Directivity measurements applied to DML (directivity plots). Ed2.

ChristianV (Homeswinghome@diyAudio)

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Abstract

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

Contents

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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?)

For all the figures:

- on the left is "as measured" with a global gain applied to each point. The gain is set to give an average 80dB SPL over the -10° to 10° measurements. The idea is to try to give the same color on that area for each test.
- on the right is the normalized version. For this one, the SPL of one frequency for all the angle 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 is the directivity index DI.

2 Coincidence frequency, directivity

2.1 Coincidence frequency

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

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 from the theory that tells us there is a relation between the coincidence frequency, the considered frequency above the coincidence and the angle of the beam in the form:

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

There is no parameter from the panel here so this relation was coded in the python script. Just by changing the coincidence frequency fc value, we can see what fits the best.

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.

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

As 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

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).

A DML below the coincidence frequency and because of the modes has an uneven directivity. Depending of the angle, the contribution of each anti-node can be constructive or destructive.

It is even worth above the coincidence frequency where the emission is in a main direction far from the axis.

The directivity of the DML in the cited papers is described as something to work on because by its nature, a DML is not as expected for a good sound.

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 direction.

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 excess the on-axis one.

In this paper, the DI is given for a 30° listening window which is the standard and also for a 20° window.

The DI at the coincidence frequency is very bad!

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

- increasing the panel material damping
- adding some edge damping

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 1 and 2

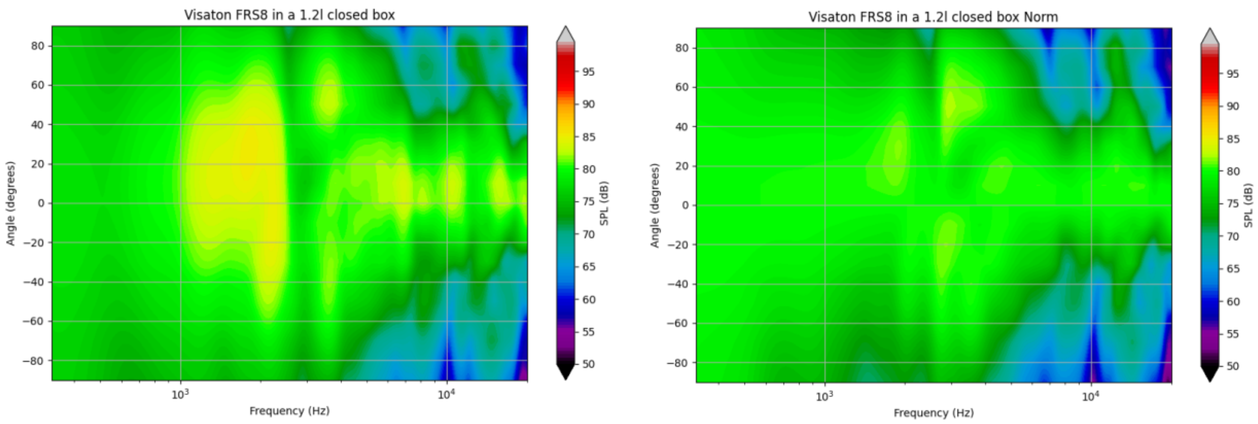

Figure 1: FRS8 horizontal directivity plot

3 EPS (Expanded Polystyrene)

As my questions about directivity started with tests of an ESP panel (30x40cm, 10mm thick, PVA coated only on the exciter side), it is 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 tube was inserted at the center to add a weight), so this panel is maybe not fully representative in HF.

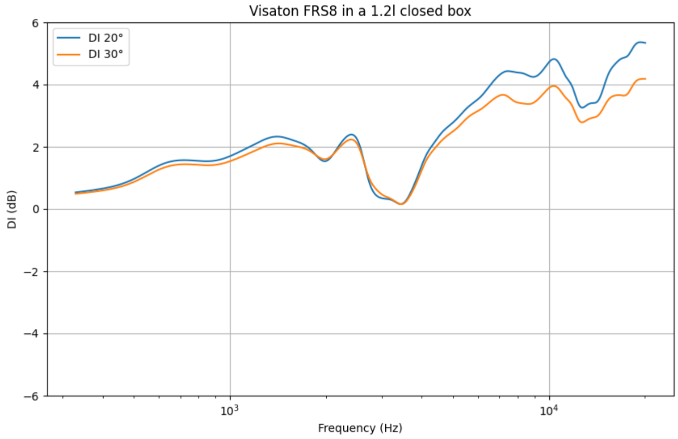

Figure 2: FRS8 DI

Anyway, here it is : see figure 3 and 4

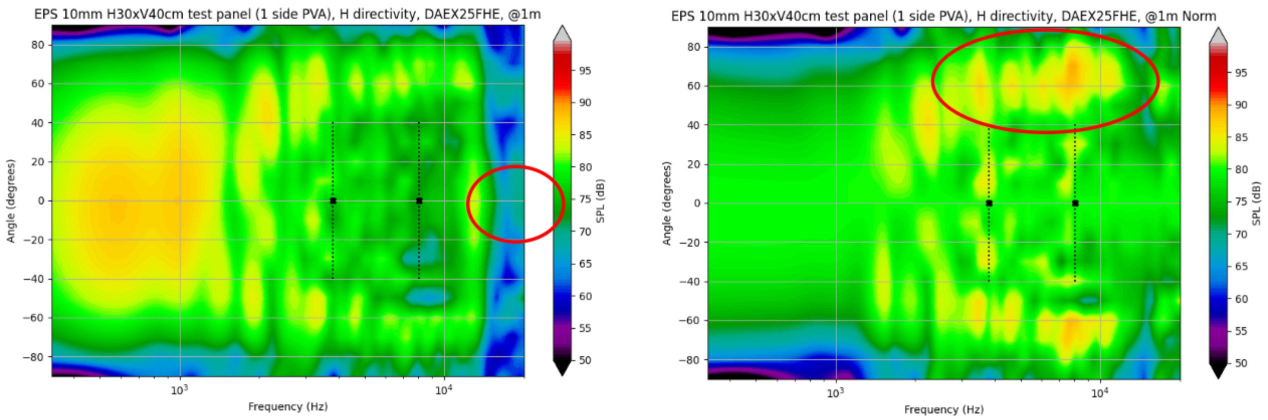

Figure 3: EPS 10mm horizontal directivity plot

It shows on the left that the panel is a bit short in HF 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... Probably not good.

Writing that, I wonder if it is something we could detect listening to the panel hand held at different angle...

From this horizontal directivity plot, I can make no assumption about the coincidence frequency. Is an EPS panel subsonic? Or is the fc not visible for some other reason like a too low HF cut off that masks the frequencies above and so the signature in the directivity plot?

In the case of this EPS panel, this minimum in the DI is at

Note that for this panel and as others about the same dimensions after, the high SPL in the 500Hz area on the left might not be a big issue. My assumption is a DML being a diffuse dipole... it is a dipole so it should behave as an open baffle. At certain frequencies the front and rear waves combines in phase and increase the level. This is another topic.

The results of this panel lead me to consider panels with a possible higher coincidence frequency. In short to increase the coincidence frequency:

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

4 PS (plain Polystyrene)

So the next test is with a clear polystyrene, the one that makes the protective window of frames. I had one sample of that (30x40cm, 1.3mm thick), no spine but a peripheral suspension made of a D shape wheather

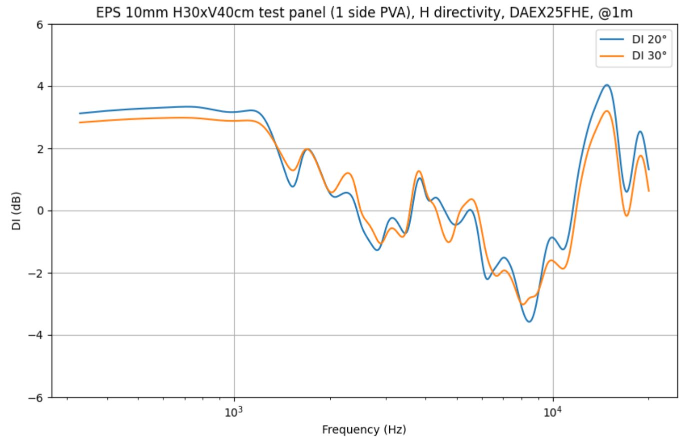

Figure 4: EPS 10mm DI

strip. This panel was used also for other tests before making a directivity measurement.

See figure 5 and 6

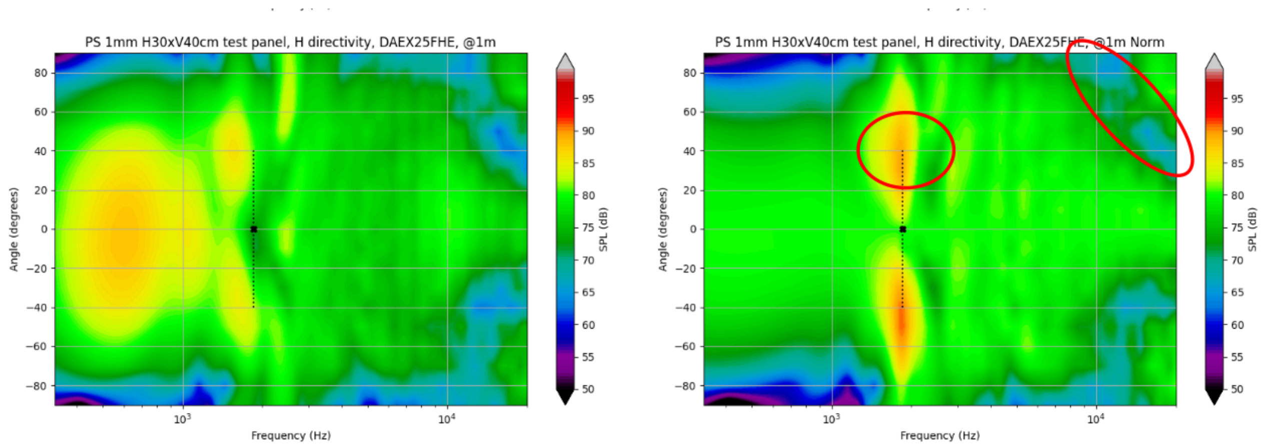

Figure 5: PS 1.3mm DAEX25FHE horizontal directivity plot

Here no evidence of the coincidence frequency, 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. So the question would be first why such a dip in this frequency range, only odd modes occur?

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 and a lower inductance which are suppose to limit the highest frequency.

Here it is the PS panel with a DAEX13CT : see figure 7 and 8

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 and the 1.5k to 2KHz/0° dip to the panel including the suspension and the exciter... or an other variation in my measurement environment!

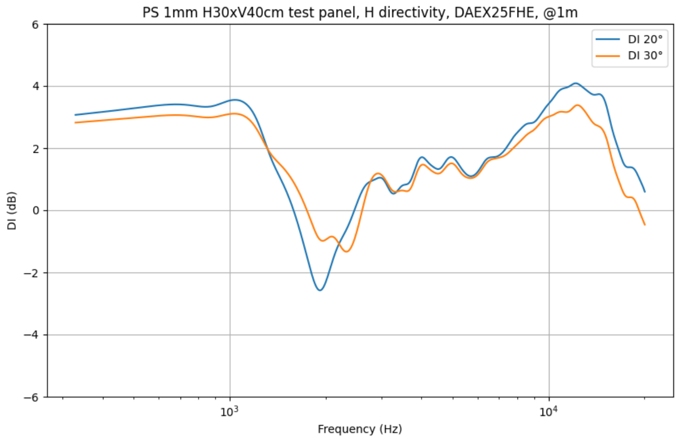

Figure 6: PS 1.3mm DAEX25 DI

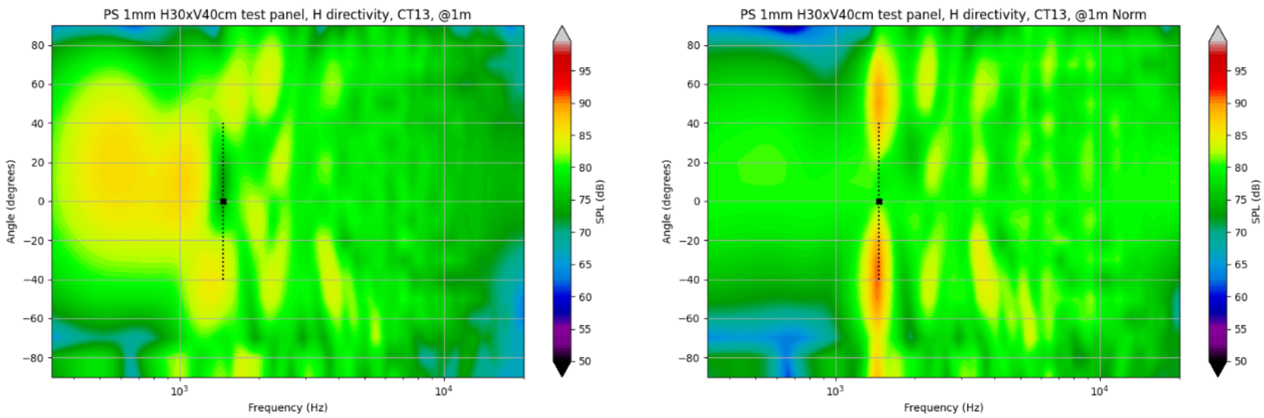

Figure 7: PS 1.3mm DAEX13CT horizontal directivity plot

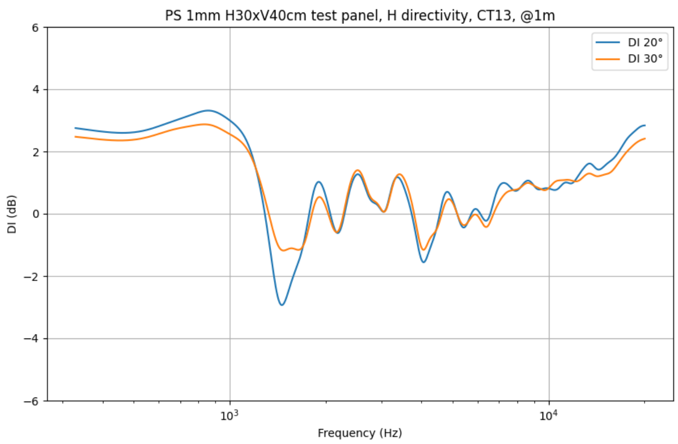

Figure 8: PS 1.3mm DAEX13CT DI

5 Plywoods

5.1 5mm “standard” Plywood

The next test is with a piece of 5mm standard plywood. Its dimensions are a bit larger than the previous panel: 34x42cm. It is also much stiffer than the previous ones.

See figure 9 and 10

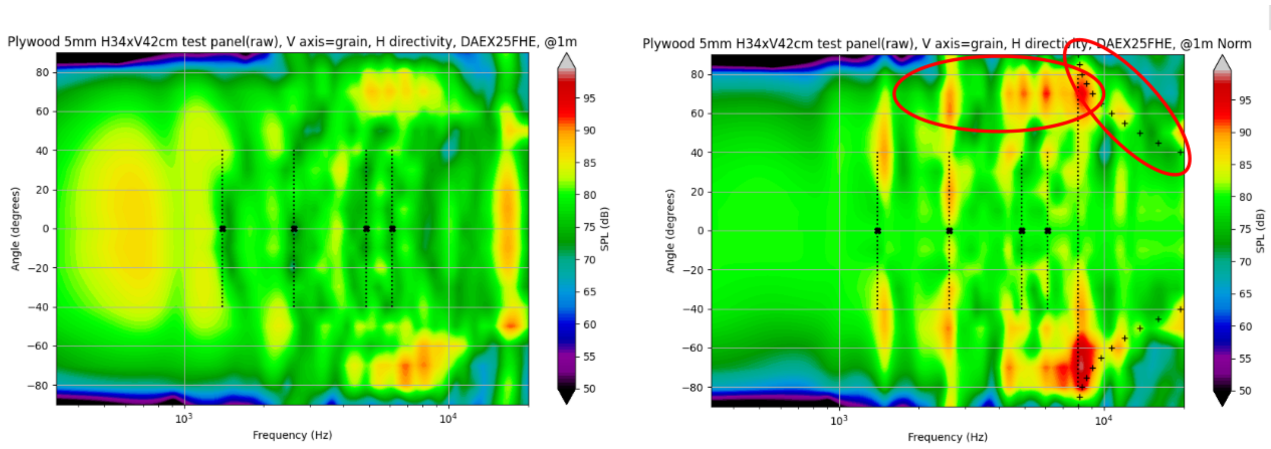

Figure 9: Plywood 5mm horizontal directivity plot

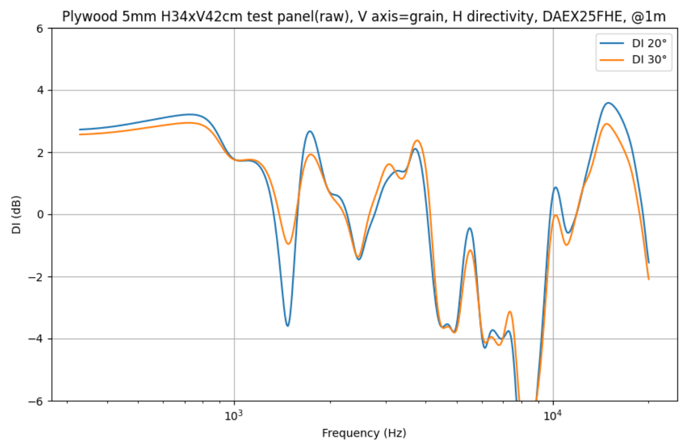

Figure 10: Plywood 5mm DI

This one 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 8000Hz.

The difficulty here is that the value of 8kHz is not the value expected for a 5mm plywood which is more around 3.5kHz supposing a 700kg/m³ density and a 9GPa Young modulus. Possibly something is wrong in this data.

The first panel shown here (EPS) was more or less in free edge conditions when the second (PS) is with a full peripheral suspension, the plywood 5mm is also in almost free edge conditions.

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

5.2 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 11 and 12 for the raw panel.

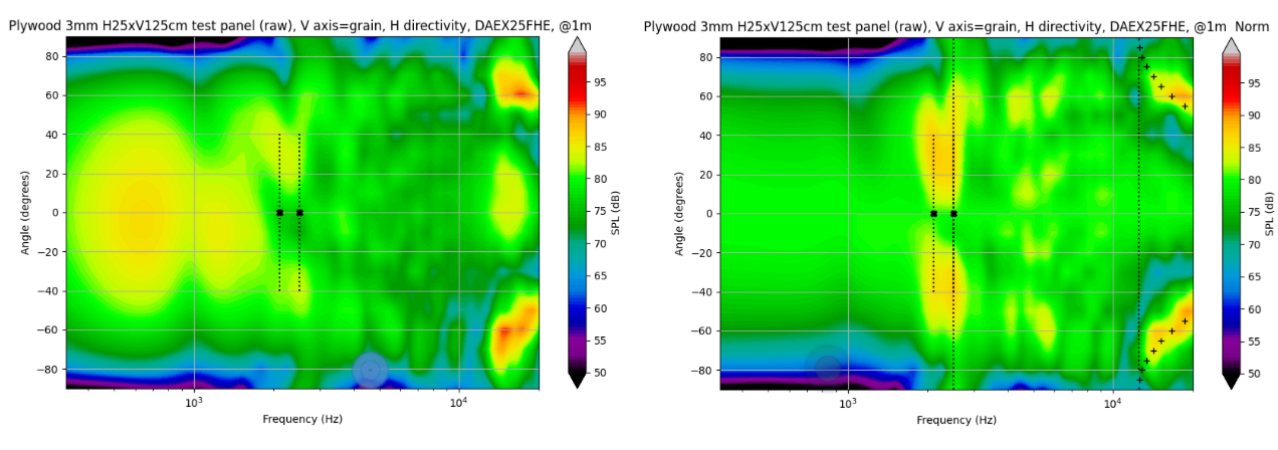

Figure 11: 3mm raw poplar plywood horizontal directivity plot

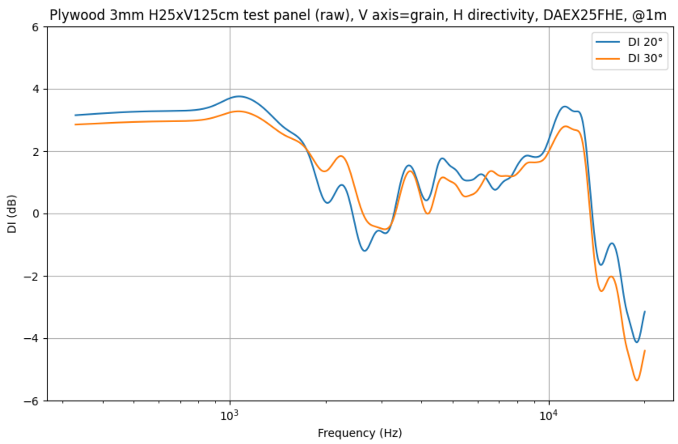

Figure 12: 3mm raw poplar plywood DI

See figure 13 and 14 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 12500Hz for both when a calculation based on a 9GPa Young modulus and a 550kg/m³ leads to 5kHz.

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.

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 varnished for it was highly diluted with the idea not to add too weight, stiffness or damping!

6 Conclusion

So first this measurement technique seems really promising.

The test of a sample of acrylic or even clear polystyrene in the 5 to 6mm thickness might make the link with the directivity plots from B Zenker's paper for a better reading mainly for the evaluation of the coincidence frequency.

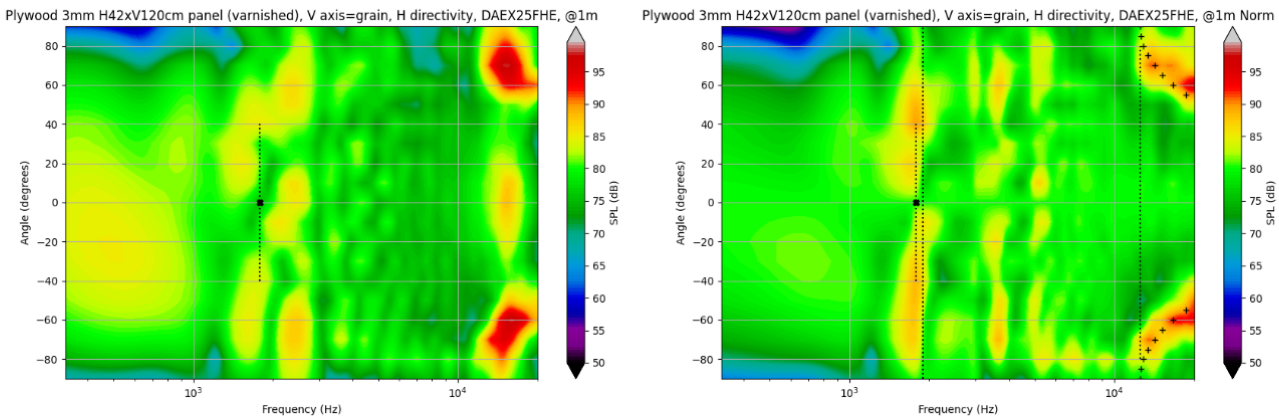

Figure 13: 3mm varnished and framed poplar plywood horizontal directivity plot

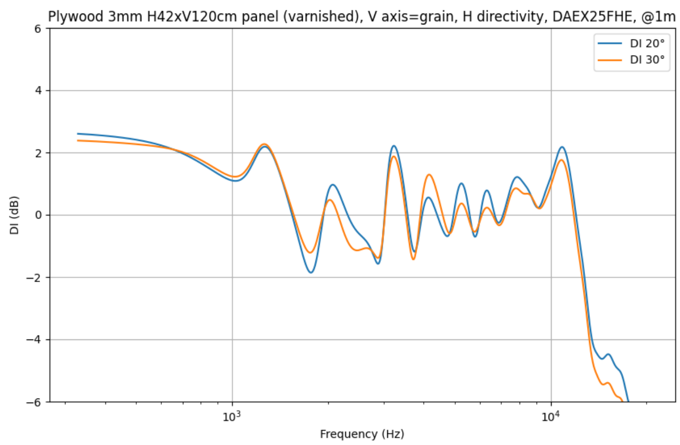

Figure 14: 3mm varnished and framed poplar plywood DI

The tap tests Eric initiates might be also a way to get more accurate characteristics of each sample for a calculation approach of the coincidence frequency.

Remark : the coincidence frequency formula is valid for an homogenous isotropic material… we have here EPS and plywood!

A possible next step of test would be to try to remove the suspension of the PS panel to see if it changes the behavior or if this material is simply more damped than the EPS.

The EPS panel as already now a new type of suspension which should be tested in directivity too.

It is interesting to see mainly from the 3mm plywood on the “as measured” directivity plot how the density of lobes increases with the frequency showing by the way the modal aspect of the directivity

More simply, it seems to be a method to select material, to choose the thinkness of a given material.

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

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/