Measurements of loudspeakers directivity patterns with ARTA

Preparation for measurement

For the assessment of loudspeaker drivers and loudspeaker systems, in addition to the axial frequency response there is also the radiation of the axis. This application note describes useful procedures for the measurement of the directivity patters of loudspeakers.

Usually the speaker is measured on a turntable with a scale to show the angle (see Figure 1.). To obtain the full-sphere characteristics, individual frequency responses have to be given for each angle increment.

The measurement microphone should be positioned so that it is aimed exactly at 0° with respect to the center (e.g., dust cap) of the loudspeaker frame or to some other specified point of reference (see Figure 2).

It is important to ensure that the chosen reference point for rotation does not change. This can be done, for example, by having the center of the baffle be positioned directly over the center of the turntable. (see Figure 2b).

If this precaution is not followed some annoying corrections will be needed. The non-central positioning of the sound source, or rather the sound propagation point, leads to the fact that, depending on the angle of rotation, the distance will change (see Fig. 2b) and thus different levels will be measured. This would have to be corrected after the measurement. In this case each individual measurement would have to be scaled to a one meter distance. In addition to following the above, all rules for making measurements in reflective environments should be applied. It is important to ensure that that the loudspeaker is positioned in the measurement space so that it is as far away as possible from the walls and other reflecting objects.

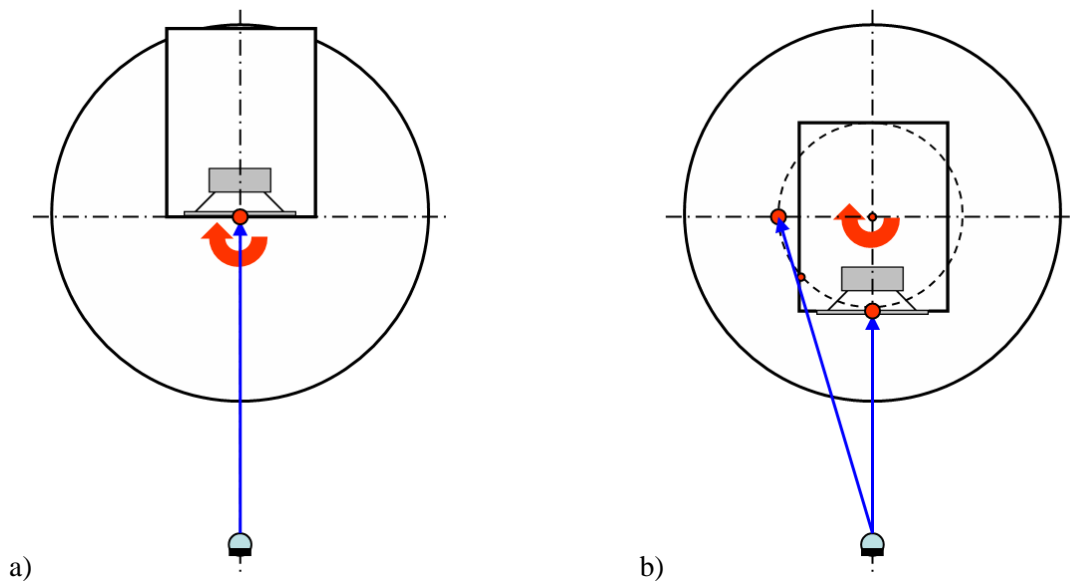**Figure 1.** LS on turntable

Figure 2. Placement of the loudspeaker on the turntable (top view)

How to do the measurement

How to run measurements with ARTA should already be known. To get a reasonable picture of the radiation the angular increment should not be too large. Usual measurement intervals are 5º or 10º, thus requiring 72 or 36 measurements. If the source has a symmetrical structure it is sufficient if only one half is measured, either the left or the right relative to the principle axis. This reduces the number of measurements to 18 or 36.
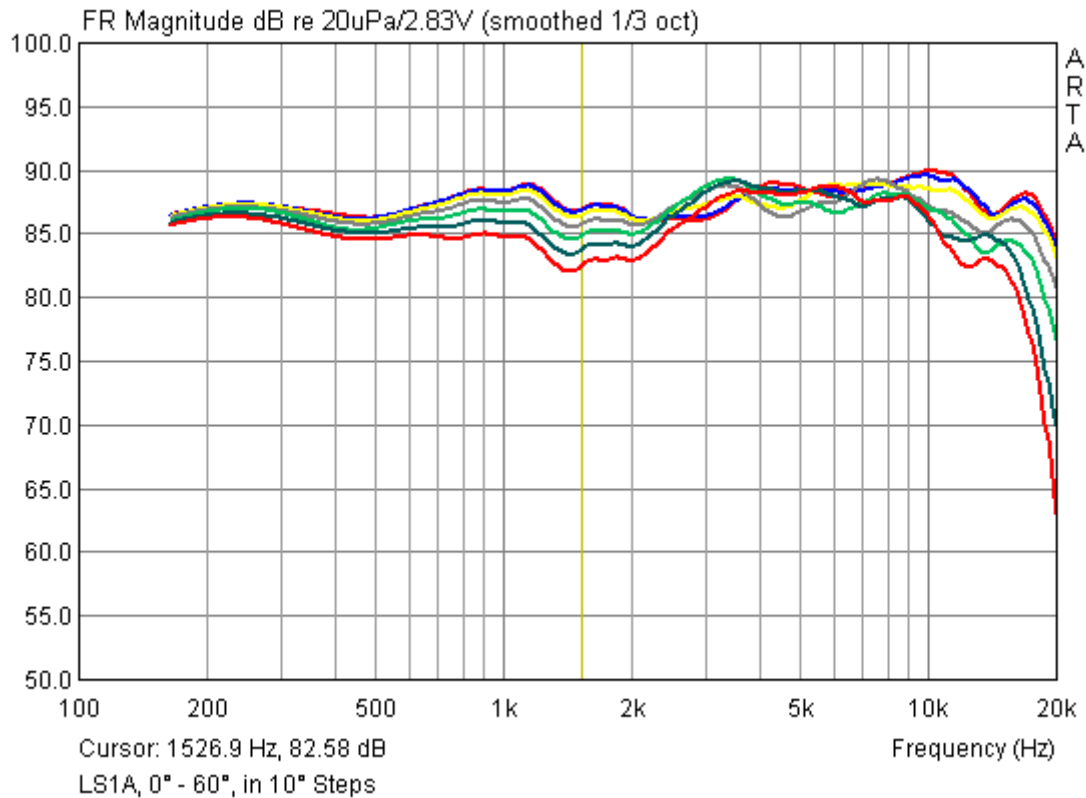

Figure 3. Individual frequency responses of loudspeaker from 0 to 60° in 10° increments

It should be evident that the measurement for all angles cannot be done in 5 minutes; some time should be taken with it. If it is desired to make many such measurements it is recommended that a turntable be constructed. An example is given in the annex of the german or spanish version..
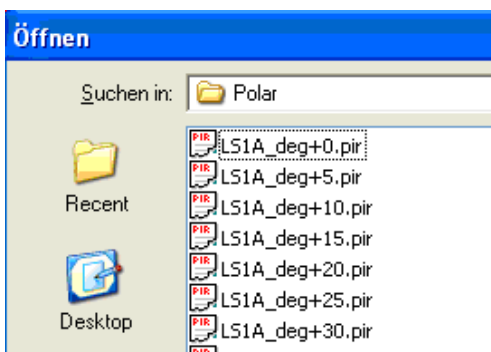
A special feature of the measurement which hasn't yet been explained is that the data is stored using a special nomenclature for the file name. It is composed as follows: Name_degSignAngle.pir where Sign is '+' or '-', and Angle is given in degrees.
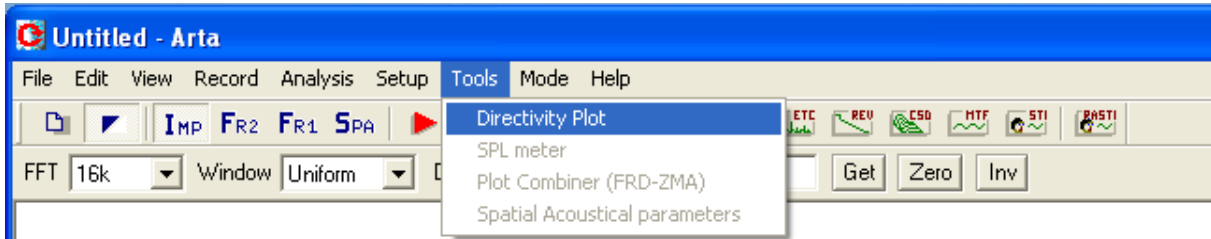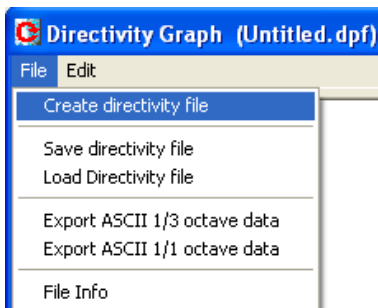
Evaluation of the measurement results

Select "**directivity plot**" from the file-handling menu.

This command will open "**Directivity graph**" window. The file menu in this window gives us following options:

If you you want to evaluate your measurement data the first time, select menu comand "**Create directivity file**".

Records which have already been edited can be opened as ".dpf" files (directivity pattern file).

Two export options are available to enable the processing or use of the data in other programs. The data can be exported as ASCII with either 1/3 or 1/1 octave frequenncy resolution.

Returning to the first analysis of test data, see Figure 4a to see the ARTA test data sorted by ascending angle. This works only if you adhere strictly to the given nomenclature.
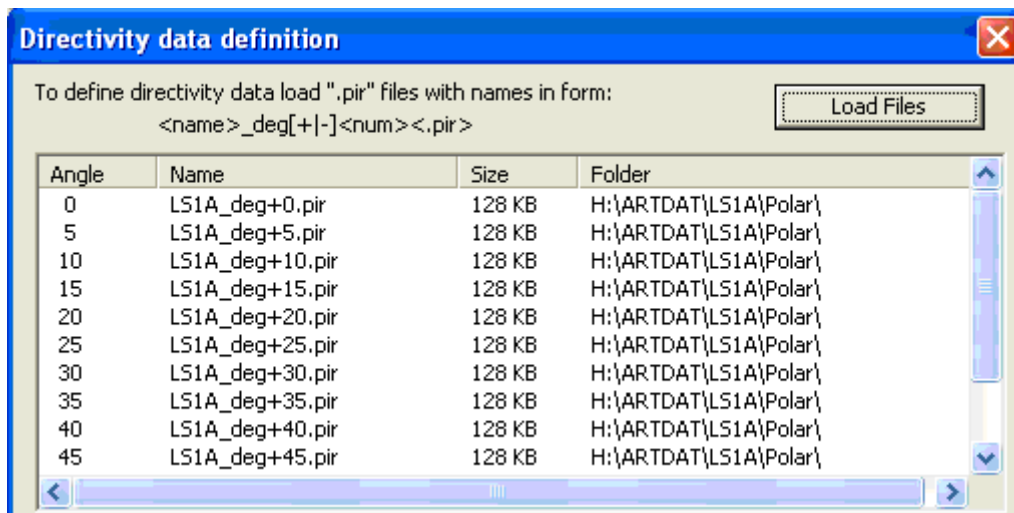
Figure 4.a Dialog Box "**Directivity data definition**"

In the section "**Magnitude**" the following must be selected (see Figure 4b):

- Degree of Smoothing (1/3 to 1/12 octave)
- Whether all of the data should be normalized relative to the 0° measurement
- Whether the test data for negative angle measurement should be mirrored

The section "**Frequency Range**" should be self-explanatory. It is especially important, however, to ensure that the chosen lower frequency limit is a sensible choice.
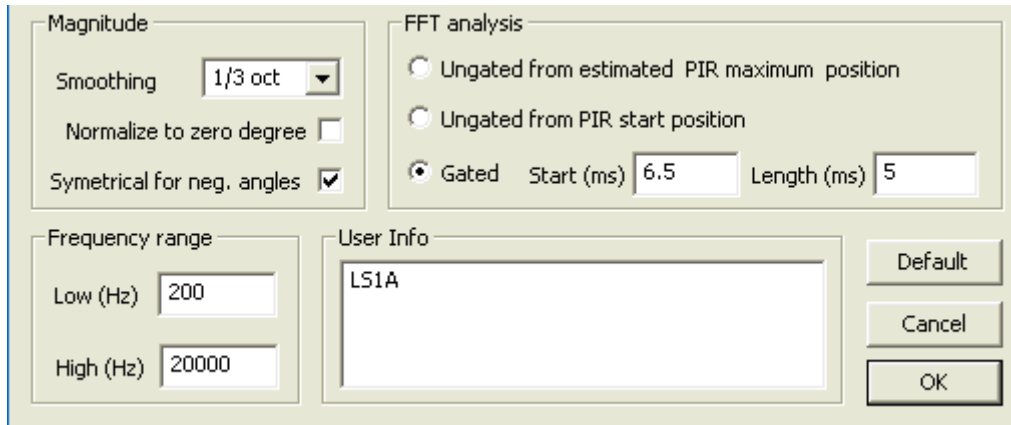
Figure 4.b "Directivity data definition" Dialog box.

The section "**FFT Analysis**" determines how the data is evaluated. Three different options are offered:

- The analysis begins with the auto-detect first peak in the impulse response
- The analysis begins with the starting position of the impulse response graph
- The analysis takes into account a window using the selected starting position and length of the window. In this case it is possible to hide the region and thus have free-field conditions.

The estimation of the reflection-free window is discussed in Application Note No. 4. With a normal ceiling height of 2.50 m, a measurement height one half of the room height and a measuring distance of about one meter, the window should be about 4.5 ms.

Click "**OK**" if the analysis of the data is correct. Choose the dialog box "**directivity graph**" with the following selection at the lower left side of the dialog box:
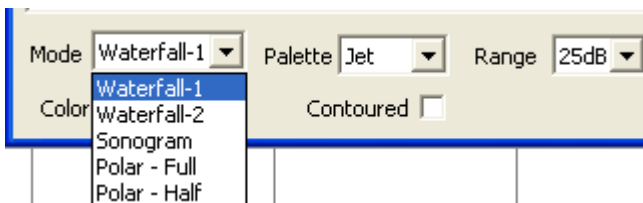
The choices for **Mode** are the classic analysis, a Polar plot, two kinds of waterfall charts, or a sonogram.

With the **Palette** one can design the color type of the graph and with **Range** the resolution in dB. Examples are given below of the effect of the selected parameters. With the "**Color**" checkbox you can choose whether the charts should be displayed in color or monochrome. "**Contoured**" controls the moving color transition between the groups of levels, this chart has the character of an isobar diagram.
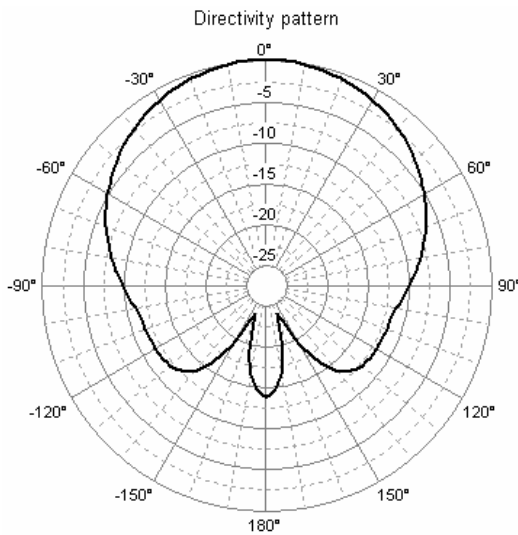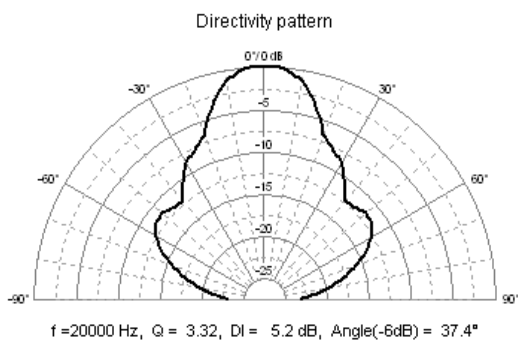
Directivity pattern types

Polar pattern

We will start to display types of directivity patterns with the traditional display, the polar pattern.
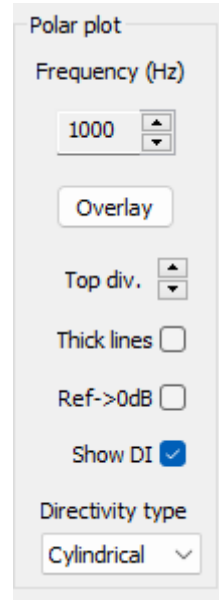
Directivity pattern

Polar Full

Choose either the notation "**Polar Full**" or "**Polar Half.**"

You will see the left top representation for the selected frequency if "**Polar Full**" is chosen.

Frequency is chosen in the polar plot panel by changing the control "**Frequency**" in 1/3 octave steps.

The level axis can be manipulated with control "**Top div**".

The check box "**Ref -> 0dB**" determines whether the pattern is normalized relative to the 0 degree level or not.

Directivity pattern

f =20000 Hz, Q = 3.32, DI = 5.2 dB, Angle(-6dB) = 37.4°

Polar Half

The checkbox "**Show DI**" determines whether directivity parameters: frequency - f, directivity factor - Q, directivity index - DI and -6dB angle will be shown below the polar diagram
The directivity factor Q is estimated as a ratio of sound intensity at reference angle to intensity that will be produced by point source that radiate the same power as directional one, at same distance.
The directivity index DI is calculated by $DI = 10 \log Q$ (dB). It is equal to difference of sound pressure level at reference angle to sound pressure level produced by point source with equal power and at same position.

For calculation of the radiator sound power, we need to assume the type of radiator spatial directivity pattern. Combo box "**Directivity type**" offers two types of patterns: **Cylindrical** and **Spherical**. Cylindrical pattern is used for tall sound columns, while spherical pattern is used for loudspeakers with circular drivers. Estimation will be correct if radiation is symmetric to reference axis (0 degree). The DI can be also estimated for loudspeaker mounted in an infinite baffle. ARTA do it automatically if finds that measurements are done for angles from -90 to 90 degrees. For the free field full space estimation measurements should be done for angles from 0 to 360 degrees or from -180 to 180 degrees.

With **Overlay** button the active curves can be saved as overlay

After selecting "**Overlay**", the "**Polar Overlay Manager**" (see Figure 5), with any chosen frequency as an overlay shown separately on or off, deleted or added. With "**Color**" the colors of the curves in the framework of the color palette are modifiable.
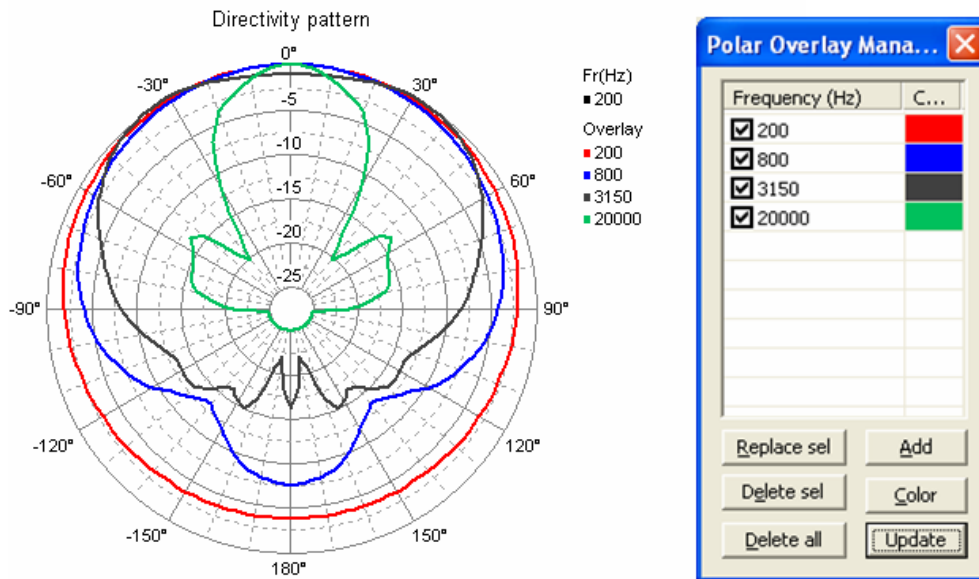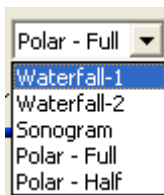
Figure 5. The Overlay Function

Other types of representation which are supported are discussed in the summary below. It covers the basic ways as well as instructions in the form of examples for the special features and their respective presentations. In addition, there are various practical examples which show the influence of a variation in parameter.
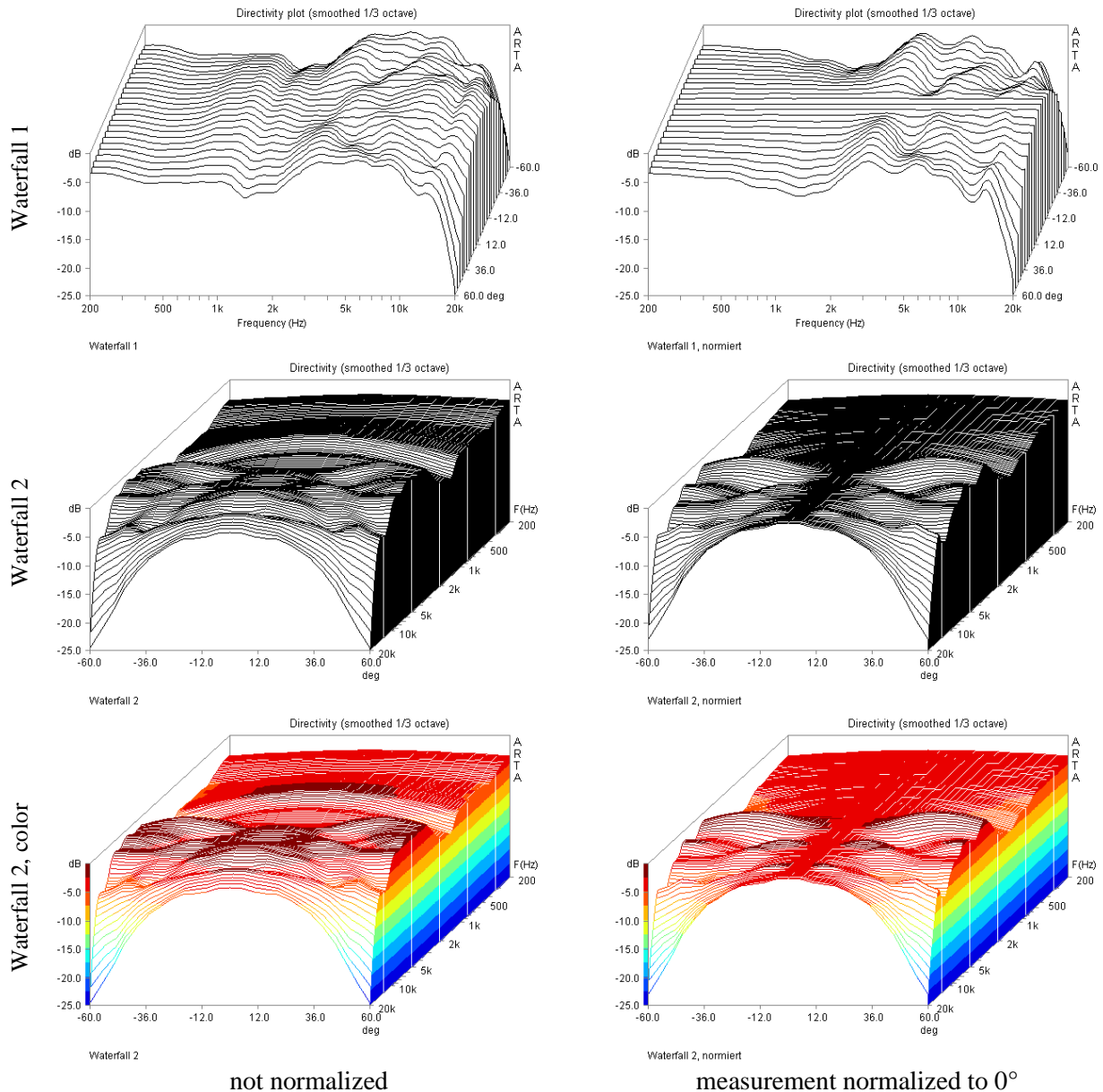
Waterfall

Figure 6. The waterfall display

The waterfall display is a form of presentation chart in which each frequency response measurement is displayed as a 'slice' corresponding to each angle. It is available in two versions.

In Waterfall 1, all measuring curves are shown from the frequency axis (side view) and in Waterfall 2 from the angle axis view (front). This has the effect that special features of the measurement can be identified better from different perspectives. The waterfall chart can also be displayed in color, with the level indicated by color information.

As additional variation is the normalization relative to the axial (0° measurement) frequency response. Note that only differences relative to 0° measurement are shown.
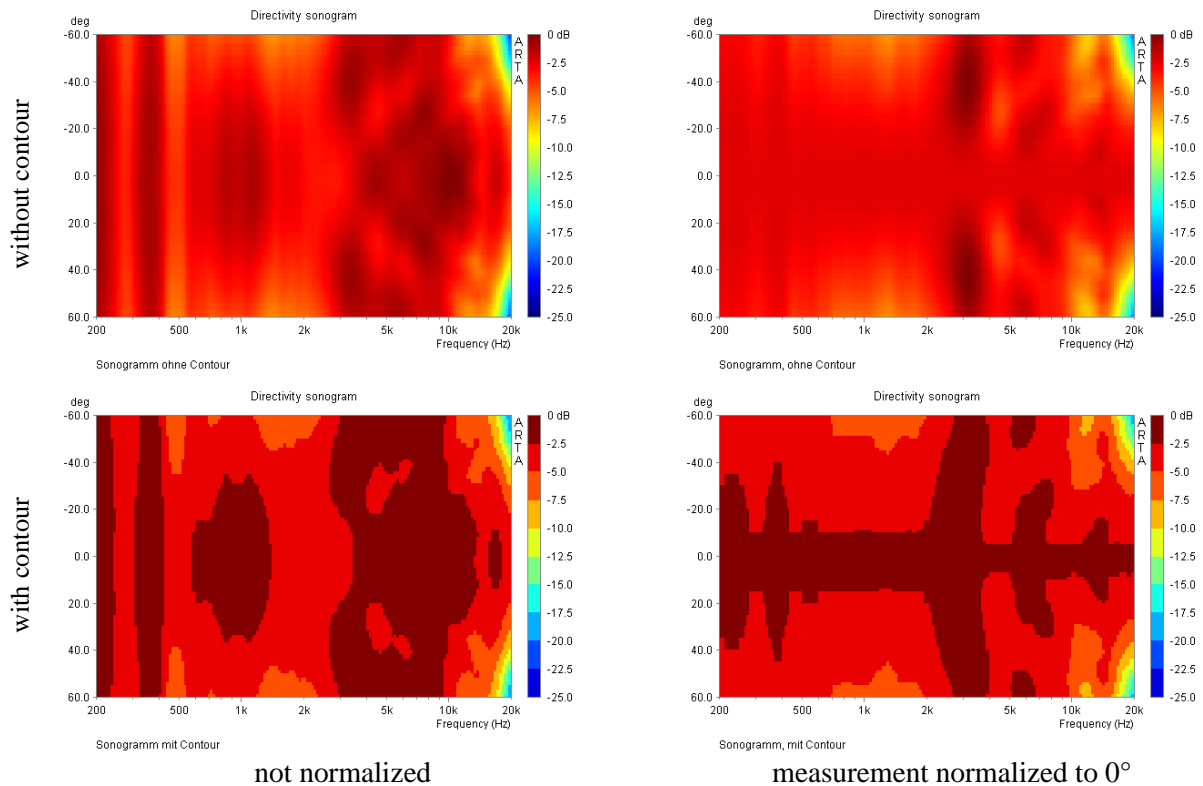
Sonogram

Figure 7. The sonogram representation

The sonogram display type is quite vivid. The levels are expressed through color differences.

The colors can be found on the "**Palette**" menu in the framework of the offer varies. By default, "**Jet**" red zones for high level and blue tones for low-level zones.

The "**Contour**" checkbox determines whether you will see smooth color transitions, or abrupt transitions with strong contrasts. The contrasting view is generally easier to interpret.

There is again the option of normalization relative to the 0° response. This is shown in the right half of Figure 7. It should be made clear that in this presentation the normalization to a constant level is an illusion, which is not representative of reality. It is recommended that both types be displayed side by side to aid the interpretation. Compare the examples shown in Figure 10 through Figure 13.

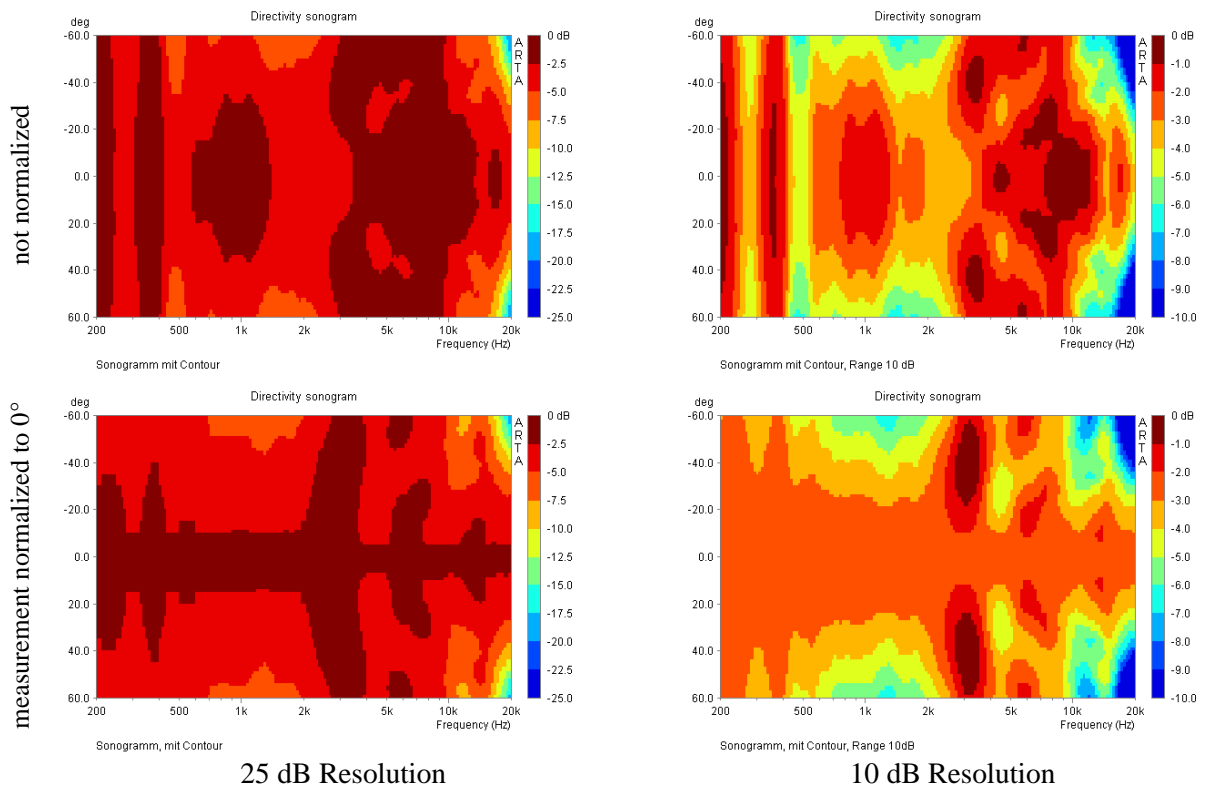**Choice of the resolution**

Figure 8. The influence of level resolution

The appearance of the charts is strongly influenced by the choice of level resolution. There are two examples in Figure 8, each with a 25 dB and a 10 dB axis. At first glance, it looks as if the charts on the left half have nothing to do with the diagrams on the right half.

Experimenting a little with the parameters is recommended, especially for first-time users of this function.
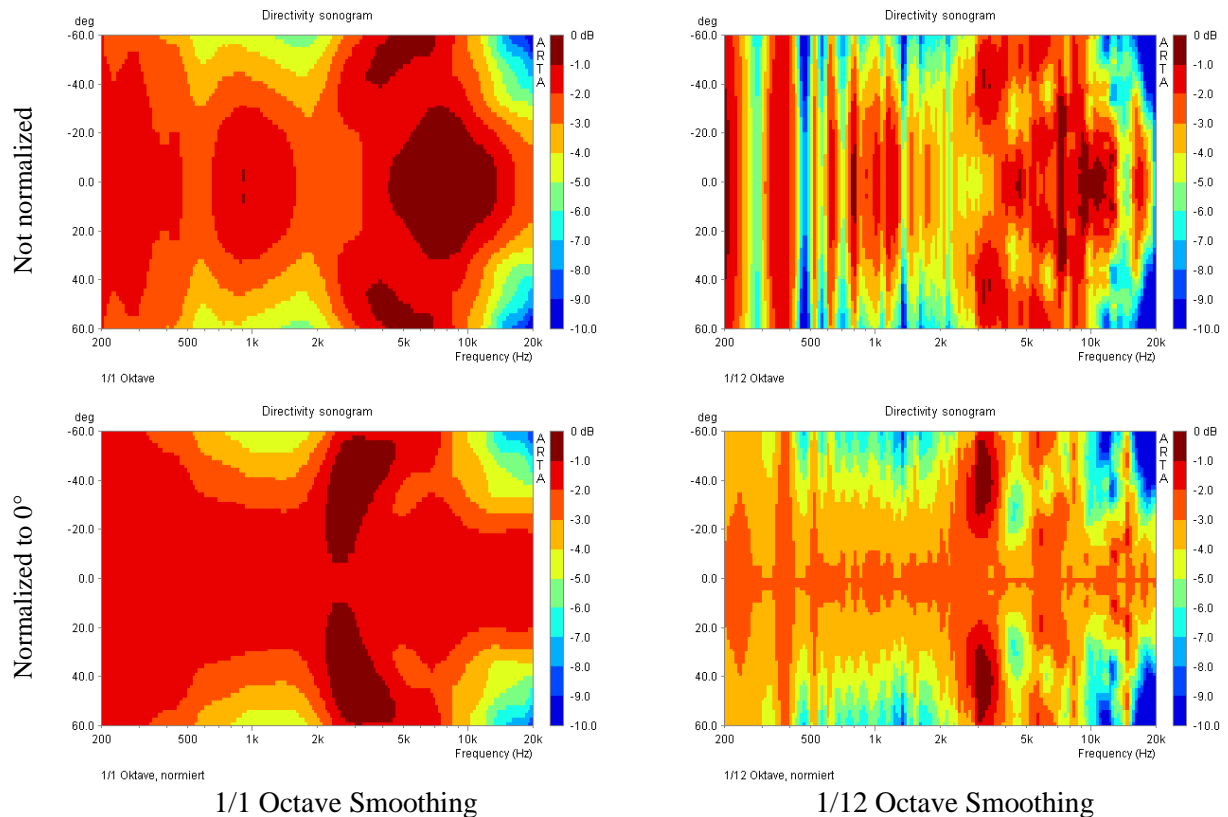
Smoothing

1/1 Octave Smoothing   1/12 Octave Smoothing

Figure 9. The influence of the choice of smoothing

The choice of smoothing has a significant influence on the clarity of presentation.

Figure 9 shows graphs with the smallest and largest possible choice of smoothing. Too much smoothing removes all the detail whereas a low degree of smoothing makes the graph difficult to interpret.

It is recommended to experiment with these parameters.

Practical Examples

The following are some practical measured examples. They are intended as demonstration and training materials.
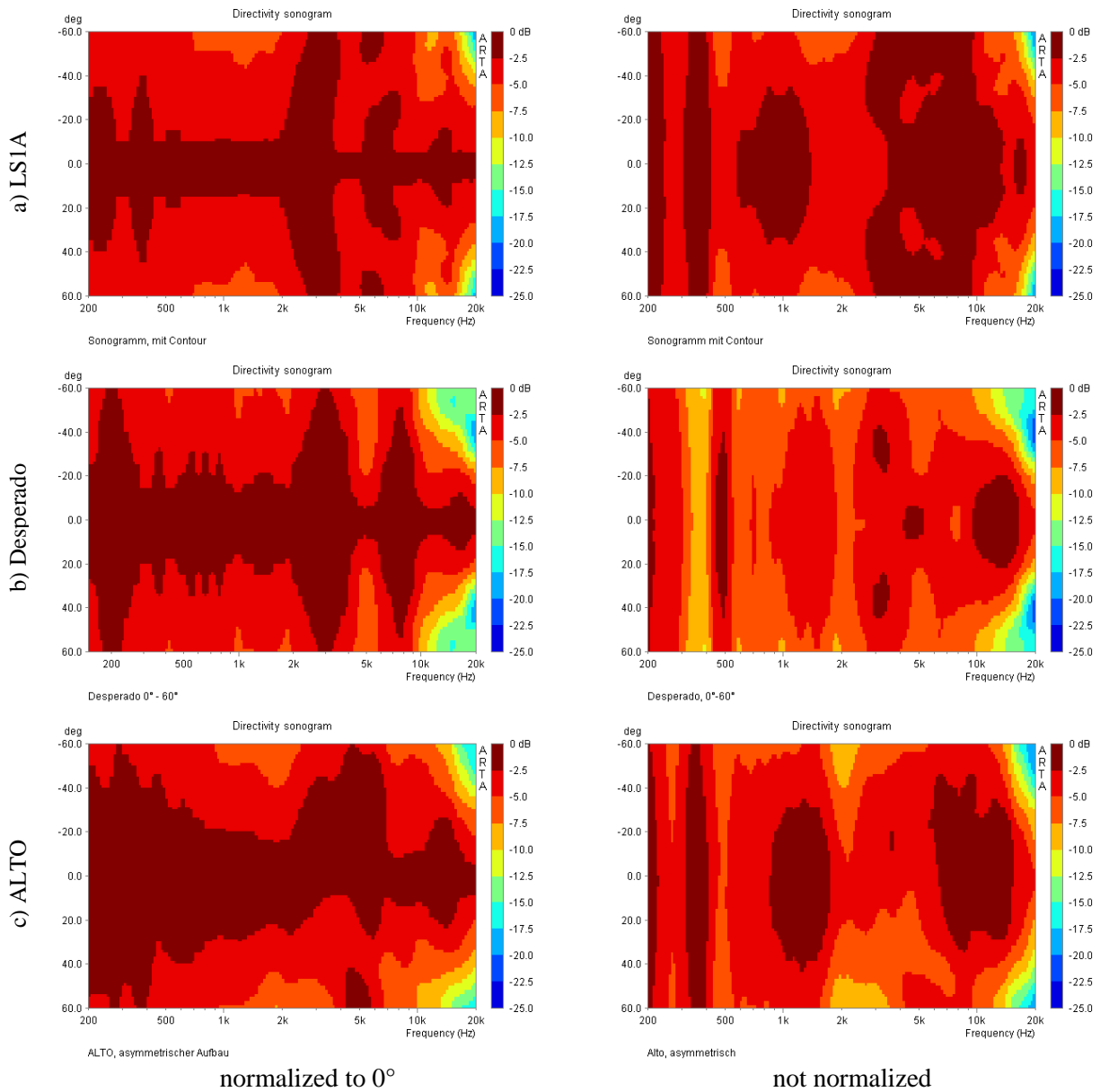

Figure 10. Practice (two-way boxes)
a) and b) with symmetric response
c) with asymmetric response

Figure 10 has three different two-way boxes. Figure 10c is the asymmetrical structure of the box very clear to see. Such effects are amplified by normalizing to 0 °.

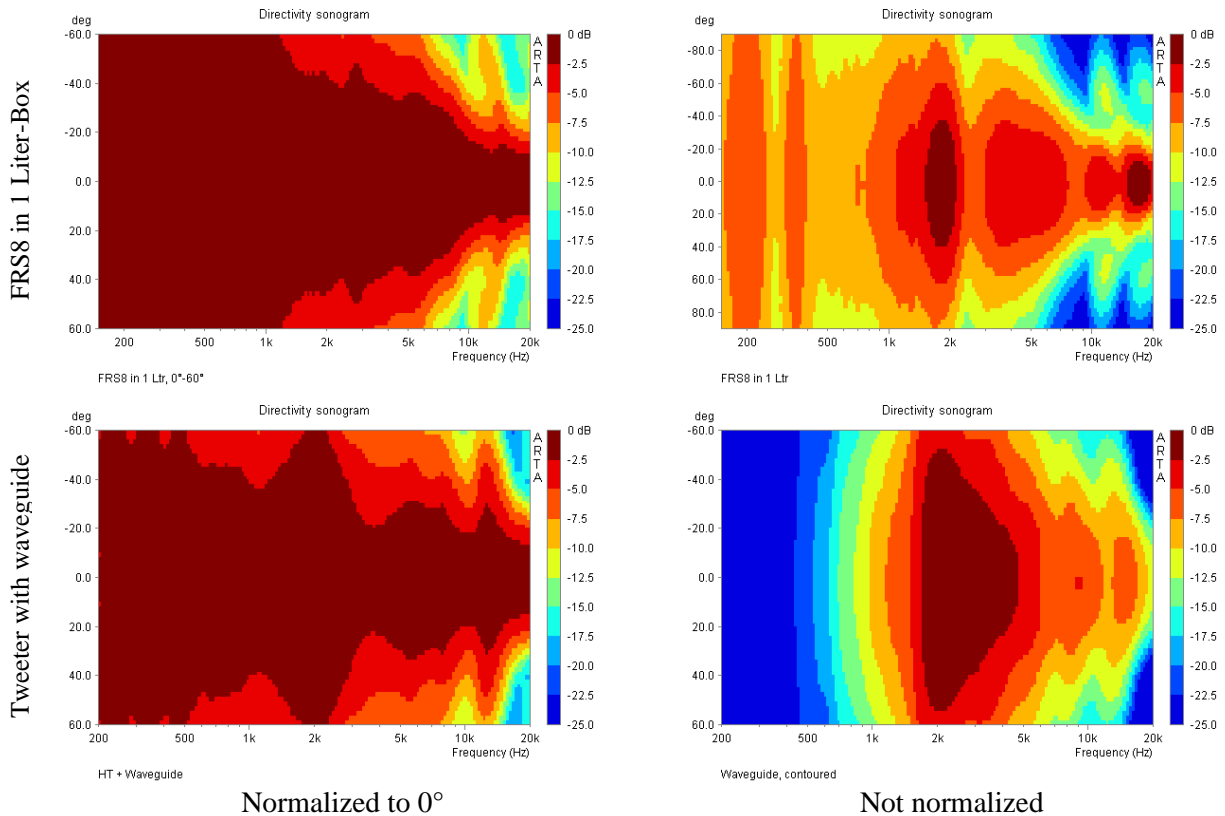Normalized to 0°   Not normalized

Figure 11. Broad-band speaker and tweeter with wave guide

Figure 11 shows the measurements for two very different individual speakers, an 8 cm wide-band driver in a small 1-Liter box and a tweeter with wave guide. This is makes it particularly clear that the standard presentation without further information can lead to mistaken conclusions.

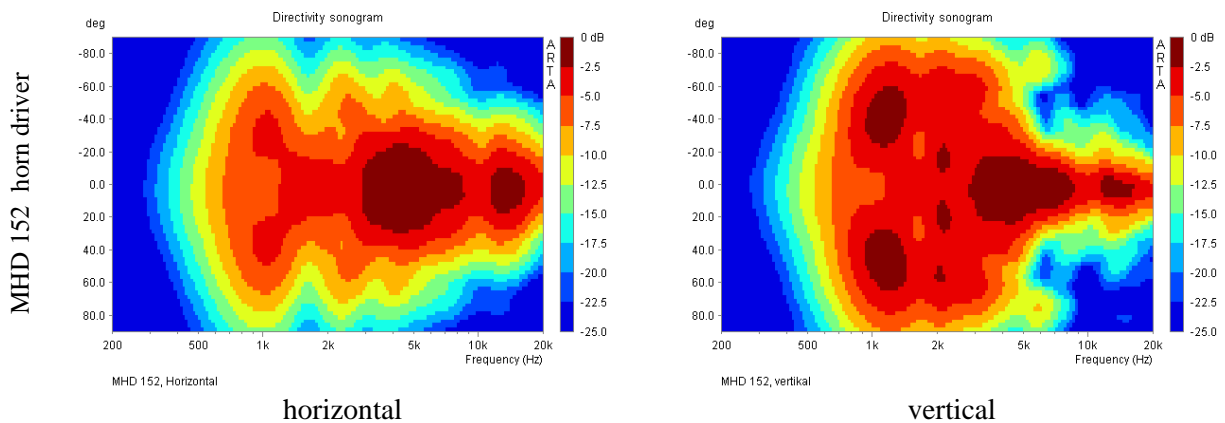horizontal   vertical

Figure 12. high frequency horn, measured horizontally and vertically

Figure 12 shows the analysis of measurements on a tweeter horn for angles from ±90° horizontally and vertically.

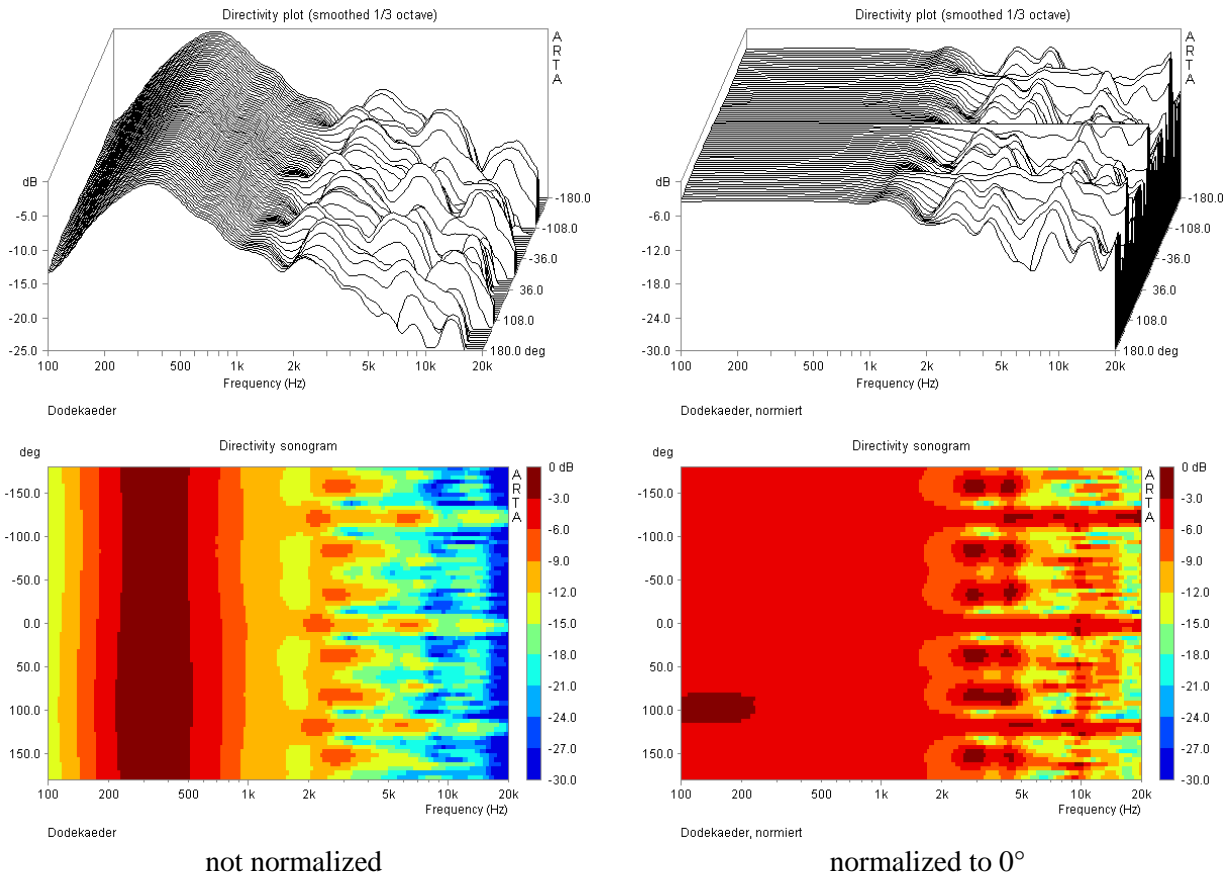not normalized   normalized to 0°

Figure 13. Dodecahedron directivity pattern

Figures 13 and Figure 14 show the analysis of measurements on a dodecahedral loudspeaker. The omnidirectional nature of this source is clearly visible in all types of display.
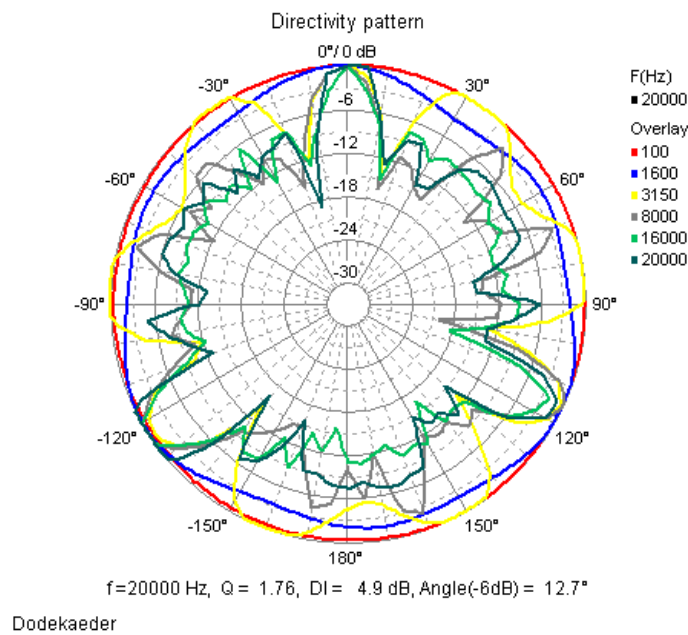

Figure 14. Dodecahedron, Polar diagram