

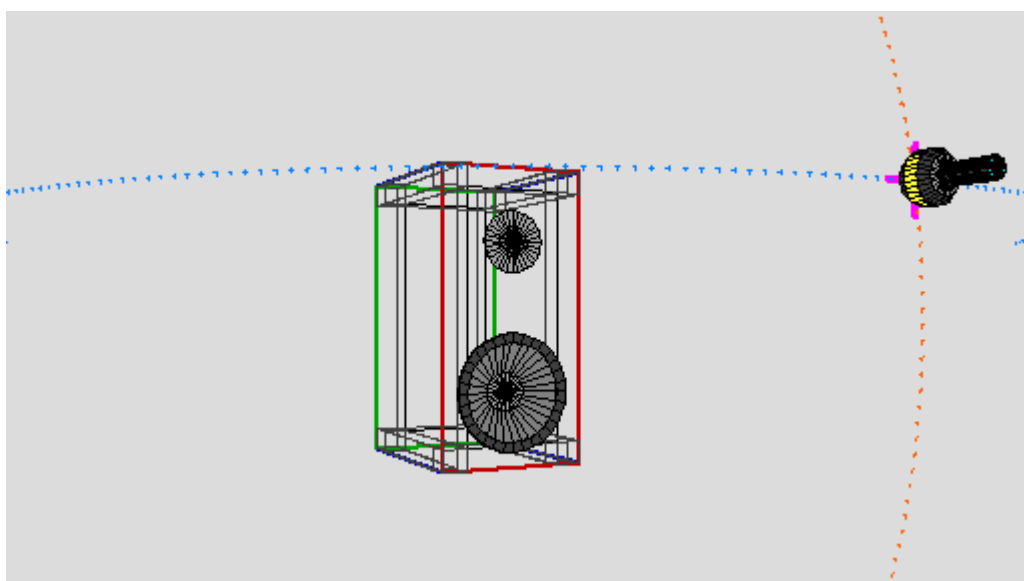
Modelling Off-axis Performance of a Loudspeaker System

The process described below is intended to mimic real-live process of evaluating polar performance of a loudspeaker system. It may start with creating driver files with properly conducted driver measurements. When finished, the full on-axis and off-axis polar characteristics would be available. It is therefore anticipated, that driver's location on the front baffle is already determined (as it would be in real-life), and the placement of the test microphone is also determined, and it would be typically on-axis of the tweeter driver, at 1 meter distance. Real-life "spinorama" would move the microphone between -90deg.....+90deg front angle and record SPL curves at 5deg intervals. The recorded SPL curves may be required to be of the minimum-phase type, and this would require some extensive post processing activities. In other words – it's a big job.

The purpose of this short paper is to present the process of modelling a complete set of on-axis and off-axis performance curves of an example two-way system, using woofer and tweeter drivers. The process includes creating woofer and tweeter driver files by using Amplitude Modeller functions. Typically, this would require a quick examination of manufacturer-supplied SPL curve, and re-creating the main SPL features in the Amplitude Modeller. The process is relatively quick, as the all-important driver's transfer function is created automatically while you create the first-cut SPL curve. There is no need to re-create small wiggles of the SPL curve, because they do not affect crossover design. There is no need to engage enclosure modelling either, because sealed enclosure would be approximated as +12dB/oct, high-pass filter, and vented enclosure would be approximated as +24dB/oct high-pass filter. Besides, this process should only serve the purpose of enabling you to make purchasing decision – if the modelling has revealed, that the final performance specification can be met. Spending 20-30 minutes on each driver should be quite sufficient to create reasonable representation of the manufacturer supplied SPL curves. When you are satisfied, that the whole model is working for you, the next step is to purchase the drivers and start serious measurements on the final enclosure.

Modelling process described here re-creates exactly that situation. Here are some basic design parameters to start with:

1. Enclosure front baffle dimensions are width $X = 30$ cm and height $Y = 60$ cm.
2. Woofer is mounted at $X = 15$ cm and $Y = 15$ cm baffle location.
3. Tweeter is mounted at $X = 15$ cm and $Y = 45$ cm baffle location.
4. Test microphone is located at the tweeter axis, at 1 m distance.
5. Driver's impedance is irrelevant to the subject of this paper, and will be assumed to be 8ohm. Obviously, in real-life, you would measure the impedance and include it in the design activities.
6. Woofer diameter is about 25cm.
7. Tweeter diameter is about 5cm.
8. In order for the SPL curves to be useful for design purposes, they must mimic real-live, anechoic measurements.

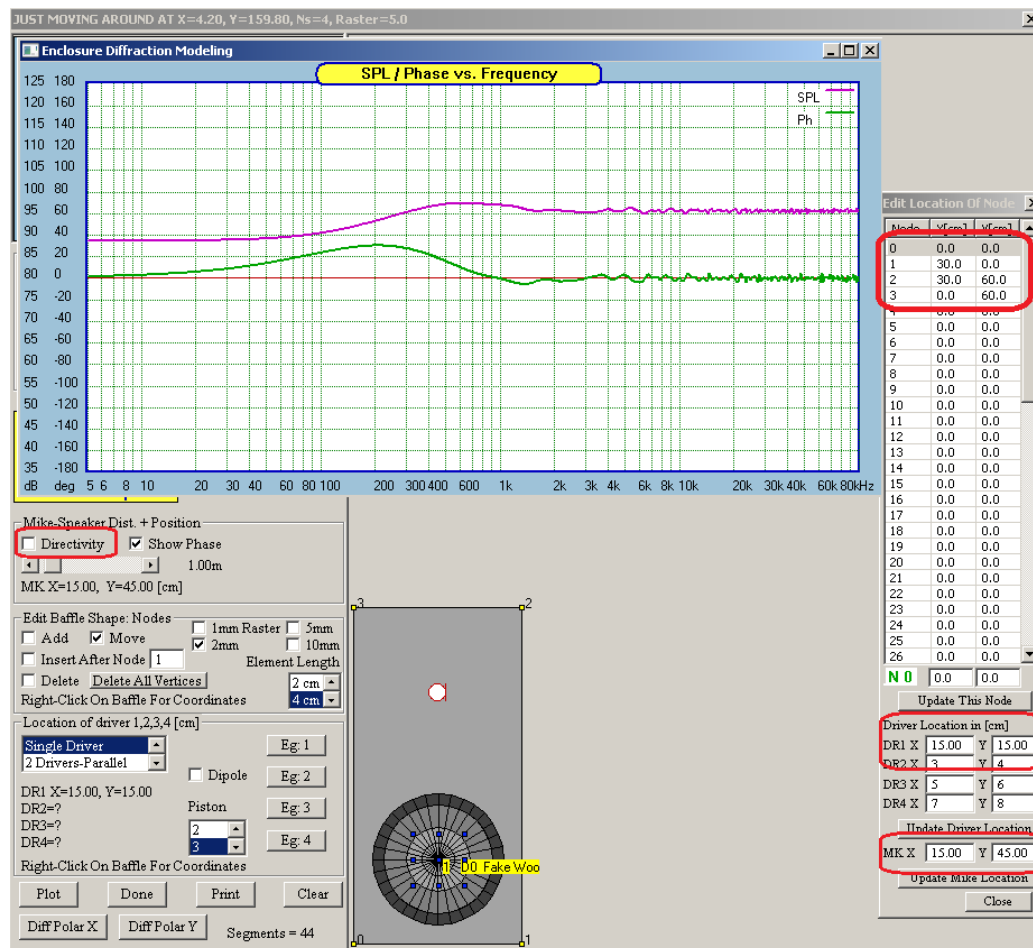


Loudspeaker system described above under free-field testing at 1W/1m conditions.

We are now in the position to create driver files. Since the drivers will be mounted in a box, modelling front baffle diffraction is as good starting point as any.

Woofer driver file

Diffraction modeller has been adjusted to reflect the exact design specifications for baffle size, driver and microphone locations – see below. Other settings also as per picture below.



The diffraction curve created above will be combined with woofer's free-field (anechoic, or 4PI) SPL performance created in the Amplitude Modeller and shown below. It is observable, that in order to focus on the issue at hand, woofer frequency response is as simple as possible. Woofer anechoic efficiency is 90dB.



When the woofer diffraction curve is incorporated, we arrive at the following SPL curve. This is the final woofer SPL response.



As a matter of exercise, you may run HBT on the modelled curve. This would confirm, that the artificially created woofer's transfer function is indeed of minimum-phase type. Save the woofer file.

The Driver Parameter Editor window shows the following settings:

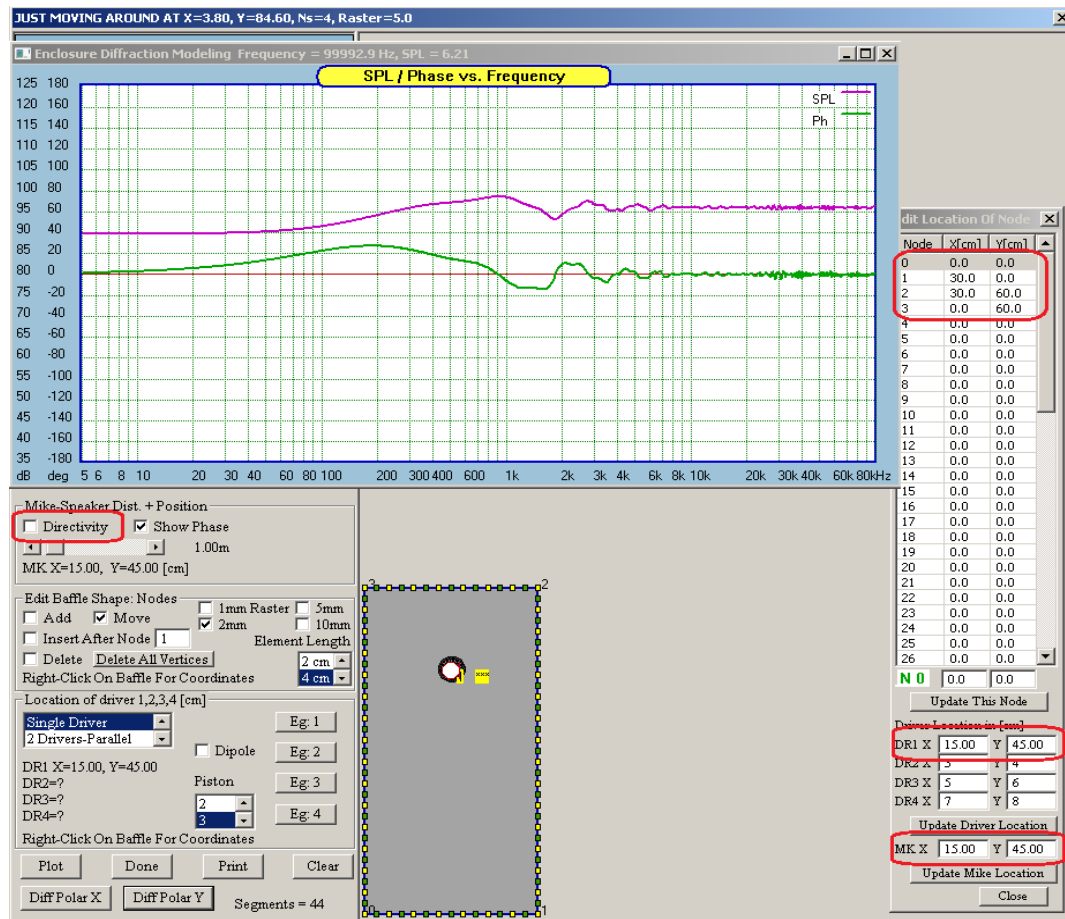
- T/S Editor:** High-Pass Tail (Stop: 15, Slope: 24, Pin: 1.0 Watt), Low-Pass Tail (Start: 10000 Hz, Slope: 24 dB/oct).
- Impedance Model:** High-Pass Tail (Stop: 5.10, Slope: 0.0), Low-Pass Tail (Start: 10000.0 Hz, Slope: 0 dB/oct).
- Hilbert-Bode Transform:** Clear, New, Help buttons.
- Inverse H-B Transform:** Dist = 1.00000[m], Delay = 2.90698[ms].
- Guiding Filter Optimizer:** Start Filter (From [Hz]: 6.0, To [Hz]: 20000.0), Level [dB]: 90.0, Counter: HP, Error: HPV, Run #: SL.

Tweeter driver file

The same as for woofer, the tweeter driver's SPL anechoic response has been design to be as simple as possible, and is shown below.



Again, for simplicity, tweeter SPL curve developed in Amplitude Modeller will be combined with tweeter's diffraction curve. We anticipate, that once combined, the tweeter 2PI efficiency will be 96dB (just for example). As a consequence, the Amplitude Modeller SPL must be levelled at 90dB – as shown on the picture above. Diffraction modeller for the tweeter has been adjusted to reflect the exact design specifications for baffle size, driver and microphone locations – see below. Other settings also as per picture below.



It is observable, that tweeter diffraction curve is way different from woofer diffraction curve. When the tweeter diffraction curve is incorporated, we arrive at the following SPL curve. This is the final tweeter SPL response. Save the tweeter file.



As a matter of exercise, you may run HBT on the modelled curve. This would confirm, that indeed, the artificially created tweeter's transfer function is indeed of minimum-phase type.

The Driver Parameter Editor window is shown with the 'Hilbert-Node Transform' tab selected. The parameters are as follows:

High-Pass Tail		Low-Pass Tail		High-Pass Tail		Low-Pass Tail	
Stop	150	Start	30000	Stop	5.10	Start	10000.0
Slope	24	Slope	24	Slope	0.0	Slope	0
Pin		1.0		Watt			

Buttons: Clear, New, Help

Dist = 1.00000[m], Delay = 2.90698[ms]

☐ Include Distance In PHASE Plots
☐ Include Distance In AMPLITUDE Plots

Guiding Filter Optimizer

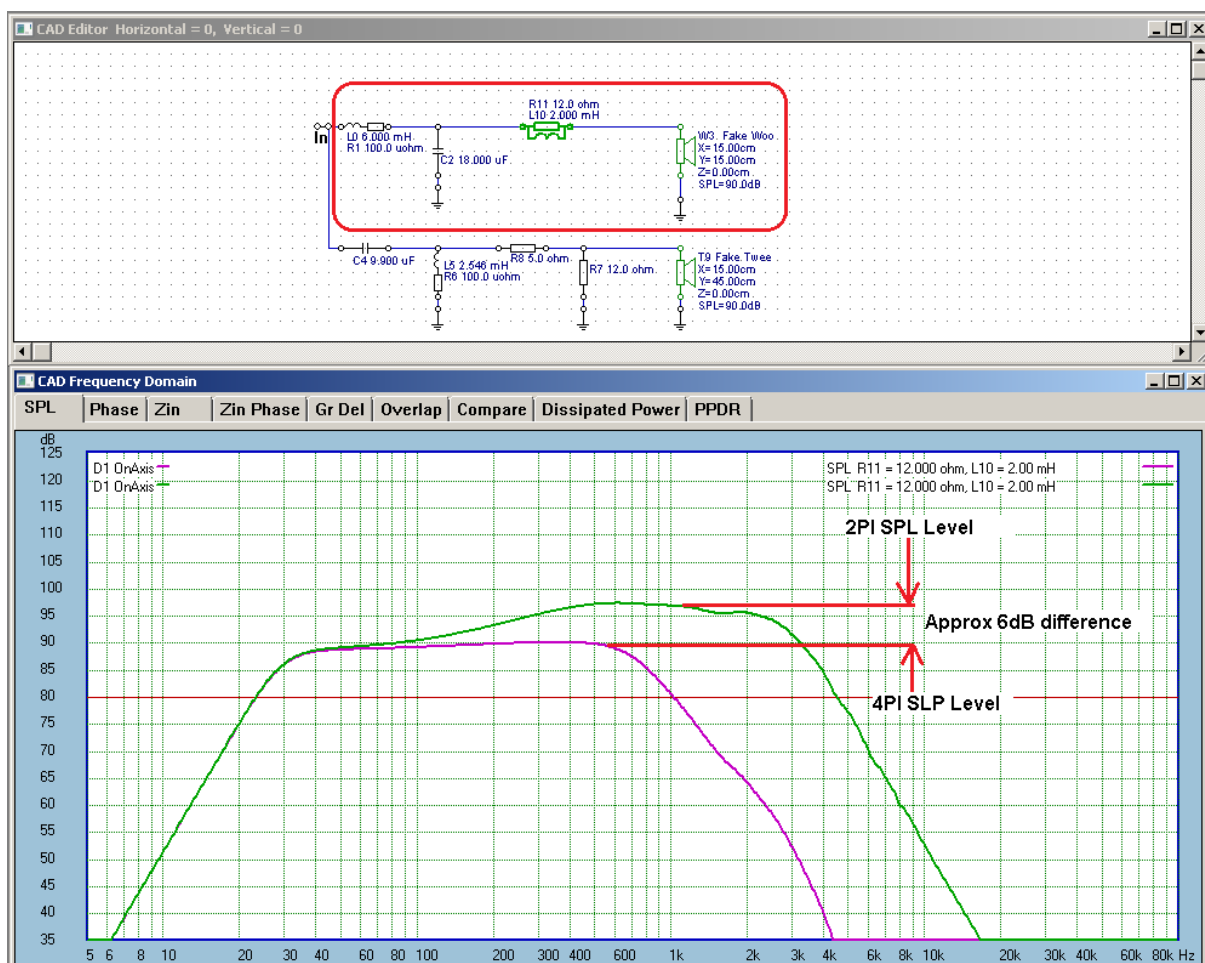
Start Filter	From [Hz]	To [Hz]
Level [dB]	90.0	Level
Counter	HP	LP
Error	HPV	LPV
Run #	SL	SL

Buttons: Amplitude, Phase, Phase Difference, Modulus, Phase, Show Minimum-Phase Guiding Filter, Create Minimum-Phase Guiding Filter

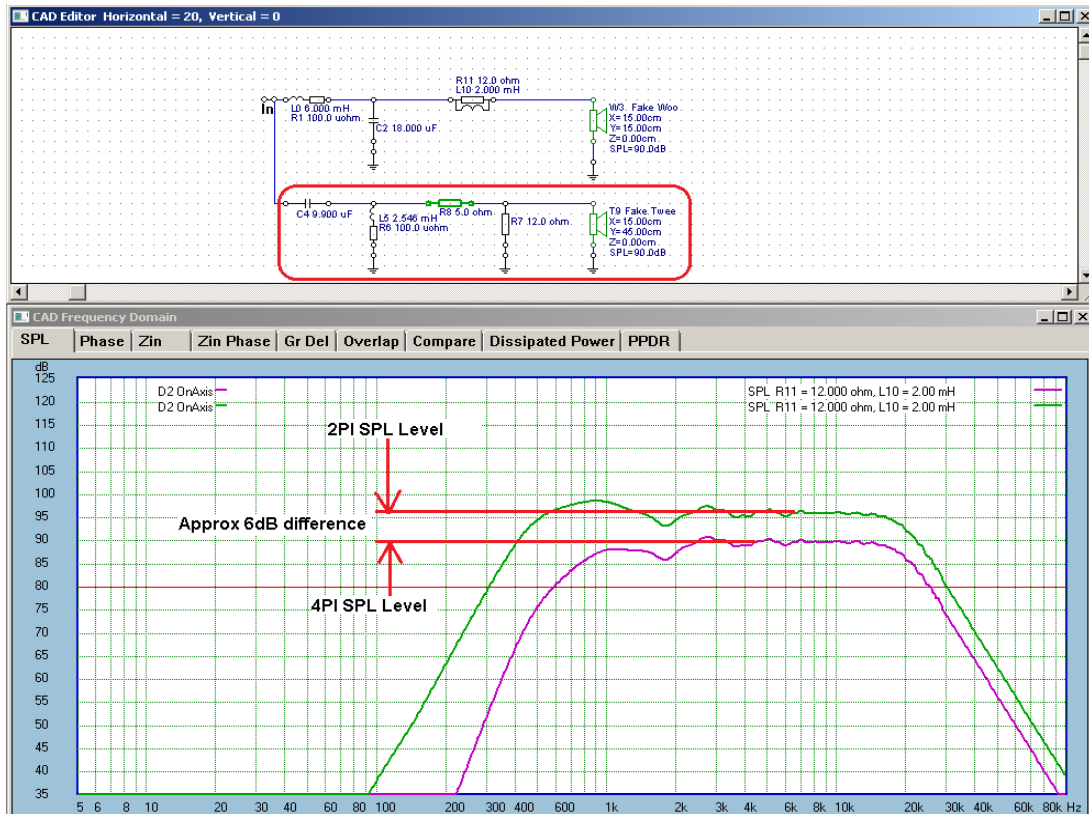
HBT parameters for the tweeter.

Crossover Design

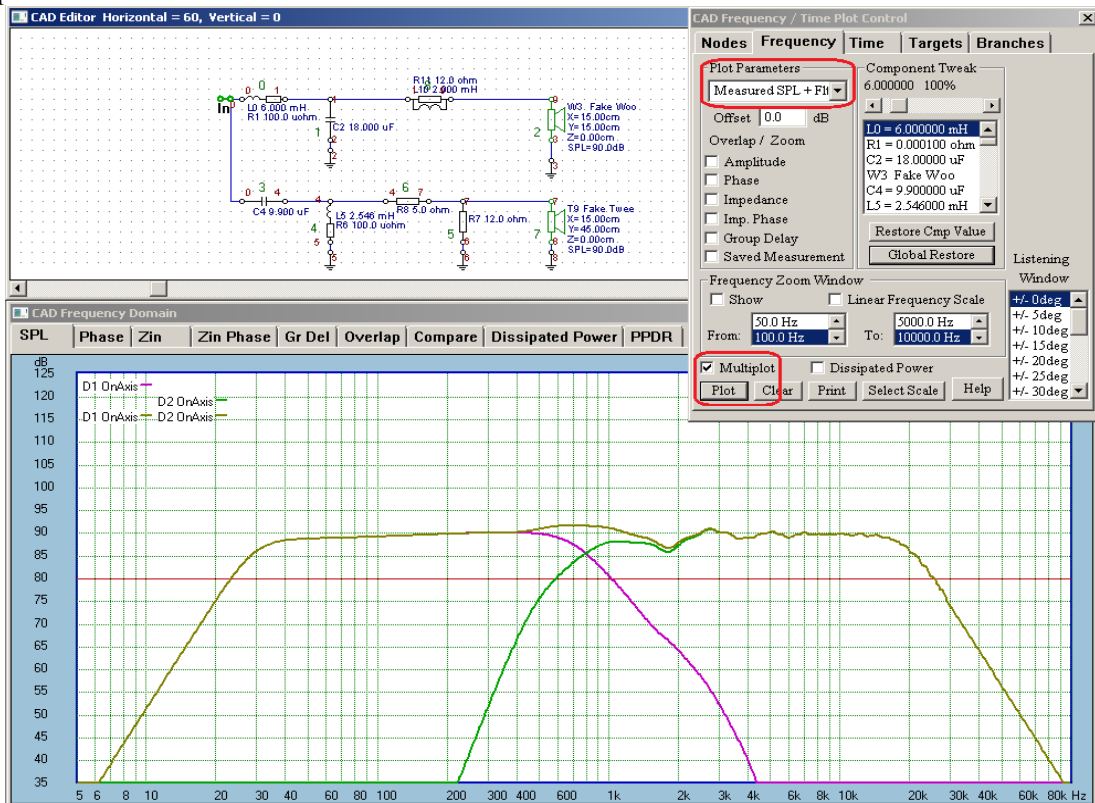
Given the efficiency differences and diffraction issues for each driver, crossover must be able to compensate for those two issues, and deliver flat frequency response within 30Hz-20000Hz. Both: woofer filter and tweeter filter must incorporate additional elements to facilitate flat frequency response as measured in anechoic chamber. We'll start with woofer branch.



In order to secure flat frequency response of the woofer branch, it was necessary to modify low-pass filter initial values and add simple **LR network** with values as shown above. Pink curve is the final woofer response.



In order to secure flat frequency response of the tweeter branch, it was necessary to modify low-pass filter initial values and add simple **L-Pad attenuating network** with values as shown above. Pink curve is the final tweeter response.



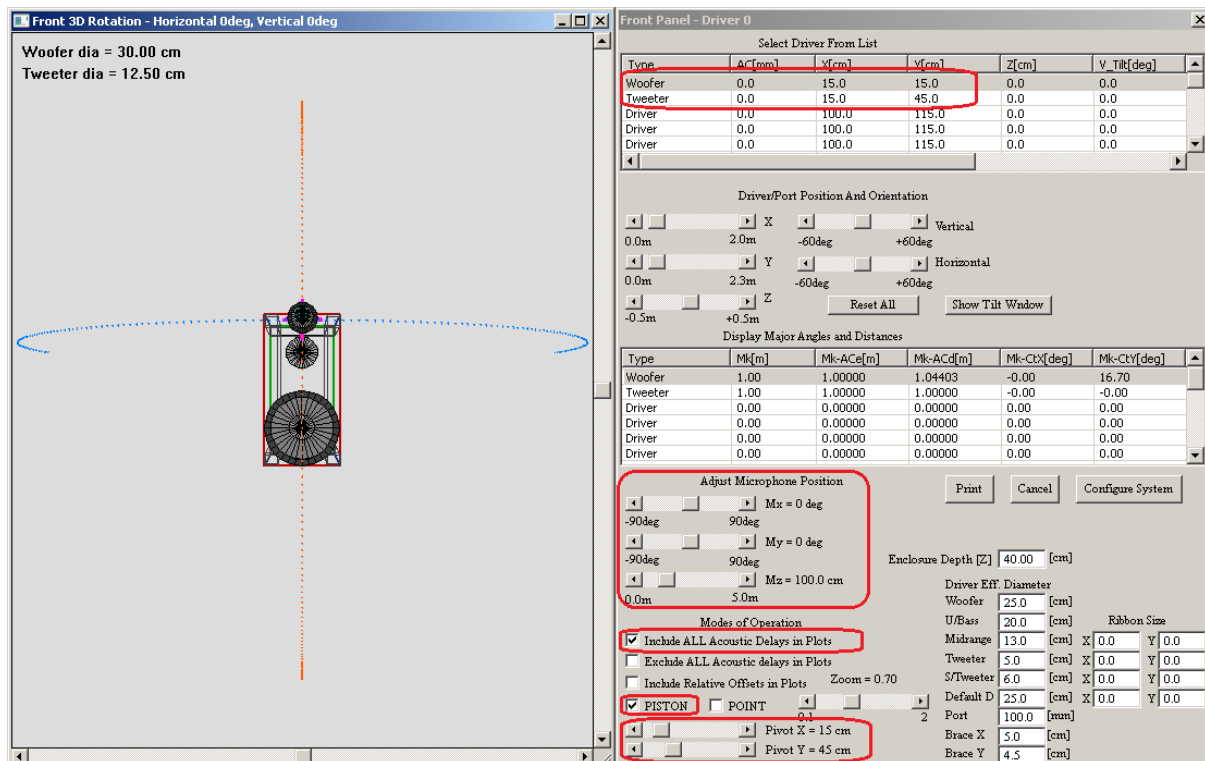
Frequency response of the complete system is shown above. It is clear, that anechoic efficiency of this system is 90dB for 1W/1m conditions. It is possible to spent more time optimizing crossover performance (like make L5=1.5mH), and this would result in flatter SPL curve. But the goal of this exercise is to illuminate the basics of the off-axis system modelling, therefore the above performance is deemed adequate for the purpose.

System Front Panel layout

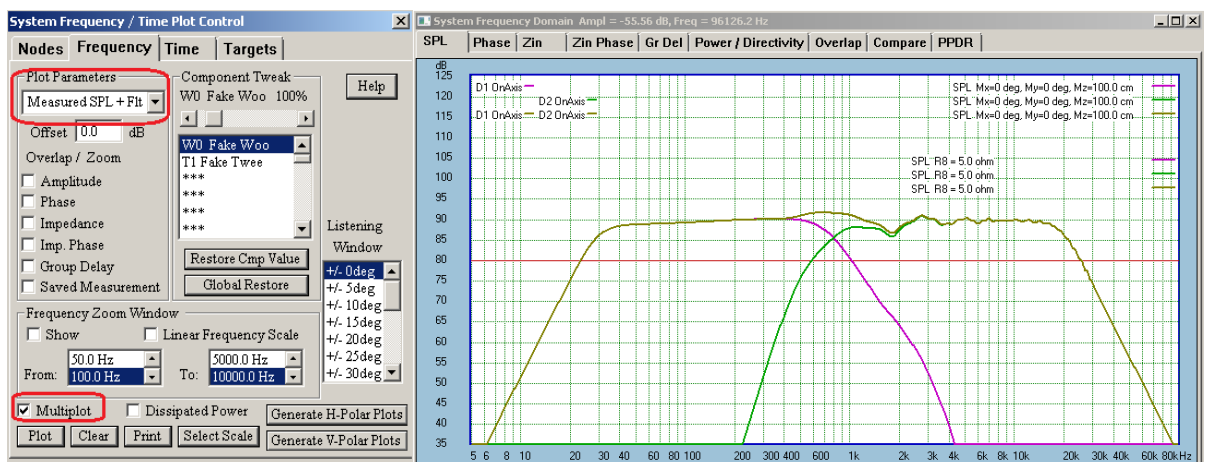
So far, we have created driver files with minimum-phase, anechoic chamber (4PI) frequency responses. Each driver has its individual diffraction characteristics embedded into the respective SPL curve. A simple crossover with compensation circuits has been designed as well, and the system frequency response deemed satisfactory. We can now move to the mechanics of the complete system simulations on the Front Panel baffle screen.

1. Adjust locations of woofer and tweeter on the front baffle, as per diffraction simulations earlier.
2. Align the microphone pivot location to the same as the mike location during the diffraction simulations, which in our case is: X = 15cm, Y = 45cm.
3. Adjust microphone initial angular location to Horizontal = 0deg, Vertical = 0deg, and distance = 100cm.

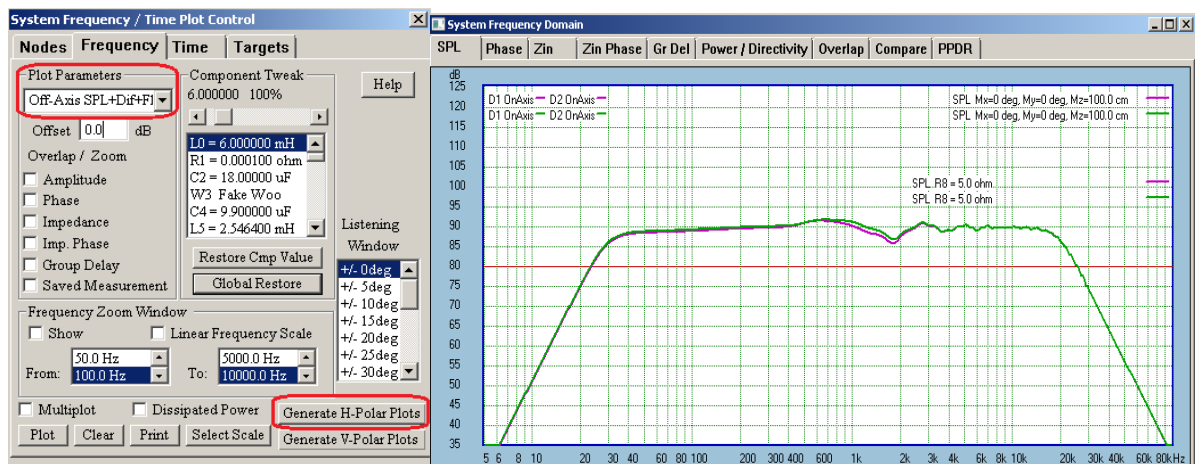
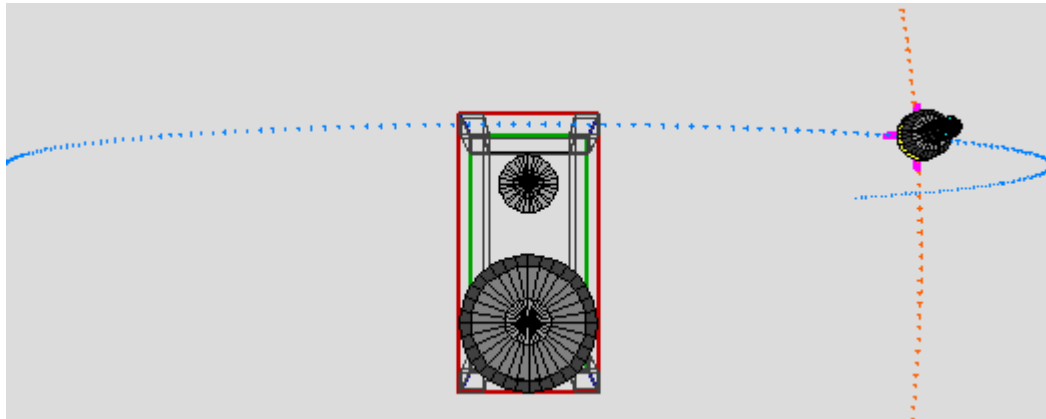
All the above requirements are the same as if you did actually measure the loudspeaker in real-life.



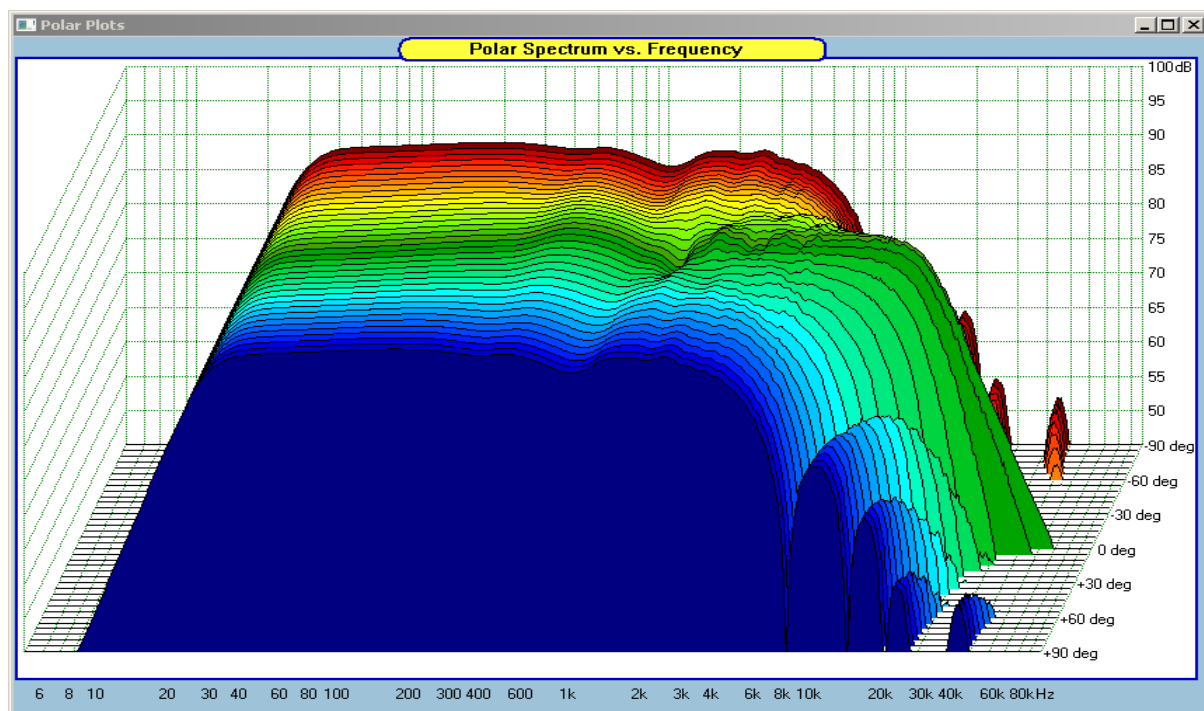
When you press “**Configure System**” button, you will be able to re-plot curves shown in the CAD section. As shown below. Please note “**Measured SPL + Flt**” plotting option.



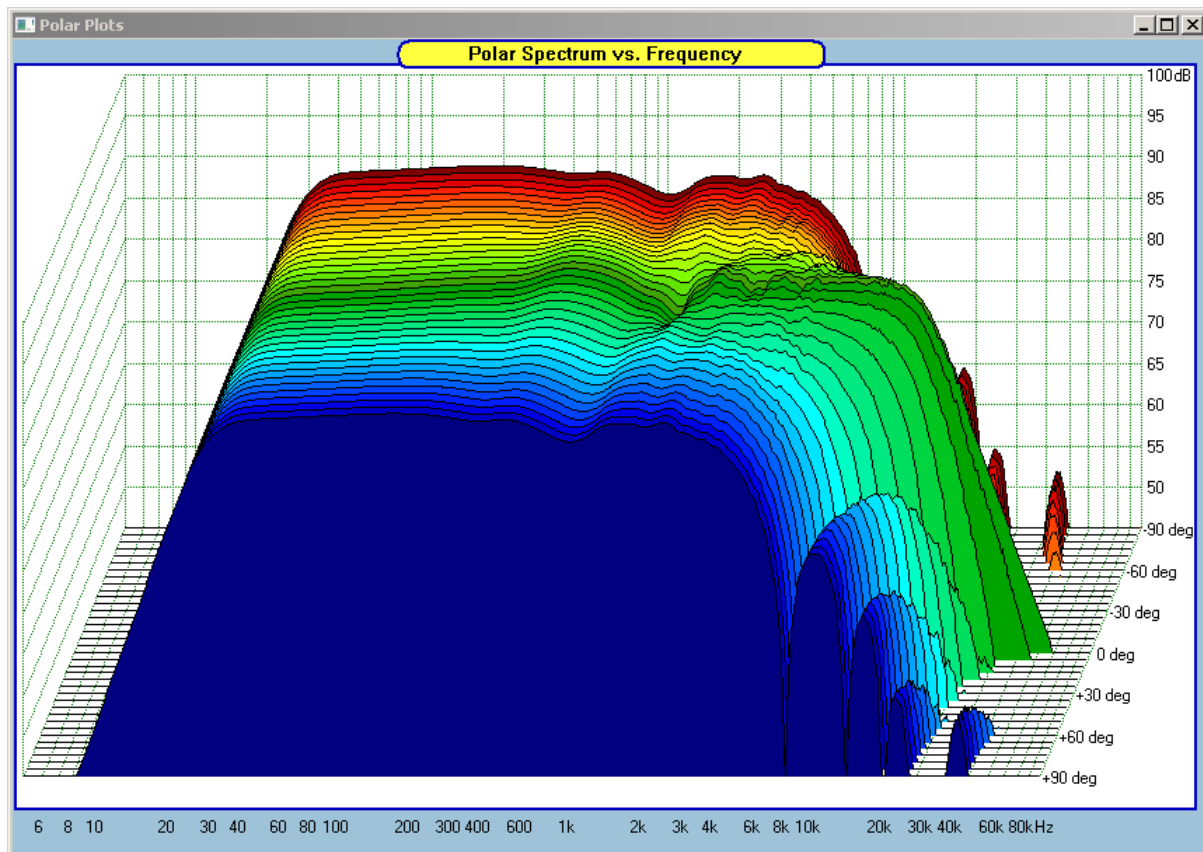
Everything looks good so far, so we can start automated “Spinorama” process. Select “Off-Axis SPL+Diff+Flt” plotting option and press “**Generate H-Polar Plots**” button. This will start graphical polar simulation process, where the microphone is moved around it’s selected pivot point from -90deg+90deg.



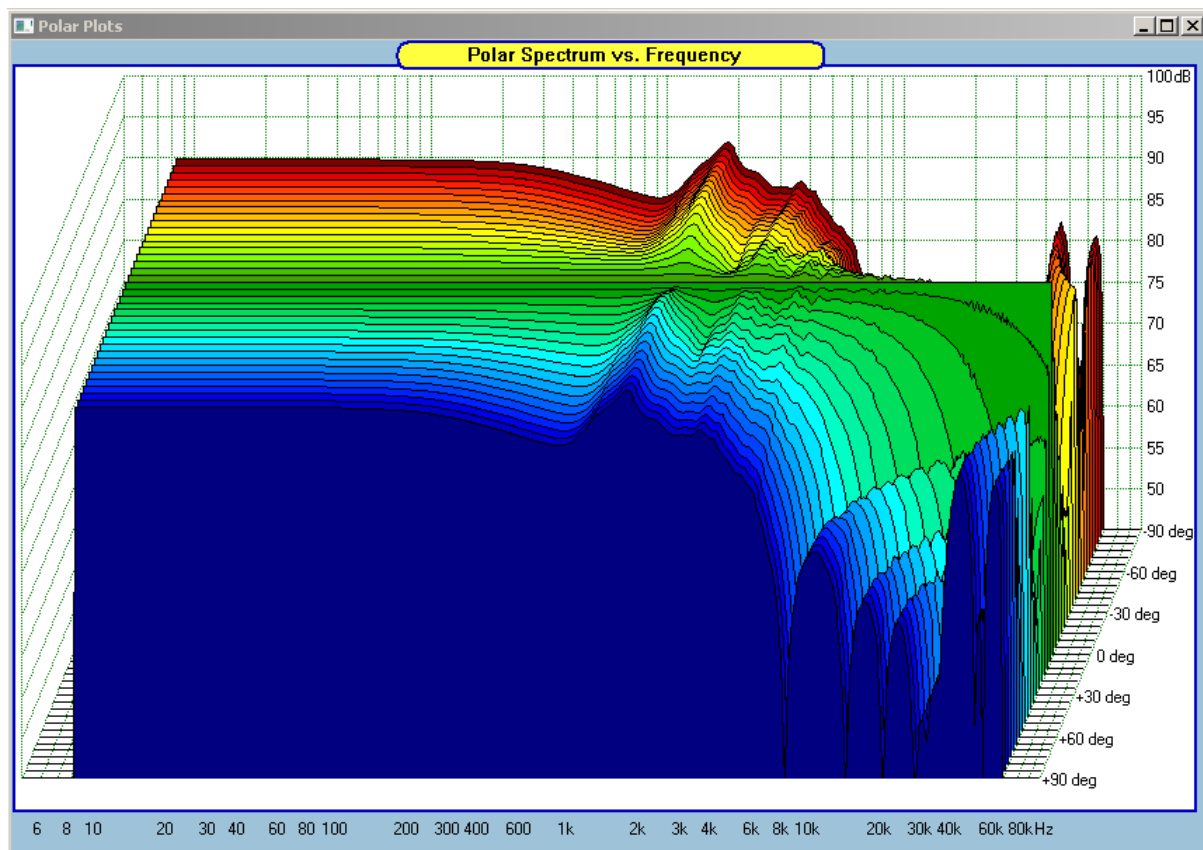
When finished, the Polar Plots screen is opened automatically and the display will look as follows:



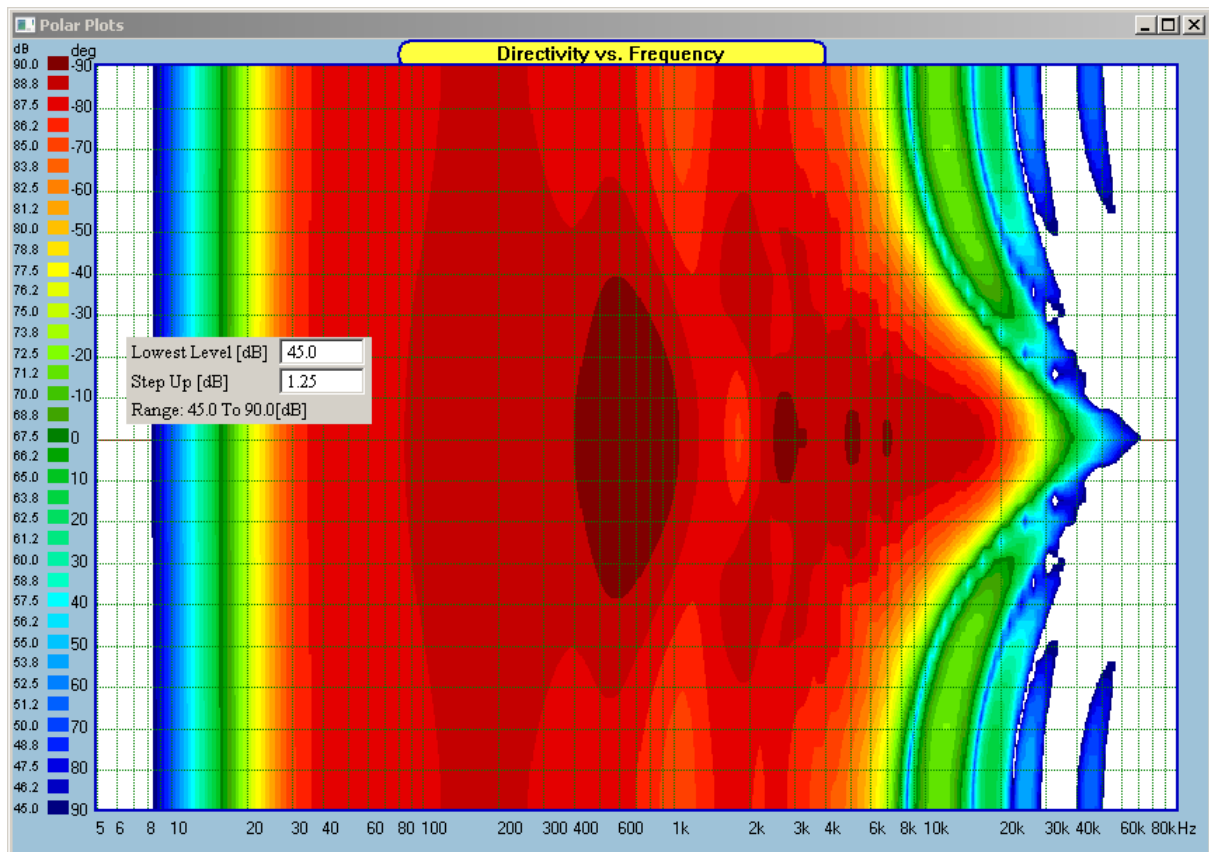
CSD View of the polar performance – Standard option



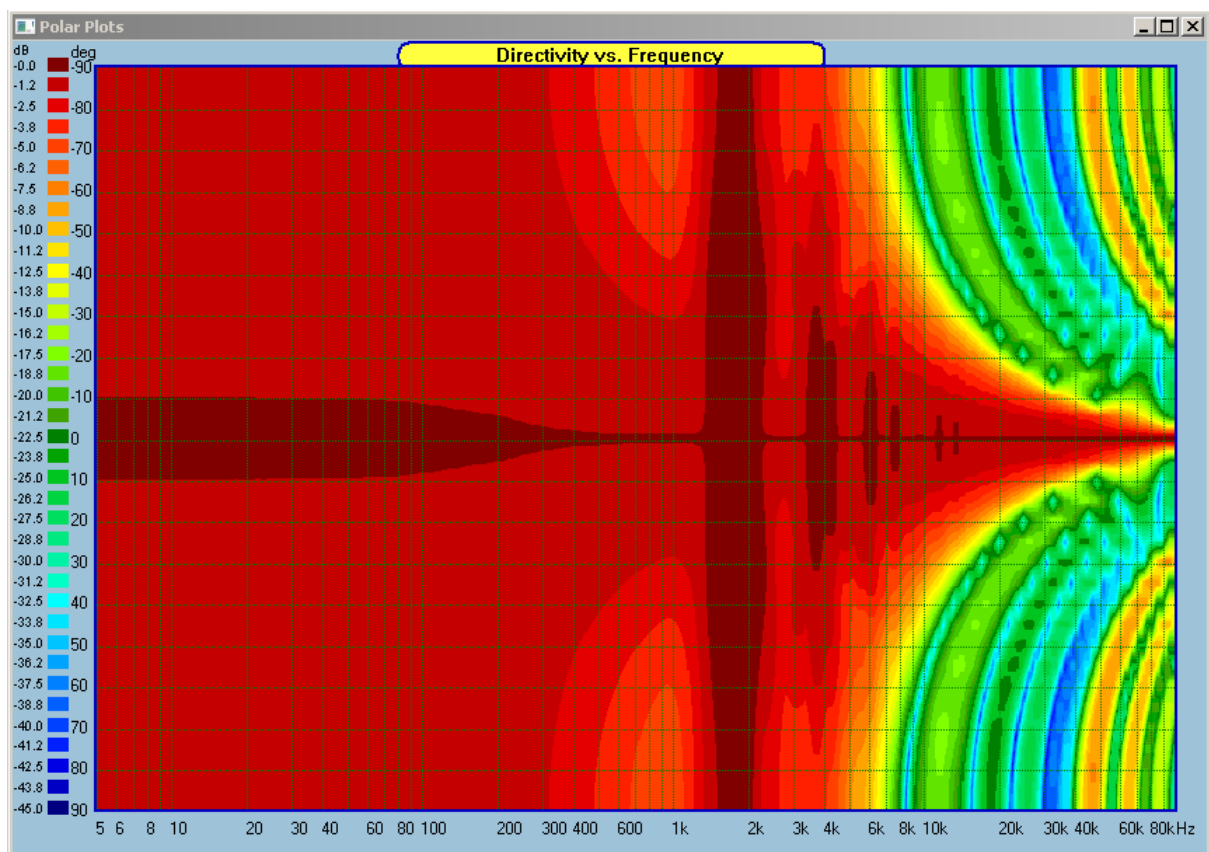
CSD View of the polar performance – Normalized option



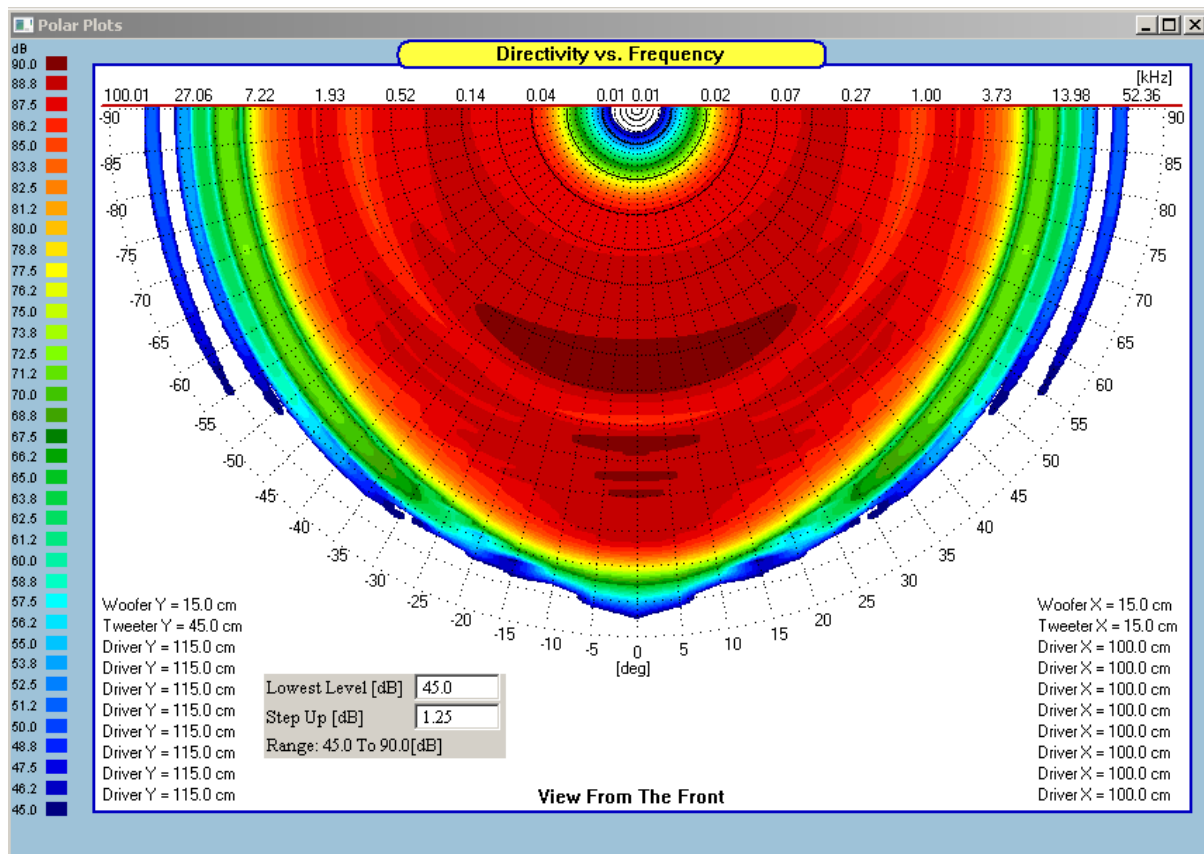
XY Coordinates View of the polar performance – Standard option



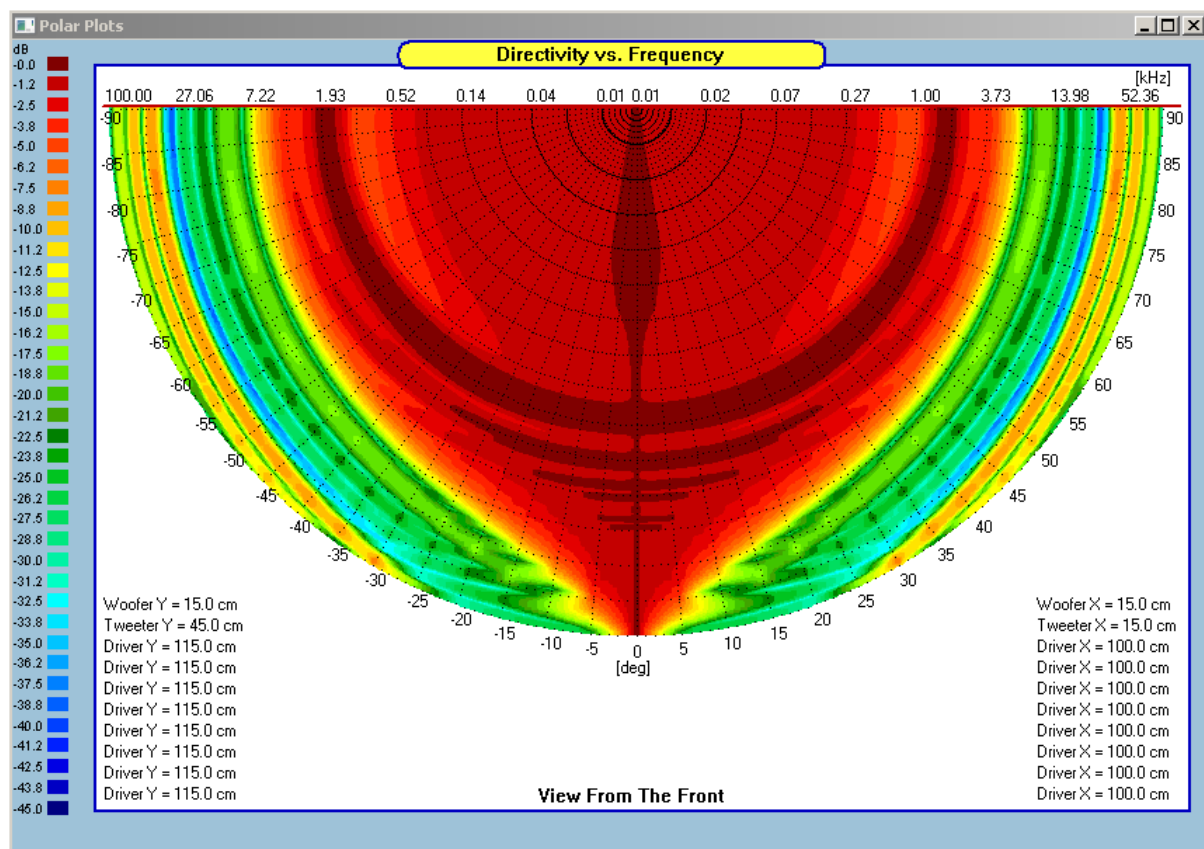
XY Coordinates View of the polar performance – Normalized option



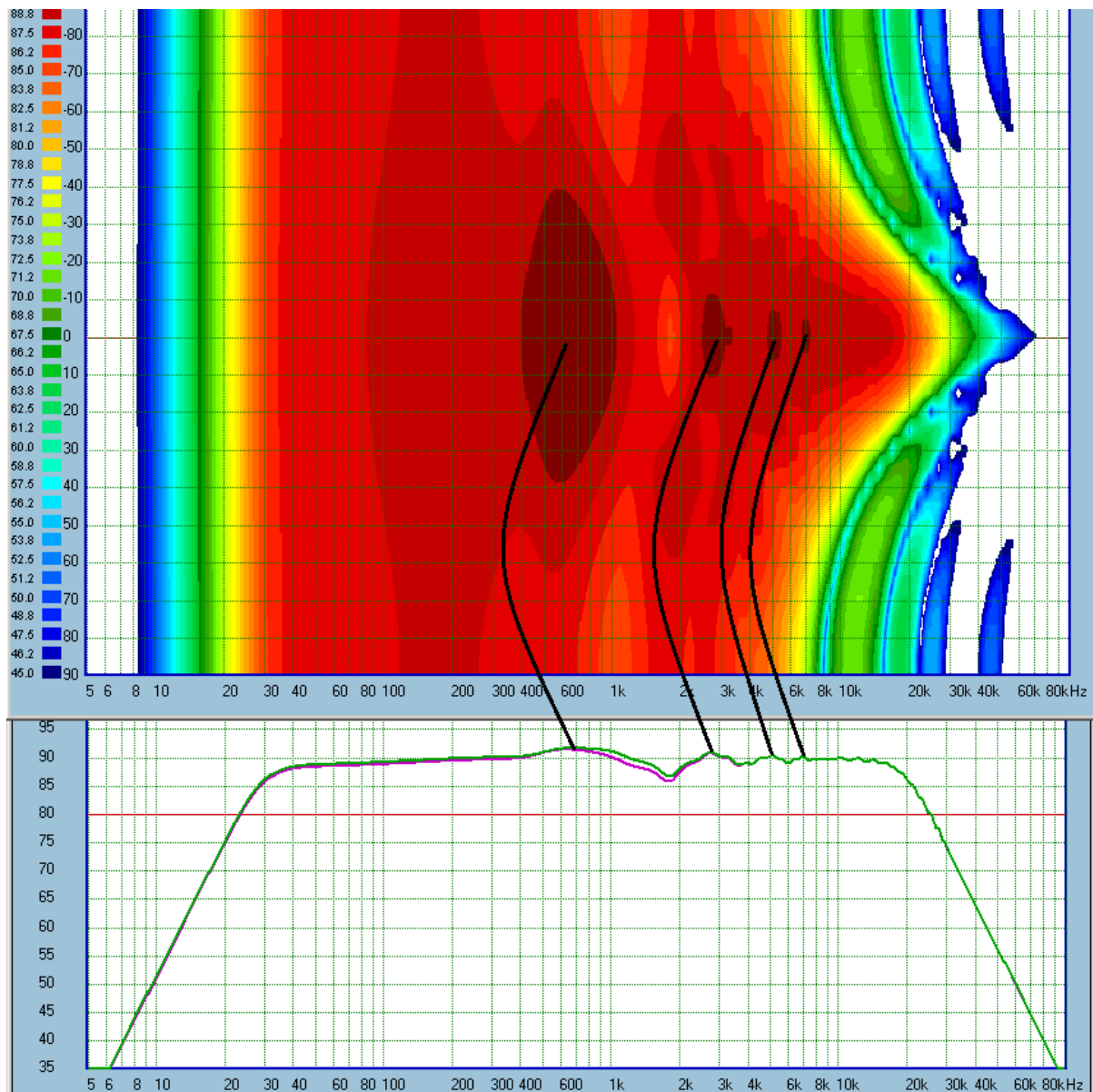
Circular Coordinates View of the polar performance – Standard option



Circular Coordinates View of the polar performance – Normalized option



It may be interesting to align the frequency scales of On-axis SPL curve with the Polar Plots graphics. It is now possible to correlate irregularities of the on-axis SPL curve with it's corresponding polar effects.



Conclusion

Process described in Part I of the diffraction modelling in SoundEasy paper, required diffraction to be removed from the measured (modelled) SPL curve prior modelling. **This is no longer necessary.**

A fully automated process for generating on-axis and off-axis performance curves and plots has been elaborated above. We started with virtually nothing – and then step-by-step created driver files with SPL data mimicking real-life anechoic chamber measured SPL curves. Taking into account SPL differences and diffraction differences for differently mounted drivers, we designed a simple crossover with a couple of compensation circuits to achieve reasonably flat on-axis, anechoic frequency response from 30Hz to 20000Hz. In the final step a fully automated process generated complete set of performance curves over the front 180deg set of angles. These curves were then used to display collected data in the variety of three distinct polar patterns. The polar graphics are produced without any unnecessary fuzziness and are displayed with clearly defined decibel range scale.

Thank you for reading
Bohdan