Computer presentation of sound-fields

By Bohdan Raczynski, December 2020

Off-axis loudspeaker performance has gained some attention in recent years. The enabling factor for this opportunity was availability of measurement and presentation software that allows the user to perform or model -90deg ….90deg SPL polar data collection. SPL information obtained from such an activity can be presented is several ways – depending of what particular aspect of the loudspeaker performance is being investigated.

This paper focuses on SPL vs. Radiation Angle performance, and will examine a couple of alternatives, when it comes to data presentation. We are firmly embedded in the frequency domain as well.

1. Traditional, horizontal and vertical polar plots. These are popular, because it is relatively quick to measure the finished loudspeaker's SPL on its horizontal and vertical axes. For each measurement point, you can either measure just SPL, or the frequency response.

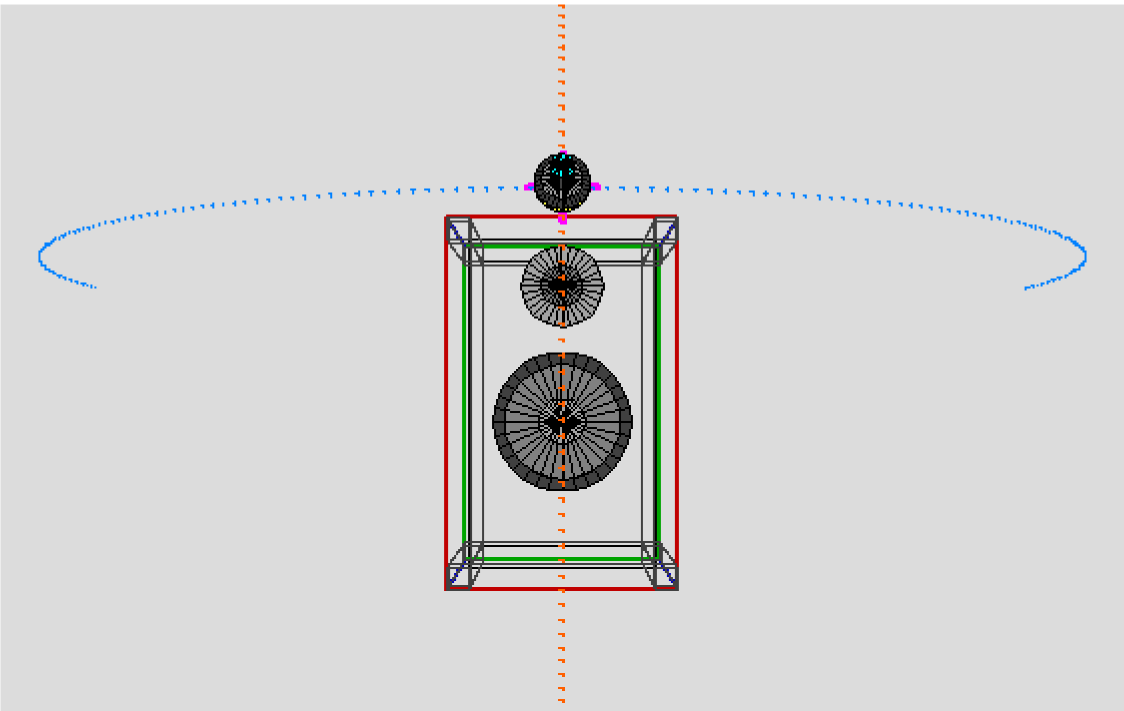
2. Constant-directivity (CD) polar plots. There are several variants of those plots: Cumulative Spectral Decay – type of plots, CD in rectangular coordinates and CD in circular coordinates. Each plot may be displayed as "standard" or "normalized" type of plots.

3. Balloon Polar Plots. These are the most time consuming.

One of the alternatives of presenting polar data is **Balloon Polar Plots**. The Balloon Polar Plots described below are a visualization of a large number of SPL data points collected over the front hemisphere of the sound-field generated by a loudspeaker system. In fact, this paper is based on 32400 data points arranged in 180 by 180 matrix. This allows SPL presentation in 1deg horizontal and 1deg vertical resolution. Collecting such enormous number of measurements is practically quite difficult and time consuming. Therefore, a modelling option is presented here, even though it is still a time consuming process. In this model, the microphone is moved in front of the loudspeaker at a predetermined distance (typically 1m), from left to right along a half-circle trajectory. This constitutes the front-hemisphere of the sound-field. The SPL, calculated for each point, is then colour-coded to indicate corresponding SPL level and placed at a radial distance from the centre of the hemisphere. Larger radius indicates stronger SPL.

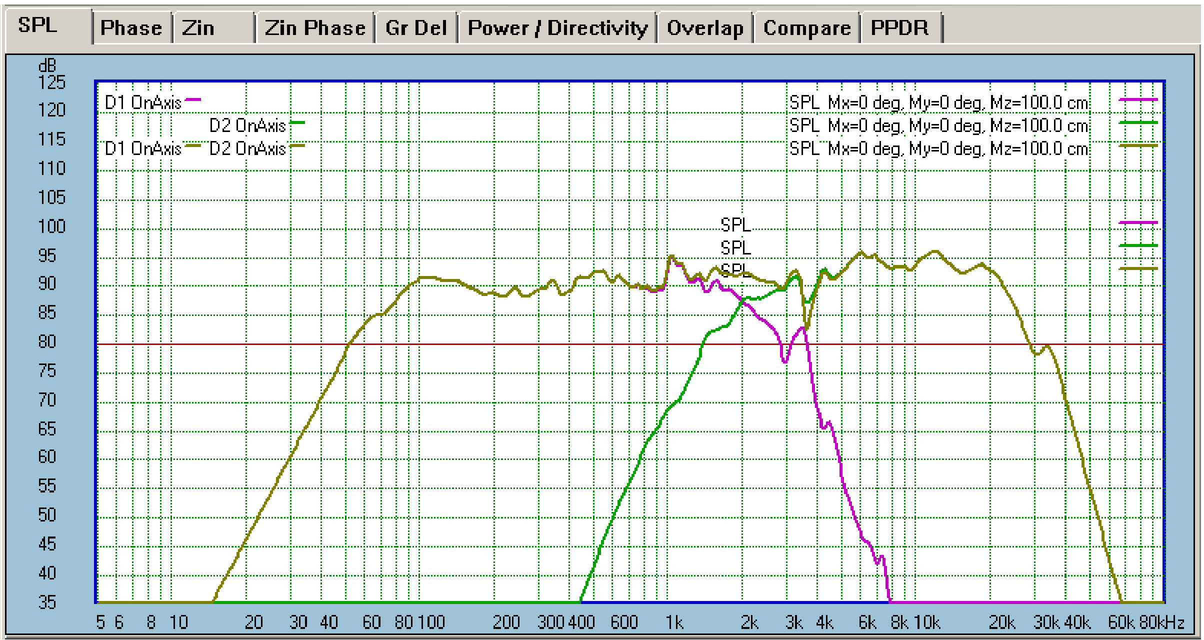
But first, we take a few small steps into the polar performance of a loudspeaker presentation. A couple of examples will be presented and various techniques of visualization of the polar data will be explored.

First, a compact, two-way loudspeaker will be examined. The general design configuration is shown on the Figure 1 below. Please note, that the **microphone pivot point is located at the front of the tweeter driver**.



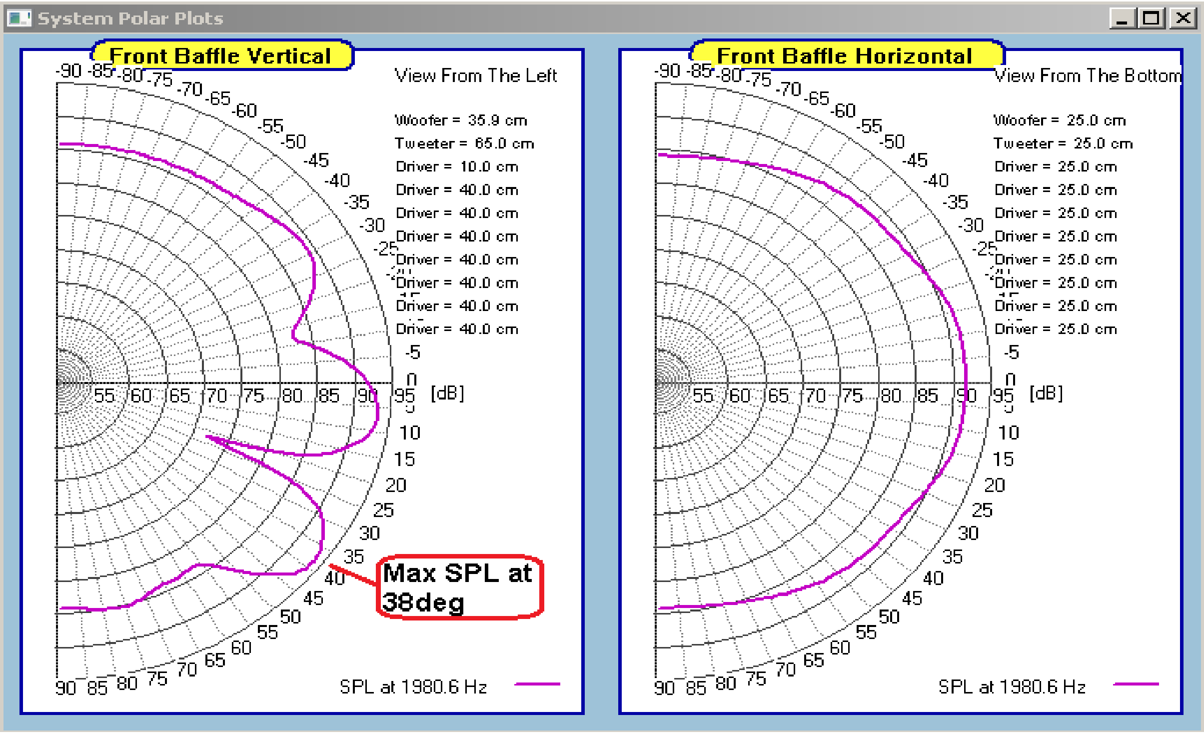
Compact, two-way loudspeaker system under investigation.

Frequency response of the loudspeaker is presented on the figure below.

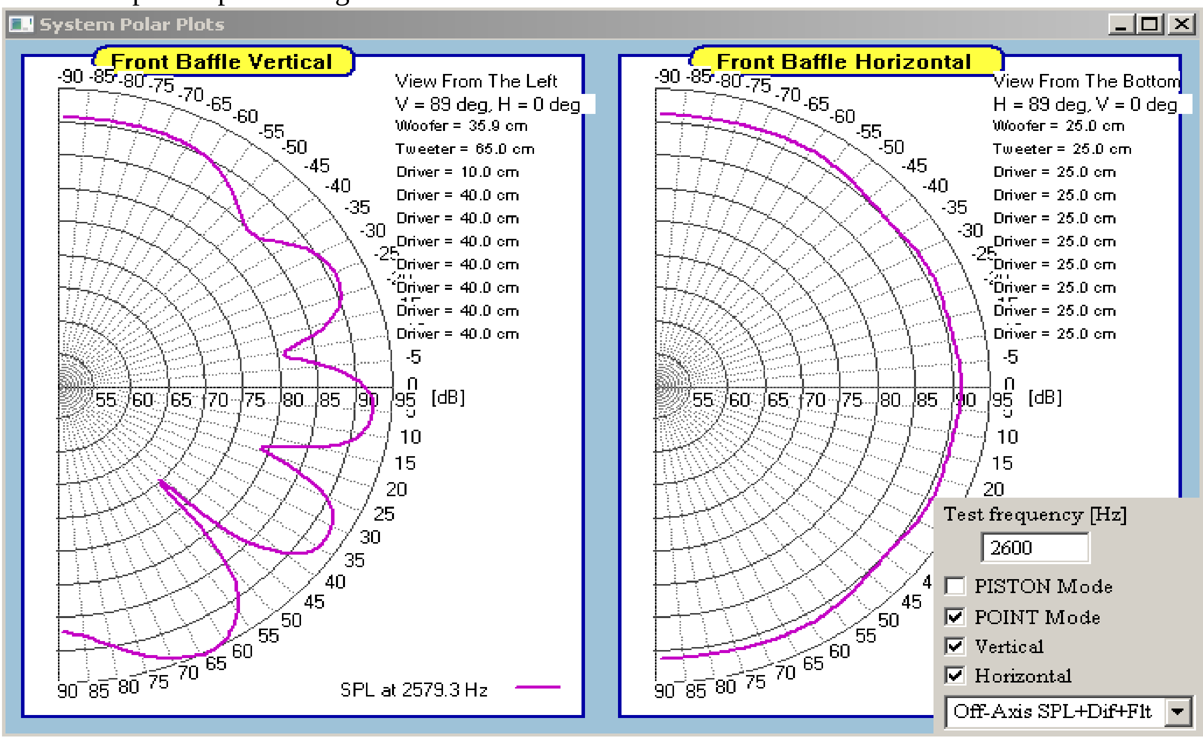


Horizontal and Vertical Polar plots

Traditional horizontal and vertical polar plots have a significant value to the designer. These plots show lobbying patterns related to crossover parameters, drivers' mutual location on the front baffle, their size, and also diffraction contribution to SPL. Sometimes, it may be possible to de-couple these three influencing factors. At least in the modelling phase of the project. Ideally, these tests would be conducted in free-field and be automated, where the loudspeaker under test (DUT) is placed on a turntable controlled by the measurement software. While the turntable is stepping through the sequence of angles, the SPL measurements are performed at every angle of interest. Vertical polar plots are simply accomplished by placing the loudspeaker on its side and adjusting other relevant test parameters. Typically, the test microphone is placed in the tweeter axis, at some reasonable distance (often at 1m-2m distance), and this becomes the pivot point for rotating the test microphone. Except that the microphone is stationary and the loudspeaker is rotating. This technique is used for other types of polar tests as well. Two examples are shown below. Horizontal and Vertical Polar plots at 2000Hz.

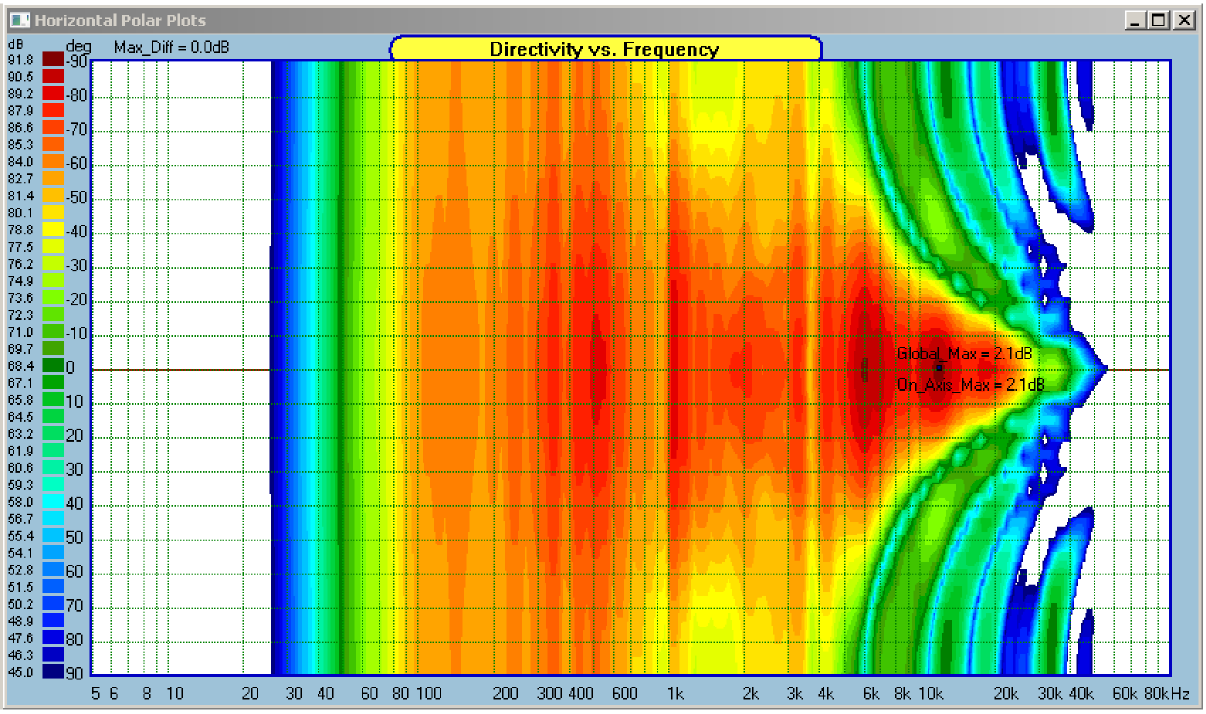


The same speaker performing at 2600Hz.

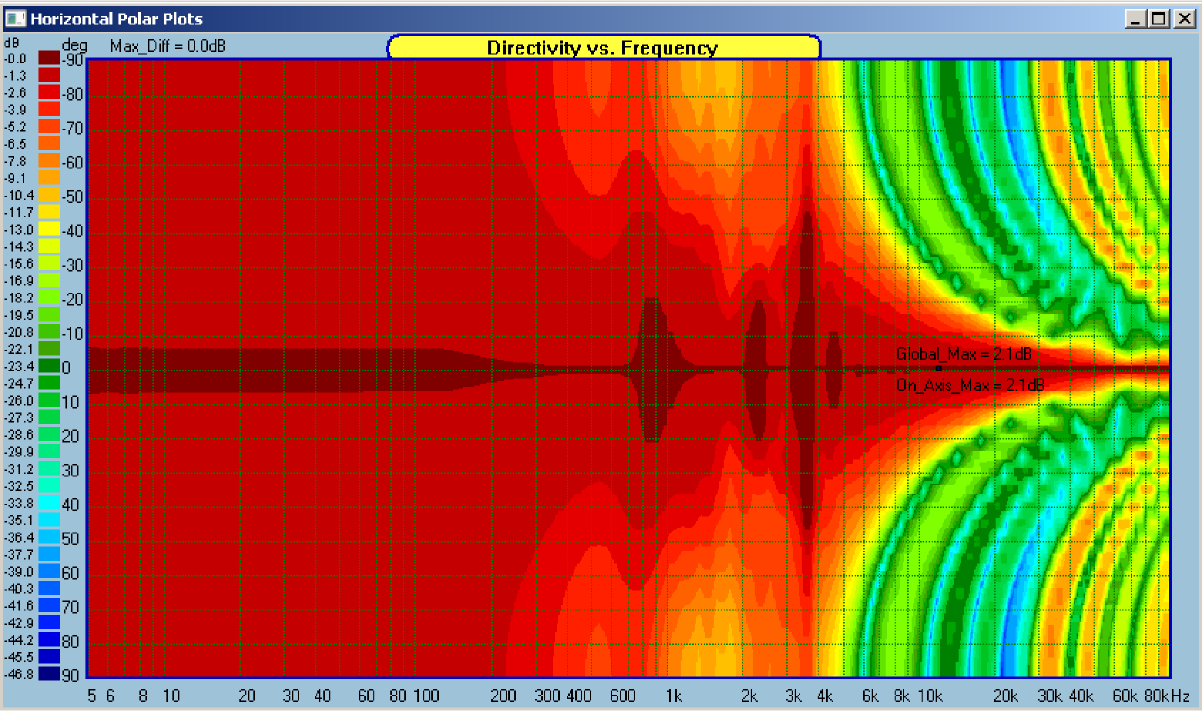


Constant Directivity Polar Plots

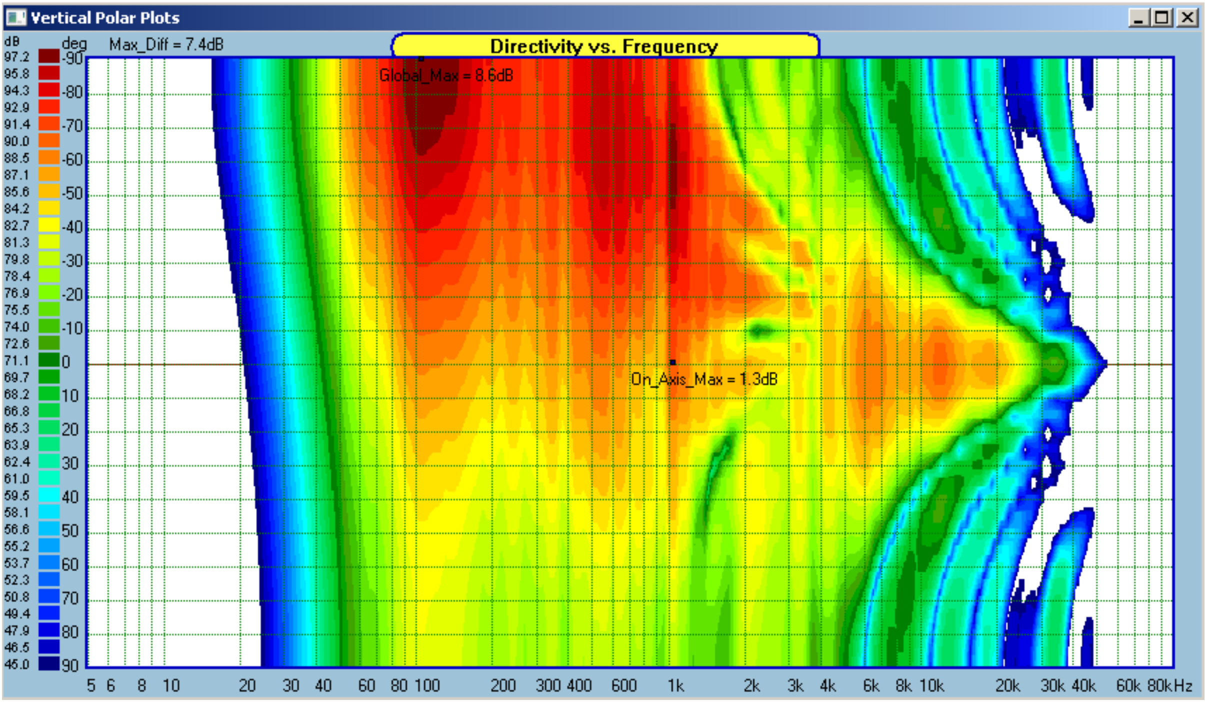
Horizontal “Constant-Directivity” (CD) plots for symmetrically built loudspeakers are likely to be symmetrical as well. On the example shown below, you will notice two parameters displayed: Global Maximum SPL = 2.1dB and On-Axis Maximum SPL = 2.1dB. In this case, global maximum SPL is located at the same spot as the on-axis maximum SPL.



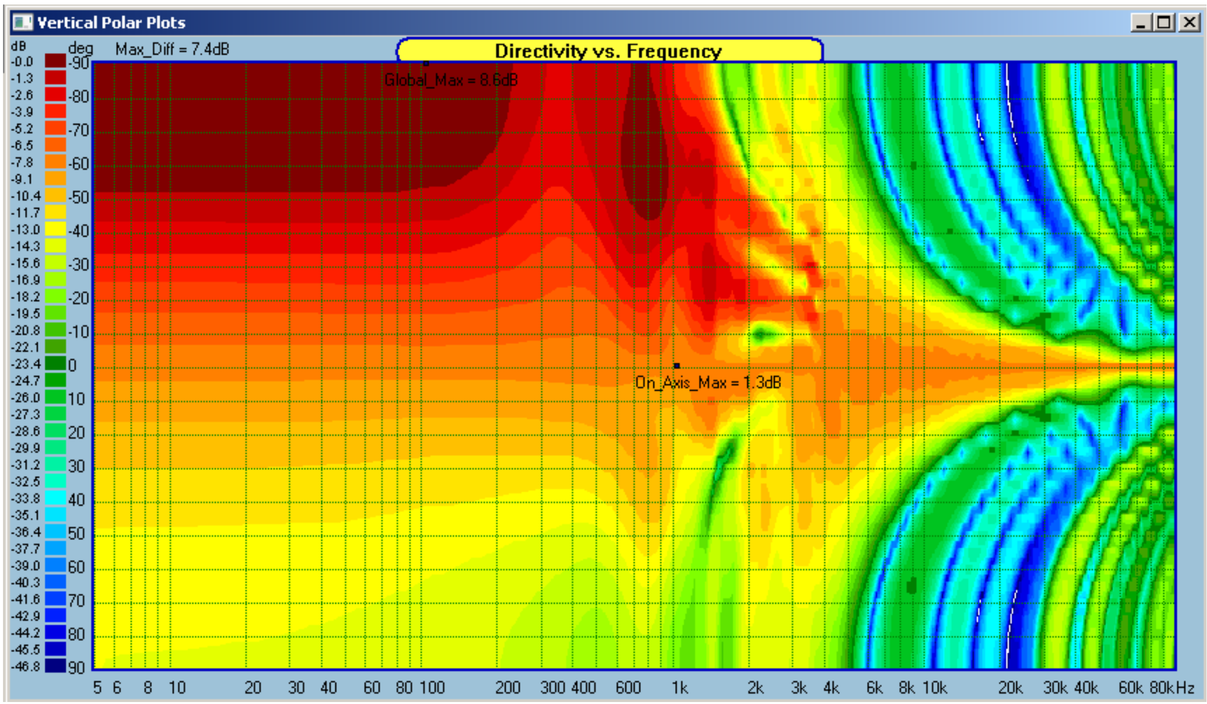
Normalization of such CD plot is performed in respect to on-axis SPL will yield symmetrical display as well. You will notice the maximum SPL is always located on the horizontal angle = 0deg (brown colour area).



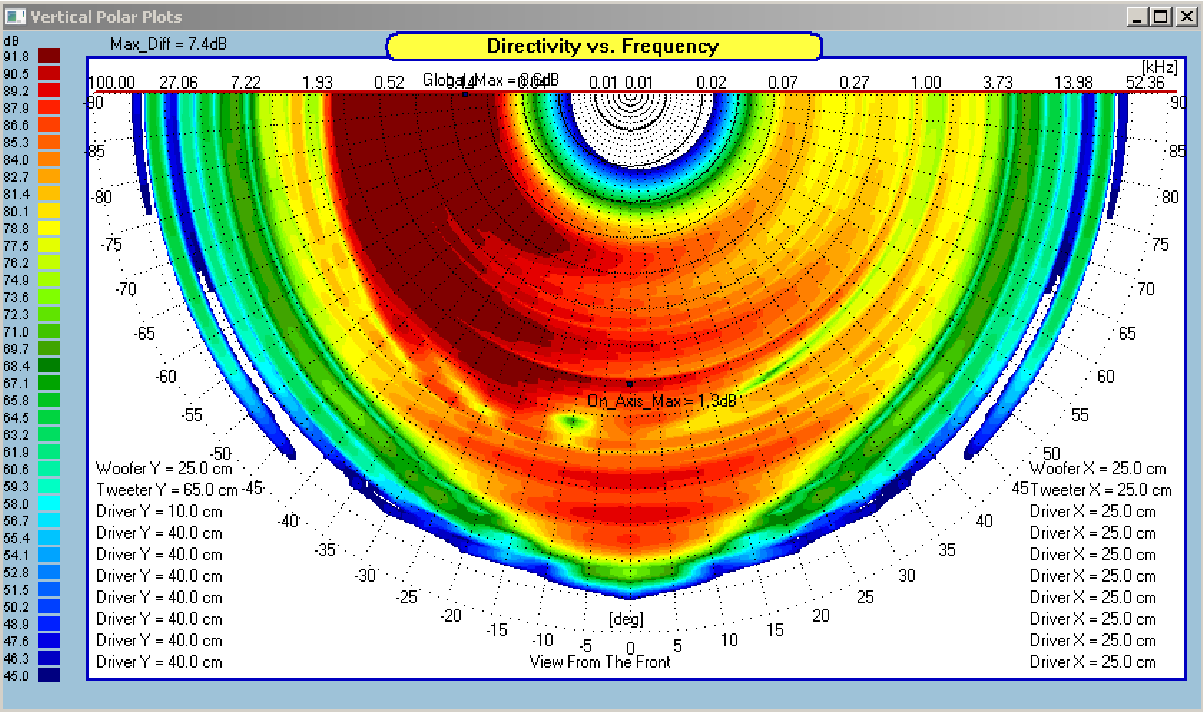
Vertical CD plots may not be symmetrical. The example shown below, clearly indicates, that maximum on-axis SPL is located at approximately 1000Hz, while maximum off-axis (global max) is located at around 100Hz. At that frequency, global maximum SPL is about 8.6dB greater than on-axis SPL at 100Hz. We can also observe, that at 100Hz, the global SPL is depicted with 6 shades darker colour than on-axis SPL.



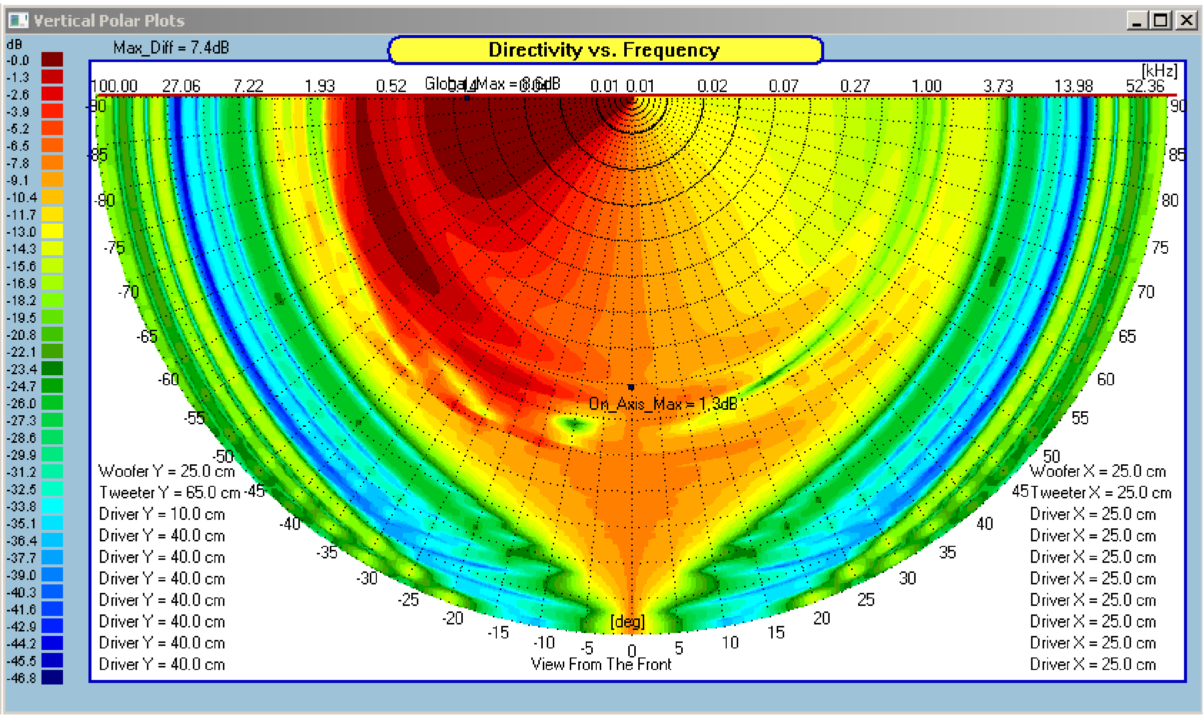
Normalization of such CD plot is performed in respect to on-axis SPL will now yield asymmetrical display as well. You will notice the on-axis (reference) SPL is also located on the vertical angle = 0deg (orange colour area). But in reference to this, the maximum SPL is now shifted north – as expected.



Circular versions of the Vertical CD plots are shown on the figures below. First, is the “standard” version.

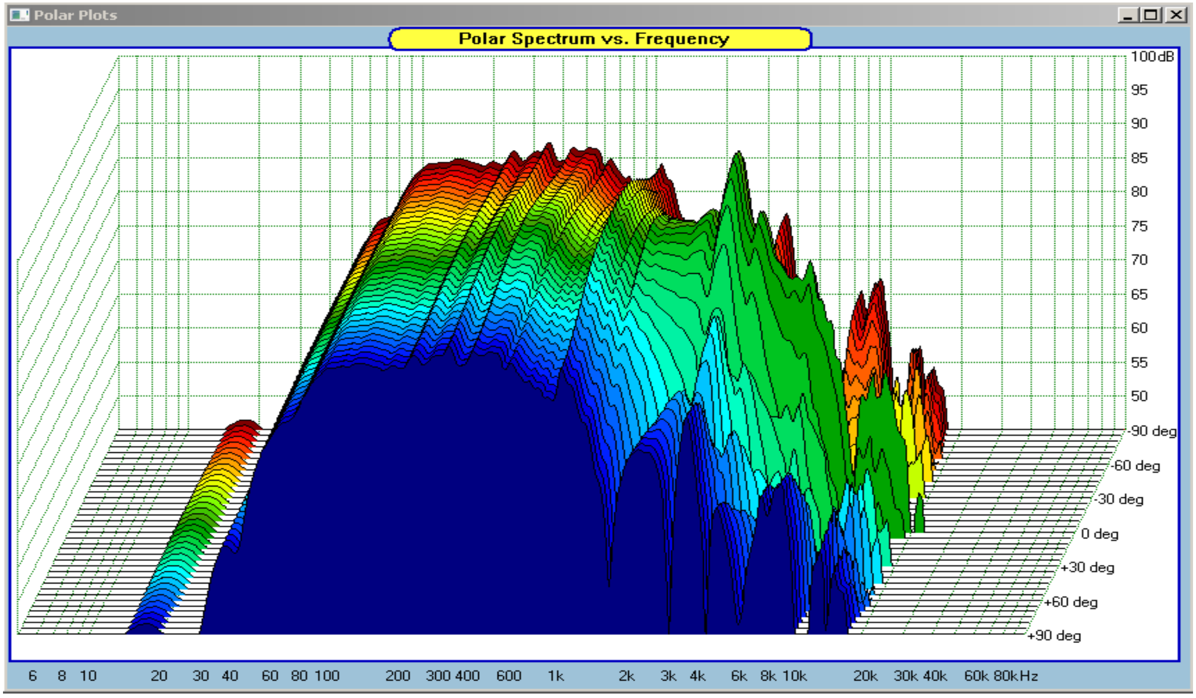


Next is the “normalized” version. Normalization of such CD plot is performed in respect to on-axis SPL will now yield asymmetrical display as well. You will notice the on-axis (reference) SPL is also located on the vertical angle = 0deg (orange colour area). But in reference to this, the maximum SPL is now shifted to the negative angles.

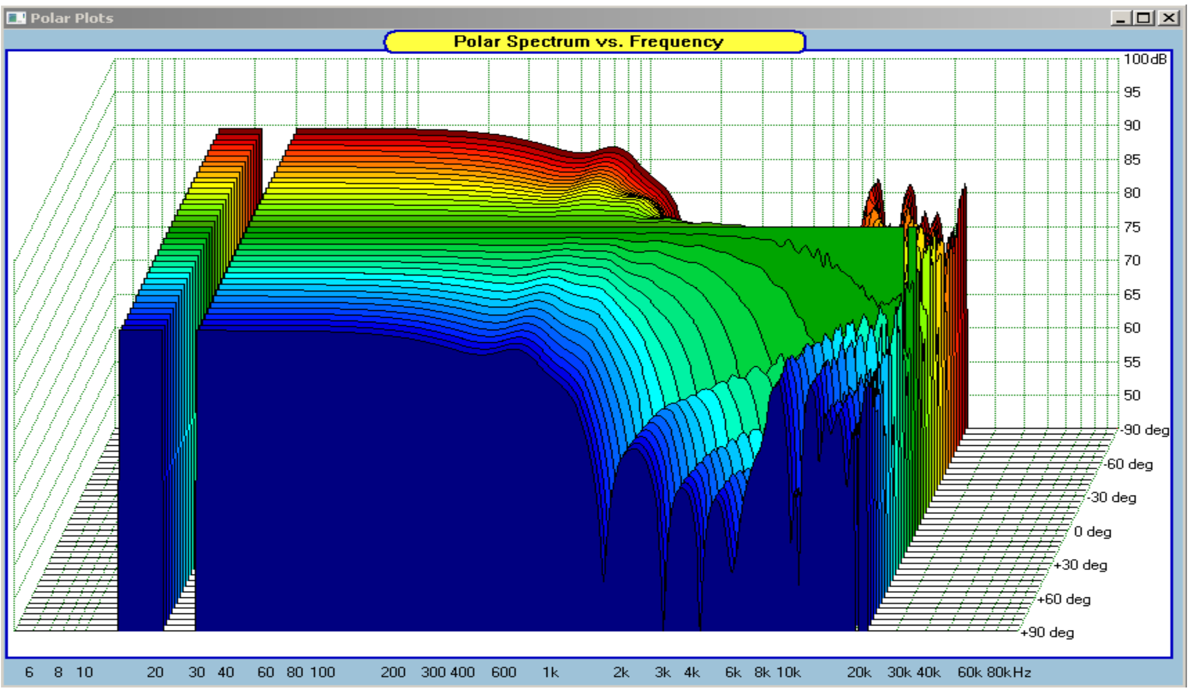


CSD – style Polar Plots

Polar plots presented as Cumulative Spectral Decay – style seem to be the most common way of visualizing the polar performance of the loudspeaker.



CSD plots, as Standard version



CSD plots, as Normalized version

The CSD-style plots provide good, clearly visible information about on/off axis performance, presented in 3D fasion. For asymmetrical systems, it is handy to be able to flip the angle axis back-to-front, so you can see both sides of the story.

Balloon Polar Plots

Final way of displaying polar data are the Balloon Plots. This technique depicts data as 3D “balloon” object. For example, the balloons can be modelled as 180 x 180 mesh of data points over front spherical coordinates. There are also some necessary additional tools, that help make the best visualization of the collected polar data:

1. Reference mesh and X/Y/Z axis are switchable ON/OFF on the balloon plots.

2. Balloons can be zoomed in/out, rotated over -90…+90deg, and screen is resizable.

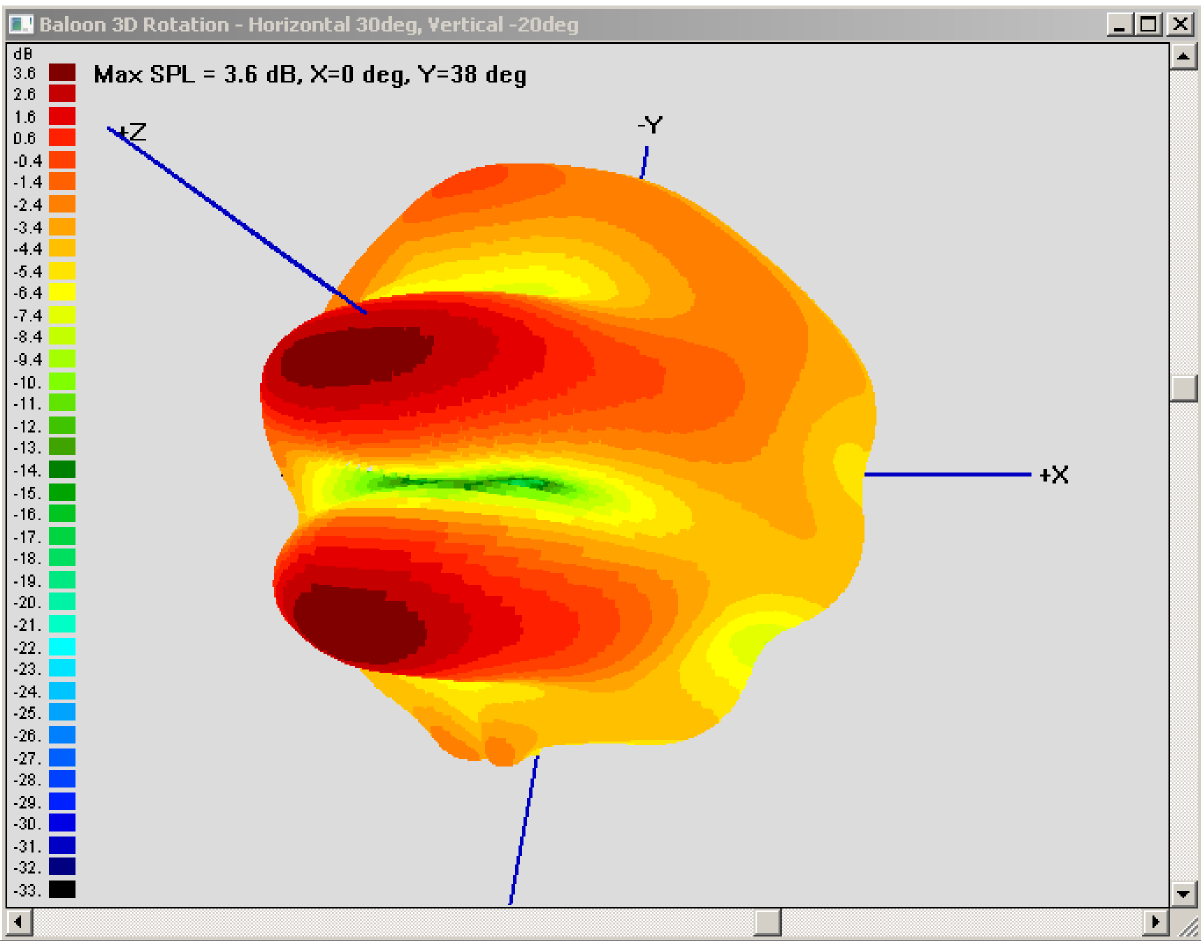
3. “Only top” or “only bottom” of the balloon can be selected for viewing.

4. Balloons can be displayed in selectable three sizes of dots. Display is SPL colour-coded.

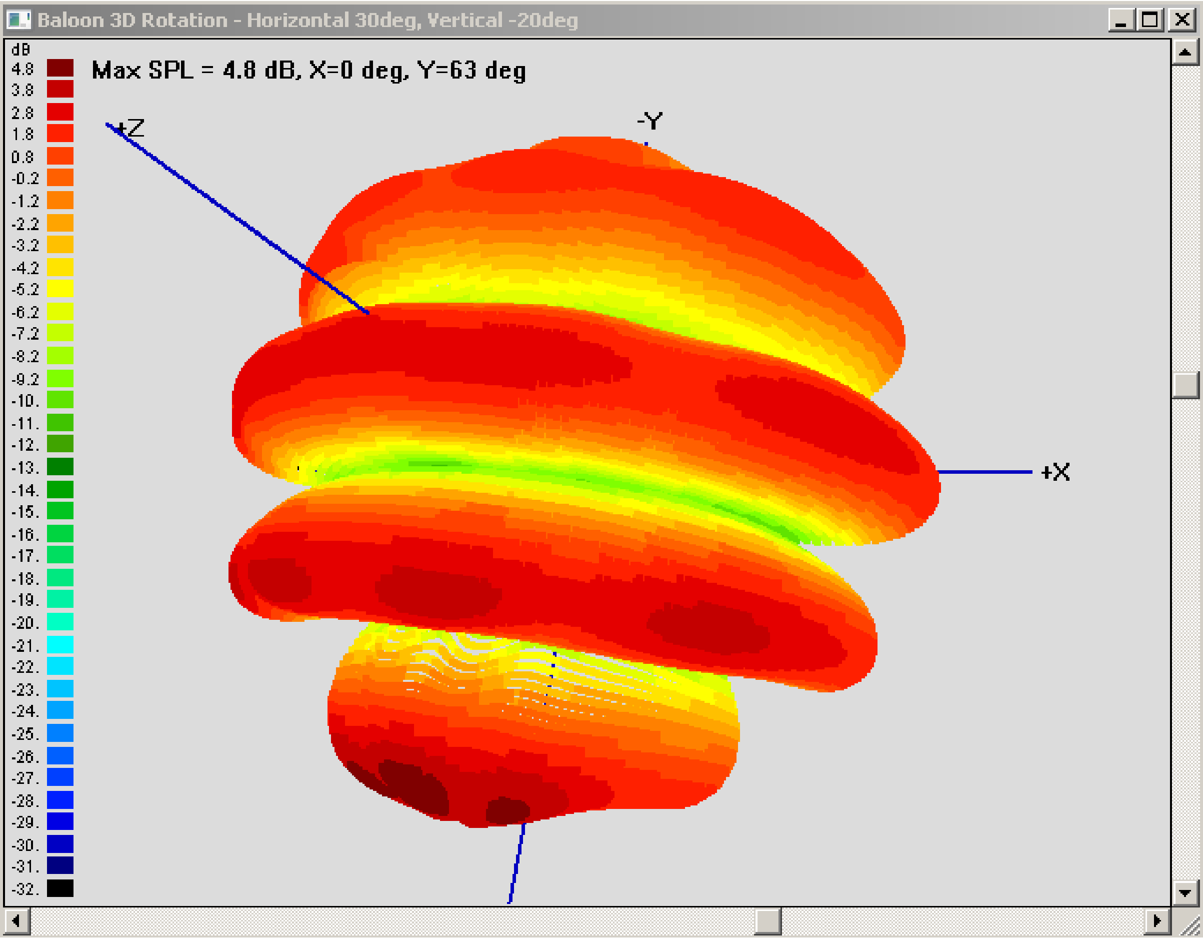
5. Interpolation of data points process is optional, and can be used to enhance the presentation.

6. “Max SPL” radiation level at horizontal and vertical angle is displayed and correlates with horizontal and vertical polar plots.

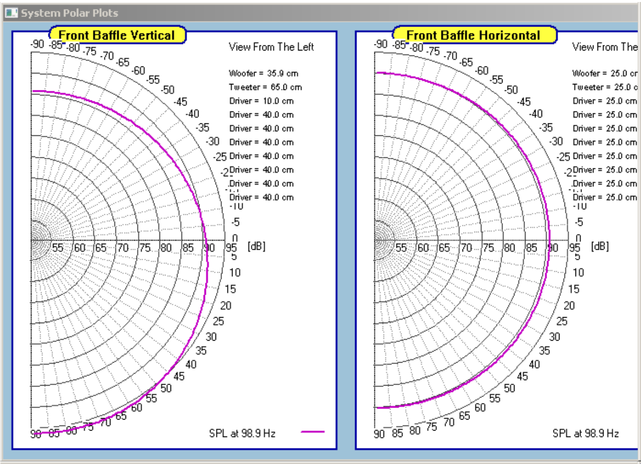
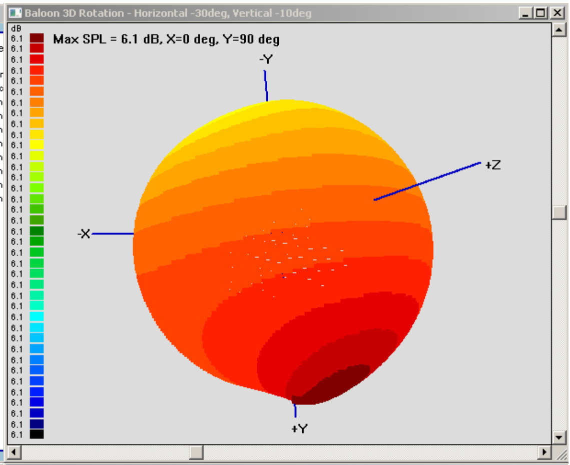
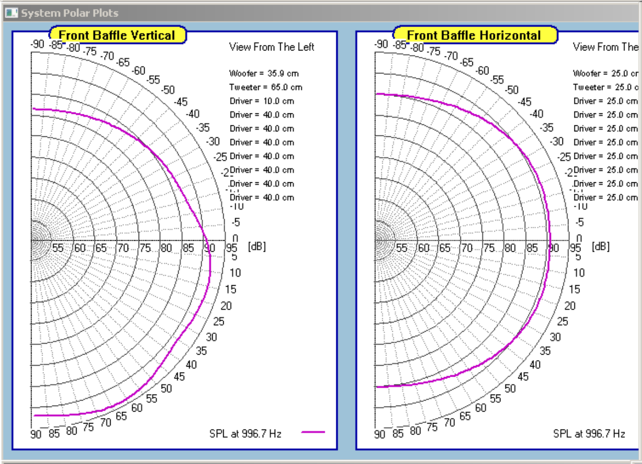
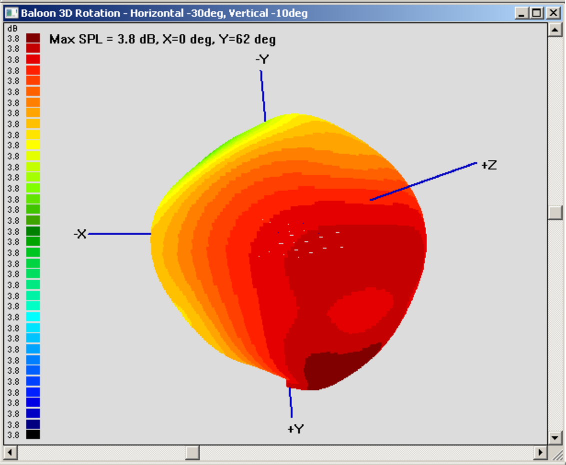
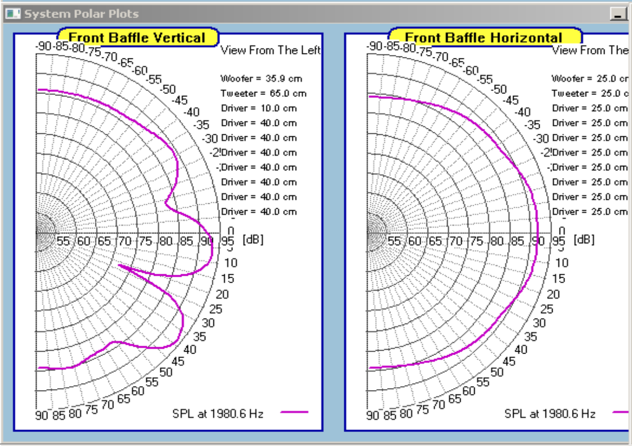
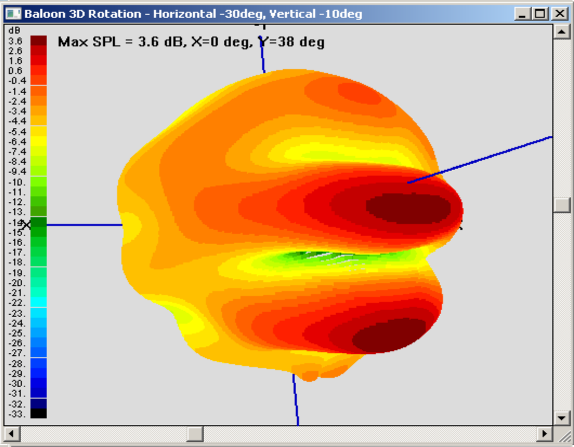
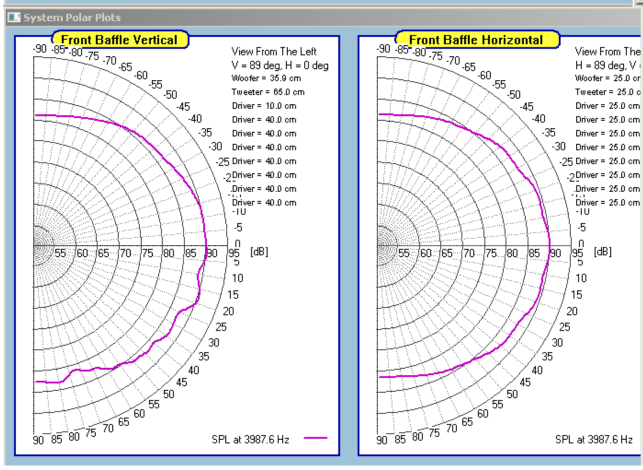
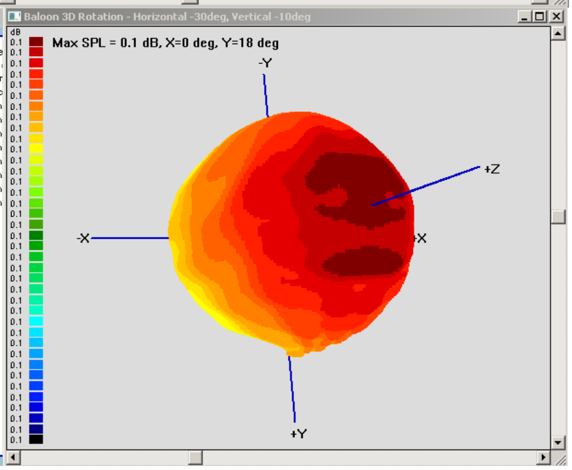
For example, Balloon 3D visualization of the 2000Hz performance of the 2-way loudspeaker is shown below.

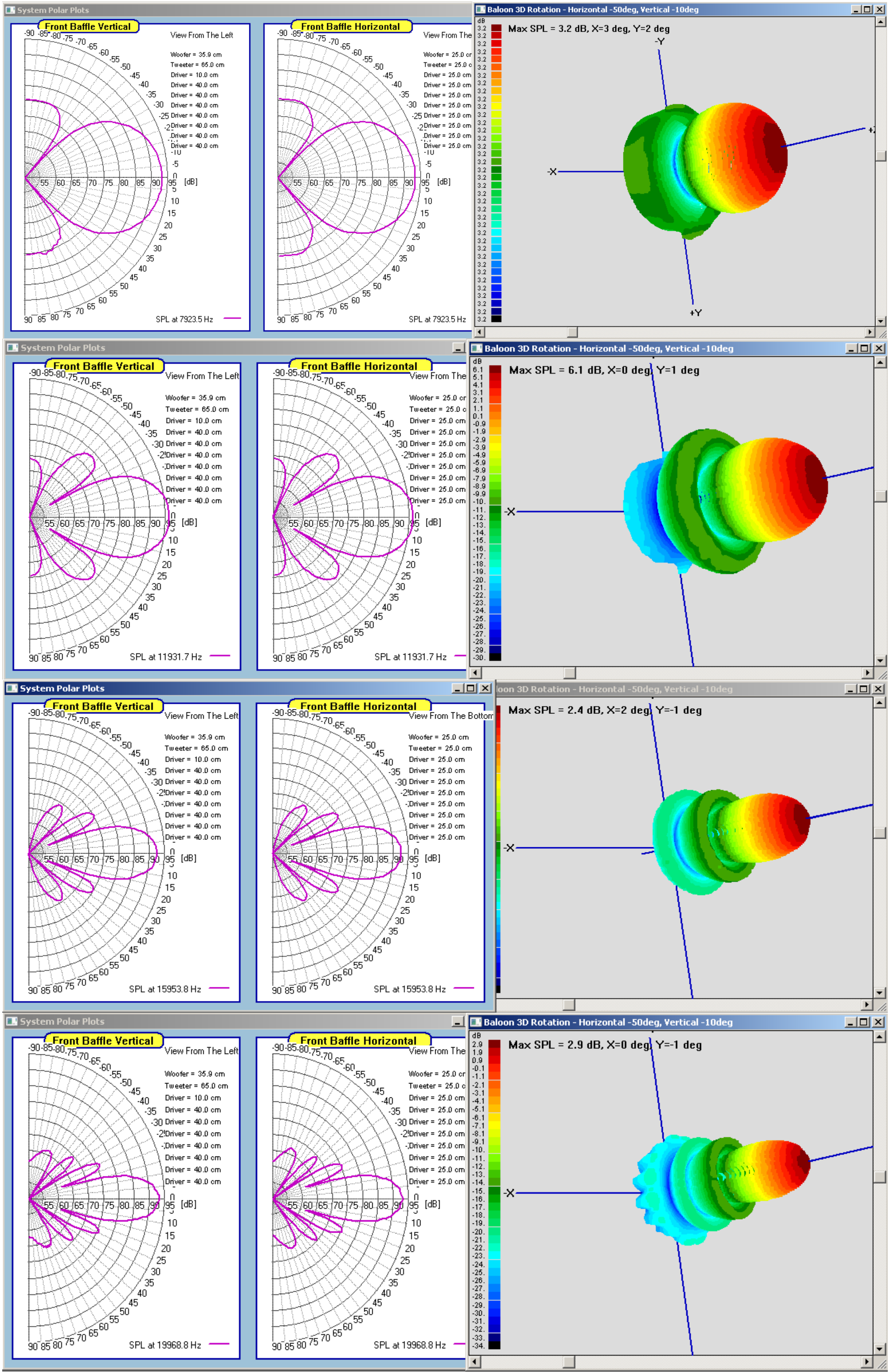


Balloon 3D visualization of the same system, but at 2600Hz.



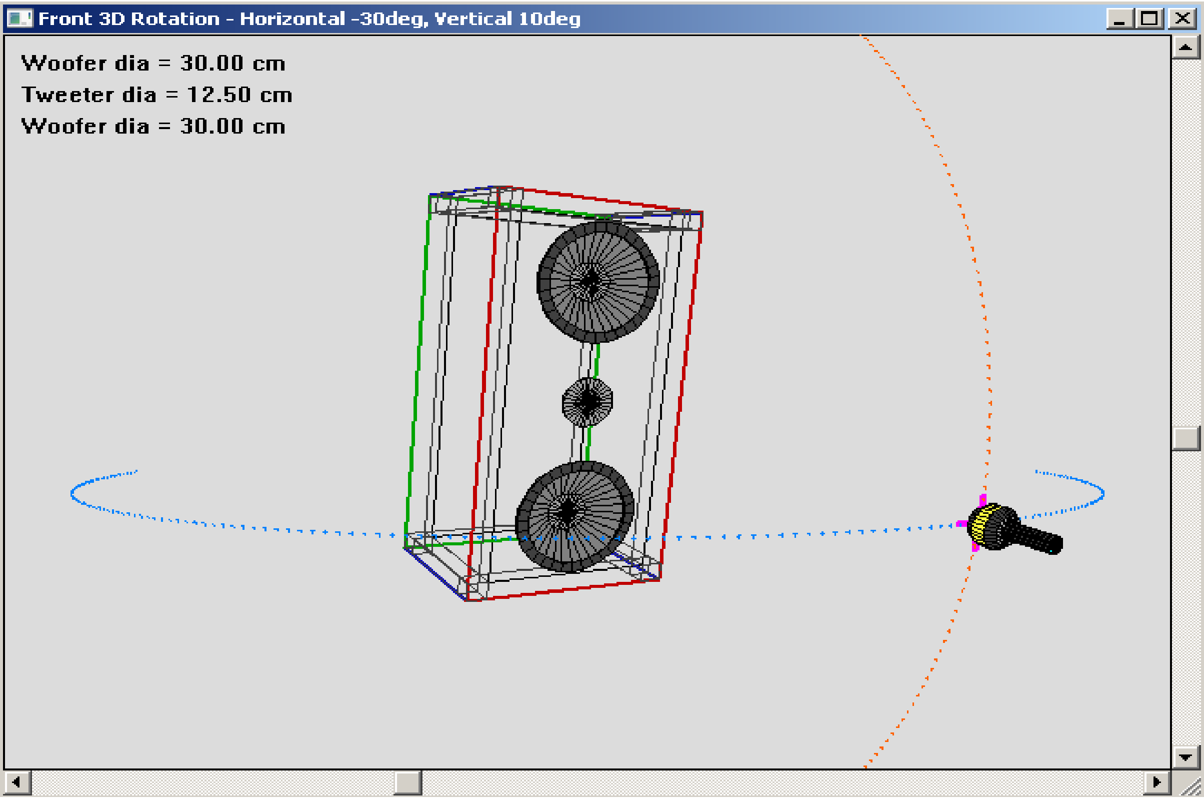
The process of generating Balloon Plots can be repeated at a number of frequencies of interests. Generally, one would expect the radiation pattern to be spherical at low frequencies. Then the pattern would change, as we approach crossover frequency. The plot collected at this point, can be quite interesting. Typically, both drivers will contribute equal SPL at the crossover point. As the frequency increases, the low-frequency drivers are becoming irrelevant, and the radiation pattern becomes exclusively controlled by the tweeter.


System Polar Plots
Front Baffle Vertical
View From The Left
Woofer = 35.9 cm
Tweeter = 65.0 cm
Driver = 10.0 cm
Front Baffle Horizontal
SPL at 98.9 Hz

Baloon 3D Rotation - Horizontal -30deg, Vertical -10deg
Max SPL = 6.1 dB, X=0 deg, Y=90 deg
-Y
+Z
-X
+Y

System Polar Plots
Front Baffle Vertical
View From The Left
Front Baffle Horizontal
SPL at 996.7 Hz

Baloon 3D Rotation - Horizontal -30deg, Vertical -10deg
Max SPL = 3.8 dB, X=0 deg, Y=62 deg
-Y
+Z
-X
+Y

System Polar Plots
Front Baffle Vertical
View From The Left
Front Baffle Horizontal
SPL at 1980.6 Hz

Baloon 3D Rotation - Horizontal -30deg, Vertical -10deg
Max SPL = 3.6 dB, X=0 deg, Y=38 deg

System Polar Plots
Front Baffle Vertical
View From The Left
V = 89 deg, H = 0 deg
Front Baffle Horizontal
SPL at 3987.6 Hz

Baloon 3D Rotation - Horizontal -30deg, Vertical -10deg
Max SPL = 0.1 dB, X=0 deg, Y=18 deg
-Y
+Z
-X
+Y

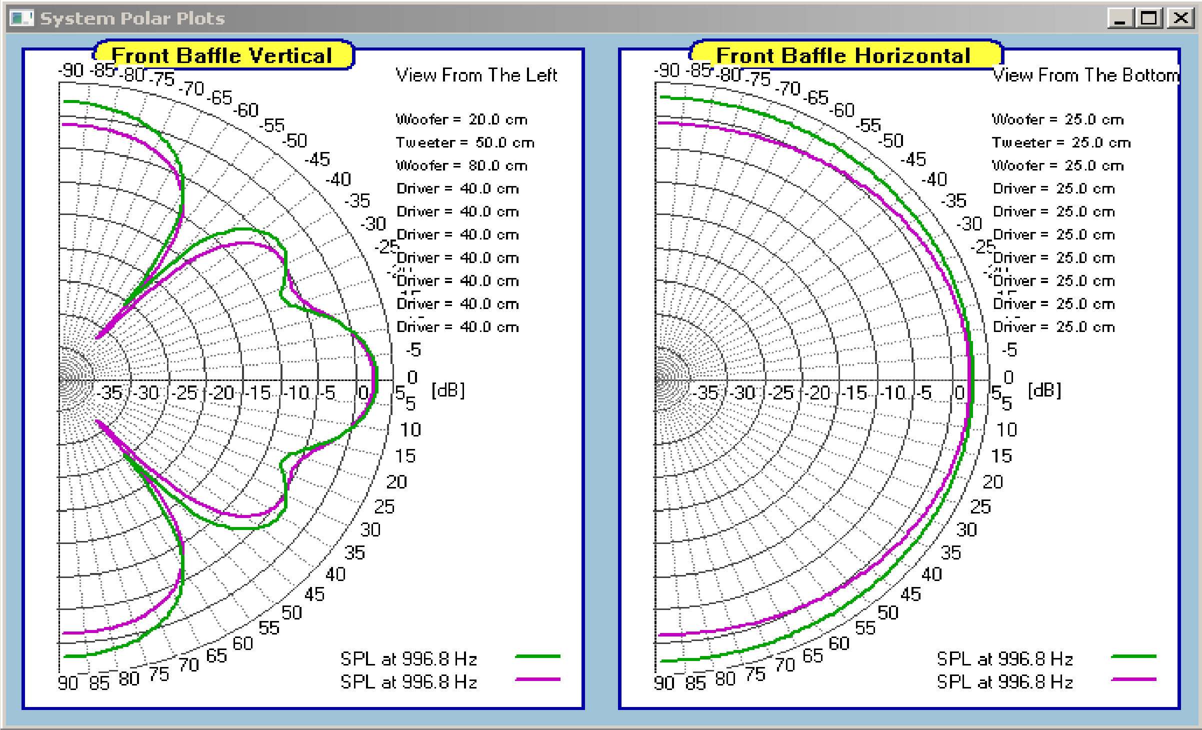


System Polar Plots
Front Baffle Vertical
View From The Left
Front Baffle Horizontal
SPL at 7923.5 Hz
Baloon 3D Rotation - Horizontal -50deg, Vertical -10deg
Max SPL = 3.2 dB, X=3 deg, Y=2 deg
SPL at 11931.7 Hz
Max SPL = 6.1 dB, X=0 deg, Y=1 deg
SPL at 15953.8 Hz
View From The Bottom
Max SPL = 2.4 dB, X=2 deg, Y=-1 deg
SPL at 19968.8 Hz
Max SPL = 2.9 dB, X=0 deg, Y=-1 deg

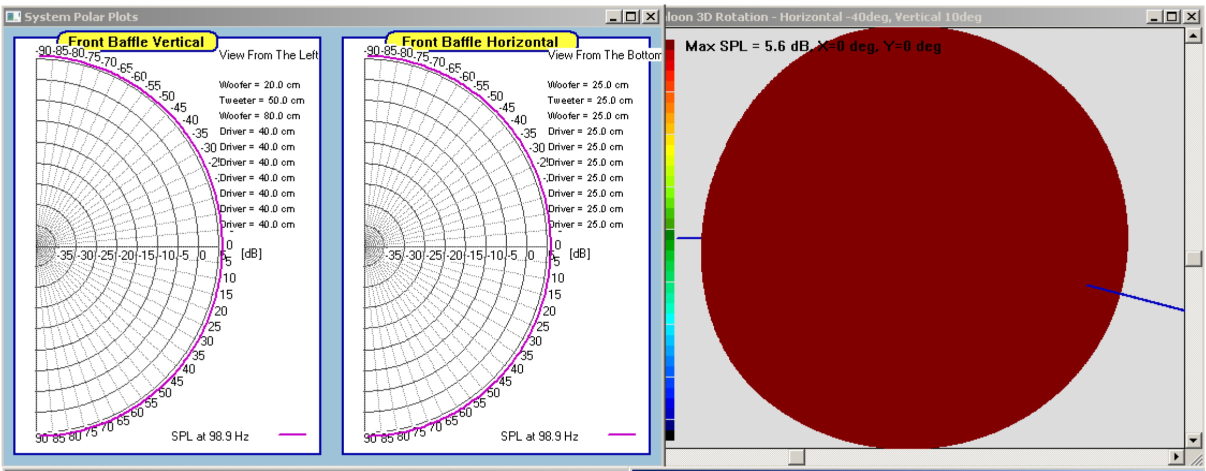
The last example of polar performance presentation is provided by **D'Appolito configuration** of drivers on the front panel. Here we have a simple system of tweeter in the middle, with two woofers on each side. Interestingly, the horizontal and vertical polar plots for this type of configuration are symmetrical, but obviously not the same.

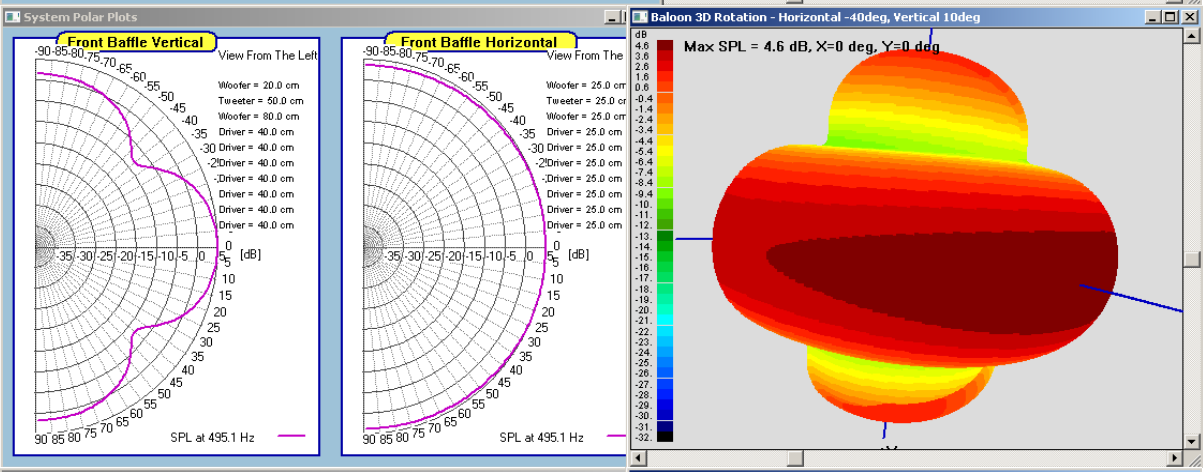


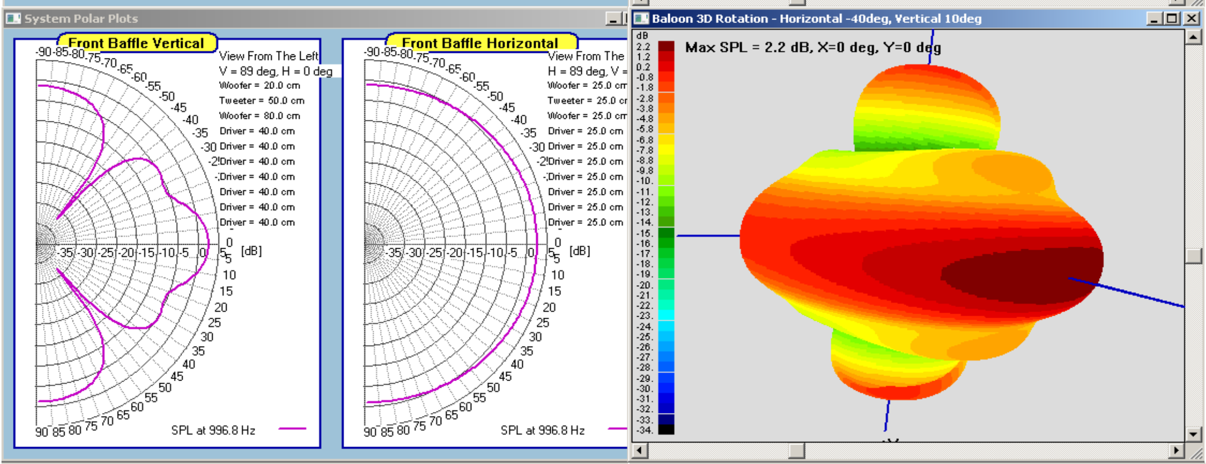
Pink – Piston Mode, Green – Point Mode

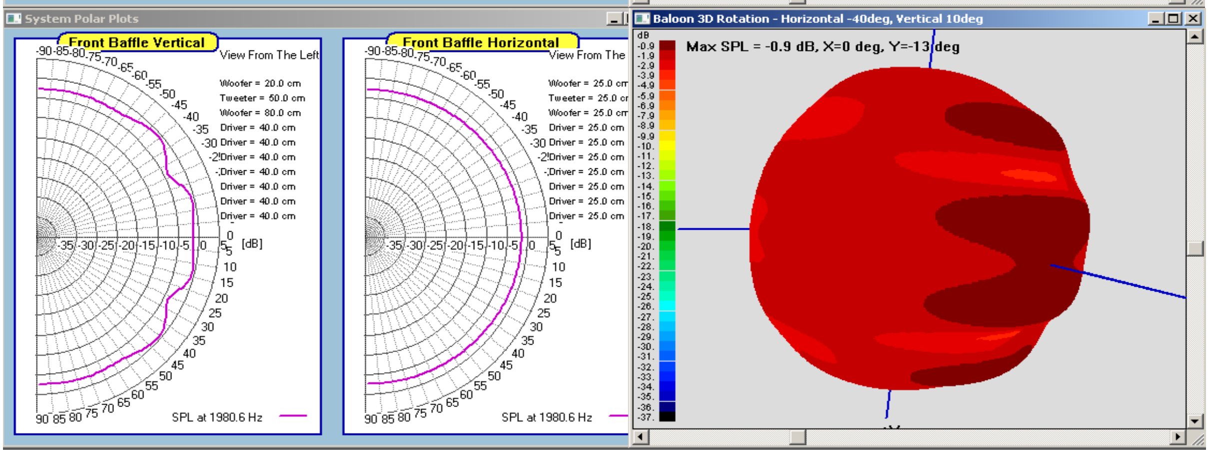


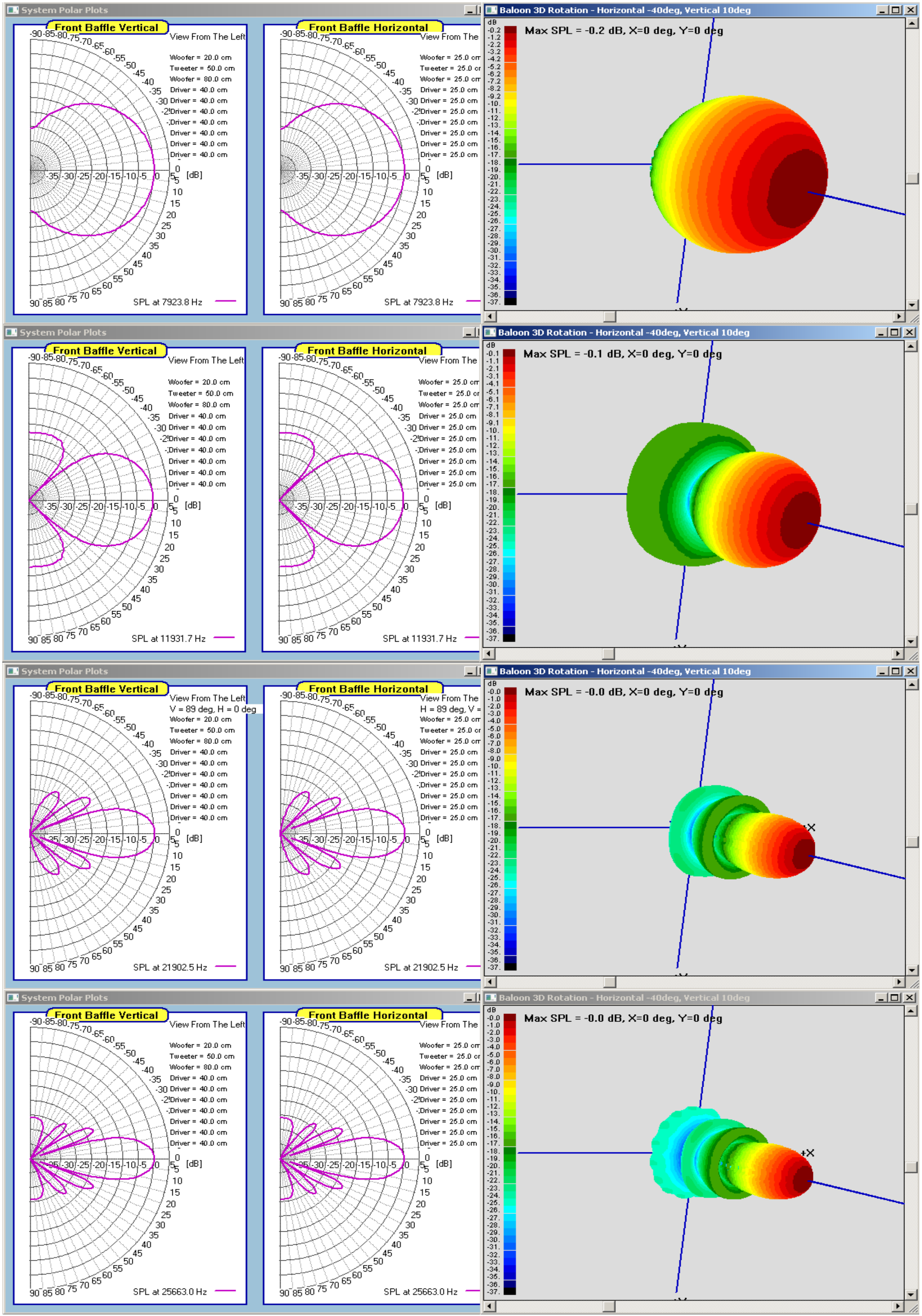
We can now present 3D Balloons for a number of test frequencies, and observe the ever-changing sound-field generated by the D'Appolito configuration.


System Polar Plots
Front Baffle Vertical
View From The Left
Front Baffle Horizontal
View From The Bottom
SPL at 98.9 Hz
Max SPL = 5.6 dB, X=0 deg, Y=0 deg


System Polar Plots
Front Baffle Vertical
View From The Left
Front Baffle Horizontal
SPL at 495.1 Hz
Baloon 3D Rotation - Horizontal -40deg, Vertical 10deg
Max SPL = 4.6 dB, X=0 deg, Y=0 deg

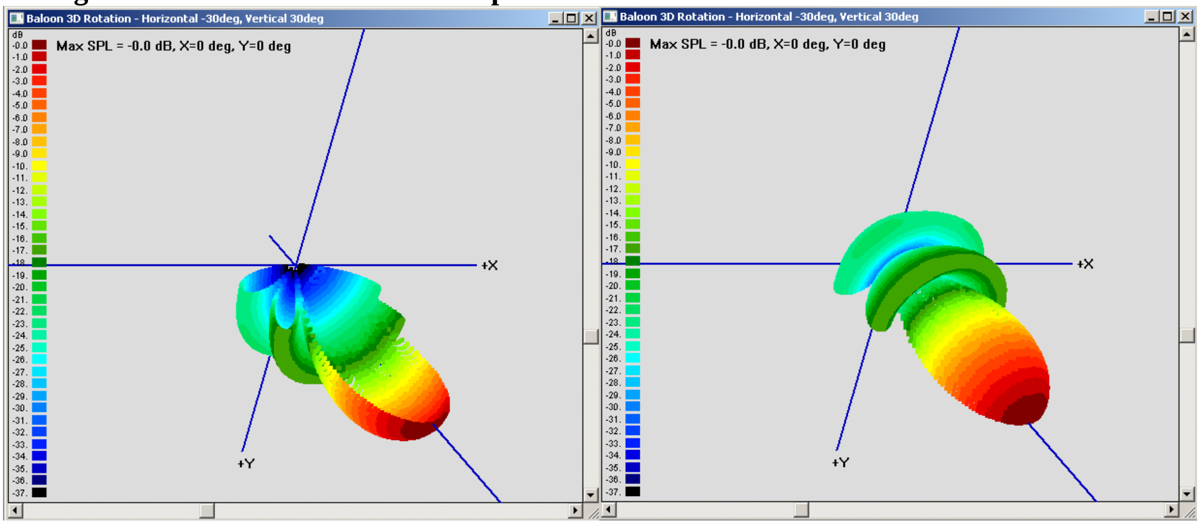

System Polar Plots
Front Baffle Vertical
View From The Left
V = 89 deg, H = 0 deg
Front Baffle Horizontal
SPL at 996.8 Hz
Baloon 3D Rotation - Horizontal -40deg, Vertical 10deg
Max SPL = 2.2 dB, X=0 deg, Y=0 deg


System Polar Plots
Front Baffle Vertical
View From The Left
Front Baffle Horizontal
SPL at 1980.6 Hz
Baloon 3D Rotation - Horizontal -40deg, Vertical 10deg
Max SPL = -0.9 dB, X=0 deg, Y=-13 deg

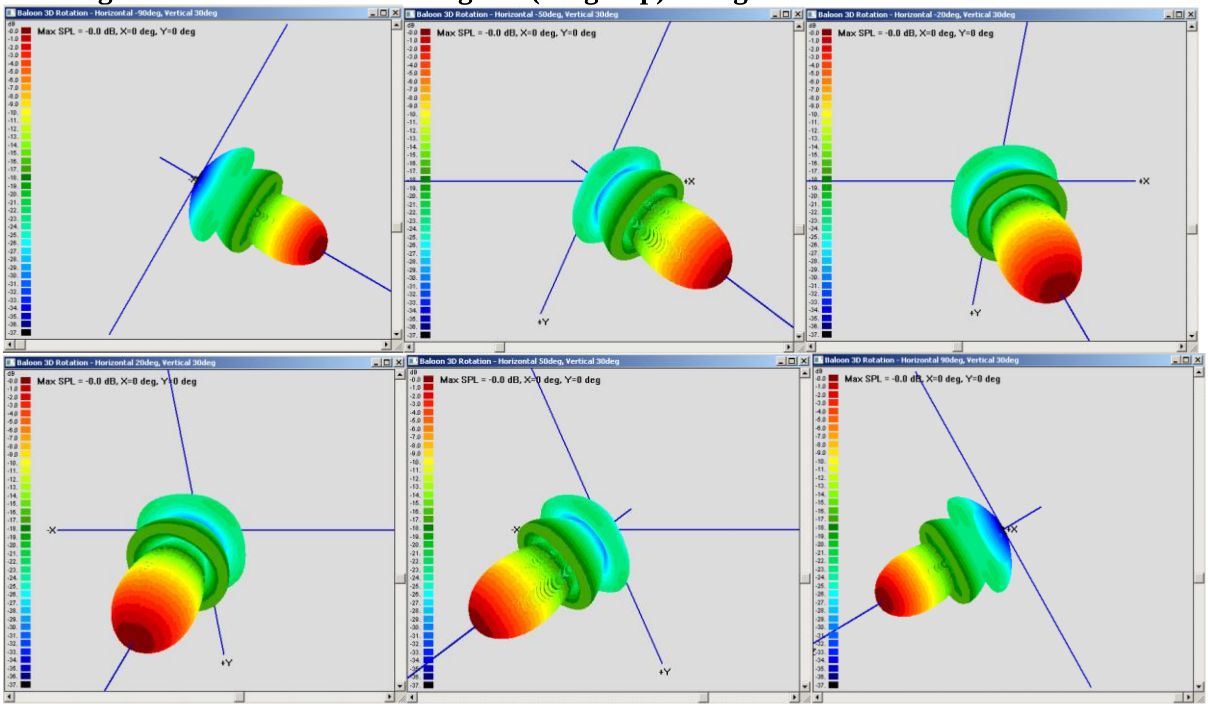


To take the full advantage of the 3D Balloons presentation, the display system could accommodate several display options. Here they are:

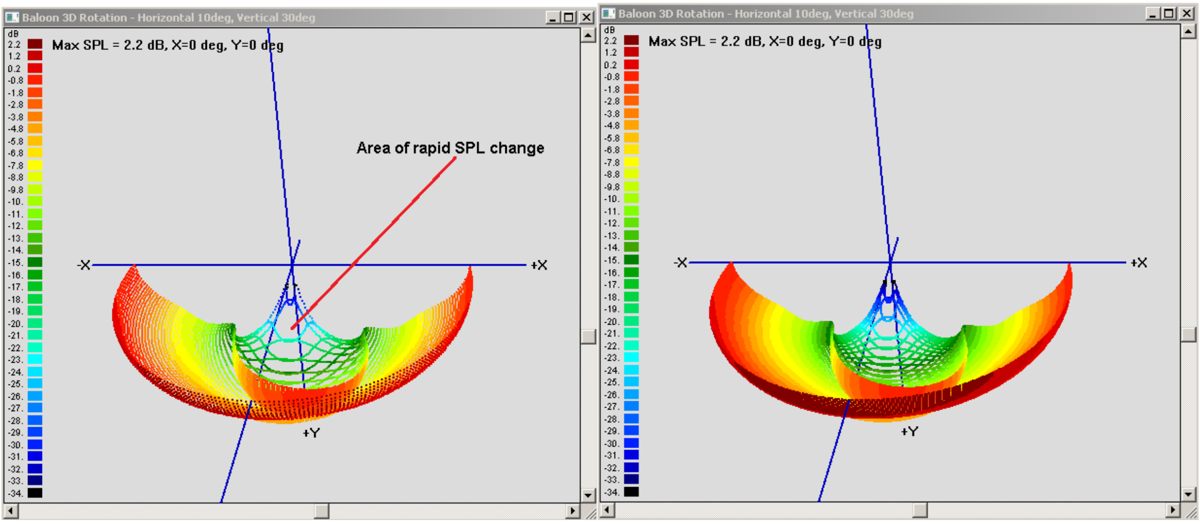
Slicing the Balloon into Bottom and Top sections.



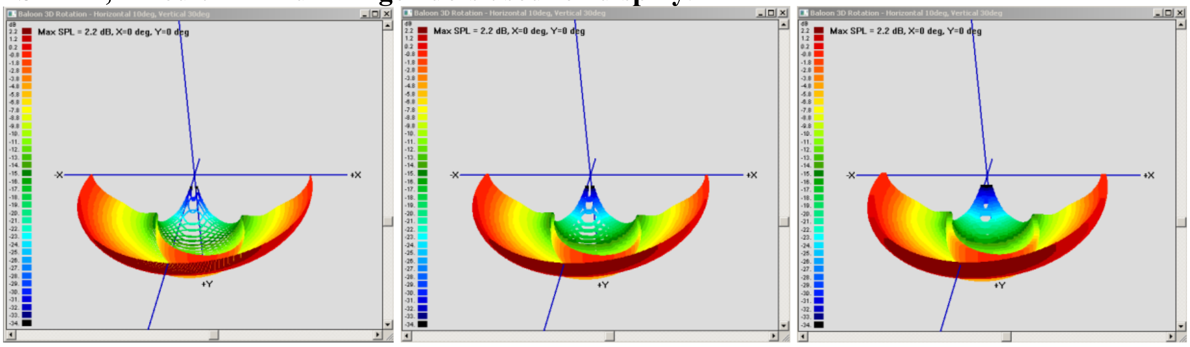
Rotating the Balloon +90…….-90 degrees (1deg step) using windows slider bars.



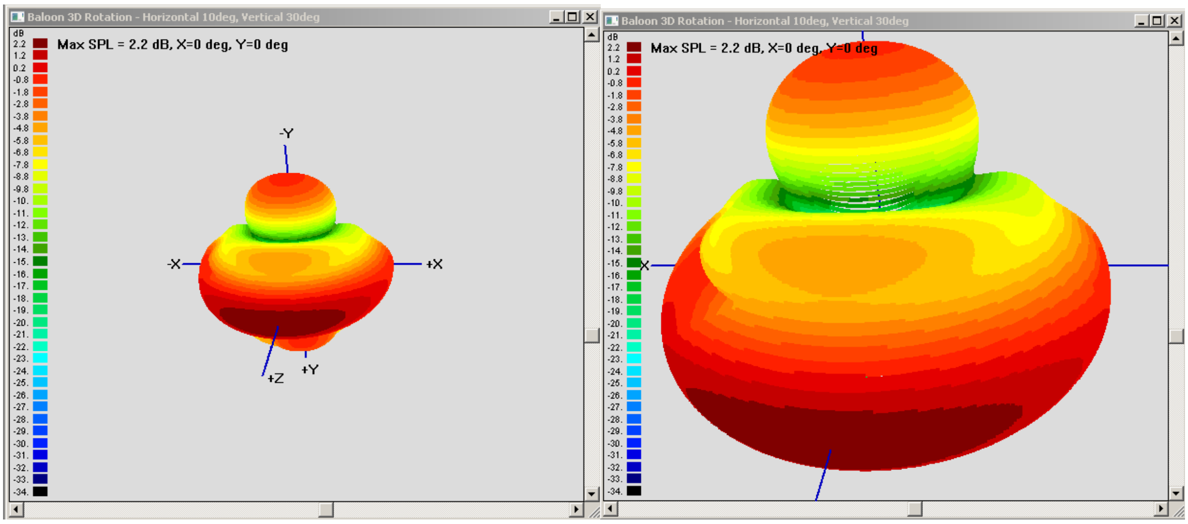
"Fill" function OFF and ON



“Small”, “Medium” and “Large” dots used for display.

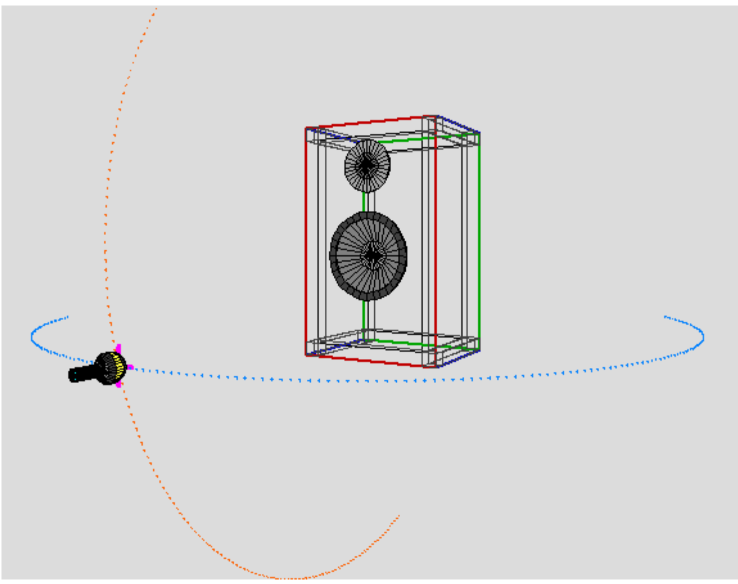


Zoom Out and Zoom In functions.

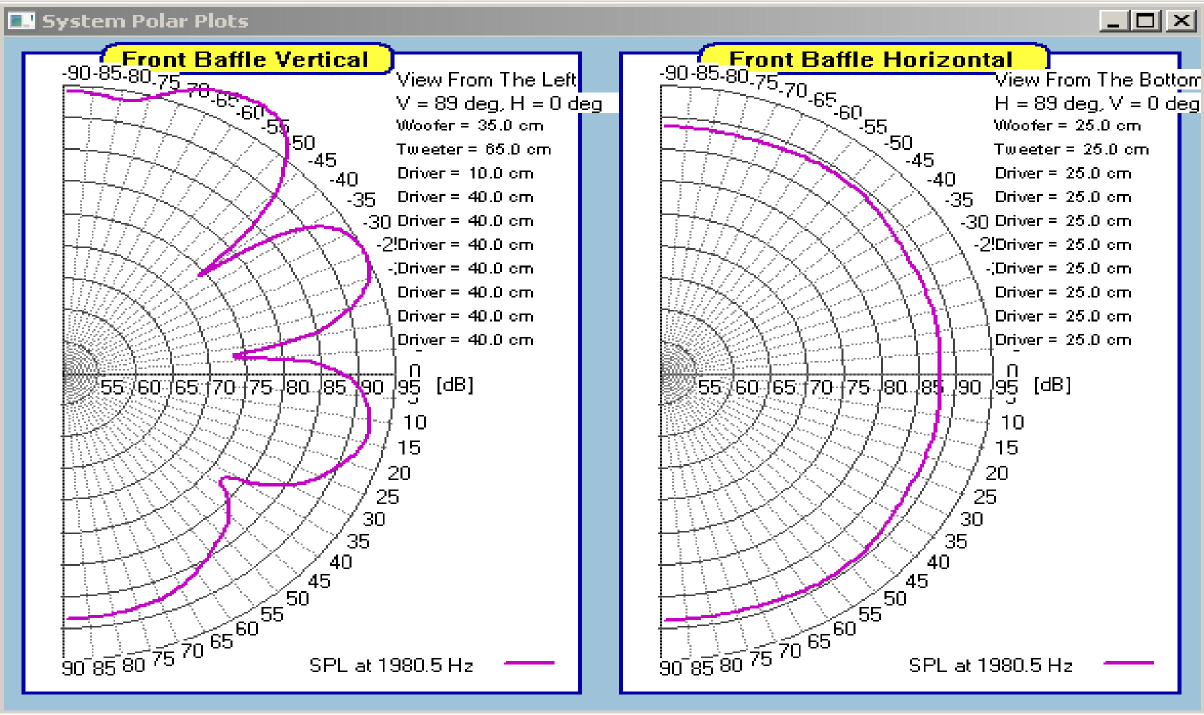


Revealing some hidden Balloon details

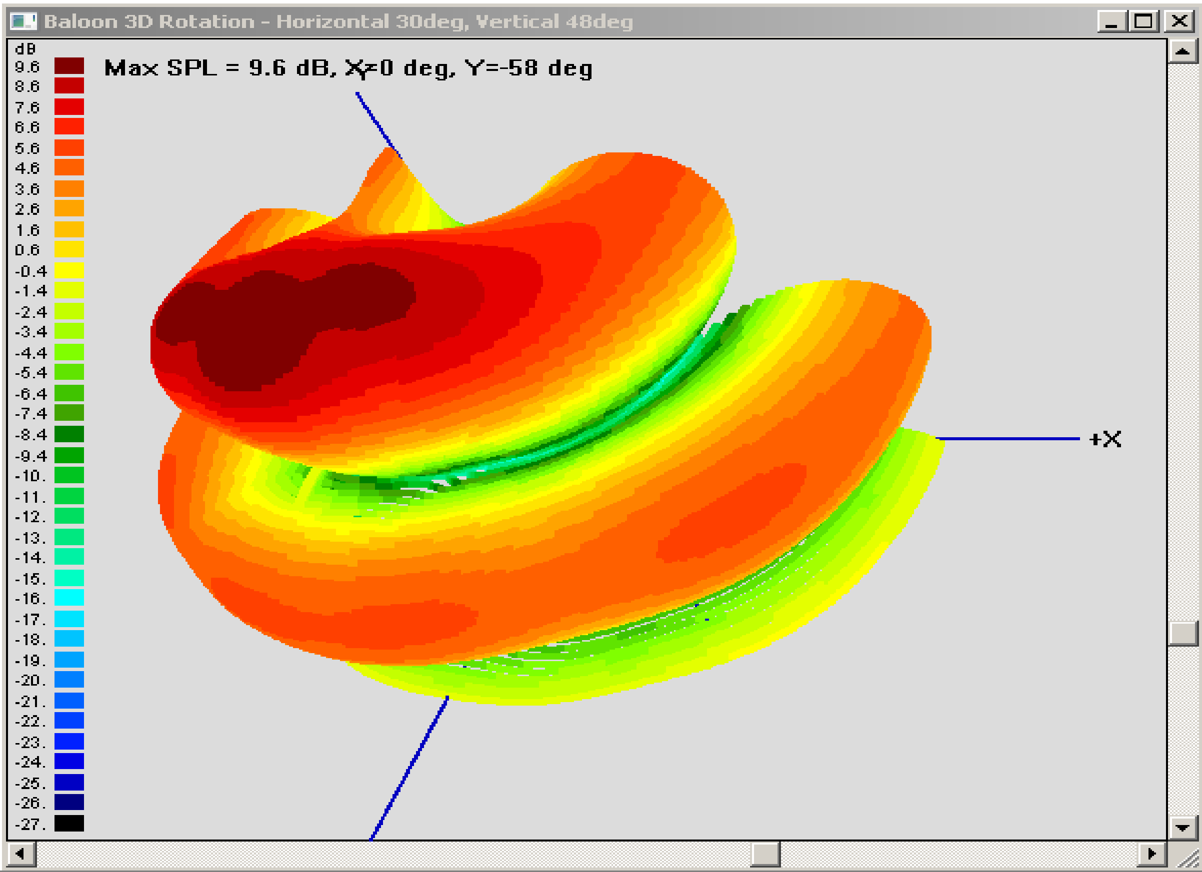
Rotating, tilting and splicing the Balloon Plot can reveal hidden details, that are not immediately obvious on standard Horizontal and Vertical Polar Plots. In the next example, the microphone pivot point was moved down, to the location 20cm below woofer axis. You would expect, that maximum SPL radiation would then appear shifted upwards.



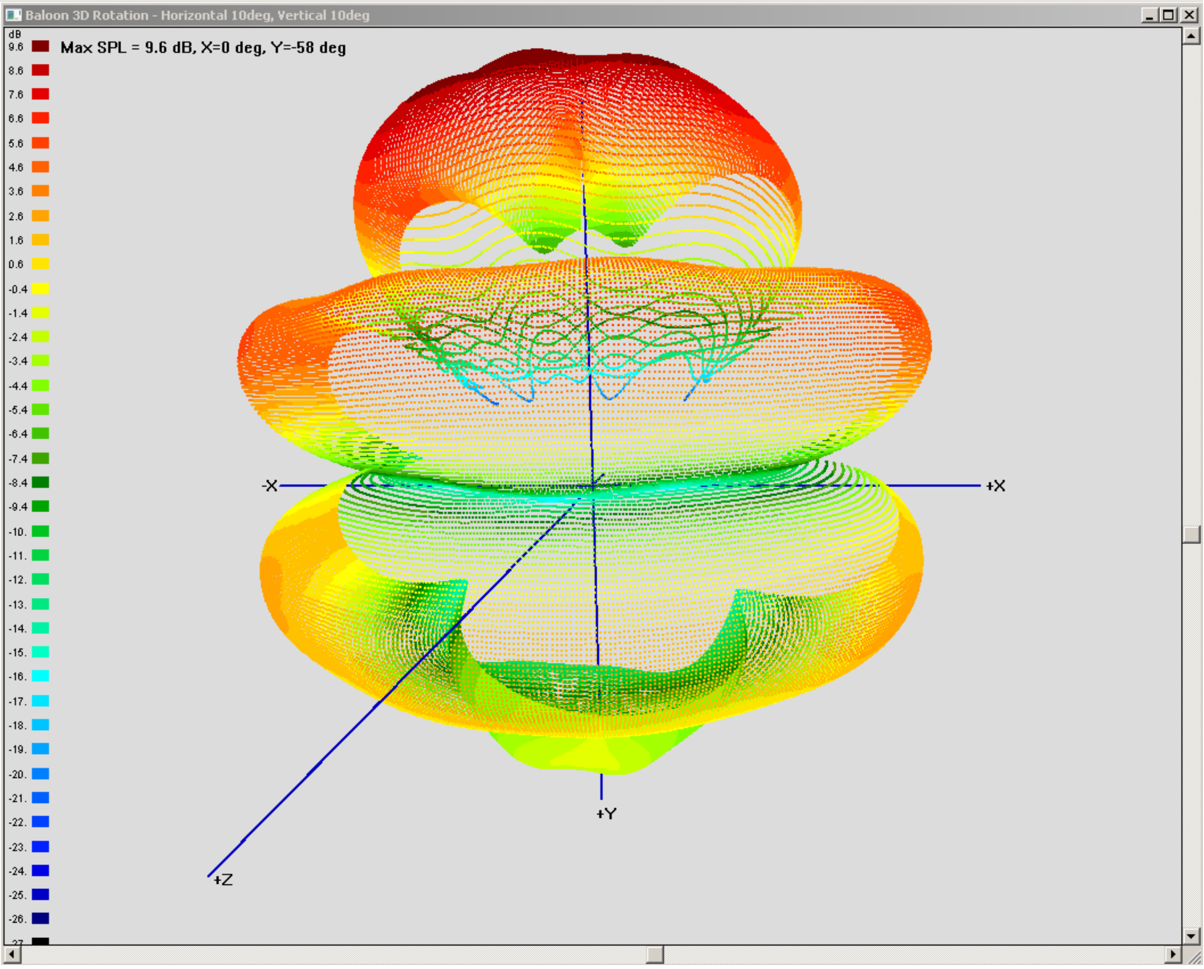
And indeed, Vertical Polar radiation patter shows, that maximum radiation at 2000Hz occurs at -50-60deg vertical angle.



But there are some surprises. The Top Section of the Balloon Plot, when rotated and tilted, reveals unseen radiation pattern outside 0deg horizontal radiation axis – see below.



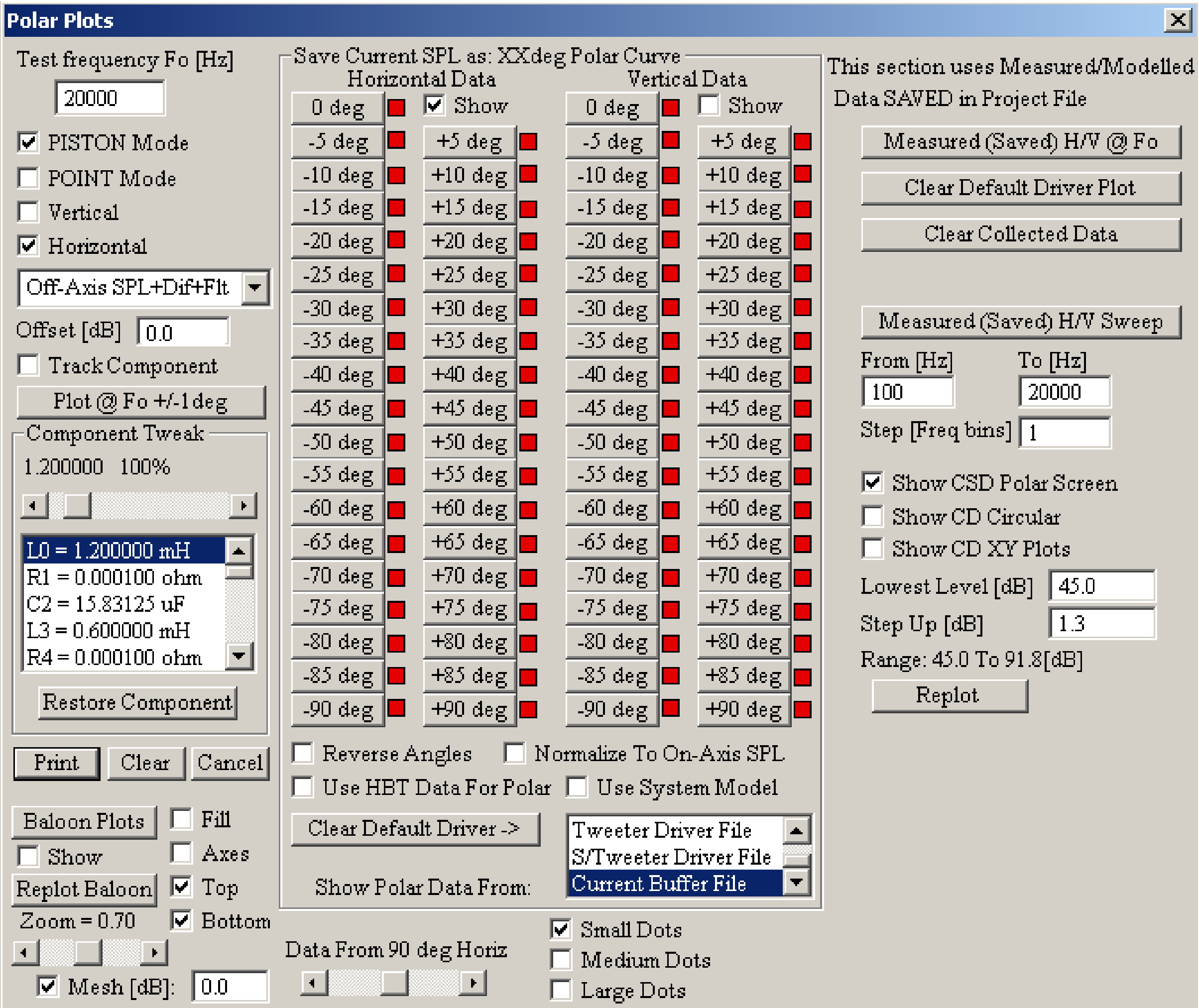
The Balloon Plots incorporated several tools allowing displayed 3D plot to be presented in the best or most revealing way. Sometimes changing the size of the display dots, and zooming-in, can make the Balloon Plot semi-transparent, allowing you to see "inside" of the balloon.



All the options presented above for generating and presenting Balloons are handled by the dialogue box with several controls - shown below.

As mentioned previously, the presentation method described in this paper, is based on 32400 data points arranged in 180 by 180 matrix. Collecting 32400 points of SPL data without fully automated measurement system would be next to impossible. So, this paper offers a glimpse into what can be done in the future, in terms of collecting and presenting accurate sound-field generated by a loudspeaker.

The number of measurement can be obviously significantly reduced by setting the incremental angle to 5deg, instead of 1deg as in this presentation. The trade-off is, that the process would run significantly faster, but you would miss some of the notches in the sound-field presentation. Now, the measurement matrix would be 36 by 36 data points, which equates to 1296 measured SPL points.



Control dialogue for all polar plots presented in this paper.