# DESIGN AND CONSTRUCTION OF TUNED CABINETS

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Summary – *This practical work corresponds to the subject Electroacoustics II, Sound Engineering program, at the National University of Tres de Febrero (UNTREF). It consists of the design, construction, and measurement of a stereo set of ventilated cabinets, designed based on Thiele's loudspeaker parameters.(taken from a Grundig brand cabinet).*

## 1. INTRODUCTION

This report will present the design of two ventilated boxes, which was carried outfrombased on the Thiele parameters of the speakersbass of the Grundig cabinets (which we sought to improve the frequency response).The speakers were previously measured in their original cabinets.

The decision to manufacture tuned boxes for these speakers was based on the limited frequency response at frequencieslowsobtained from the measurement of the speakers in their original cabinets. Therefore, it is essential for the final design of the enclosures to take into account impedance and frequency response measurements.

Using simulation softwareThe cabinets were designed to have a capacity of approximately 84 liters (which were later reduced by the thickness of the wood) and to be tuned (with a tuning frequency of 65 Hz).They were built with 18 mm thick MDF wood.

## 2. MARCO THEORETICAL

A tuned cabinet, without the speaker, acts as a second-order acoustic bandpass filter. The concept is to turn the box into aHelmholtz resonatorThis is achieved by adding an opening in the box that acts as an acoustic mass, interacting with the acoustic compliance. The resonator generates a phase inversion, so the sound coming out of the tube is in phase with the speaker.

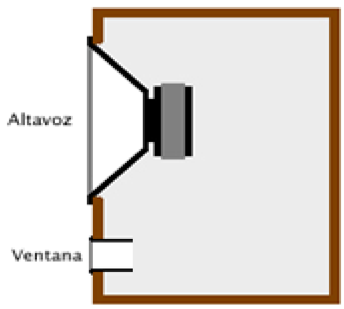


*Figure 1: Tuned box diagram.*

The electro-mechano-acoustic equivalent circuit of the ventilated box is shown in Figure 2.

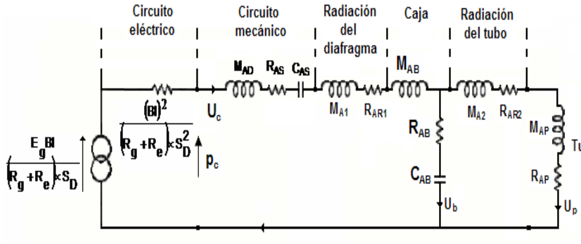


*Figure 2: Equivalent circuit of a ventilated box.*

Figure 3 shows the normalized coil electrical impedance as a function of frequency, for different types of filters.

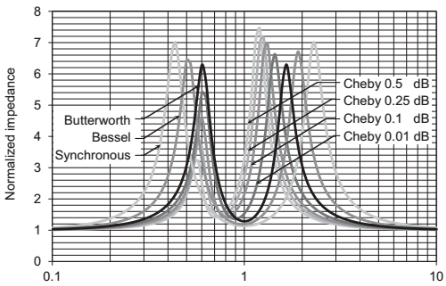


*Figure 3: Normalized impedance curve versus frequency in a tuned box.*

The frequency response is shown in Figure 4.

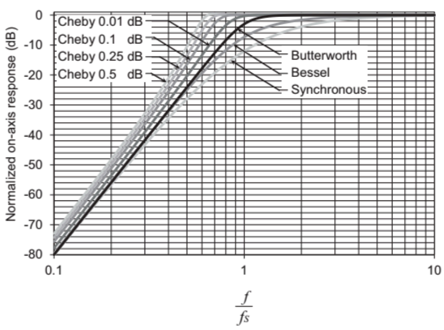


*Figure 4: Normalized frequency response in a tuned box.*

To calculate the box dimensions, the following Thiele parameters are required:

$Q_{ts}$: Total damping factor

$f_s$: Resonant frequency in open air

$V_{as}$: Volume equivalent to the compliance of the suspension.

$C_{ab}$: Acoustic compliance ofthe ventilated box.

$$f_0 = \frac{1}{2p\sqrt{M_{ab}C_{ab}}} \quad (1)$$

Where $f_0$is the tuning frequency of the cabinet, $M_{ab}$is the acoustic mass in the port and$C_{ab}$It is the acoustic compliance associated with the volume of the box$V_v$.

$$C_{ab} = \frac{V_v}{r_0 c^2} \quad (2)$$

$$M_{ab} = \frac{r_0 l_{and}}{S_d}$$

(3)

$S_d$ corresponds to the surface of the port and$l_{and}$ is the effective length of the same.

$$l_{and} = \frac{M_{ab} S_d}{r_0}$$

(4)

## 3. MEASUREMENT AND RESULTS OF THIELE PARAMETERS

| Thiele and Small parameters<br>Speaker 1(bass driver of the first cabinet) | | |
|---|---|---|
| Fs (Resonance Frequency) | 125 | Hz |
| Re (Electrical Resistance) | 5,724 | Ohms |
| $Q_{ts}$(Total Quality Factor) | 1,1 | - |
| $Q_{is}$(Electrical Quality Factor) | 1,461 | - |
| Vas (Volume of Air Equivalent to C)$_{ms}$) | 11,85 | 1 |
| $S_d$(Effective Radiation Area) | 0,02 | $m^2$ |
| $X_{max}$(Maximum Displacement) | 8 | mm |
| Le (Moving Coil Inductance) | 0,322 | mH |

| | | |
|---|---|---|
| n (Performance) | 1,533 | % |
| The (Maximum Power) | 200 | IN |

*Table 1: Thiele parameters measured on the first speaker.*

| Thiele and Small parameters<br>Speaker 2 (second cabinet bass driver) | | |
|---|---|---|
| Fs (Resonance Frequency) | 113,1 | Hz |
| Re (Electrical Resistance) | 5,555 | Ohms |
| Qts (Total Quality Factor) | 1,147 | - |
| Qes (Electrical Quality Factor) | 1,51 | - |
| Vas (Equivalent Air Volume in Cms) | 10,36 | l |
| Sd (Effective Radiation Area) | 0,02 | $m^2$ |
| Xmax (Maximum Displacement) | 8 | mm |
| Le (Moving Coil Inductance) | 0,322 | mH |
| n (Performance) | 0,960 | % |
| The (Maximum Power) | 200 | IN |

*Table 2: Thiele parameters measured on the second speaker.*

## 4. DESIGN

### 4.1 Volume and dimensions

Using WinISD beta speaker design software, conclusions were drawn regarding the tuning and volume of the speaker. Once the data from the tables above was entered, it was observed how the frequency response changed by modifying the volume and tuning frequency of the speaker.box. Finally, ifHe decided on a medium-sized volume (so as not to increase the lobe size of the frequency response at the speaker's resonant frequency), and a tuning frequency that allows for a relatively good extension of the bass range (65 Hz).When choosing the dimensions,He sought to avoid proportional dimensions so as not to provoke modal resonances.The graph in Figure (5) corresponds to the curve that was simulated with the software and which was attempted to be approximated with the design of the boxes.

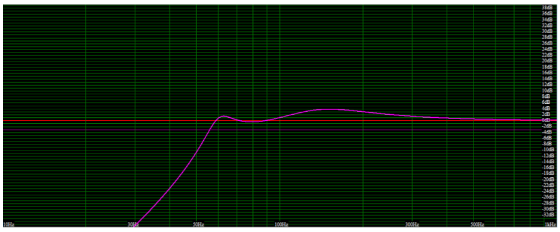

*Figure 5: Simulated frequency response in WinISD*

### 4.2 Port design

Fromdecide the resonant frequency, the design of the surface and the length of the port were thought taking into account the equations of the previous section.

According to equation (1), and replacing values we have:

$$65\ Hz = \frac{1}{2\,p\sqrt{M_{ab}C_{ab}}}$$

Taking into account equation (10), and replacing the values of air density, speed of sound and considering that the volume of the box is 84 liters:

$$C_{ab} = \frac{84\ l}{1{,}18\ \frac{Kg}{m^3}\left(344\ \frac{m}{s}\right)^2}$$

$$C_{ab} = 6,01\ 10^{-7}\ \frac{m^4 s^2}{Kg}$$

With this compliance, the acoustic mass can be obtained by simply clearing it from equation (1) and replacing values:

$$M_{ab} = \frac{(65\ Hz\ \ 2\pi)^{-2}}{6{,}01\ 10^{-7}\ \frac{m^4 s^2}{Kg}} M_{as} = 9,96\ \frac{Kg}{m^4}$$

Depending on the volume adopted for the cabinet and the distribution of dimensions, different values were considered for the port surface. This resulted in different port lengths, which in no case should exceed the depth of the box. Finally, a rectangular window measuring 218.4 cm2 (36.4 cm x 6 cm) was chosen, since, as shown in the following calculation, it yields a reasonable and constructively feasible effective length. Applying equation (4):

$$l_{and} = \frac{9{,}96 \frac{Kg}{m^4}\ 0{,}02184\, m^2}{1{,}18 \frac{Kg}{m^3}}$$

$$l_{and} \cong 18\ cm$$

To determine the final length of the window, we simulated it using rigid cardboard. Measurements were then taken, varying the length, and then the wood used to fit the window was cut.

## 5. CONSTRUCTION

18" MDF was used for the cabinet construction because it degrades less than particle board due to its rigidity. A thickness of 18" was chosen to ensure that the wave emanating from the rear of the diaphragm would be reflected off the rear wall and used in conjunction with the port to increase the low-frequency reproduction bandwidth. The cabinet design was initially planned to feature two 8.2 cm diameter ports, but since a plastic tube of that size could not be found, the port was placed at the bottom of the cabinet. The cabinet dimensions chosen are shown in Figure 6.

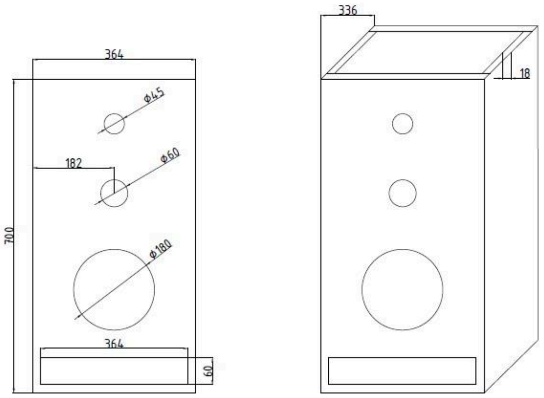


*Figure 6: Cabinet dimensions in millimeters.*

The purchased MDF board measured 2.5 x 1.85 meters, so it was cut and assembled to achieve the aforementioned design. Figure 7 shows the cabinet manufacturing process.

*Figure7: Assembly process of the designed cabinet.*

Finally, the cabinet walls were joined with screws and glued to seal them to prevent leaks that could cause irregularities in the impedance curve. Prior to all this, absorbent materials were added to the rear of the speaker. Additionally, to improve the reproduction of the midrange and treble drivers, the openings in which they are located were rounded, resulting in better impedance matching across the drivers (pseudo-horn effect).Figure 8 shows the two finished cabinets.

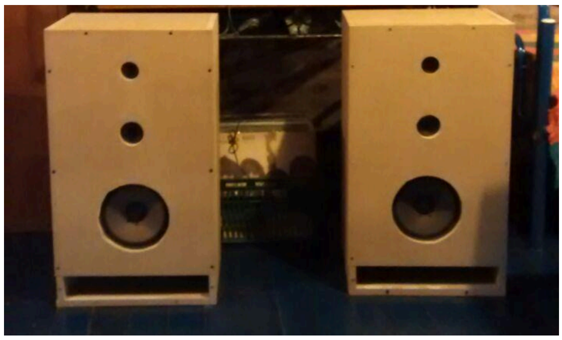

*Figure8: Cabinets in their final presentation.*

## 6. CABINET MEASUREMENT

### 6.1 Impedance

To obtain impedance information, we used the DATS device, which connects the computer to the speaker via a very simple connection. It has proprietary software that generates an impedance curve using a frequency sweep.

### 6.2 Frequency response

An audio card connected to the computer is used; one channel is connected to the Earthworks

M50 measurement microphone. Another channel corresponds to feedback from the same board (reference channel). The transfer curve is a comparison of one channel and the other when pink noise is generated using Smaart 7 software. To make a correct measurement, it is necessary to calculate and correct the delay between the signal generated on the PC and the analog signal picked up by the microphone.

The resulting graph is shown in theFigure 9. The annex presentsthe graphics of each speaker, the port, and a midpoint between the woofer and the port.

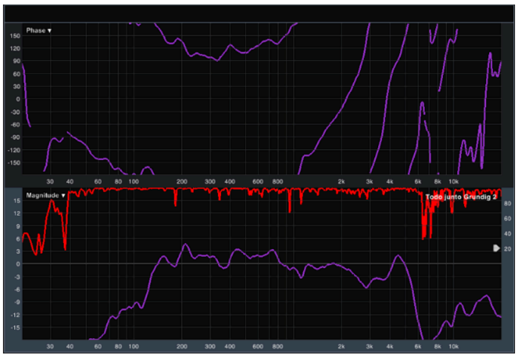


*Figure 9: Measurement with Smaart 7 of the cabinet.*

## 7. RESULTS

The three pillars of this report are based on obtaining results from the perspective of the electrical performance of the speaker as a transducer, acoustic behavior (frequency response), and subjective assessment.

Considering that the port calculation yielded a length of approximately 18 cm, impedance and frequency response measurements were made with a port length of 25 cm, 20 cm, 16.5 cm with and without absorber inside the box. At this point, and observing that there was noTo achieve the desired bass extension, it was decided to measure the cabinet using only the window as ventilation (without a board behind it extending its length). It was observed that the desired resonant frequency was exceeded.Finally it was decided to choose oneboard length of 5 cmWhen measuring impedance and frequency, it was found to fit the initial requirements. Figure 10 shows the frequency response of the first cabinet designed.

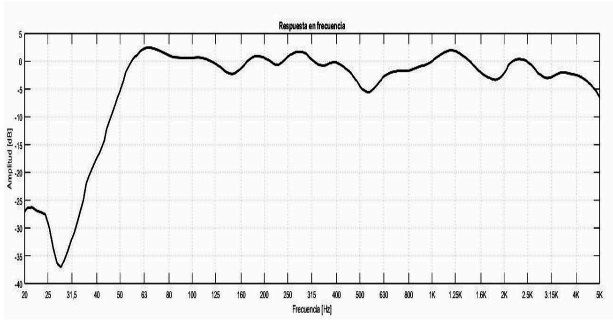


*Figure 10. Frequency response of the designed cabinet*

### 7.1 Impedance

First, the impedance curve measurements were taken with the cabinet without the port and without an absorber, and then with a 25-volt port and with an absorber. The difference between these measurements can be seen in Figure 11.

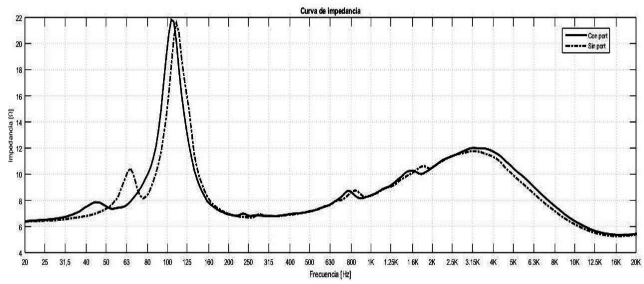


*Figure 11. Difference between cabinet with and without 25cm port.*

Figure 11 shows how the curve softens in the frequency range between 40 and 80 Hz, where the tuning frequency is located. It can also be seen that adding the port and absorbent material shifts the system's resonant frequency slightly toward lower frequencies. This effect is due to the acoustic compliance of the cabinet, combined with the added effect of the absorbent material. Figure 12 shows this effect in more detail in the frequency range between 50 and 150 Hz.

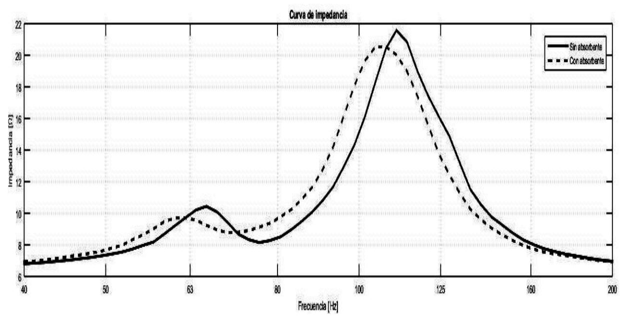

*Figure 12. Difference between cabinet with and without 25cm port.*

It is interesting for fine analysislCompare the speaker impedance curve without any cabinet and the resulting curve using the design built with 5cm port andabsorbent.Figure 13 shows this comparison.

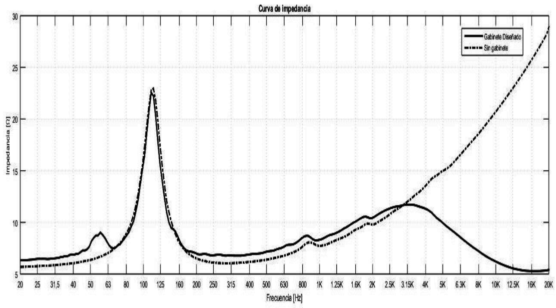


*Figure13. Comparison of impedance curve between speaker without box and the speaker in the designed cabinet.*

From Figure 13, a peak in impedance can be seen at approximately 55 Hz due to the tuning frequency achieved at 65 Hz. Another interesting finding occurs for frequencies greater than approximately 3 kHz, where it can be observed that the impedance curve of the designed cabinet drops due to the parallel formed between the three speakers when the measurement is made with the DATS, since said measurement is made from the terminals at the output of the entire system (3 speakers). At the same time, a slight shift in the resonant frequency of the system can be observed due to the action of the cabinet.

### 7.2 Frequency response

In order to see the changes in frequency response caused by the tuned cabinet, it is worth observing how the speaker behaved.with its original box, according to figure 14.

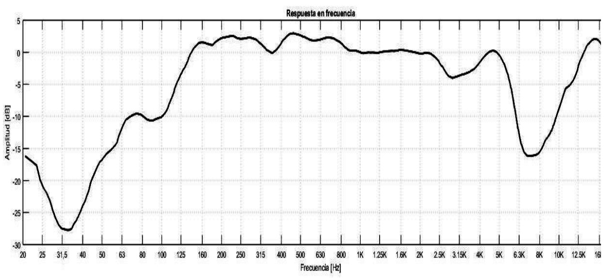


*Figure 14. Frequency response of the system with the original cabinet.*

Then, the frequency response curves were obtained by varying the port length to 20 cm and 16.5 cm without absorber as shown.can be seen in figures 15 and 16 respectively.

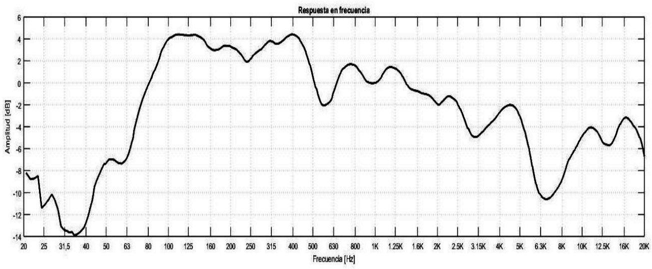


*Figure 15: Frequency response with 20 cm port without absorber.*

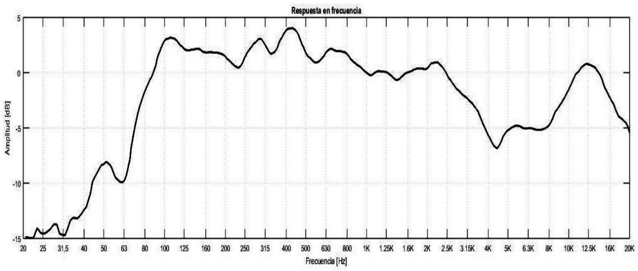


*Figure 16.Frequency response with 16.5 cm port without absorber.*

With the procedure described above, for the designed cabinet of 84 liters and rectangular port of 36.4 cm x 6 cm x 5 cm, the frequency response of figure 17 was obtained:

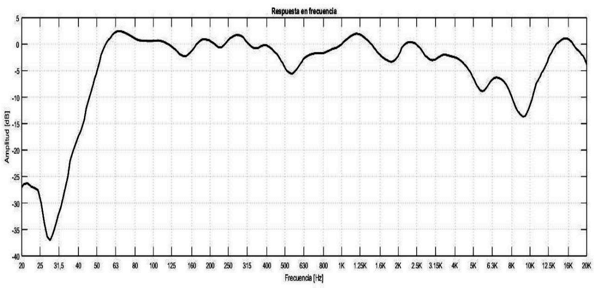


*Figure 17. Frequency response of the final designed cabinet.*

It can be observed that the frequency response shows relatively small variations within the frequency range.125 Hz y 10K. It is also possible to see thatThe lower cut-off frequency, from which low frequencies begin to be attenuated, is around60 Hz.

Regarding the reproduction of mid and high frequencies (where significant cancellations are observed), it was concluded that higher quality would be achieved by building a crossover that would allow for more precise crossover frequencies to be determined (where the reproduction of each driver would begin to attenuate) as well as the in-phase summation of the drivers in their vicinity. The original crossover (used in this work) consists of two high-pass filters to prevent the mid and high drivers from reproducing low frequencies, but it does not have any type of cutoff for the low frequencies or to prevent the mid drivers from reproducing high frequencies.

## 8. CONCLUSIONS

Figures 18 and 19 show the impedance curves of cabinet number 1 and number 2 respectively.

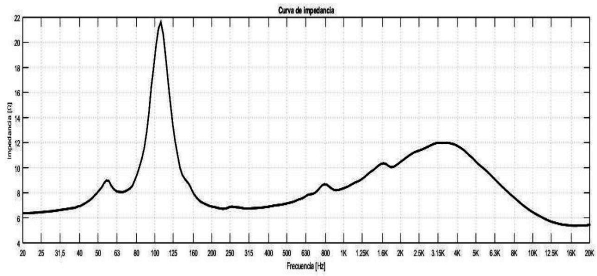


*Figure 18. Impedance curve of the designed cabinet number 1.*

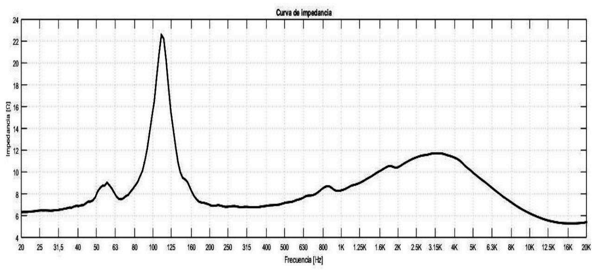


*Figure 19. Impedance curve of the designed cabinet number 2.*

From the figures18 and 19, it is observed that the frequencydand speaker resonance in thefirst cabinetshifted from 125 Hz to115 Hz approximately. In turn, in the case of other cabinet, the resonant frequencywent on to118 Hz approximately.This happened because of the addition of absorbent inside the walls of the box.and the operation of the ventilated box itself.

From the impedance graph it is seen that the tuning frequency is finally64Hz for the first cabinet and 63Hz for the second.

This is consistent with the fact that the frequency response graphs show a lobe around these frequencies, which was what was initially sought to extend the bass, and also what was predicted by the simulation.

On the other hand, the port design in theory yielded a value of 18 cm of effective length, which meant athe physical length of between 10 to 14 cm. PBut the truth is that a 5cm wood was used and the frequencyThe tuning range was still determined around 65 Hz, which was what was sought.To understand this visible difference between both measurements, it is important to know that the correction calculations that exist to obtain the effective length are actually designed for cylindrical ports, despite working with windows of equivalent section., and that the acoustic mass does not work in exactly the same way if its dimensions vary too much (along with its shape).

## 9. REFERENCES

Leo L. Beranek, ‘Acoustics’ 2nd Ed., 1969, Bs.

## Annex A

This appendix presents Smaart 7 graphs, measured with an omnidirectional Earthworks microphone.

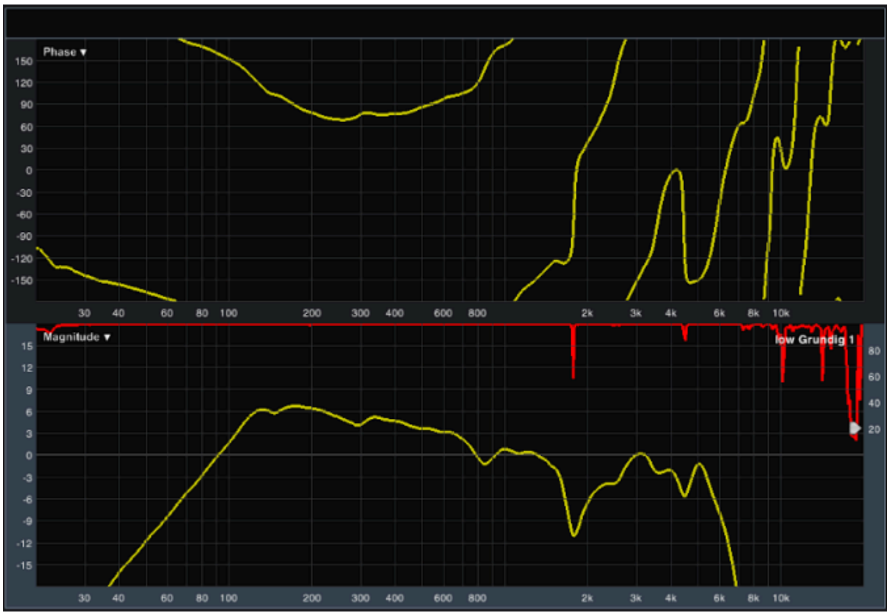


*Figure 1A: Measurement with Smaart 7 of the Low speaker*


*Figure 2A:Measurement with Smaart 7 of the Mid speaker*


Figure 3A: Measurement with Smaart 7 of the High speaker


Figure 4A: Measurement with Smaart 7 of the port