Directivity measurements applied to DML (directivity plots). Ed4.

ChristianV (Homeswinghome@diyAudio)

11 Feb. 2025

Abstract

After an introduction to the coincidence frequency and the directivity index, this document shows some directivity plots of DML made from different materials and evaluate their coincidence frequency.

Contents

Ed4: Additional sources about directivity (videos), a FR of the rear side is added when possible and also a FR of the lateral emission, 2 new materials: XPS 20mm and XPS/depron 9mm. New values and elements in the conclusion.

Disclaimer : this paper is written in the context of DIY DML building with the target to identify some design rules to help in the panel construction. This document is not written in the context of any academic or scientific work. Its content is reviewed only by the feedback it can get while posting it in audio DIY forum like diyAudio.

This document was exported from a markdown file with pandoc. Done : February 11, 2025.

1 Introduction

All the directivity plots here were done following the method described in a previous paper Directivity measurements applied to DML (how do to it?)

Thanks to Eric and Thomas who sent me their files.

For the different panels after, the results are shown in 2 figures, one showing the directivity plots, the second polar plots at different frequencies.

For the directivity plot figure:

- on the up left is a “as measured” directivity plot with the same global gain applied to each point. This gain is set to give an average 80dB SPL over the -20° to 20° measurements. The idea is to try to give the same color on that area for each test.
- on the up right is the normalized version. For this one, the SPL of one frequency for all the angles is compensate by the gain giving 80dB for 0° (= all the points of the on axis FR are at 80dB). After testing it, it might be this view is a bit “extreme” as if there is a dip, it is compensate by a gain that won’t be used in reallity.
- below on the left is the frequency response in the 20° listening value (SPL mean value in the window) and the directivity index DI.
- on the right of the DI, there is a polar directivity plot based on an equalization over the 20° listening window, with a limited gain. The values are thresholded in the +/-3dB band to give a uniform color to better show the directivity singularity.

Here is the color scale of the 2D directivity plots.

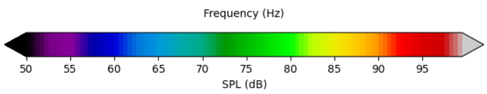


Figure 1: Directivity plot color scale

The polar plots at at the third of octave frequencies. They are “slices” of the directivity plot (raw values).

2 Coincidence frequency, directivity

2.1 Coincidence frequency

The bending waves in a thin plate are said dispersive to say their speed increases with the frequency, more precisely with the root square of the frequency. From slower than the speed of the sound in the air, this speed in the plate can become faster than in the air if the material can support it (mainly if it resists “enough” to the shear stress)

If the shear modulus is not high enough, the speed in the panel reaches a maximum value possibily lower than speed in the air.

The coincidence frequency, if it exists, is the frequency at which the speed of the waves in the panel are equal to the speed of the sound in the air.

This value is important as it defines how the panel vibration will be transfered to the air and so the direction of the radiation.

According to the theory:

- Below this frequency, the panel is supposed to have enough lobes to be considered omnidirectional.
- At the coincidence frequency, the emission is supposed to jump to 90°.
- Above, as the frequency increases, the main lobe angle decreases.

2.1.1 Coincidence frequency evaluation

The evaluation of the coincidence frequency in the results below is based on an information that tells us there is a relation between the coincidence frequency, the considered frequency above the coincidence and the angle of the beam at that frequency in the form:

$$\frac{f}{fc} = \frac{1}{sin^2(\alpha)}$$

There is no parameter from the panel here so this pattern can be plotted easily in a directivity plot independently of the plate material characteristics. Just by changing the coincidence frequency fc value, we can see what fits the best.

A function in the plotting python script was added to reflect the mean SPL value of the points along the curve above. The idea being a good candidate for the coincidence frequency is where this function gets a maximum; where the curve goes through to all the maximum of the expected lobes.

2.2 Directivity and DI (directivity index)

The importance of the directivity, as for all audio sources, based on the work of Toole, Olive, Evans, is reminded in different papers about DML like [1], [2].

The general requirement about the directivity of a loudspeaker is to have a smoothly increasing directivity.

For more about the directivity and the associated measurements, see for example : ASR Understanding Directivity Error in the Measurements

See also 2 linked documents : a paper from Sausalito Audio [3] and the CTA 2034 standard "Standard Method of Measurement for InHome Loudspeakers" [4].

This video How to Pick Your Speakers Using Spinorama Measurements? is also a good introduction to the directivity measurements and how the information are shown.

Those 2 videos are also a good introduction to the directivity topic and the influence of the directivity on the listening experience according to the type of music: Audioholics, What Is Loudspeaker Directivity and Audioholics, Narrow vs Wide Dispersion Speakers: Which is Better?.

There is also the site spinorama.org that shows many measurements made on loudspeakers. Here is the link to spinorama.org help page with the links to the main papers about spinorama.

"Spinorama" seems to refer to the whole procedure from the measurements in the horizontal and vertical plane to the post-processed frequency responses shown in a standardized way

So, as in this document the whole process is not applied, the goal being to share the directivity map, the words "directivity plot" are used here instead of "spinorama" in the first edition. Other possible namings are "contour plot", "directivity chart", "polar map".

The directivity plot can be in the horizontal plane, horizontal directivity plot (rotation according the vertical axis), or in the vertical plane, vertical directivity plot (rotation according to the horizontal axis, in practice to do it , the speaker is turned by 90°, refer to the pictures in the standard CTA2034 [4]).

See figure 2 below.

An indicator of the directivity is DI, directivity index which shows the difference in SPL between the emission in the listening window and in all the directions.

The implementation proposed in p11 of [2] is in the Python script. The result is shown below the directivity plots. This implementation is simplified compare to the CTA2034 [4] but nevertheless very informative.

The requirement about the directivity is translated by a smoothly flat or increasing DI and for sure no negative values that shows the level off-axis exceeds the on-axis one.

In the standard, the DI is given for a +/-30° in the horizontal plane and +/-10° in the vertical plane listening window. In this paper, the listening window is limited to +/-20° denoted LW20 and the DI DI20.

The DI at the coincidence frequency can be very low!

In [2], 2 ways to improve the panel directivity are suggested:

- increasing the panel material damping
- adding some edge damping

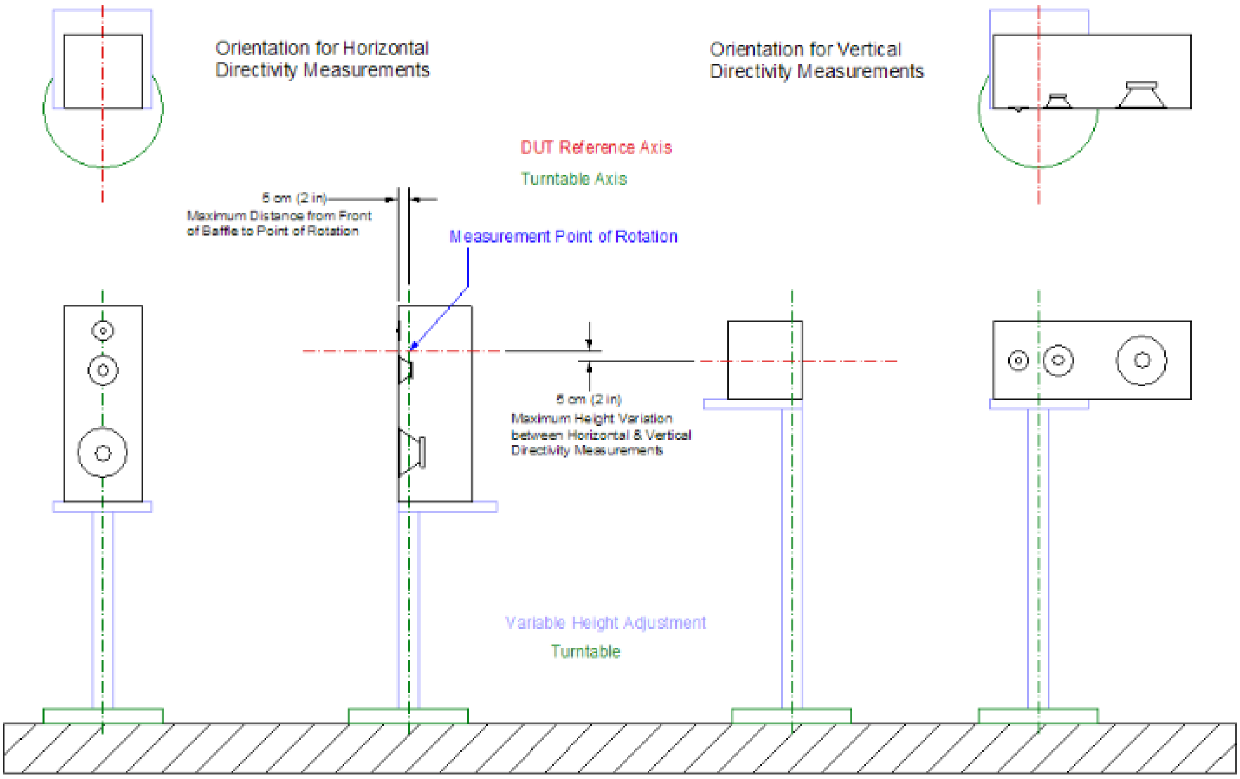


Figure 2: CTA2034: horizontal and vertical directivity measurements

2.3 Examples from the "litterature"

2.3.1 Tectonic

The directivity plot below is from the Tectonic DML500 specifications

See figure 3.

In this case, the detection pattern of the coincidence frequency, in blue at different positions on the graph, doesn't match with the measurement. There is no other example like that after,… neither explanations.

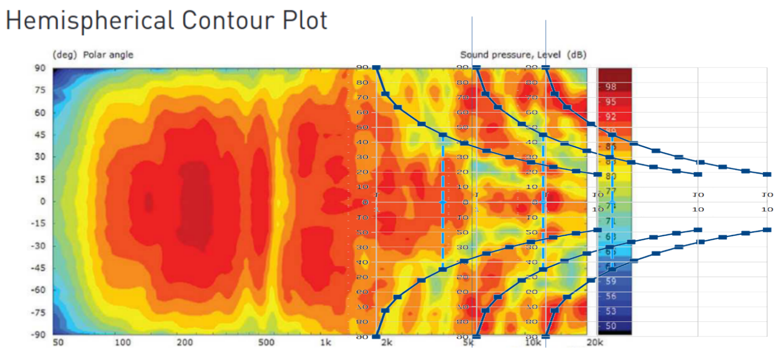


Figure 3: Tectonic DML500 directivity plot

2.3.2 B Zenker's experiments

In his paper Upper Frequency Limit of Flat Panel Loudspeakers - Evaluation of the Voice Coil Break-Up Modes, B Zenker shows several directivity plots. One is below showing a good match with the detection pattern.

See figure 4

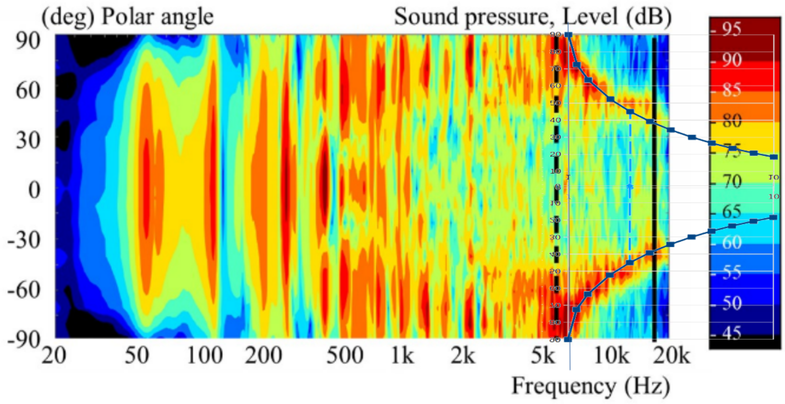


Figure 4: B Zenker's paper" directivity plot

3 Stantard drivers measurements

3.1 FRS8 in a closed box (monopole)

As an example, here is the horizontal directivity plot and DI of a 8cm full range Visaton FRS8 in a small 1.2l closed box.

See figure 8 and 9

3.2 FRS8 on open baffle (dipole)

The same FRS8 in a 33x41cm open baffle (dimensions chosen similar to the DML dimensions after)

See figure 10 and 11

Note the dip near 1400Hz typical of an open baffle. At this frequency, the directivity pattern as the shape of 4 lobes visible in the normalized directivity plot.

There is also a strong emission to the rear near 2200Hz. At this frequency, there are 3 main directions of emission in front and a large lobe to the rear with a higher level. There is no dip at 90° as expected from a dipole.

3.3 Tweeter Fostex FT17H

This unit was in my old 3 way column. To have an idea of the directivity of a this kind of tweeter

See figure 12 and 13

4 Glass panel (coincidence frequency check)

4.1 5mm glass panel

To check the accuracy of the coincidence frequency measurements, Eric tested a panel of glass. See his post #12753

The caracteristics of the glass being known : $E = 70GPa, \nu = 0.22, \rho = 2500kg/m^3$, with a 5mm thickness and $c = 343m/s$, it comes $f_c = 2392Hz$.

The plate was 31x52cm driven by a DAEX25FHE.

See in figure 14

Due to the low damping of the glass and so the very strong modes, the data have been exported smoothed at 1/24 octave (for the previous plot of ed1 and 2, it was a 1/6 octave smoothing). The 1/24 octave smoothing is adopted for all the materials after.

It is visualy difficult to be precise in this example. The fc seems to be in the 2kHz to 3kHz range which is not so bad. The estimation function gives its maximum at 2421Hz which is really close to the expected value.

4.2 1.7mm glass panel

Eric tested also a thin 1.7mm thick 20x51cm glass panel with the DAEX25FHE.

The glass parameters are as before. The expected coincidence frequency is 7136Hz.

From the python script it comes fc = 6950Hz. Not too bad!

See figure 15

5 EPS (Expanded Polystyrene)

5.1 EPS 10mm

As my questions about directivity started with tests of an EPS panel (30x40cm, 10mm thick, PVA coated only on the exciter side), it was the first horizontal directivity plot I did.

No spine, no peripheral suspension (central tape + sponge tip).

Note that the central area, inside the voice coil perimeter, was already tweaked in order to try to remove a peak at 11kHz (a small wood pipe was inserted at the center to add a weight), so this panel is maybe not fully representative in HF.

Anyway, here it is : see figure 16 and 17

It shows on the left that the panel doesn't extend fully to the extrem highs but more interesting and more visible on the right that the SPL from about 2k to 8k are higher in the direction 40 to 70° than on-axis. It is visible in the DI plot which is decreasing.

From this horizontal directivity plot, I can make no assumption about the coincidence frequency; neither the search function detects one.

Note that for this panel and as others about the same dimensions after, the high SPL in the 500Hz area on the left followed by some dips.

Before these directivity measurements, the listening results of this panel lead me to consider panels with a possible higher coincidence frequency (this was before the directivity plots). 2 possibilities:

- For a given plain material reduce the thickness
- Change the material to an heavier or softer one (less stiff).

It is the origin of the tests of the plain transparent polystyrene here after.

5.2 EPS 20mm

A 35x80cm panel made of a light EPS 20mm was tested.

It is the first panel by the order of this paper measured from +180°/-180°. As expected the known strong emission from the rear in the 2/3kHz range is clearly visible at it is from all the measurements showing the rear side.

This panel is a good example to summerize all the directivity singularities found (see conclusion).

Here again the highs are limited. A "drum effect" is visible around 15kHz (resonance of the area of the plate inside the voice coil diameter).

The directivity plot doesn't show a coincidence frequency pattern. The dips in the DI suggest possible values.

Finally, the value of 12.3kHz is adopted. This value matches pretty well with the position of the on-axis peak (explanation after) and with one possible point of the pattern in the 18/19k range in the directivity plot.

Even if it is not the same EPS raw material as the previous panel, this fc for a 20mm thick panel should explain that for the 10mm EPS, the fc is not visible. As being thinner, its fc should be higher in the frequency range so above 20kHz.

See figure 18 and 19.

6 PS (plain Polystyrene)

The next test is with a clear polystyrene (transparent polystyrene), the one that makes the protective window of frames. I had one sample of that (30x40cm, 1.3mm thick), no spine for the -90/90° plot, it was added after for the -180/180 plot. The panel is framed with a peripheral suspension made of a D shape wheather strip. This panel was used also for other tests before making a directivity measurement.

See figure 20 (-90/90° plot from ed1 and ed2)

See figure 21 and 22 (-180/180°)

Here no evidence of the coincidence frequency, this is expected by the characteristics of the material and the low thickness of this plate.

There is no more higher SPL in the 40° to 80° as the EPS one but it appears a too high level in the 2kHz/40° (x mark and dotted line) and a lack of SPL in a kind of oblique channel in HF.

The high level at 2kHz/40° in the normalized view is caused by the dip seen at 2kHz/0° which ask for an important gain correction.

The directivity plot made from -180 to 180° shows some asymetry which seems not due to a measurement error (done twice). This asymetry is less or even not visible in the plot of ed1. The difference is the introduction of an horizontal spine. Some asymetry seems present in other plots.

The rotation axis was centered on the panel width and exciter is 30mm off axis. This cause an angle error of less than 1.7° (max for 0°, 180°) which is not sufficient to explain the asymetry.

The DI shows similiraties with the FRS8 in open baffle one in the mids which would confirm that in this range, the DML behaves as an open baffle but this is a full different topic.

On this panel, I changed the DAEX25FHE by a small DAEX13CT. The idea behind was to see what happened whith an exciter having a lower moving mass, a lower inductance which are suppose to limit the highest frequency.

Here it is the PS panel with a DAEX13CT : see figure 23 and 24.

No more "channel" in the HF area but a high level remains; slightly lower in frequency at 1400Hz. As the difference compare to the previous test is the exciter (same 2/5 location for both), the "channel" seems purely linked to the exciter characteristics and the 1.5k to 2KHz/0° dip to the panel including the suspension and the exciter.

After watching the videos from D. Anderson on Youtube (Earth tones Electronics), an additional parameter is the dimension of the exciter panel interface. To reduce the diameter increases the frequency of the drum effect which might improve the HF.

On the CT13 polar plots, the good quality of the the radiation in high frequencies is noticable.

7 Plywoods

Several sources, woods and thickness were tested.

7.1 5.9mm "triply" poplar Plywood

This measurement is from Eric

See figure 25 and 26

The plot shows a coincidence frequency at 5300Hz, some singularities in the high angles before and an increasing directivity in the highs.

7.2 5mm "standard" Plywood

The next test is with a piece of 5mm standard (in France) plywood. Its dimensions are 34x42cm.

This panel was measured in both directions.

See figure 27 and 28 for "along the grain"

See figure 29 and 30 for “across the grain”

This panel seems suffer of all what was seen before : the high SPL in the 40° to 80° direction, the HF “channel”, the 2kHz/0° dip and many other dips. In addition the dotted line and the cross points make an assumption about a possible coincidence frequency which is evaluated here at 6900Hz in the stiffer direction at 5200Hz in the other direction

The 5mm plywood panel was also in almost free edge conditions.

The 5mm plywood seems too stiff (too low coincidence frequency) and not damped enough (material damping or edge damping?).

7.3 3mm Poplar Plywood

To continue with the available samples, 2 poplar plywood panels were tested; one being waiting for next panel build, the second being the large plywood panels I made maybe 2 years ago.

One is 25x125cm, no suspension, no spine while the existing panel is 42x120cm, with a spine and a peripheral weather foam.

See firgure 31 and 32 for the raw panel.

See figure 33 and 34 for the varnished panel.

Those panels show the same characteristics as the previous one.

With the same method as for the 5mm plywood, the coincidence frequency evaluation is 13000Hz for both, the vertical axis being along the external grain. If not measured, the coincidence frequency in the second direction is probably lower (higher stiffness).

A dotted line at the frequency of a hump in the rear side FR is added to see if it as some relation to the front behavior. It is at 2.5kHz for the 25cm raw panel and 1.9kHz for the 42cm plywood panel. Not clear at this moment but this rear side hump is visible at +90° and -90° as a kind of leakage at the limit of the directivity plot. It is also the range of the front lobes at 45°.

Some high frequency high SPL being visible on those panels, it seems they are still a little to thick.

They seems also not damped enough even for the varnished one. The varnish used was highly diluted with the idea not to add too weight, stiffness or damping!

7.4 2mm Basswood plywood

See figure 35 and 36 for the basswood panel “along the grain”

See figure 37 and 38 for the basswood panel “across the grain”.

The coincidence frequency is evaluated at 16500Hz when the axis is along the grain for 12300Hz in the second direction.

The plots show also the increases of directivity with the frequency and the important lobes in the range 1kHz to 5kHz.

The 3 lobes in front with an even more important rear level is visible at 2kHz.

8 CF balsa composite

8.1 CF balsa with poron suspension

Those measurements are from Eric.

See figure 39 and 40 H plane

See figure 41 and 42 V plane

The coincidence frequencies are clearly visible at 5300Hz and 15000Hz which is in a much larger ratio than what seen for the plywoods.

What is noticable here it is the bending stiffness in both direction are measured similar by Eric. The hypothesis is an important difference in the shear modulus according to the directions.

8.2 CF on DIY end grain balsa

Those measurements are from Thomas.

This composite is made with a DIY end grain balsa core.

From the plots, the coincidence frequency is evaluated at 5.9kHz

See figure 43 and 44

9 3D printed plate

9.1 2mm 3d printed PLA 0.2m skins

Thomas tested a 2D printed plate. It is a 250x235mm, 2mm thick, plate made of PLA with 0.2mm skins driven by a TEAX25C05-8 exciter.

No coincidence frequency is visible on the directivity plot. The search index doesn't give a useful information.

See figure 45 and 46.

10 Canvas panel

One canvas panel being available, it was included in the measurements.

Note the central pad is made of 2 perpendicular layers of 1mm each balsa board (not of plywood as more usualy)

See figure 47 and 48

No coincidence frequency is detected. The directivity increases in the highs above 8kHz

The 4 lobes and 5 lobes already seen in the other panels (all here are in an open back configuration) and in the FRS8 in open baffle are clearly visible.

The rear side shows also levels higher than in the front.

11 XPS (eXtruded PolyStyrene)

11.1 XPS 20mm

This 60x125cm panel was PVA coated on both sides. The front got acrylic paint. The thickness of the exciter area on the front side was reduced in a form of a cup shape in the idea to limit the level in the higths.

See figure 49 and 50.

11.2 XPS/depron 9mm

This test was done with a remaining 60x60cm piece of raw depron 9MM (shiny white XPS used for insulation). No sanding, no coating.

See figure 51 and 52.

12 High frequency peak vs coincidence frequency and exciter interface diameter.

As mentionned before, D. Anderson introduced in his video the relation between the coincidence frequency, the driving diameter of the panel (which is usually the voice coil diameter) and the peak in high frequency after which the SPL drops.

The peak is suppose to occur when the wave length of the wave in the panel is close to the interface diameter.

Let's call f_h this frequency.

From the relations giving the coincidence frequency f_c and the wave length in the panel (see for that for example Dave Anderson's thesis [5] p106 eq 8.18 and 8.20), it comes the following relation :

$$d_{interface} = \frac{c_{air}}{\sqrt{f_h \cdot f_c}}$$

In order to check the pratical validity of this relation, the different f_c and f_h values from the measurements shown here were collected and here is the plot.

See figure 5

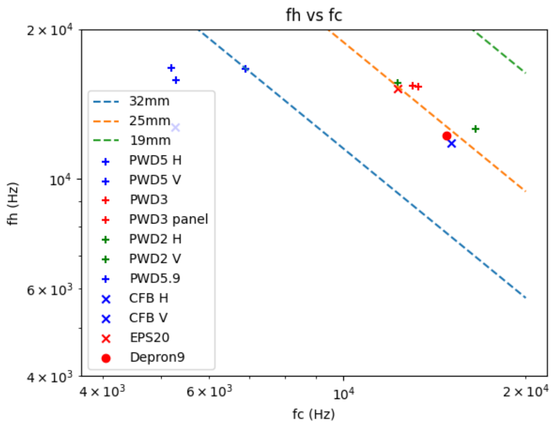


Figure 5: fh vs fs

There is a strong limitation which is the relation is for an isotropic plain material where the materials tested are for most of them anisotropic, orthotropic and even composite…

Nevertheless, it is interesting to have a look…

With the test of the CT13 on the PS1 panel, it is an invitation to test the reduction of the diameter of the panel interface as it is inaugurated by HvdZ in is post #13102.

13 Conclusion

Short conclusion for a long paper?

- The directivity measurements are feasible for a DIYer in a standard environment with a tool like REW. An additional tool to plot the data in the form of a directivity plot is welcome!
- It allows to detect the coincidence frequency (or at least an interval of frequencies). See an example in figure 6
- The measurements of this document confirm that decreasing the thickness of a given material increases the coincidence frequency (see the plywoods). The coincidence frequency of a soft, heavy and thin material is also high.
- Those measurements show also that a panel having the same stiffness in its both direction may show different coincidence frequency according to these directions.
- If no coincidence frequency is detected, the panel doesn't suffer from the strong associated lobes. A test with the same material thicker might confirm the coincidence frequency of the thinner is out of the audio range.
- It is confirmed that the ring diameter of the exciter voice coil makes a low pass filter. The cut off frequency can hide the coincidence frequency which can be an advantage for the panel use or a drawback in test. In test an interface with a smaller diameter (smaller exciter or concentrator) might help in the fc detection
- The measurements have also shown other directivity singularities for open back DML with an exciter in the standard positions. Some of those singularities are similar to the one of a small large range on an open baffle of same dimensions which will need more investigations. See figure 7 for a list of the singularities.

So without hesitation, to add to the DML builder toolbox.

Table of the measured coincidence frequencies:

Material	Direction 1	Direction 2
EPS 10mm	> 20kHz °	no mes.
EPS 20mm	12.3kHz	no mes.
PS 1.3mm	> 20kHz	no mes.
PWD poplar "Triply" 5.9mm	5.3kHz	no mes.
PWD standard 5mm	6.9kHz	5.2kHz
PWD poplar 3mm	13kHz	no mes.
PWD basswood 2mm	16.5kHz	12.3kHz
CF balsa (non end grain)	15kHz	5.3kHz
CF balsa (end grain)	5.9kHz	no mes.
3D printed PLA	> 20kHz?	no mes.
Canvas panel (balsa pad)	> 20kHz?	no mes.
XPS 20mm	> 5.7kHz	no mes.
XPS depron 9mm	14.8kHz	no mes.

Markdown table generator

° with a limitation in the highs… so the fc might be hidden.

no mes.: not measured

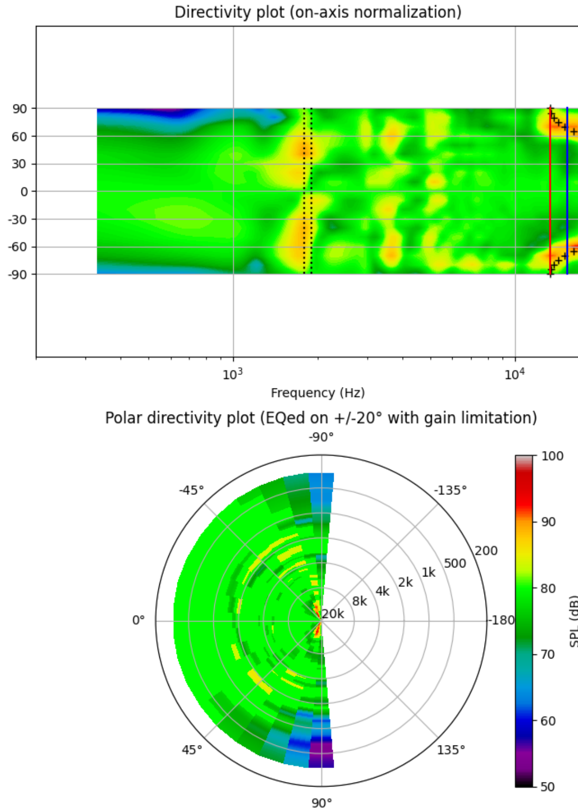
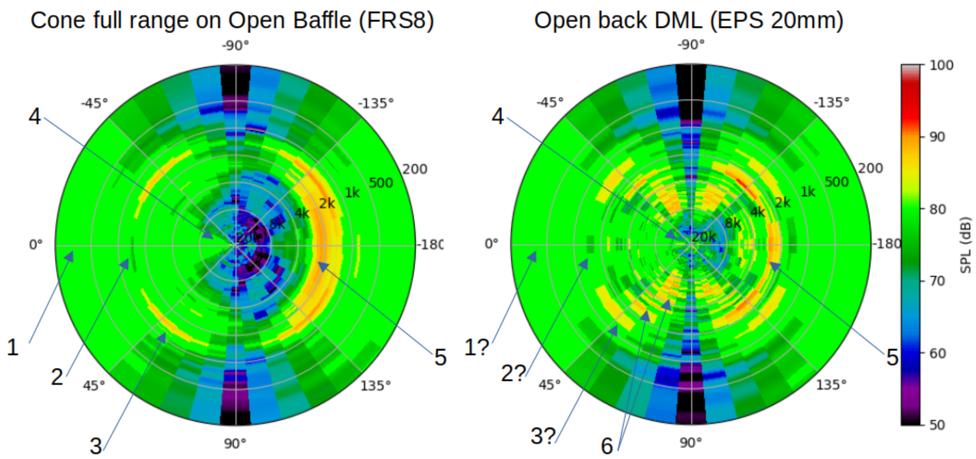


Figure 6: Example of coincidence frequency pattern



1 : dipole peak (not visible due to EQ)
2 : dipole dip
3 : dipole lobes
4 : HF high directivity
5 : cavity noise
6 : high angle mids/high mids lobes (specific to DML?)

Figure 7: Cone loudspeaker on OB and Open Back DML directivity singularities

14 Directivity and polar plots

14.1 Standard drivers

14.1.1 FRS8 closed box

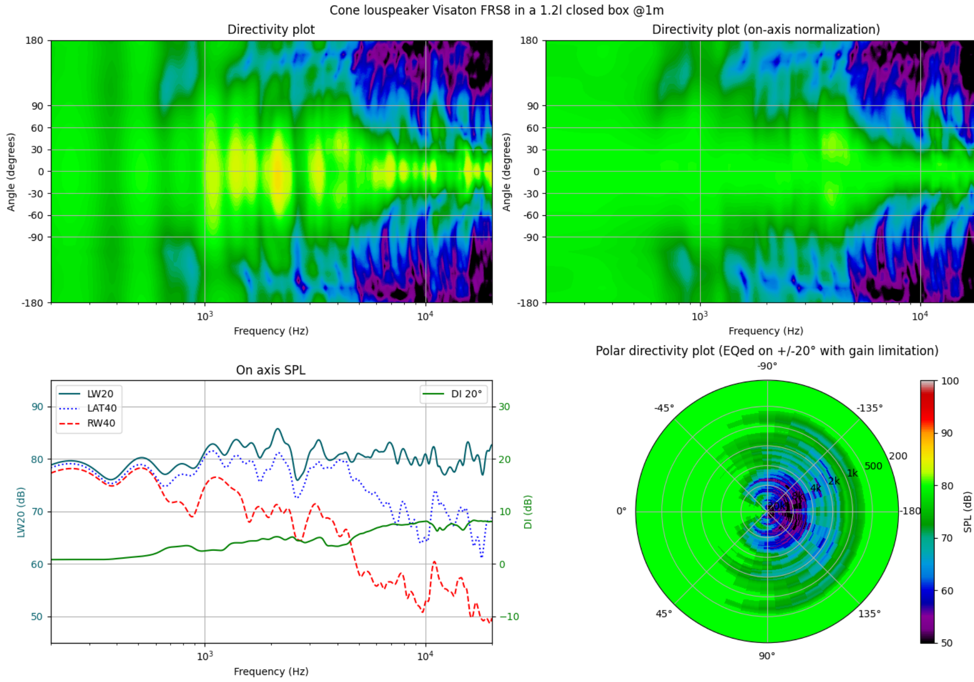


Figure 8: FRS8 closed box horizontal directivity plot and DI

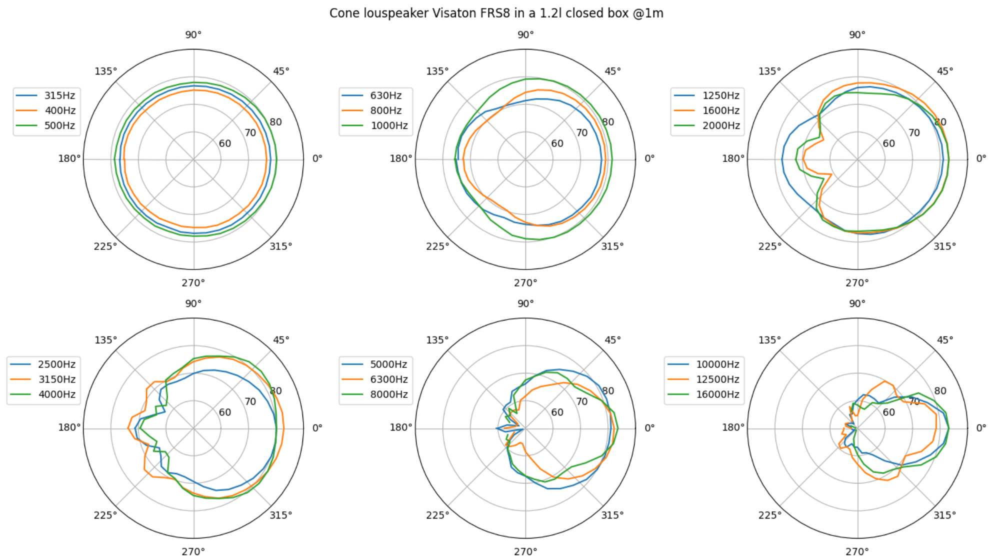


Figure 9: FRS8 closed box polar plot

14.1.2 FRS8 open baffle

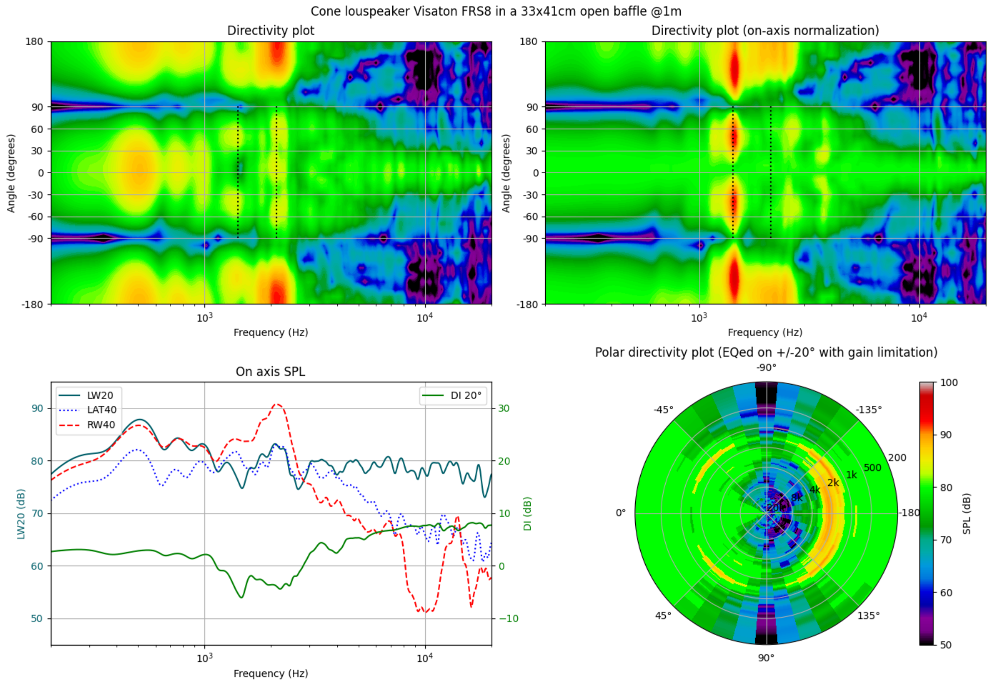


Figure 10: FRS8 open baffle directivity plot and DI

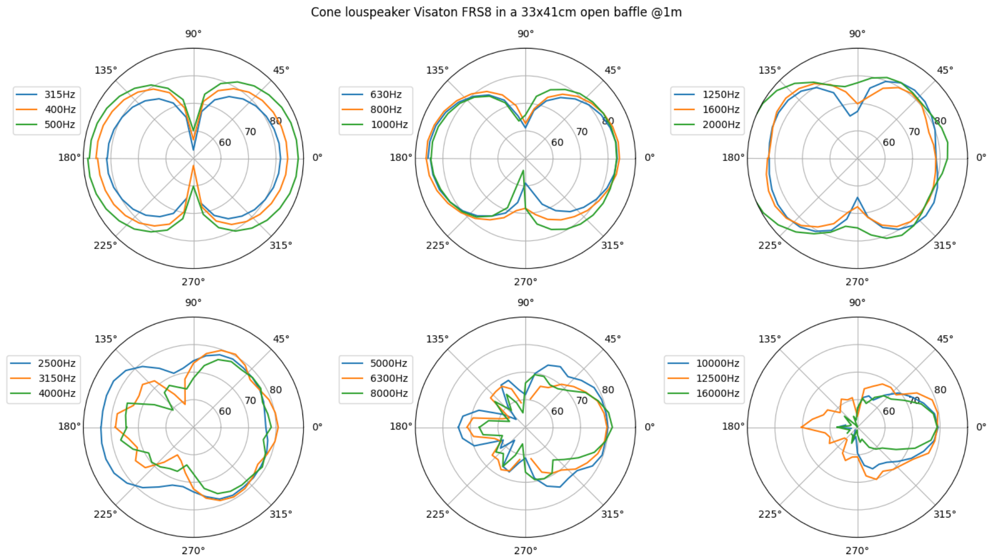


Figure 11: FRS8 open baffle polar plot

14.1.3 FT17H

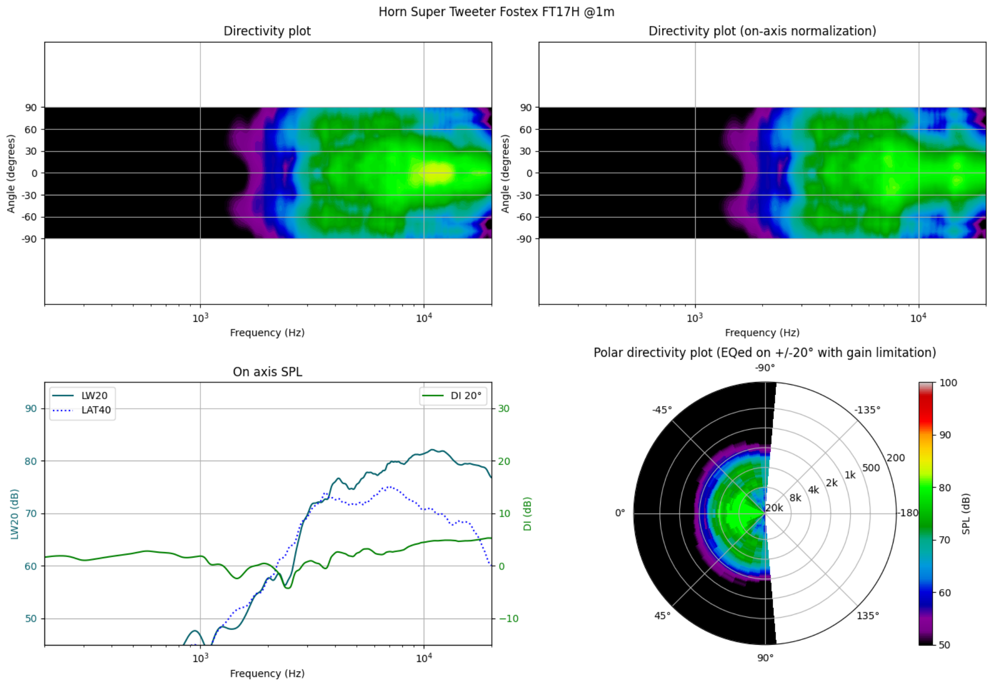


Figure 12: FT17H directivity plot and DI

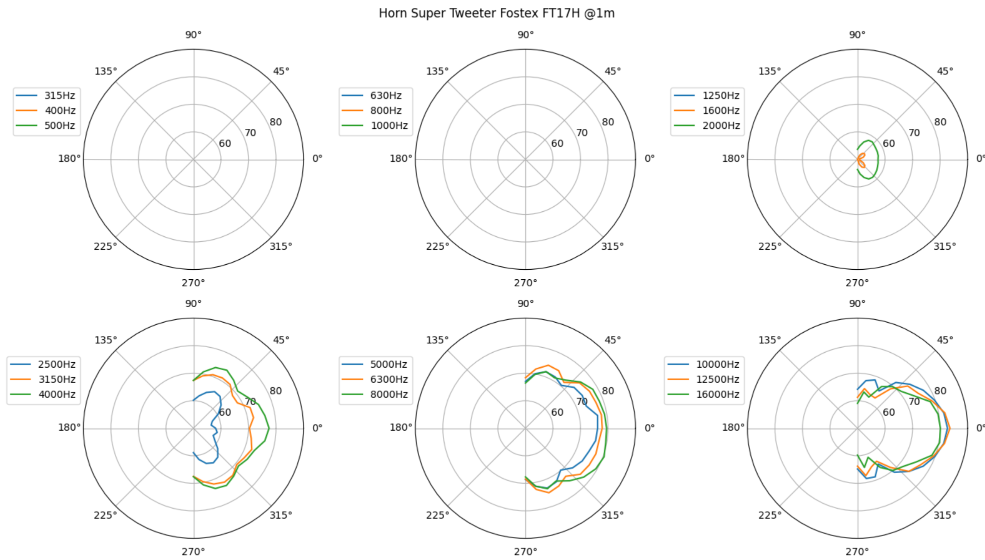


Figure 13: FT17H polar plot

14.2 Glass panel

14.2.1 5mm glass panel

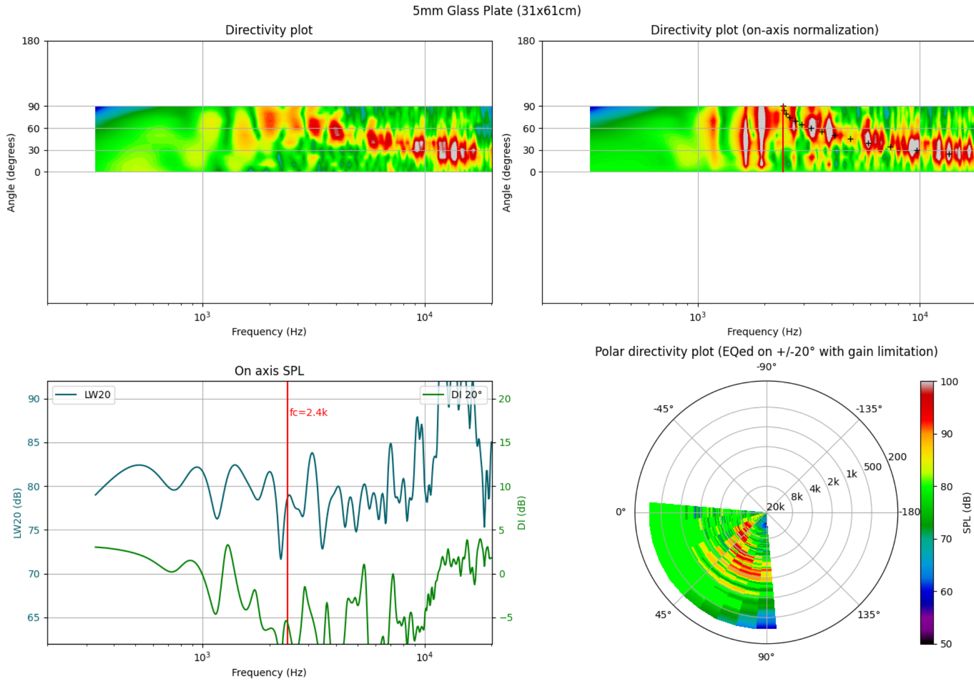


Figure 14: Glass panel directivity plot and DI

14.2.2 1.7mm glass panel

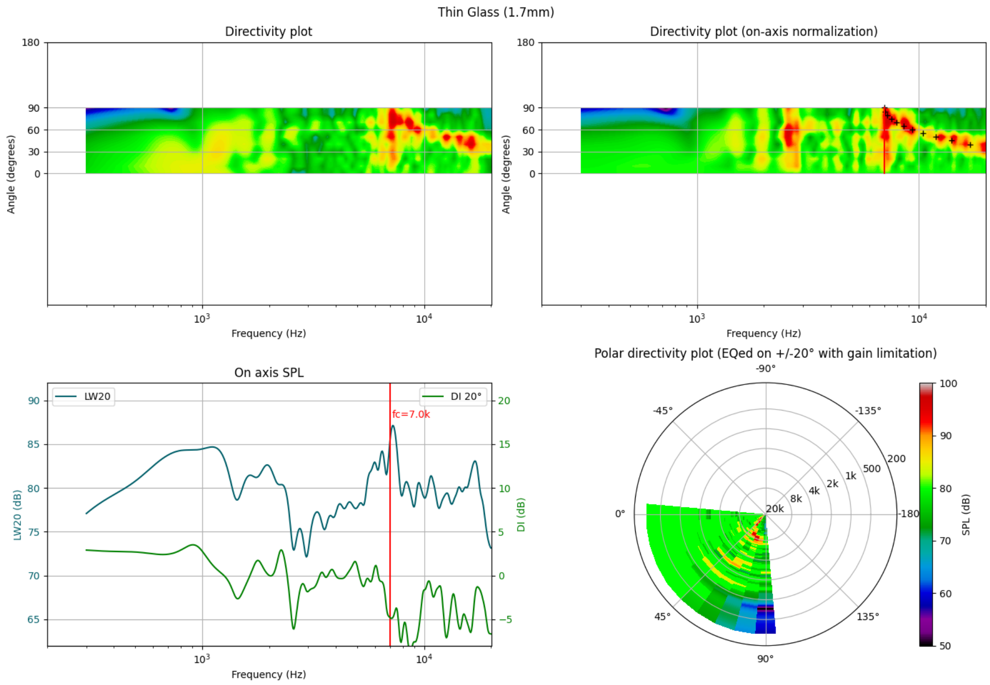


Figure 15: Thin glass panel directivity plot and DI

14.3 EPS

14.3.1 EPS 10mm

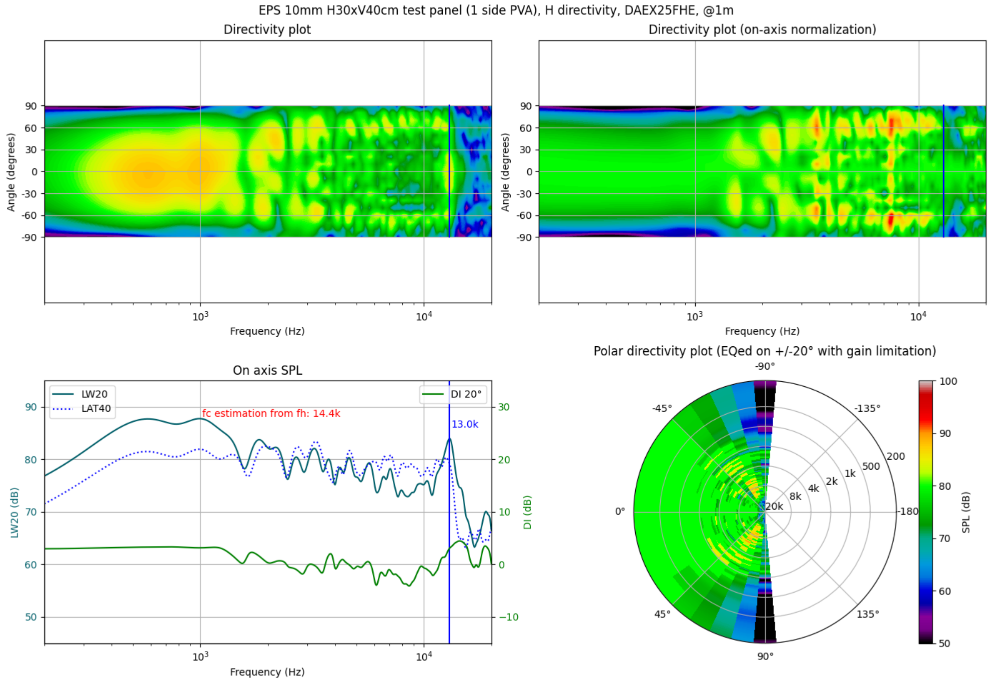


Figure 16: EPS 10mm horizontal directivity plot

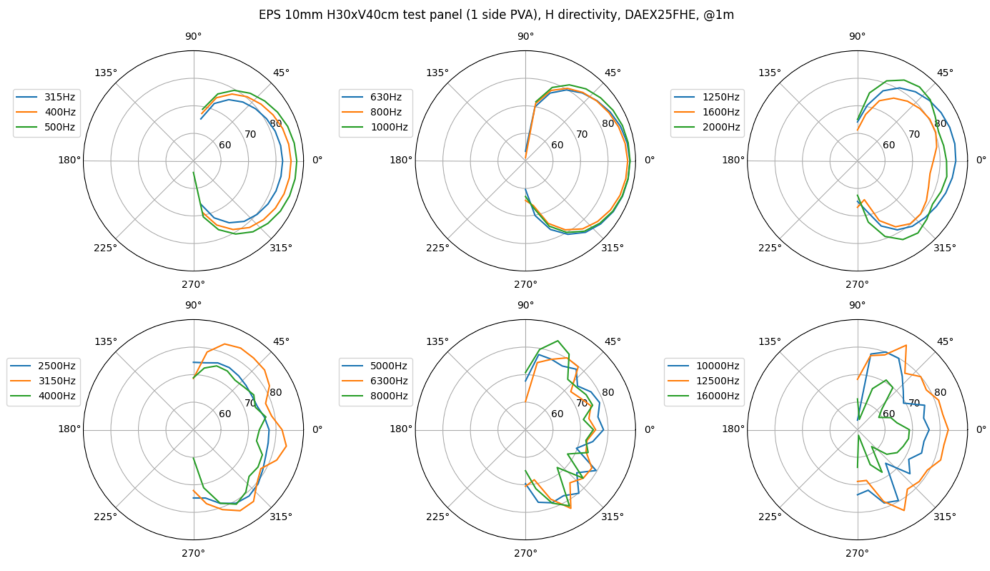


Figure 17: EPS 10mm polar plot

14.3.2 EPS 20mm

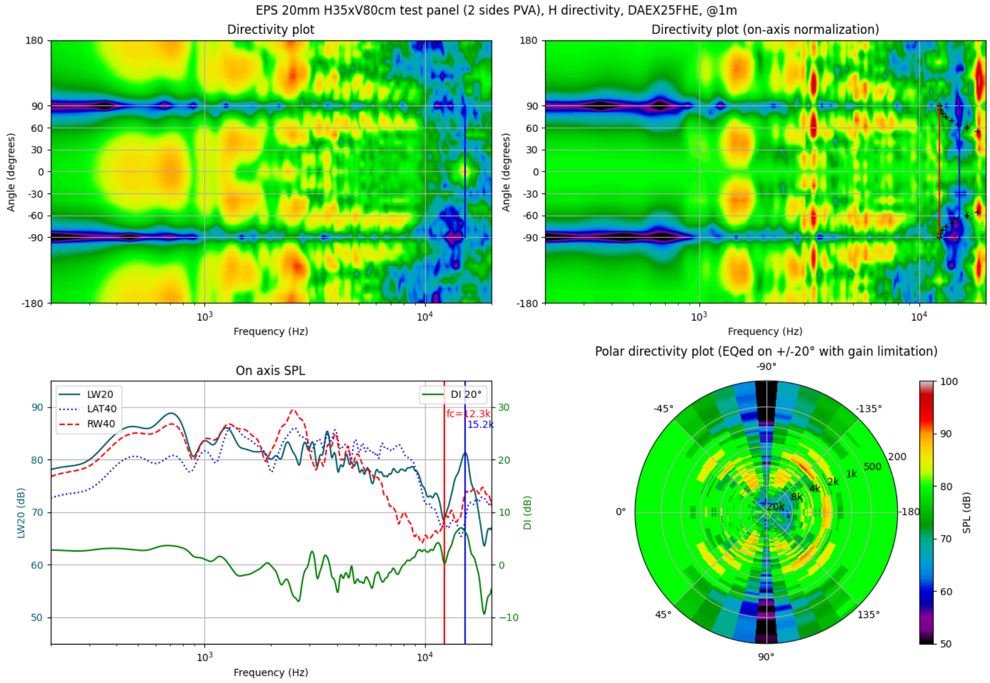


Figure 18: EPS 20mm horizontal directivity plot

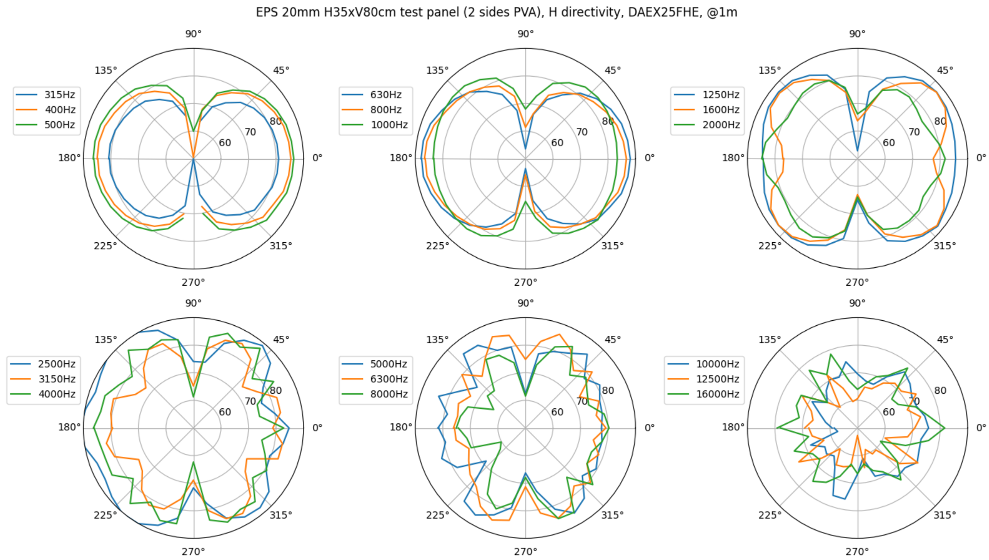


Figure 19: EPS 20mm polar plot

14.4 Polystyrene

14.4.1 Polystyrene 1.3mm DAEX25FHE

+/-90° from ed1:

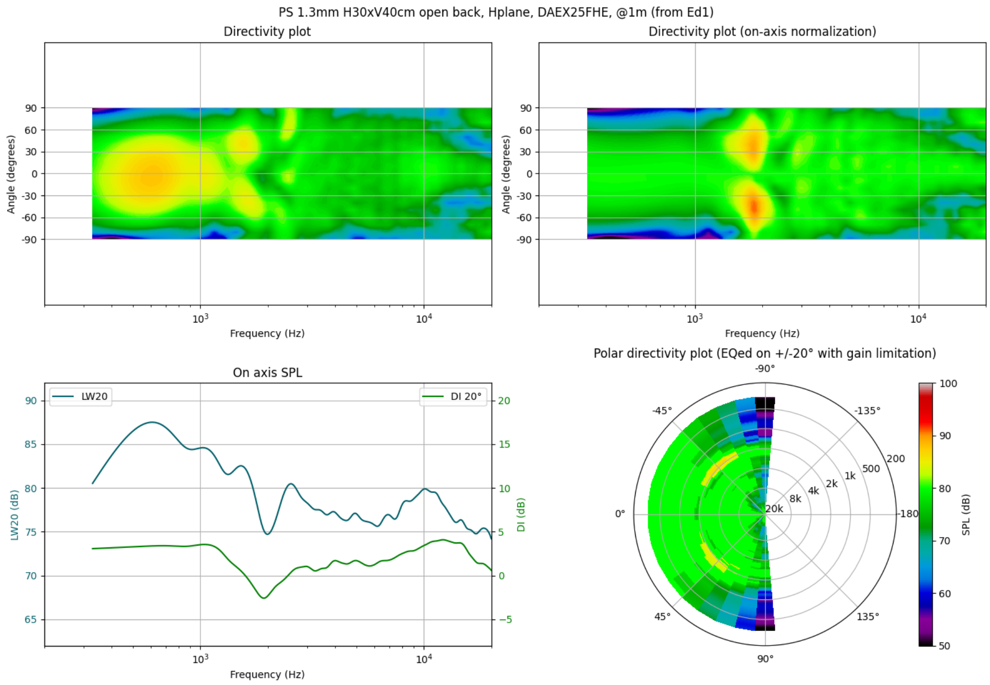


Figure 20: PS 1.3mm DAEX25FHE horizontal directivity plot from Ed1

+/-180° from ed3:

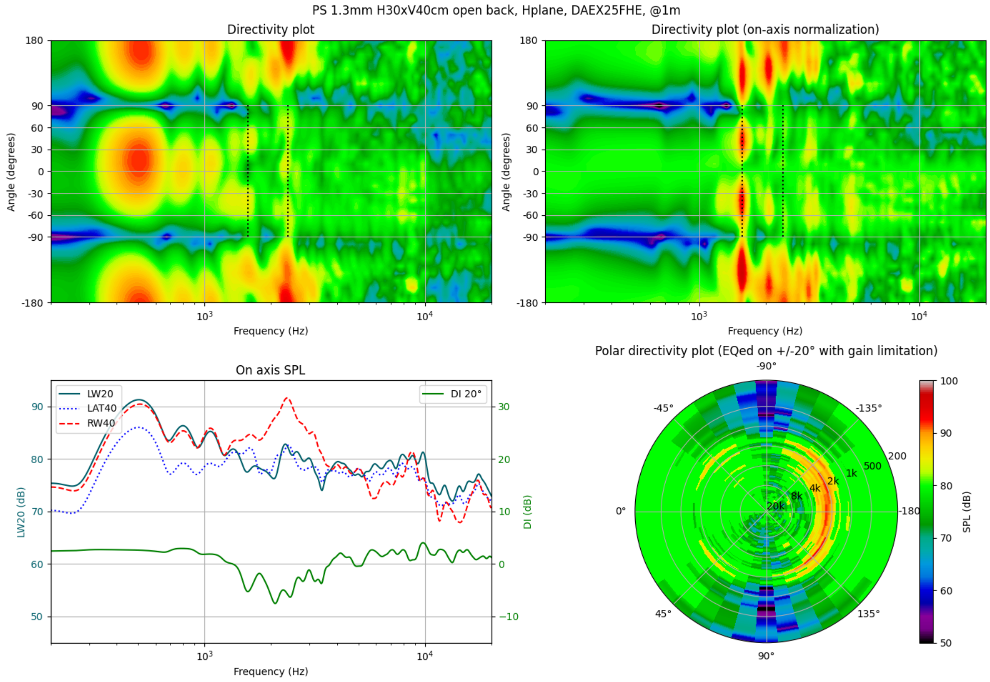


Figure 21: PS 1.3mm DAEX25FHE horizontal directivity plot from Ed3

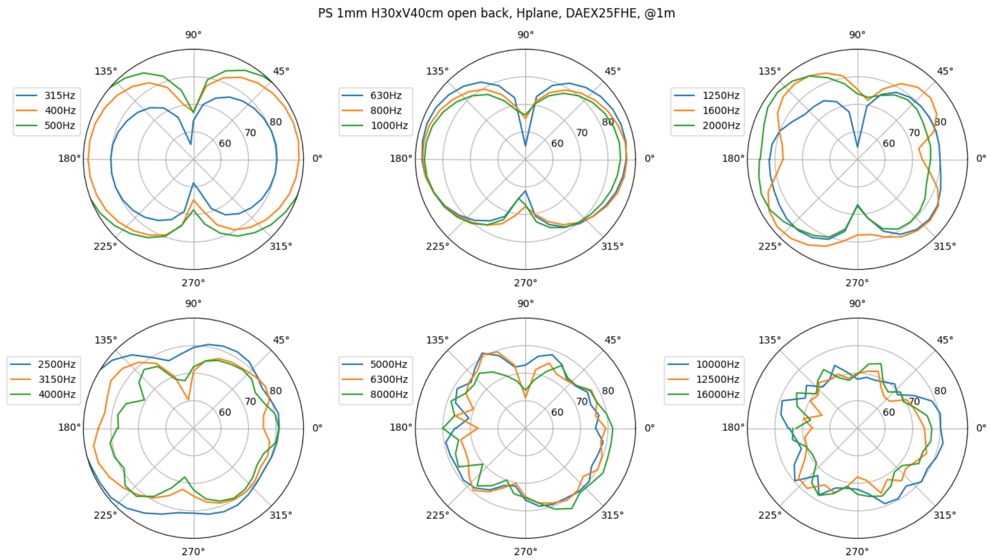


Figure 22: PS 1.3mm DAEX25FHE horizontal polar plot

14.4.2 Polystyrene 1.3mm DAEX13CT

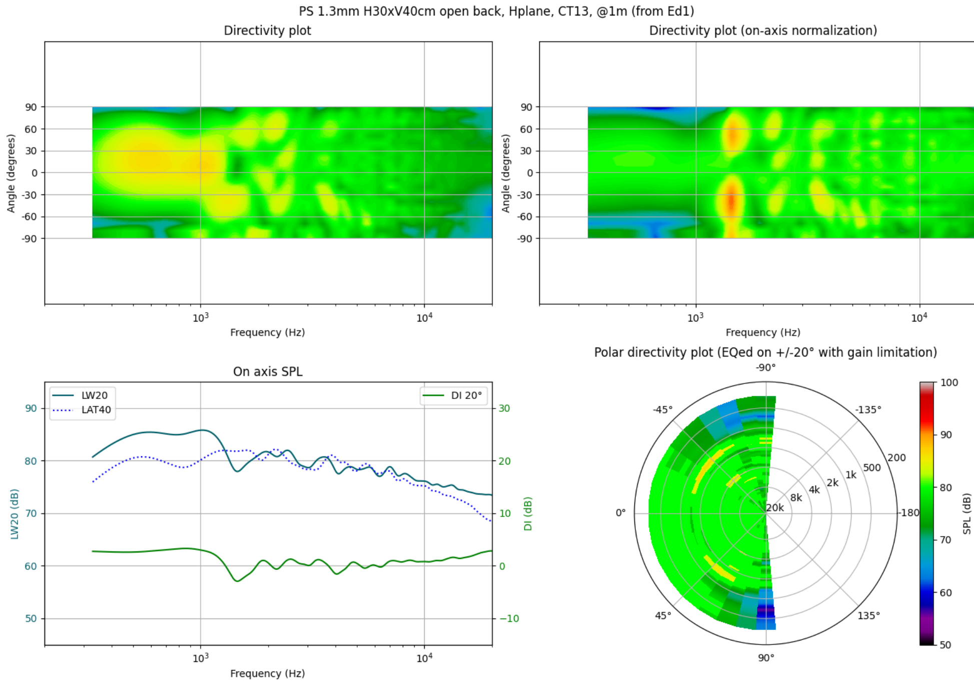


Figure 23: PS 1.3mm DAEX13CT horizontal directivity plot

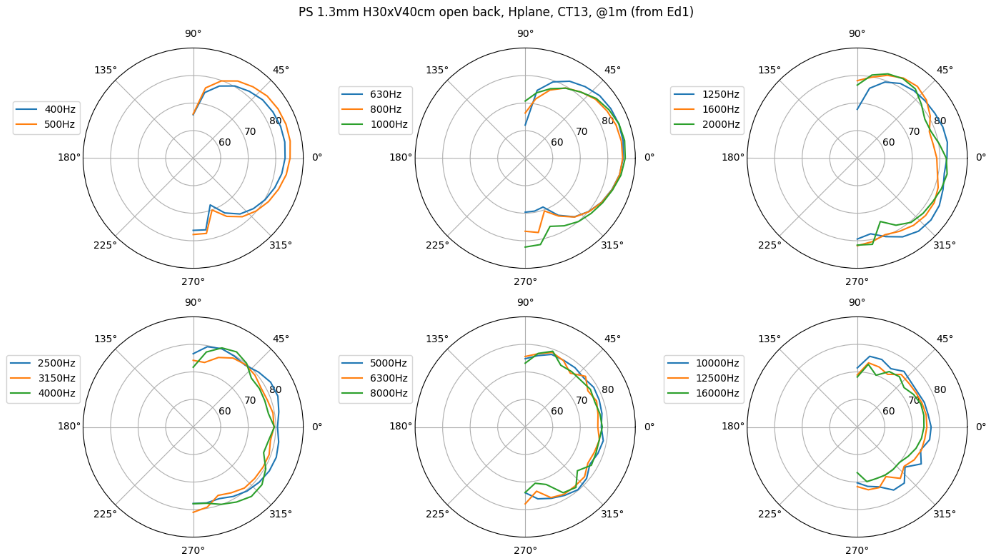


Figure 24: PS 1.3mm DAEX13CT polar plots

14.5 Plywood

14.5.1 5.9mm poplar Triply

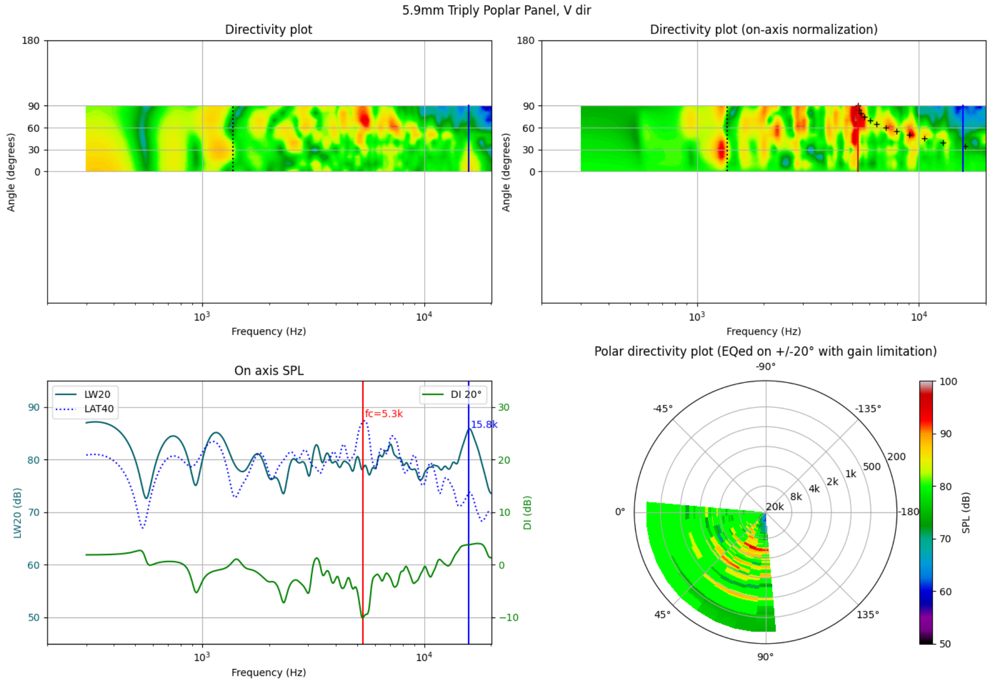


Figure 25: Plywood 5.9mm directivity plot

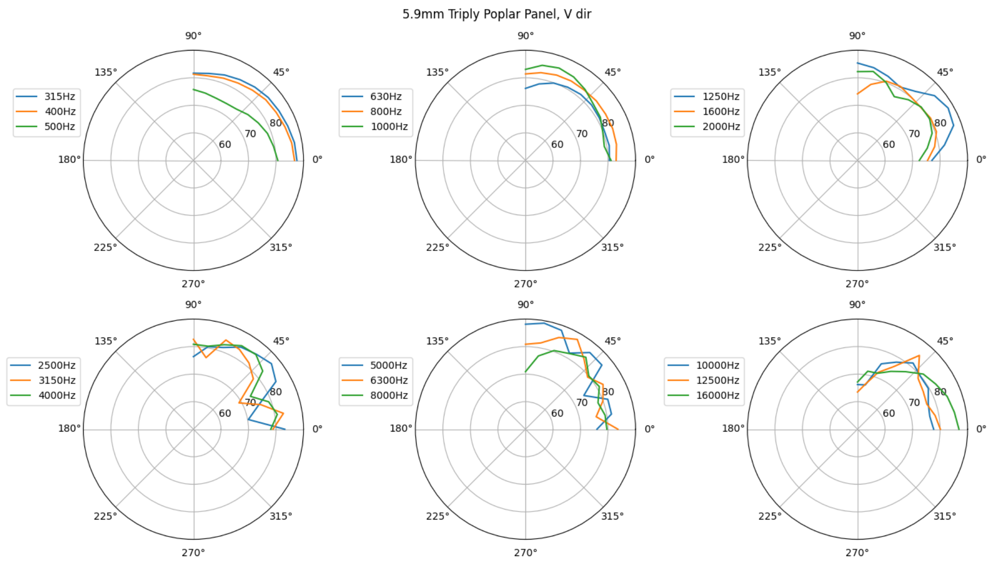


Figure 26: Plywood 5.9mm polar plot

14.5.2 5mm standard plywood

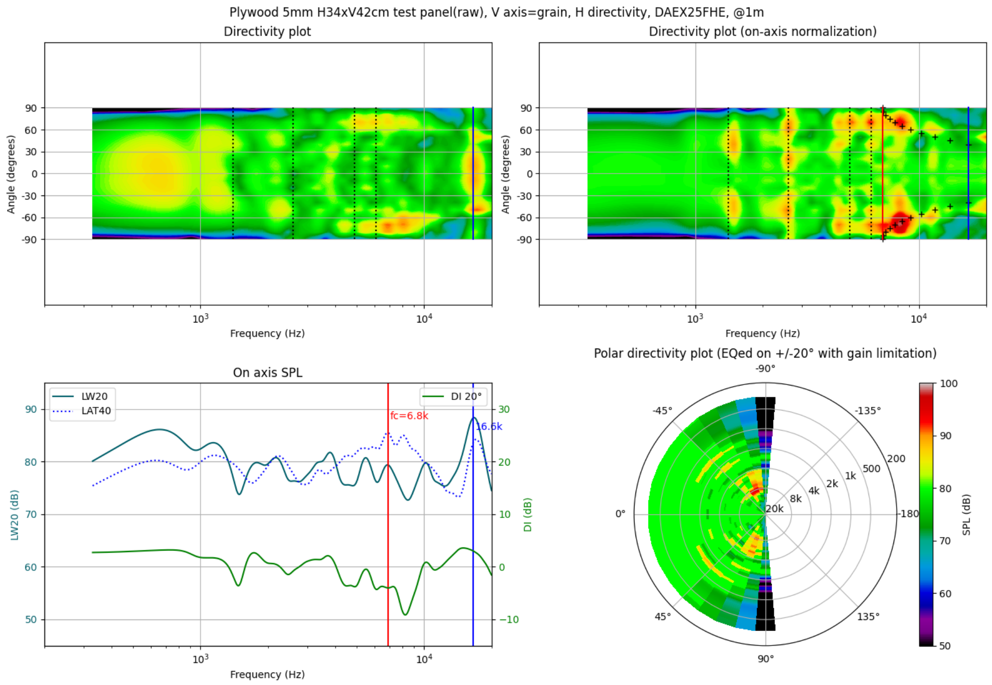


Figure 27: Plywood 5mm horizontal directivity plot

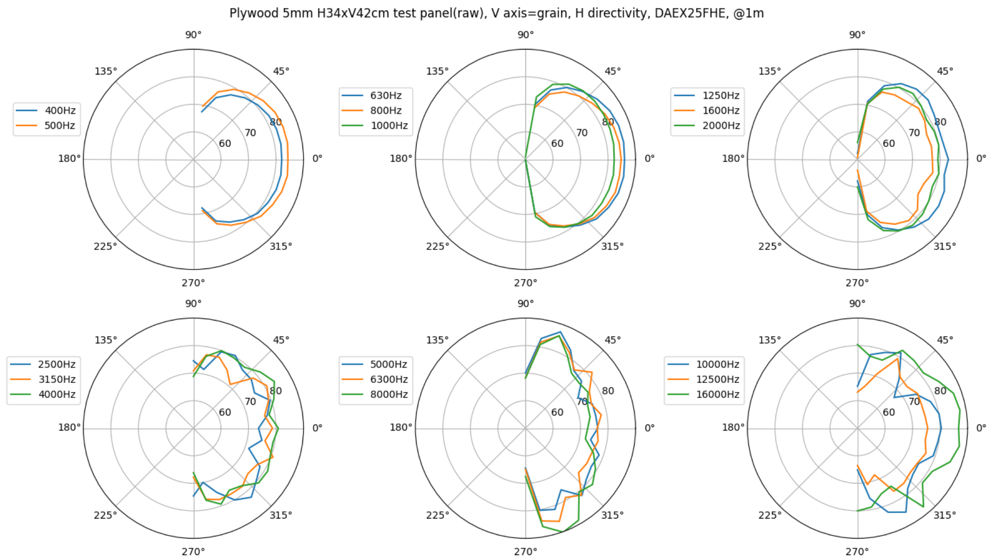


Figure 28: Plywood 5mm horizontal polar plot

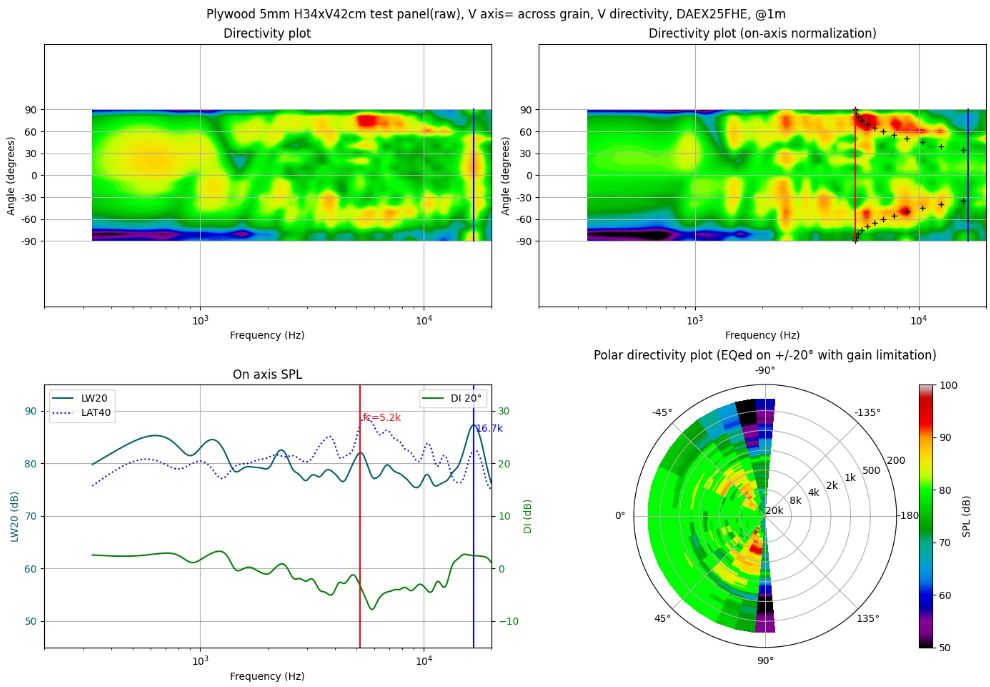


Figure 29: Plywood 5mm vertical directivity plot

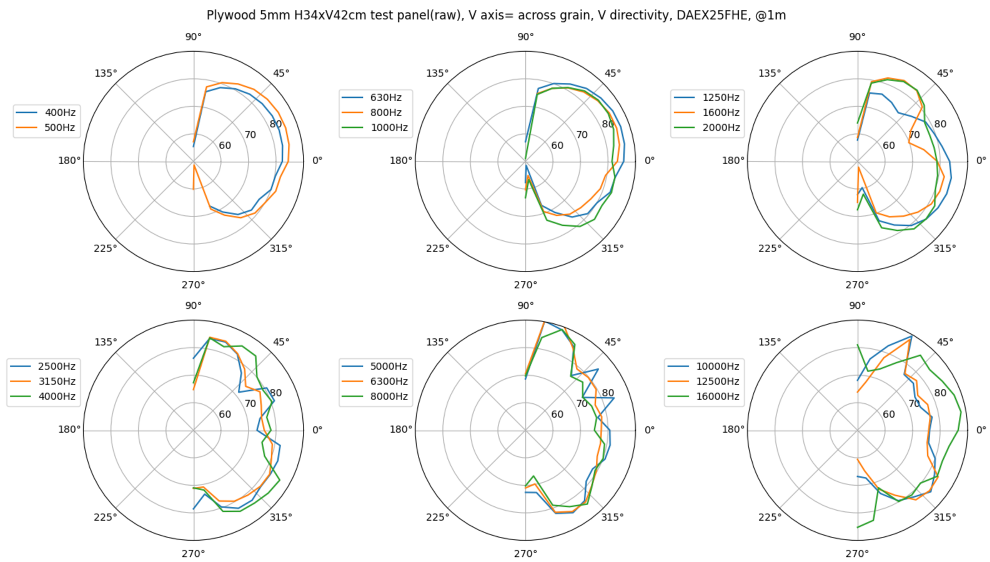


Figure 30: Plywood 5mm vertical polar plot

14.5.3 3mm poplar plywood

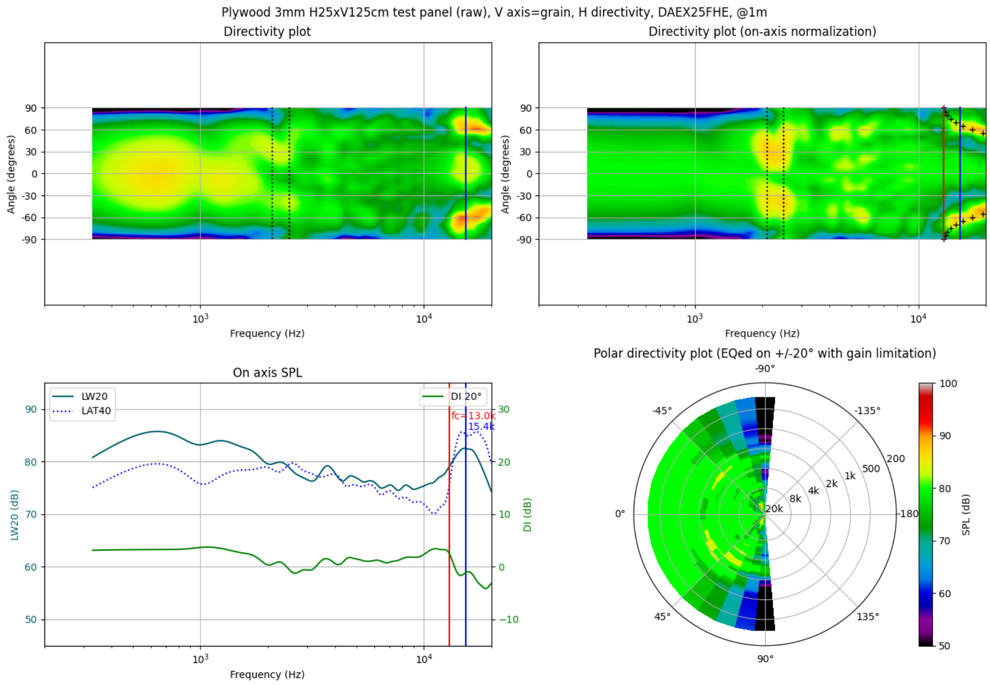


Figure 31: 3mm raw poplar plywood horizontal directivity plot

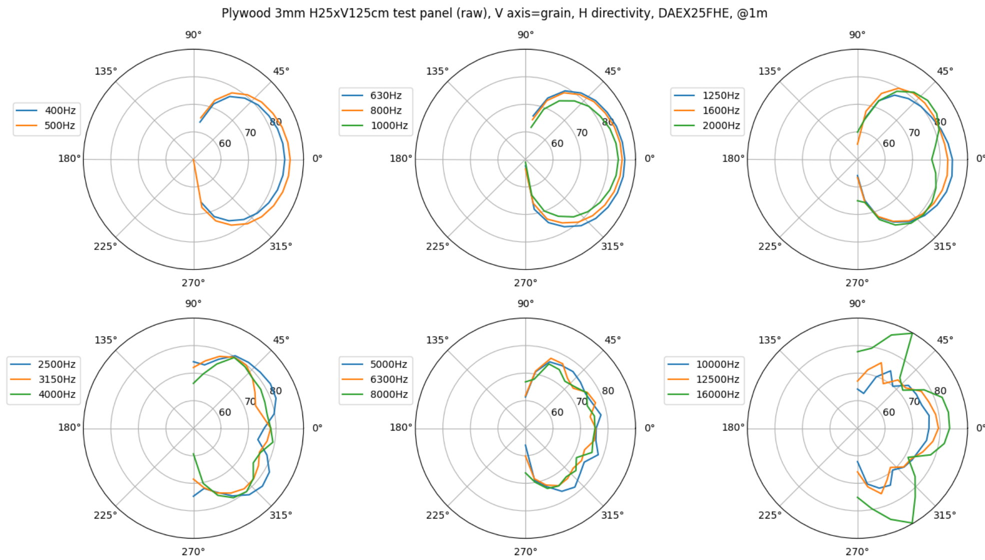


Figure 32: 3mm raw poplar plywood polar plots

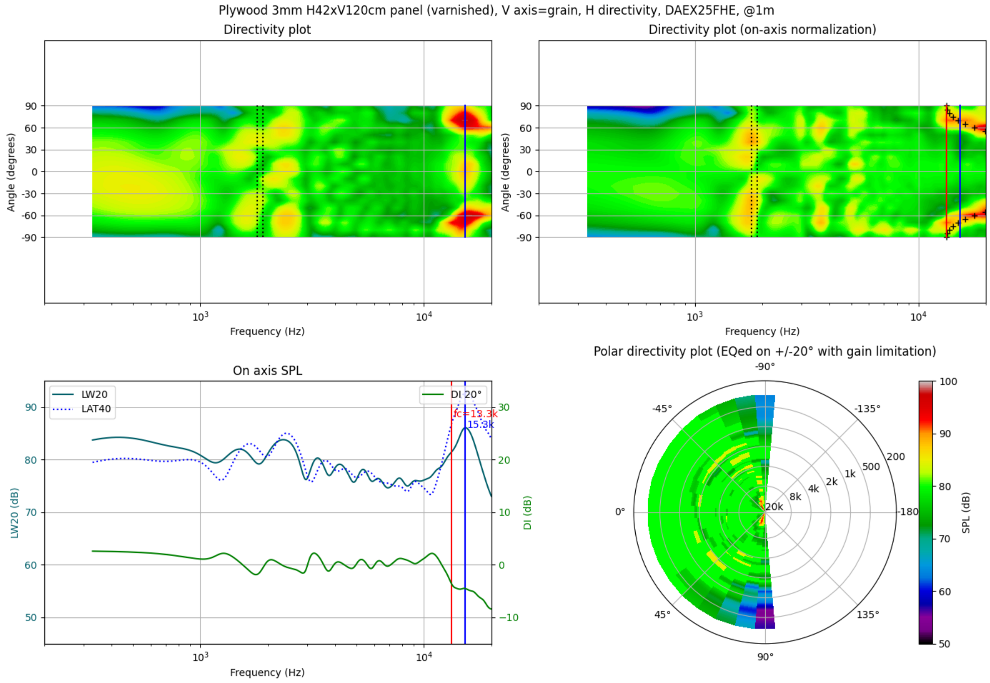


Figure 33: 3mm varnished and framed poplar plywood horizontal directivity plot

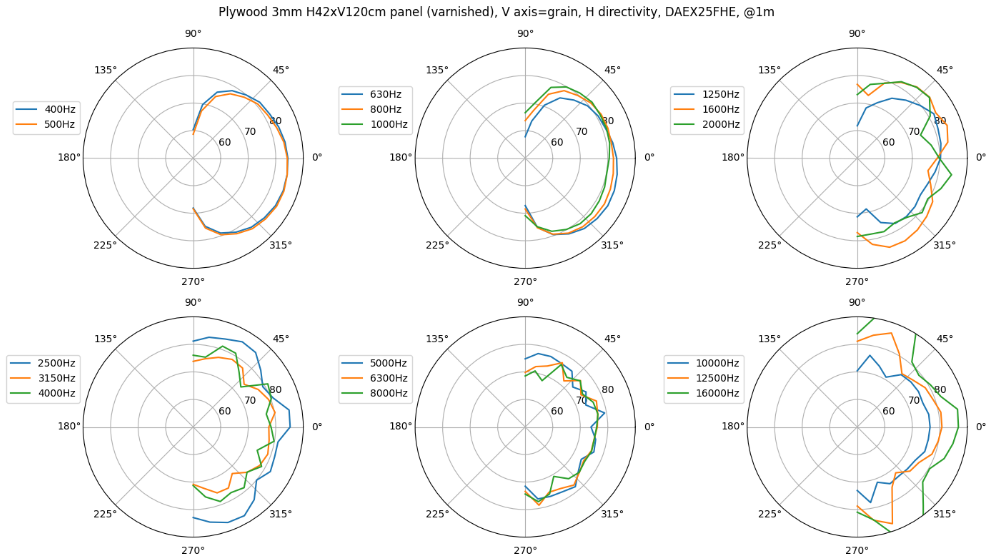


Figure 34: 3mm varnished and framed poplar plywood polar plots

14.5.4 2mm basswood plywood

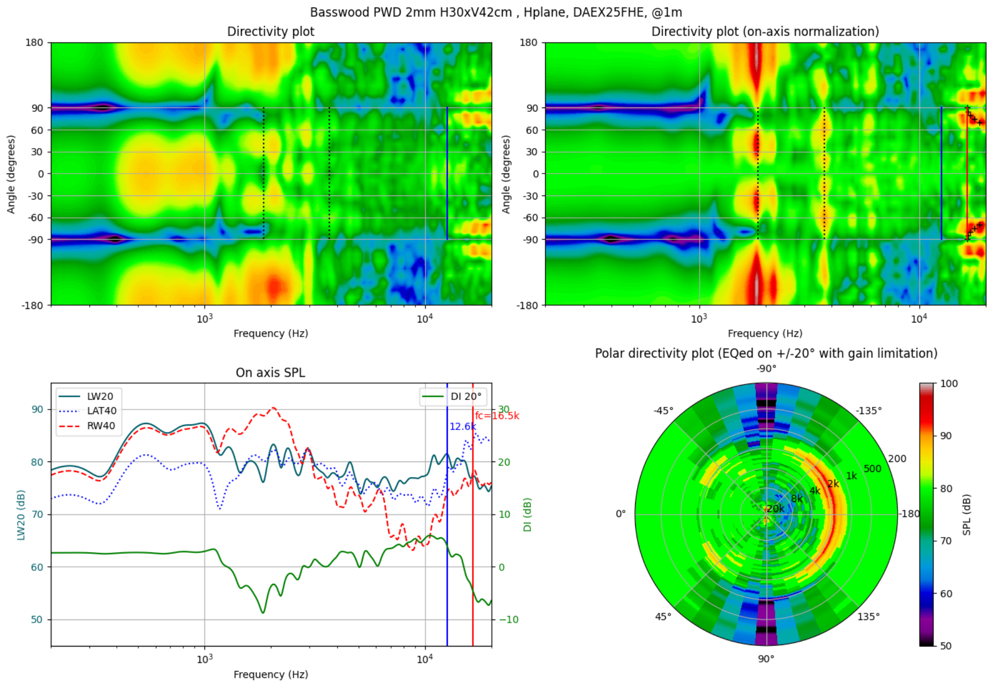


Figure 35: 2mm Basswood plywood horizontal directivity plot

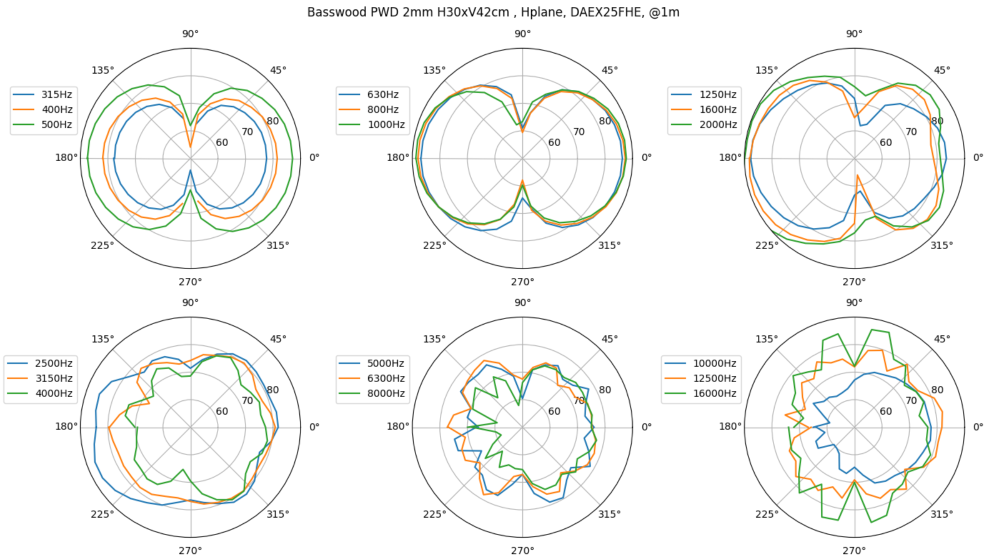


Figure 36: 2mm Basswood plywood horizontal polar plots

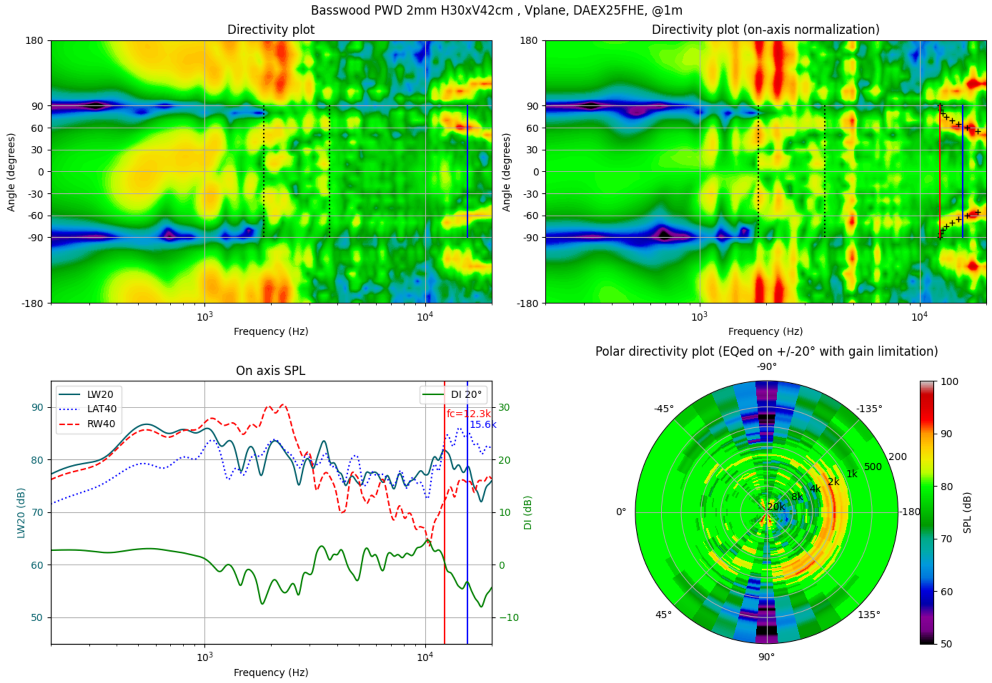


Figure 37: 2mm Basswood plywood vertical directivity plot

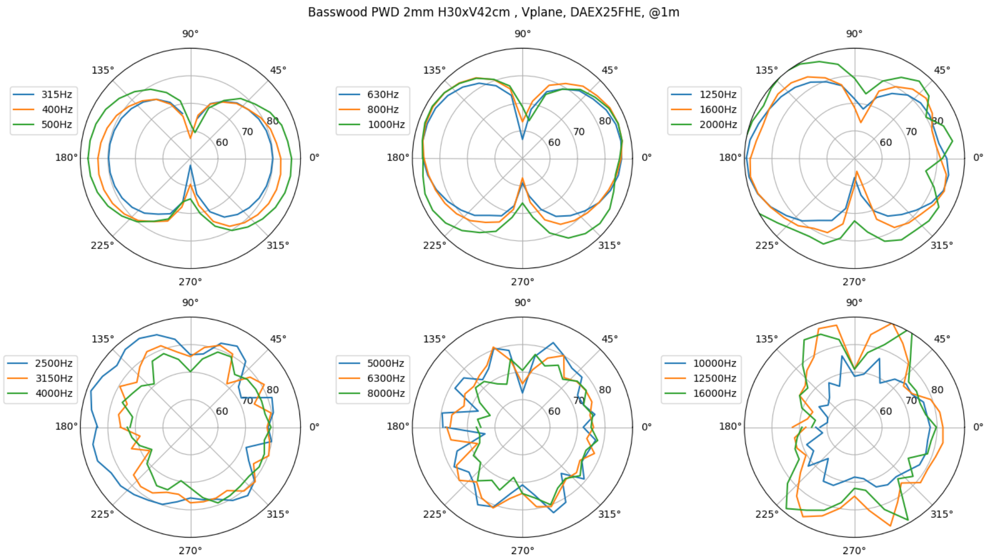


Figure 38: 2mm Basswood plywood vertical polar plots

14.6 CF balsa

14.6.1 CF balsa with poron suspension

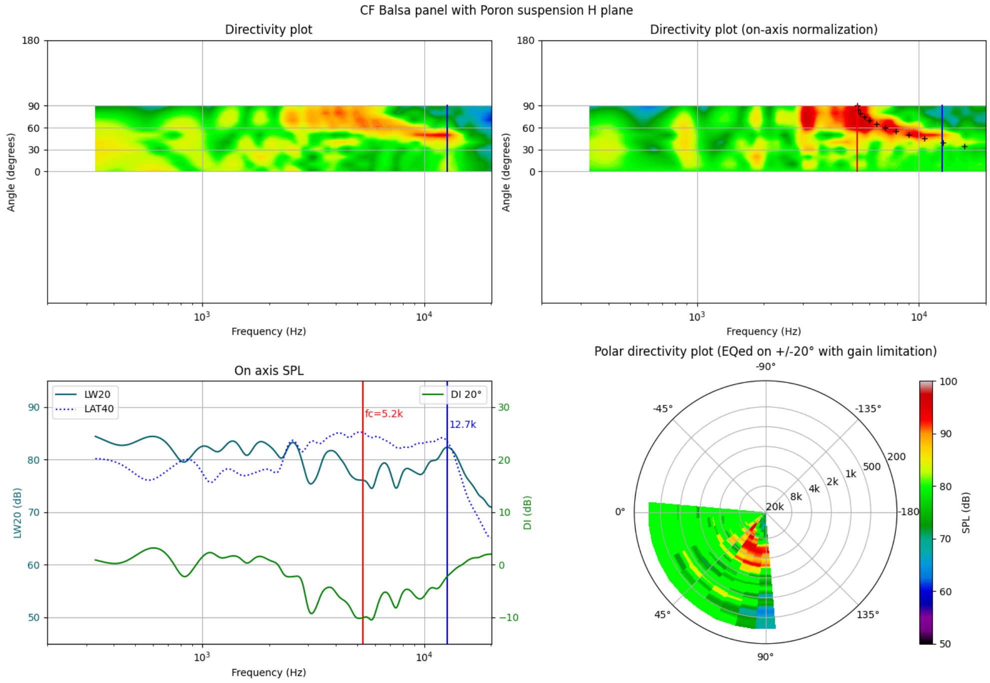


Figure 39: CF balsa poron horizontal directivity

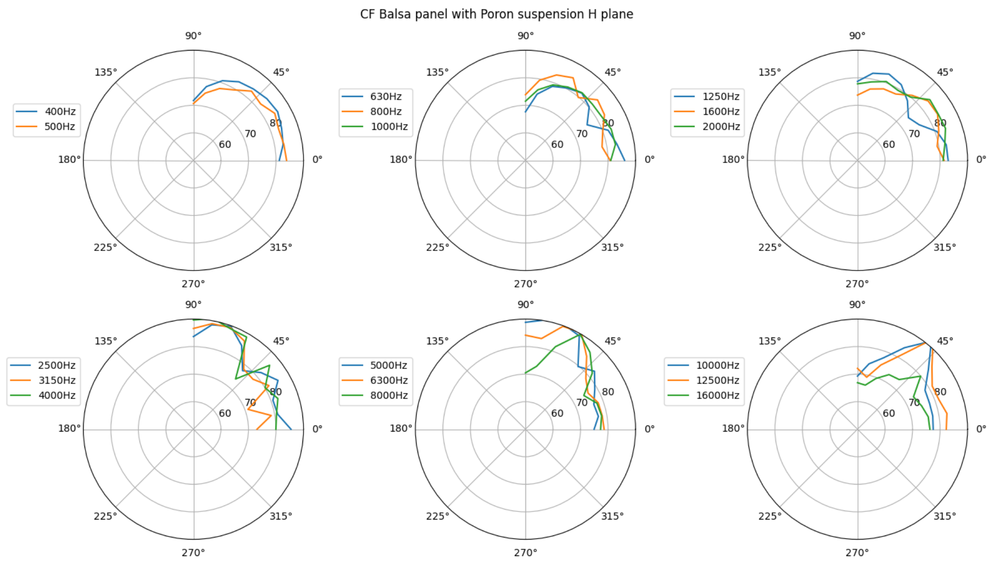


Figure 40: CF balsa poron horizontal polar plots

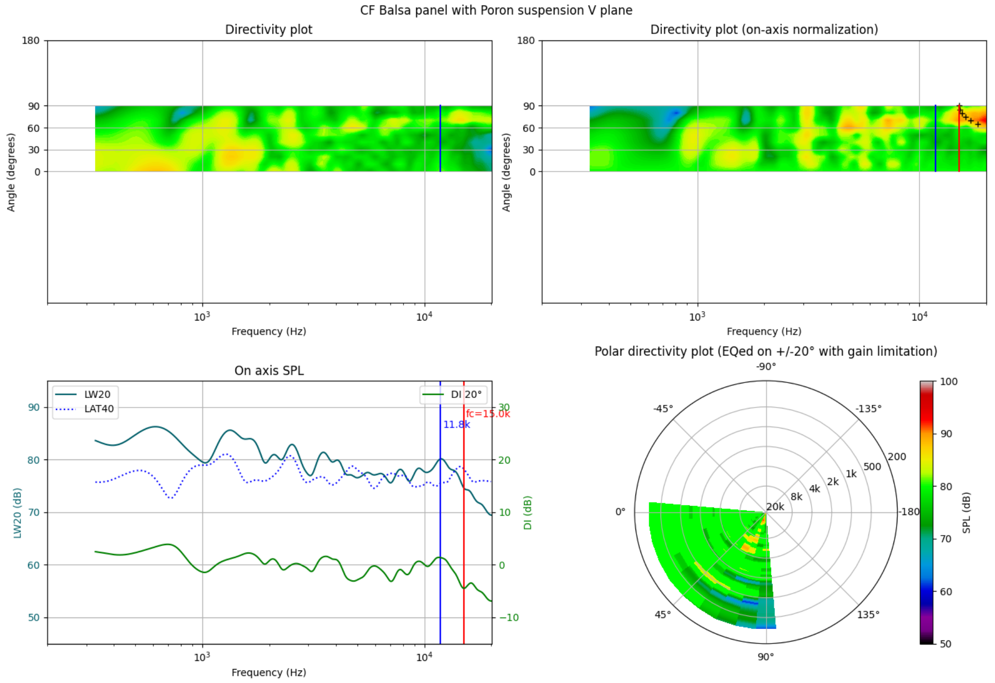


Figure 41: CF balsa poron vertical directivity

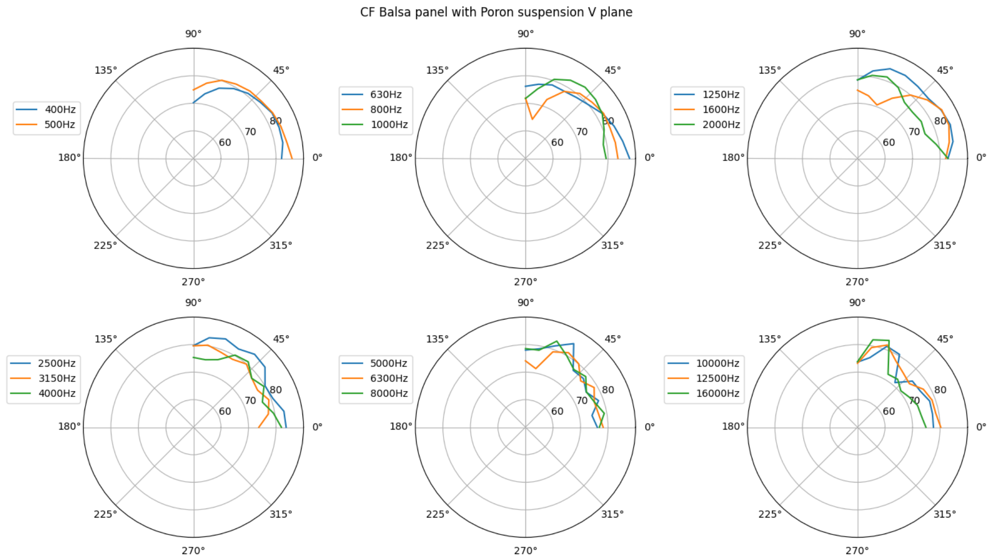


Figure 42: CF balsa poron vertical polar plots

14.6.2 CF balsa (end grain)

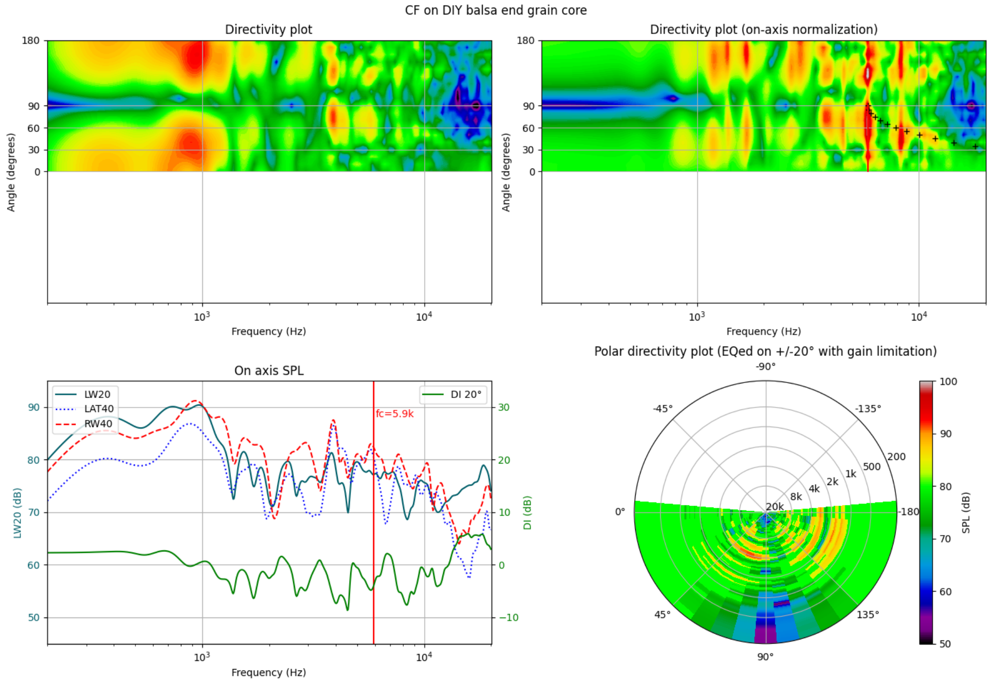


Figure 43: CF balsa end grain directivity

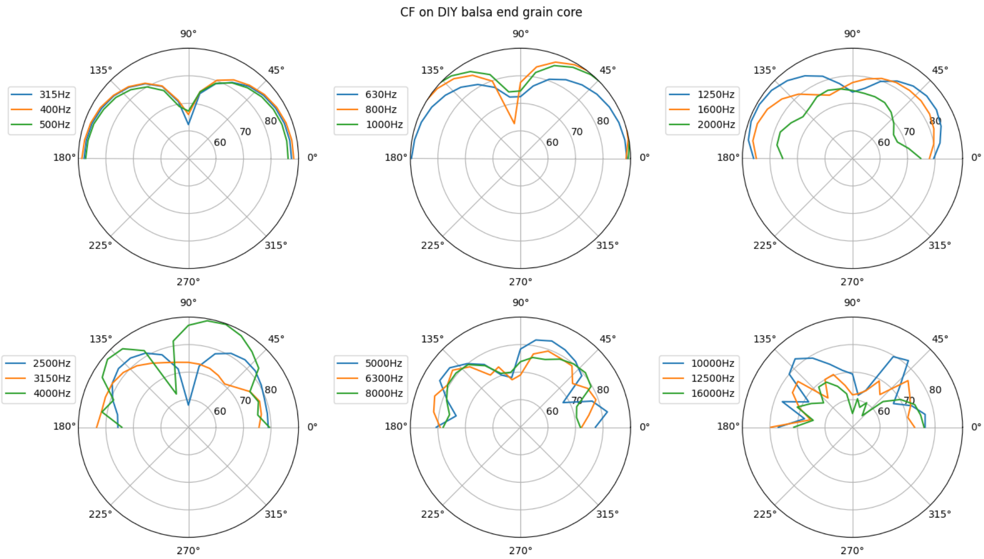


Figure 44: CF balsa end grain polar plots

14.7 3D printed plate

14.7.1 2mm 3d printed PLA 0.2m skins

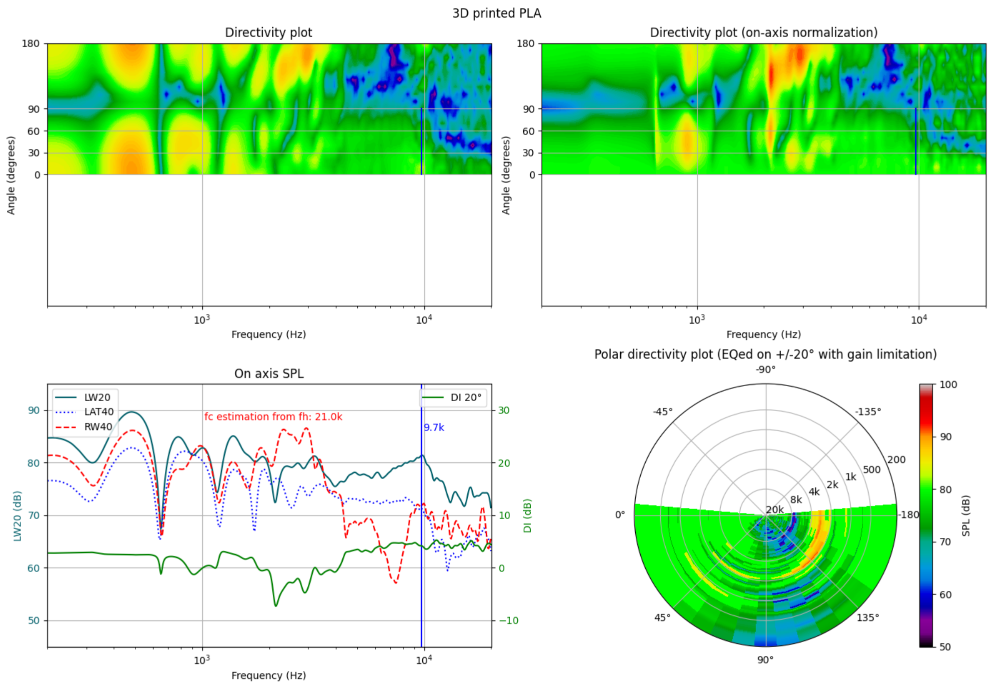


Figure 45: 3D printed PLA directivity

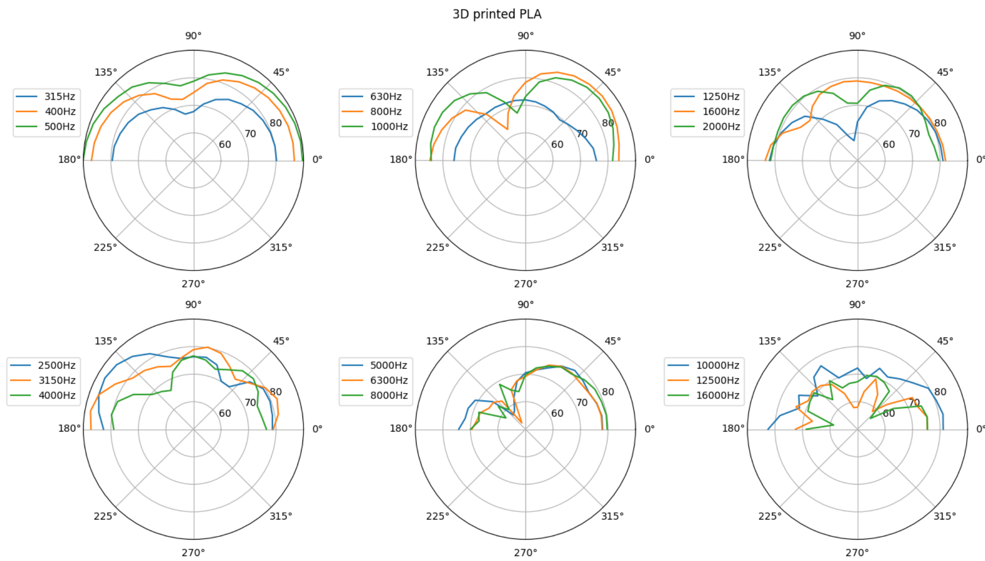


Figure 46: 3D printed PLA polar plots

14.8 Canvas panel

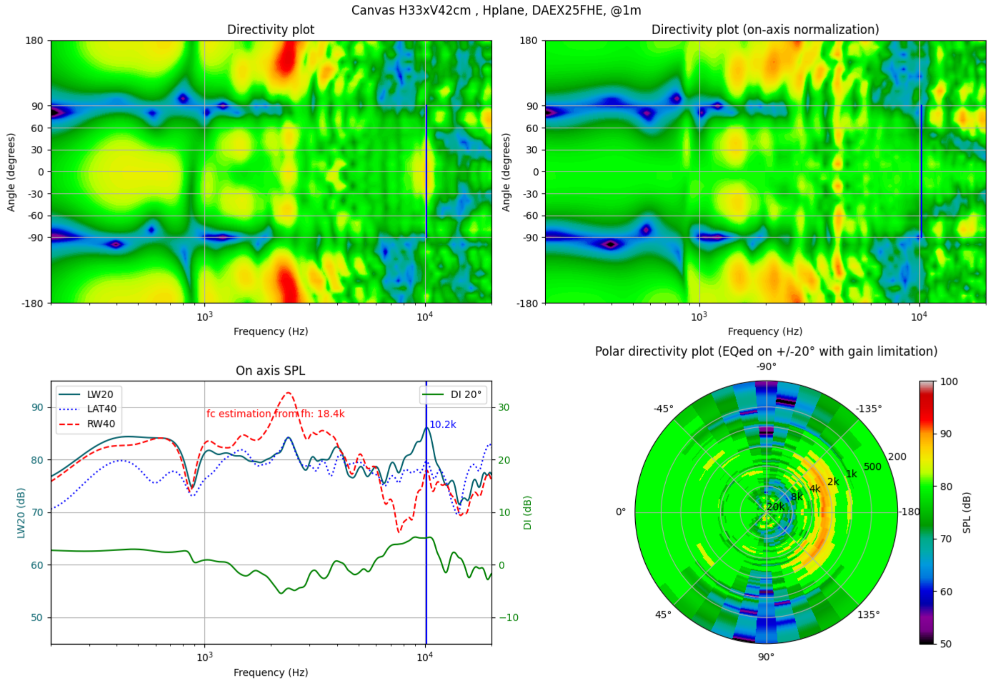


Figure 47: Canvas panel horizontal directivity

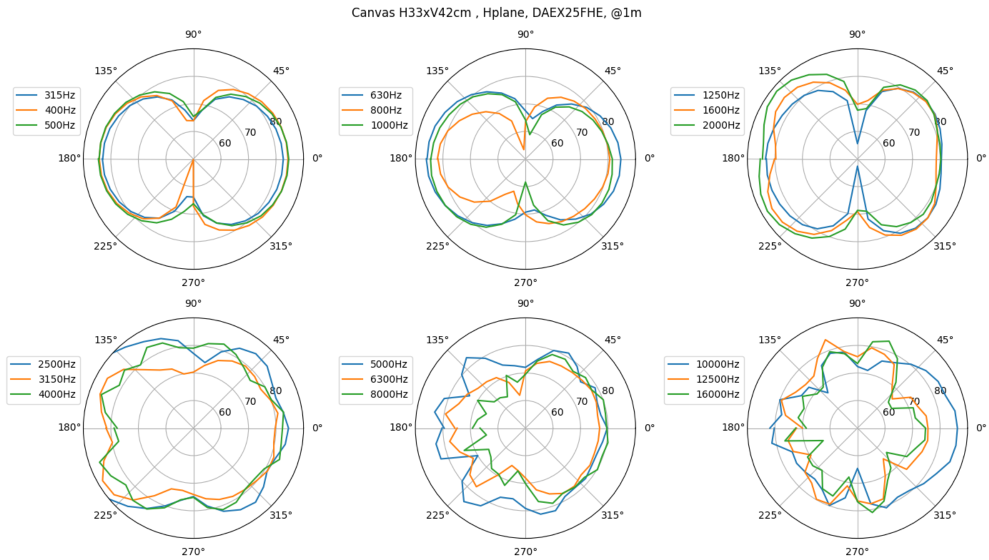


Figure 48: Canvas panel horizontal polar plots

14.9 XPS

14.9.1 XPS 20mm

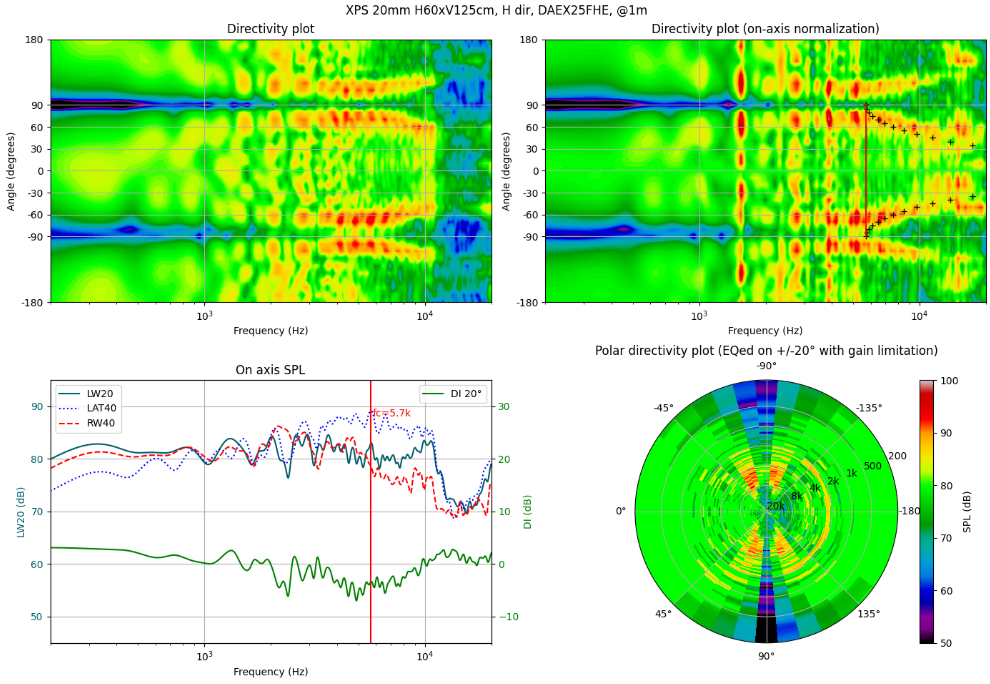


Figure 49: XPS 20mm horizontal directivity

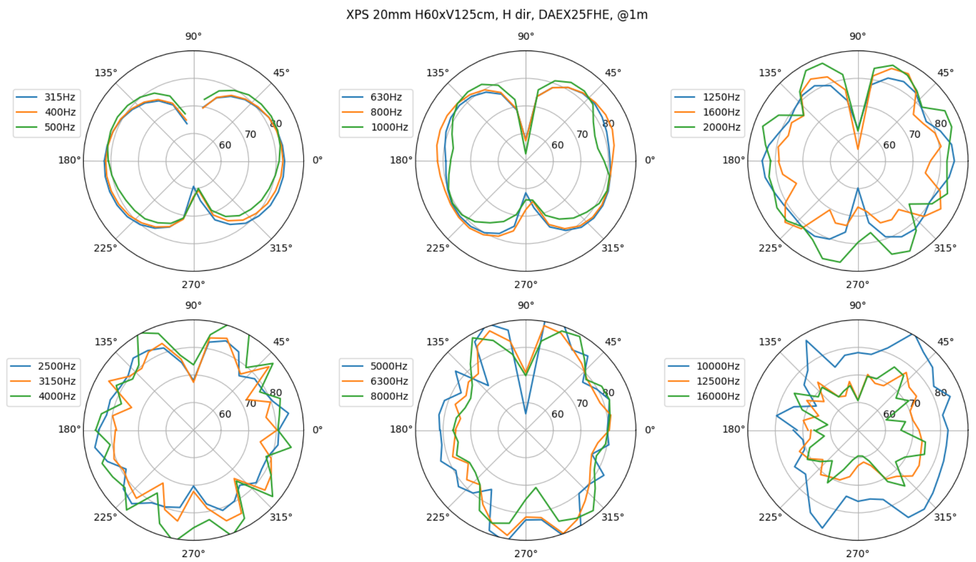


Figure 50: XPS 20mm horizontal polar plots

14.9.2 XPS depron 9mm

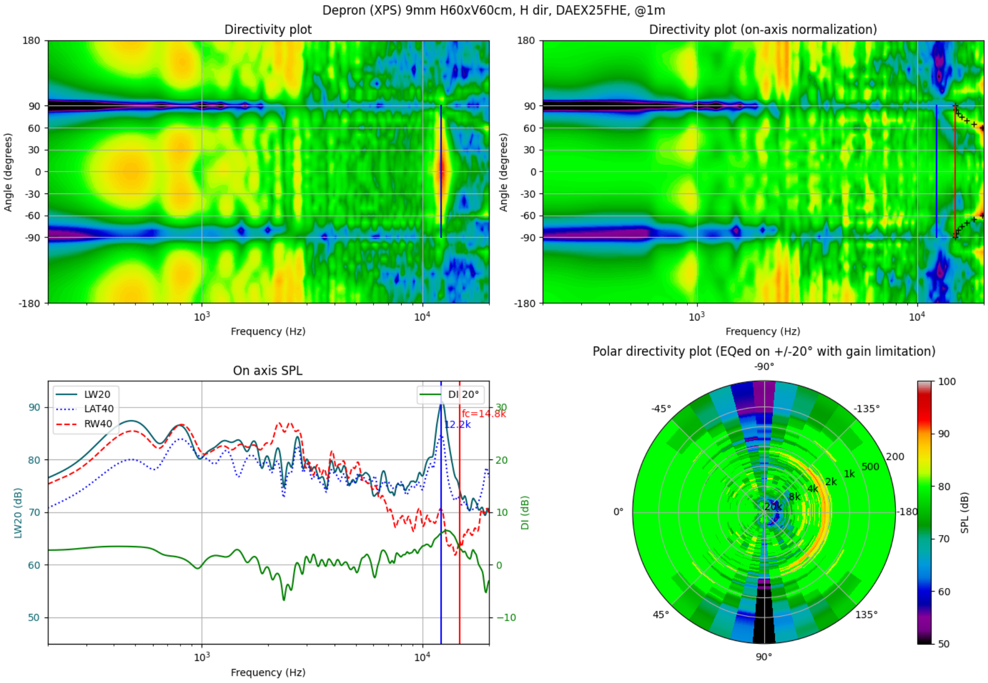


Figure 51: Depron 9mm horizontal directivity

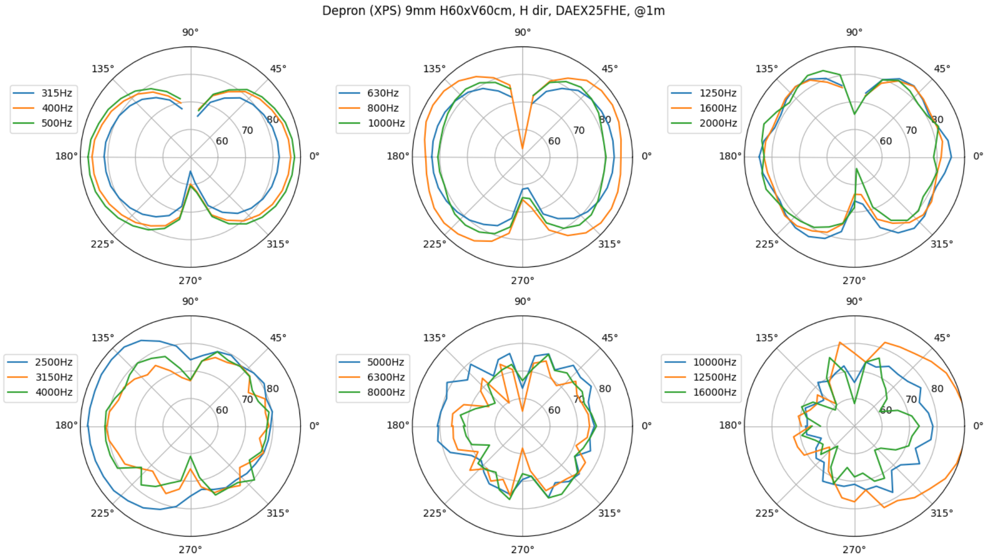


Figure 52: Depron 9mm horizontal polar plots

References

[1] B. Zenker, S. Merchel, and M. Altinsoy, "Optimized radiation pattern and time response of flat panel loudspeaker due to the specific damping of the boundary conditions," 2020. Available: https://tu-dresden.de/ing/elektrotechnik/ias/aha/ressourcen/dateien/professur/publikationen/Zenker2020optimized_-_Optimized_Radiation_Pattern_and_Time_Response_of_Flat_Panel_Loudspeakers.pdf?lang=en

[2] B. Zenker, R. Schurmann, S. Merchel, and E. M. Altinsoy, "Improved directivity of flat panel loudspeakers by minimizing the off-axis radiation below coincidence," *Applied Sciences*, vol. 11, no. 15, p. 7001, 2021, Available: https://www.mdpi.com/2076-3417/11/15/7001/pdf

[3] M. LaCarrubba, "Interpreting 'spinorama' charts," Available: https://www.sausalitoaudio.com/wp-content/uploads/2018/07/Interpreting-Spinorama-Charts.pdf

[4] A. CTA, "Standard method of measurement for inhome loudspeakers," 2015, Available: https://www.audiosciencereview.com/forum/index.php?attachments/ansi-cta-2034-a-pdf.45978/

[5] D. A. Anderson, *Driver-array based flat-panel loudspeakers: Theoretical background and design guidelines*. University of Rochester, 2017. Available: http://hdl.handle.net/1802/32266