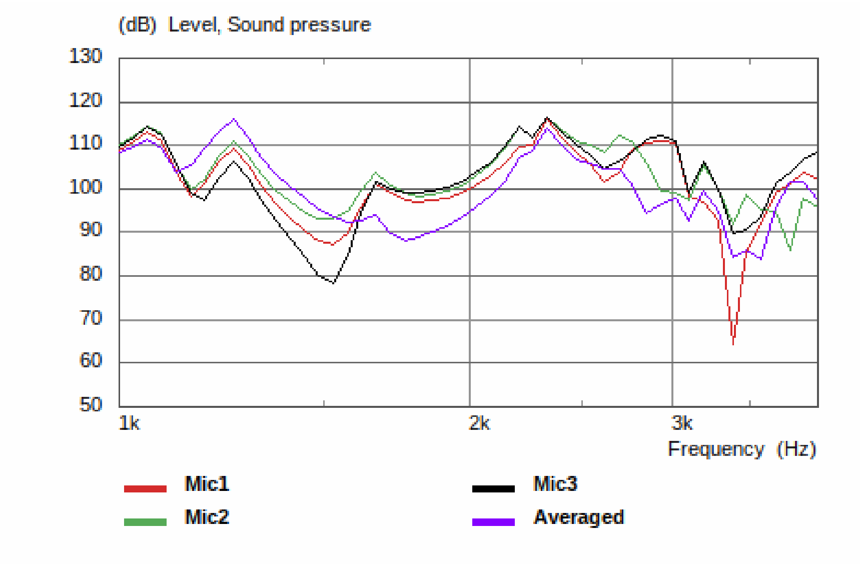
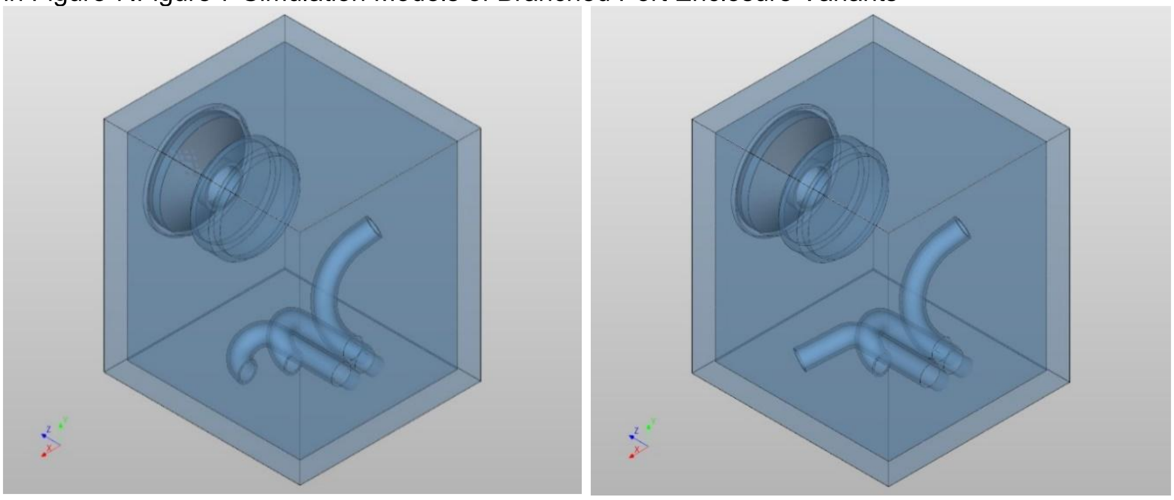


Figure 6 Average the complex pressure of shortlisted positions

The graph shows that the average of the selected 3 mic locations results in much lower SPL at 1.2kHz, 1.5kHz and 2.4kHz compared to the maxima in the overall dataset suggesting that these may be good locations to terminate the ports.
A 3-branch ported system was conceived as illustrated below, reflecting a combination of internal port locations considered to be optimal in reducing the modal amplitude at the targeted frequencies. The length and total area of the ports was equivalent to the straight port, and therefore the effective tuning remained, but in this embodiment the internal entrances to the port were spatially distributed as shown in Figure 7.Figure 7 Simulation Models of Branched Port Enclosure Variants



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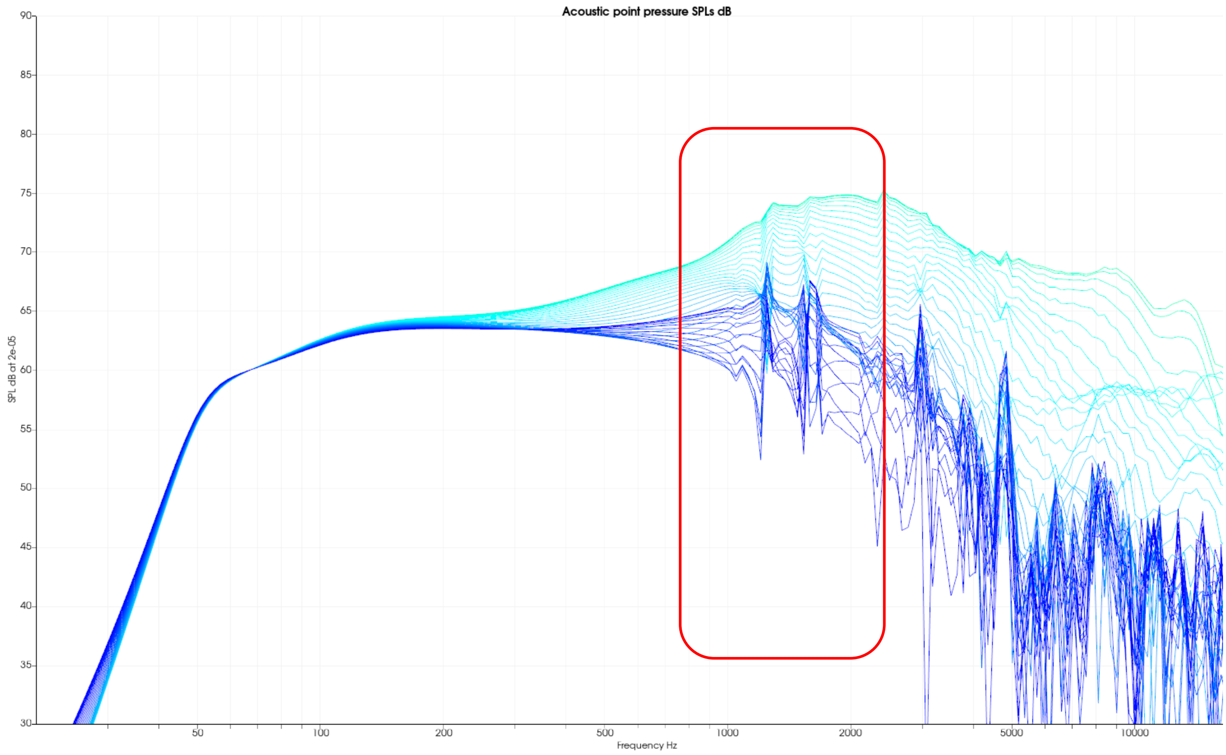

Figure 8 First Iteration of Branched Port System

The results indicate that the resonance peaks between 1 and 2kHz can be reduced without adding any absorbency to the interior of the enclosure. This also means that the low frequency performance was not compromised by the modification.
The initial branched port system was revised by reconsidering one of the ports entrance locations to produce a second dataset to see if improvements were possible.

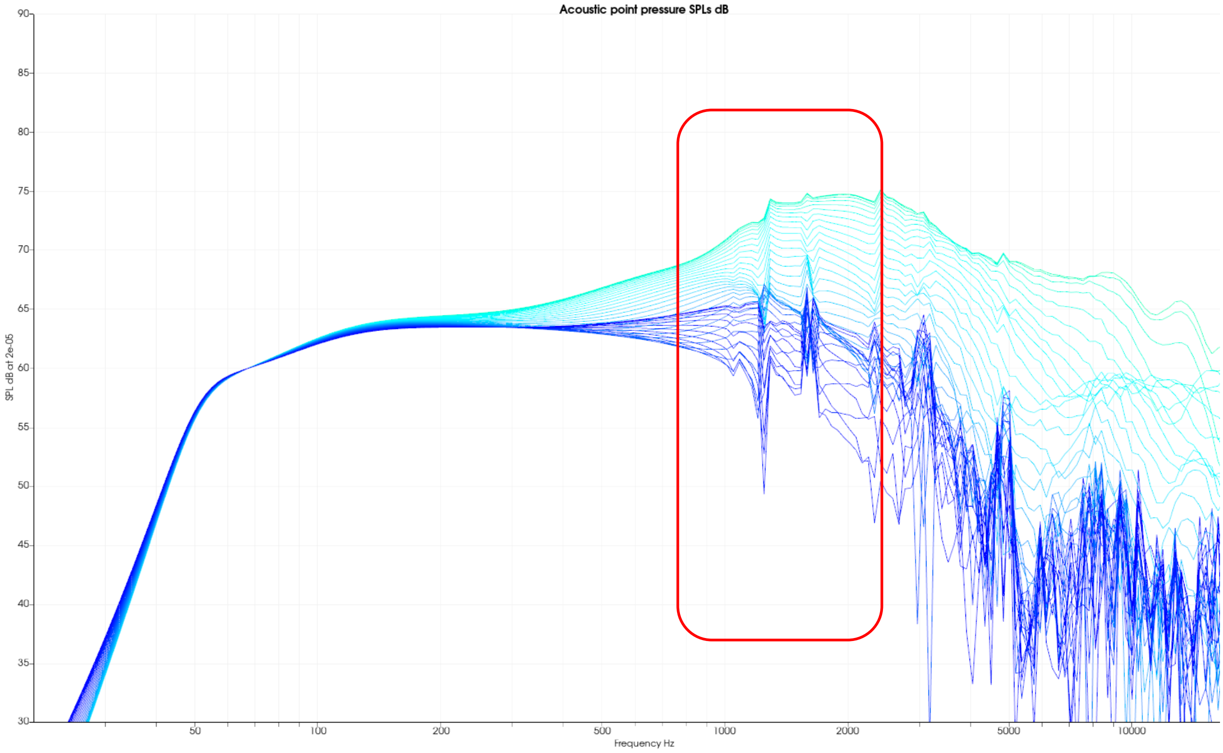

Figure 9 Revised Iteration of Branched Port System

The second variation of the branched port design appeared to offer further reductions in the magnitude of the resonant artefacts from the port, addressing to a lesser extent higher order modes at 2.7kHz and 4.8kHz.

Both of the branched port results demonstrated marked improvement over the straight port at 1.2 and 1.5kHz suggesting that the principle could work in a realistic scenario.

In order to understand how effective this idea was in practice, a physical prototype was constructed.

4 EXPERIMENTAL DATA

Figure 10 Prototype of 2L Satellite Loudspeaker with Branched Port Detail

The prototype loudspeaker was used to validate the simulation work and understand the benefits that could be gleaned from the branched port in a real scenario. Standard 22mm ID plumbing pipe was used for the straight port which conveniently divided into 3 standard 12mm ID flexible tubes to maintain broadly the same cross sectional area. Additional fittings were 3D printed to allow the tubes to be consolidated and oriented as required.
To obtain the low frequency response in the absence of an anechoic chamber, the microphone in box method was used outlined in [3].

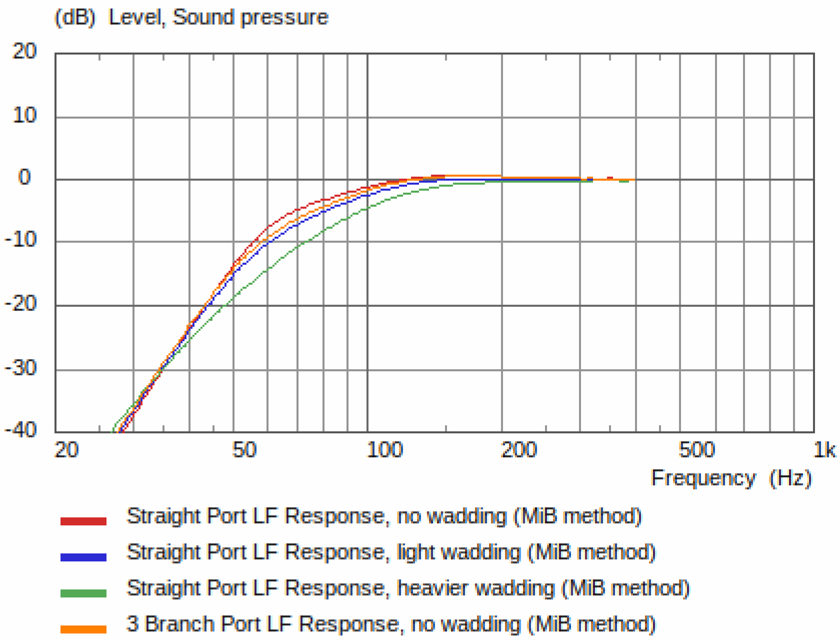

Figure 11 Low Frequency Response Comparison using Microphone in Box Technique

The 4 scenarios tested were the original straight port design without additional absorptive wadding, the straight port with infill of 7 kg/m^3 density, straight port with infill of 21 kg/m^3 density and the branched port system without additional wadding.

The effect of absorption on the low frequencies was rather marked and even lower density treatment reduced the output at 65Hz by 2.8dB increasing to ~8dB for the heavier infill. The 3-branch port also exhibited some loss, but of the order 1dB or so. This loss was attributed to increased air turbulence due to the air oscillating at high speed around the sharp edges of the flexible tubes [2].

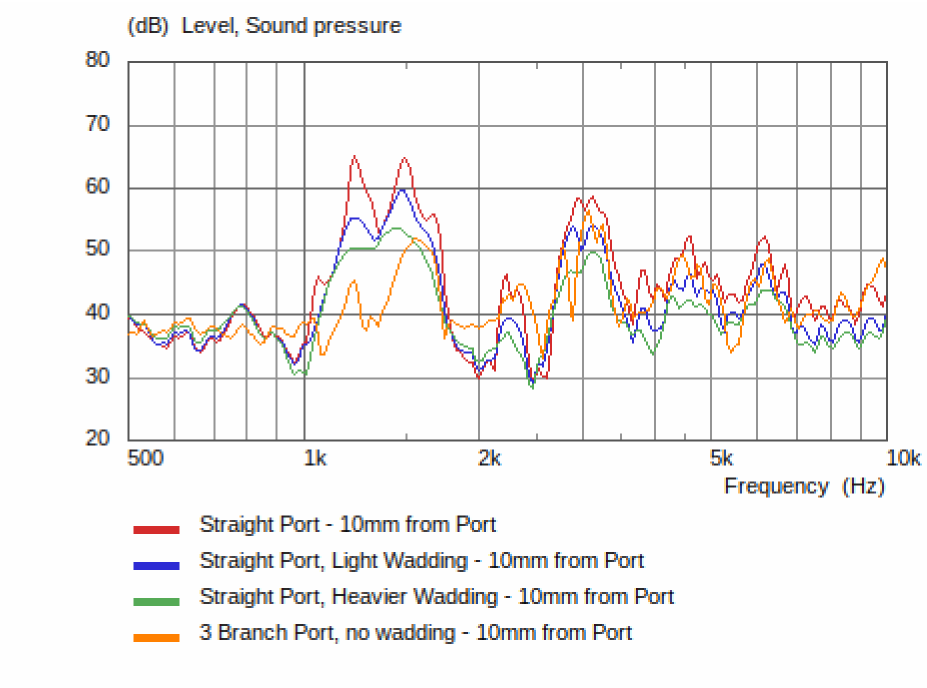

Figure 12 Measurement Taken 10mm from Port Exit

Experimental assessment of the mid-frequency port output was conducted differently than for the numerical modelling as no anechoic chamber was available for the study. Measurements taken at 10mm from the port rear exit however clearly indicate the presence of internal enclosure modes with the straight port as the worst case. The peaks at 1.2 and 1.5kHz agree with the results from earlier simulations. Adding absorption to the system with the straight port lowered the magnitude of these features by as much as 15dB at 1.2kHz and 11dB at 1.5kHz and has some effect both at these two frequencies and more generally. The 3-branch port system reduced the magnitude of the 1.2kHz peak by nearly 20dB and by 12dB for the 1.5kHz peak. The branched port therefore offered more effective attenuation of the port outputs at these two frequencies whilst only having a minor impact on bass performance.

5 LIMITATIONS

It was noted that the modes outside those that were targeted were not significantly reduced when the branched port was implemented, indicating that the combination of port entrance locations was sub-optimal for more general attenuation. This appears to be a limitation of the technique which might be mitigated by:

- Employing a more sophisticated means to interrogate the internal pressure field over a broader range of mode-shapes to compute the port entrance locations
- Increasing the number of branches

A further issue that is true for most ported systems is large signal performance degradation which is discussed in detail in [2]. Noise and losses resulting from high-speed turbulent air as it oscillates in the port is likely to increase due to the geometric complexity of the branched arrangement. Some design effort may be required to minimise sharp transitions at the port entrances.

6 CONCLUSIONS

The concept of a branched port system to mitigate the output of spurious mid-band resonances from the port was tested using predictive simulations which were validated experimentally. The purpose of this paper was not to provide a fully optimised implementation of the approach, but to provide a simple demonstration of the branched port concept. A rudimentary method of identifying candidate positions in the enclosure to locate the internal port entrances was therefore presented.
Finite/ boundary element models provided a valuable platform for experimentation, where the physics of a coupled, distributed system could be demonstrated within what is now a common engineering workflow in loudspeaker design. The creation of “virtual prototypes”, where the branched ports were explicitly defined showed that a reduction in port output could be achieved by as much as 15dB at the modal frequencies targeted. It was noted that outside the target frequency range for the ports tested, there was reduced benefit from the branched port. Extending the frequency range where port output is suppressed may involve a greater number of ports at strategic locations in the enclosure.
The trade-off between adding absorbent wadding to suppress mid-band enclosure modes and the loss of bass was highlighted and it is proposed that in some cases, the branched port technique could be useful where absorbent materials may not be used – for example, in loudspeaker systems that are exposed to the elements.
It is hoped that generally this technique offers the loudspeaker designer an additional choice when designing port loaded systems that operate higher in frequency.

7 FURTHER WORK

Following the investigation on the satellite loudspeaker, it was felt that the concept may have been put to better use if a loudspeaker with higher aspect ratio dimensions was used as the reference prototype. The modal distribution in the satellite speaker was rather sparse – the main axial mode acting front to rear. The absence of axial modes in the other axes was due to the near centrally located driver in the baffle. This positioning meant that these modes were only weakly driven if at all.

This idea could be developed as follows:

- A more efficient means of determining the optimal port entrance locations within the enclosure
- Investigate an optimal number of branches to be distributed such that a broader bandwidth of suppression could be achieved
- Different branching/ manifold schemes such as branches from a central port
- Effect of branching on large signal performance

8 REFERENCES

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2. Salvatti, A., Devantier, A., and Button, D. J., ‘Maximizing performance from loudspeaker ports’, JAES. 2002.
3. R. H. Small. Simplified Loudspeaker Measurements at low Frequencies, JAES. 1972.
4. PAFEC User Manual Level 8.8