Diffraction Model in SoundEasy V26

Diffraction model implemented in SoundEasy is predominantly based on the works of Tore Skogberd, R.M Bews and Malcolm. J. Hawksford. Their scientific papers are in public domain, are available for download and I will be quoting the authors extensively in this brief explanation.

[1]. “Application of the Geometric Theory of Diffraction (GTD)to Diffraction at the Edges of Loudspeaker Baffles”, R.M. Bews and M.J. Hawksford, JAES, Vol 34, No10, 1986 October.

[2]. “Loudspeaker Cabinet Diffraction”, Tore Skogberg, Acoustical Technology, Ørsted●DTU – 2006.

What is an edge diffraction of a loudspeaker cabinet

Simple and elegant diffraction model is presented in [2] on page 56.

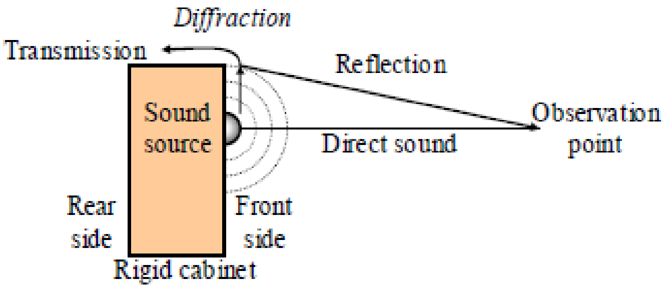


Figure 51 – Graphical presentation of diffraction. The observation point at the front side receives direct signal from the loudspeaker unit as well as a reflection due to the diffraction at the cabinet edge while the shadow zone receives a transmitted signal.

Please note, that the model presented above, only shows the “first order” reflections. The model can be extended to include higher order reflections, where the first reflection signals travels along the front baffle towards the opposite edge and then being re-reflected again and again.

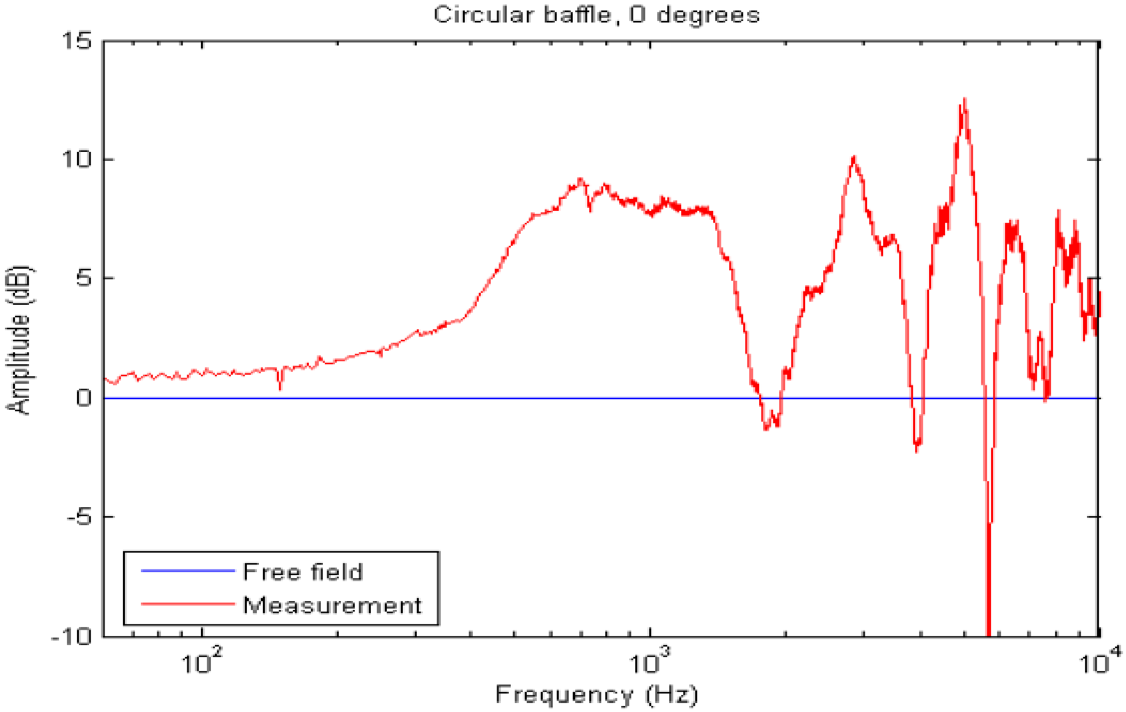
Skogberg concludes: “A consequence of the reflection theory is that the model must include a *reflection coefficient*, which proved the first obstacle to attack since the reflection coefficient could be related to such different subjects as the wedge angle, the observation angle and frequency. The values found in the literature were contradicting, as will be shown below, so an expression for the reflection coefficient was derived and the value calculated to –0.60.”

R = -0.60 indicates, that 60% of the signal is reflected back into the front side and 40% is transmitted to the shadow (rear) side.

How does diffraction manifests itself

Using anechoic chamber and very claver approach to measuring edge diffraction alone, Skogberg was able to offer the following test results for two baffle shapes: circular and rectangular. For circular baffle, Skogberg makes the following observations:

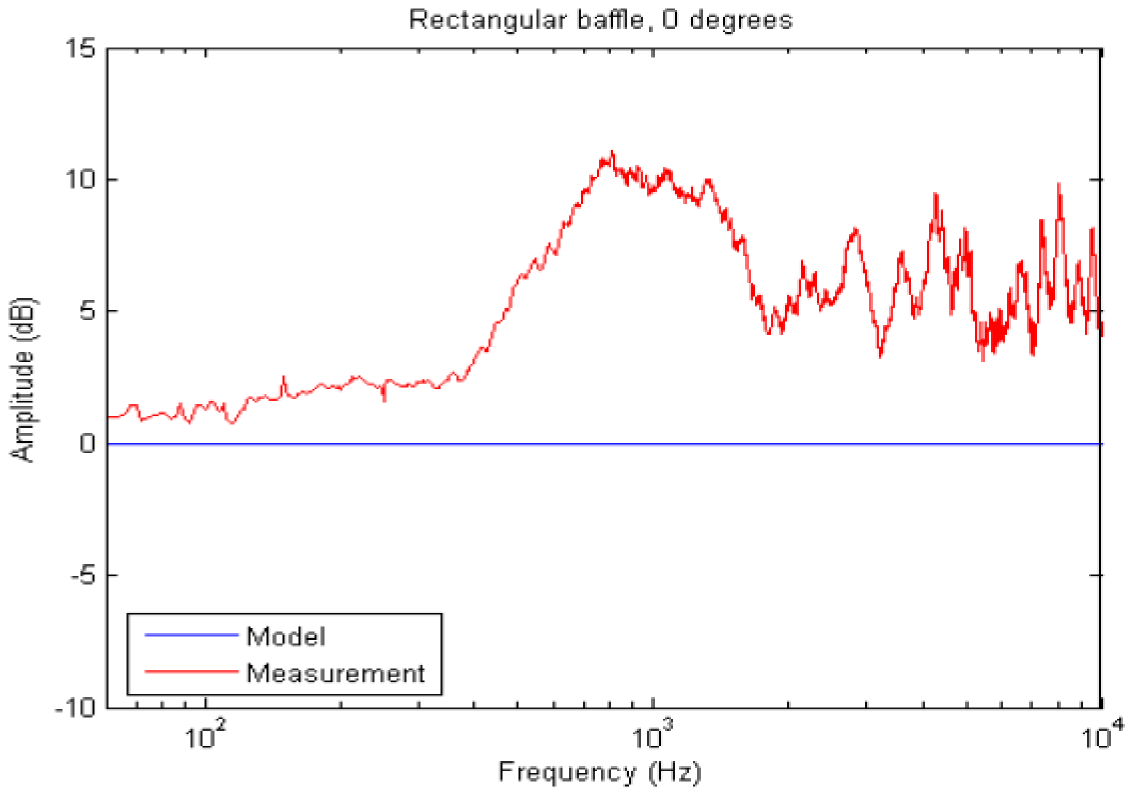
"The sound pressure was measured at the centre of the baffle for angles from 0° (on-axis) to 180° (rear side) in 30° increments with the microphone pushed through a hole at the centre of the baffle. The reference was free-field so 0 dB corresponds to the sound pressure from a point source without baffle and this level is approached toward the low-frequency end. Low frequencies are not affected by the baffle but the high-frequency response is greatly influenced by the baffle, which is seen as the 10 dB increase in level from 500 Hz to 1 kHz and the ripple at higher frequencies. The cross-over frequency due to the baffle is 400 Hz, which is in reasonable agreement with the estimated value for $kB = 1$, which is 320 Hz for the circular baffle with 170 mm radius."



It is observable, that the measured diffraction curve levels off below 150Hz. Edge diffraction effect does not really affect low frequencies. So the loudspeaker placed in an anechoic chamber will not exhibit any adverse SPL effects below the frequency where the diffraction curve starts to rise. For those frequencies, the loudspeaker placed in an anechoic chamber approximates point source in free-field.

This is important. We have a paramount requirement for the frequency response measured in anechoic chamber to be flat. Therefore, the low-frequency end of loudspeaker SPL performance determines the overall system efficiency. This SPL level can not be changed, Therefore, it becomes the baseline of the system's efficiency performance. Anything that adds SPL to the baseline needs to be removed (supressed).

For the rectangular baffle, Skogberg makes the following observations:
"The amplitude response was measured for a rectangular baffle 200 mm wide by 340 mm high. The basic behaviour is much the same as the response for a circular baffle; the level is increased from 0 dB at low frequencies to around 10 dB at 1 kHz where the large dimension equates one wavelength. However, the high-frequency response is less ragged since the phase of the reflected signal is blurred by the different path lengths between the test point and the edge of the baffle."

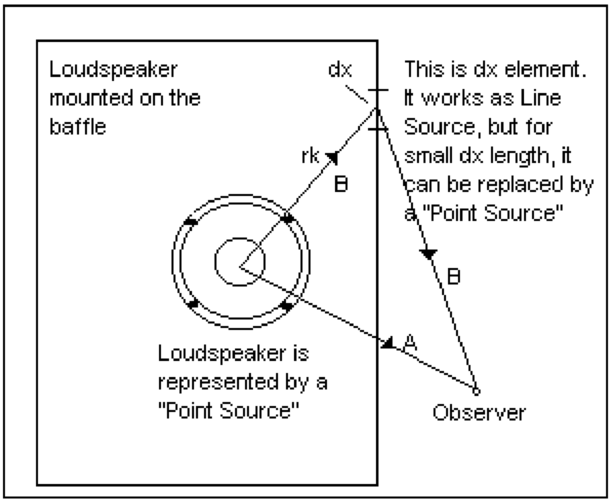


How is diffraction calculated in SoundEasy

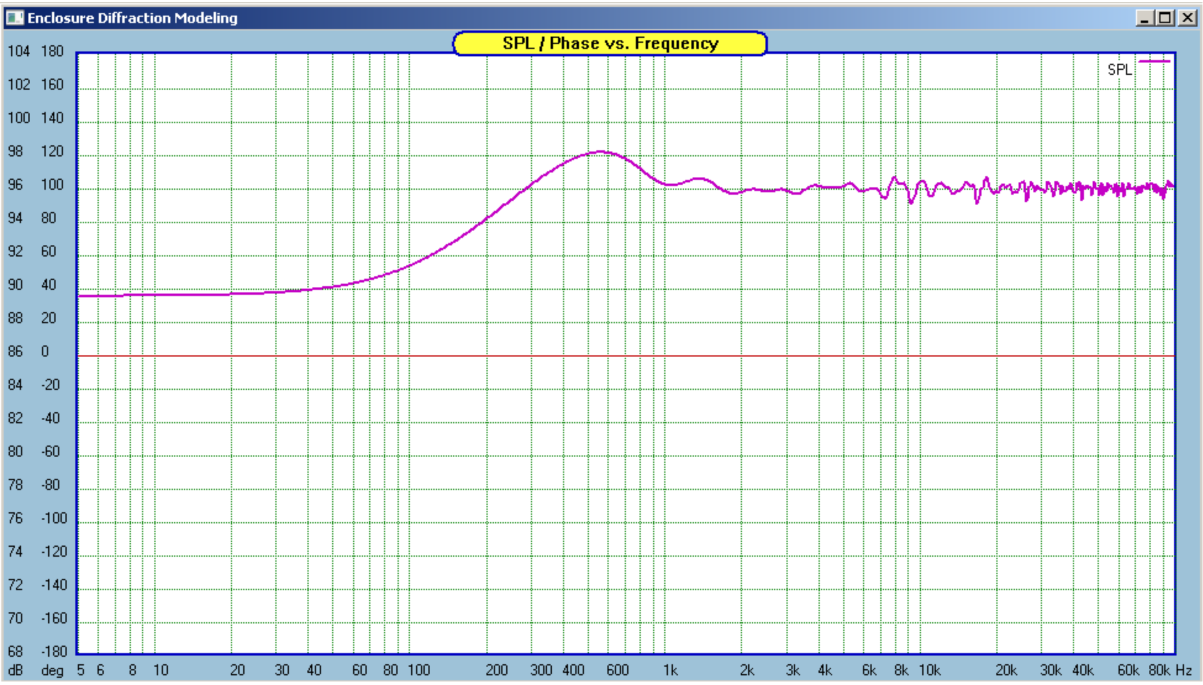
Mathematical expressions for calculating diffraction within SoundEasy follow closely expressions derived by Bews and Hawksford in [1].

Loudspeaker enclosure or baffle and the placement of the driver contribute up to +10dB to the frequency response of the system. The GTD using ray model is applied to determine the exact amount of SPL deviation due to the diffraction. In this model, sound rays, B, propagate along the surface of the baffle and are scattered when encounter the edge of the baffle. This secondary sources combine with the direct rays, A, produced by the loudspeaker and the resulting frequency response is far from being flat.

To calculate the contribution of baffle edge, total length of the baffle edge is quantised into a number of sections of length ***dx***. The average distance from each section to the "point source" representing the loudspeaker is ***rk***. If ***dx*** is made sufficiently small, it can be replaced with a "diffraction point source". Knowing the SPL of each "diffraction point source" and the distance to the observer, it is possible to predict the total SPL from the driver and all of the diffraction sources. The program automatically divides each baffle side into a number of ***dx*** line elements.



GDT concept



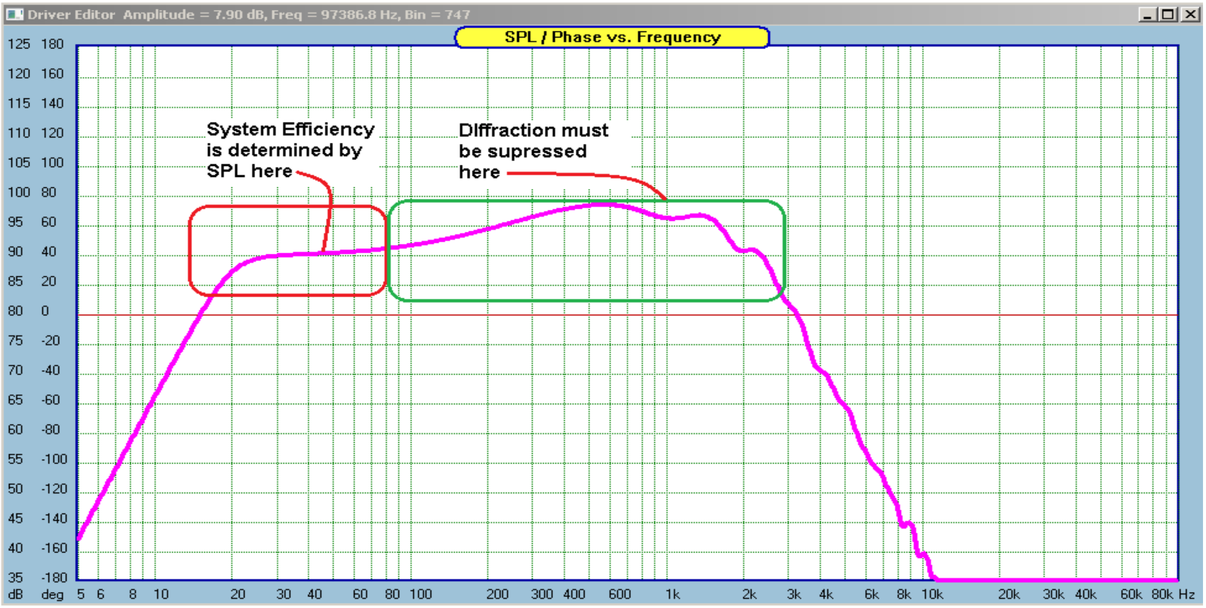
Example of calculated diffraction curve.

"Diffraction step", "diffraction loss", "baffle step", and other names have been associated with the diffraction phenomenon. Regardless how you call it, you must deal with it.

SoundEasy implements diffraction modelling scheme, which allows you to calculate diffraction curve alone. This is based on the explanations provided above. We are now in the position to review the implications of the approach described in [1] and [2].

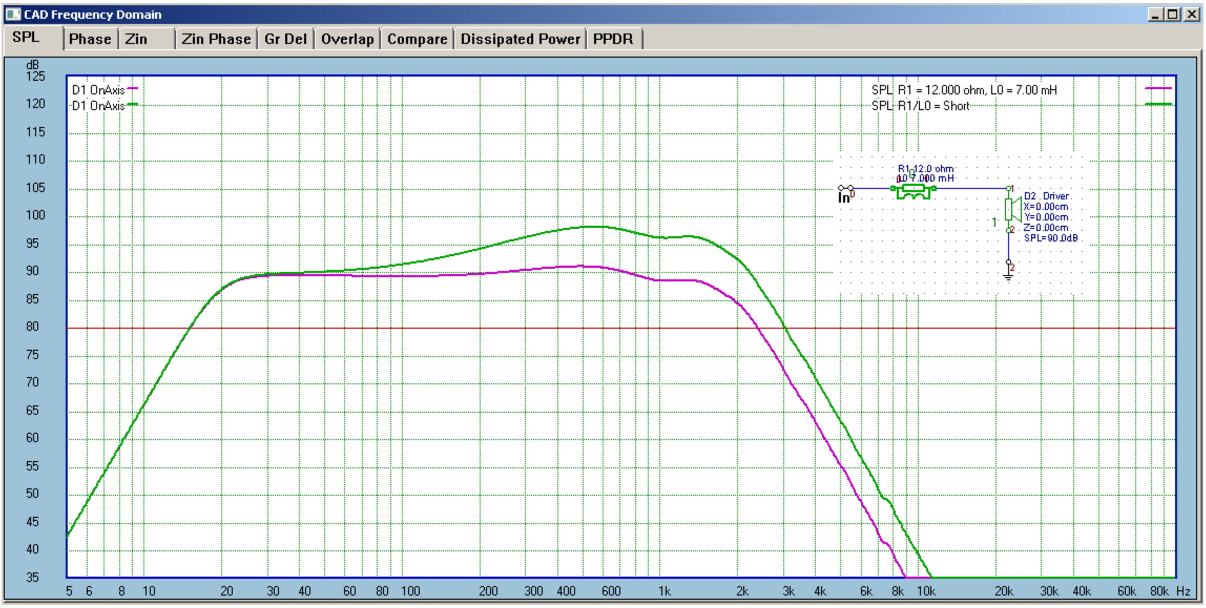
What are the implications of the diffraction modelling

1. System efficiency is anchored exactly where it needs to be. It is determined by the low-frequency free-field performance of the woofer driver below the diffraction onset. It is the first requirement for designing a loudspeaker system with flat frequency response.

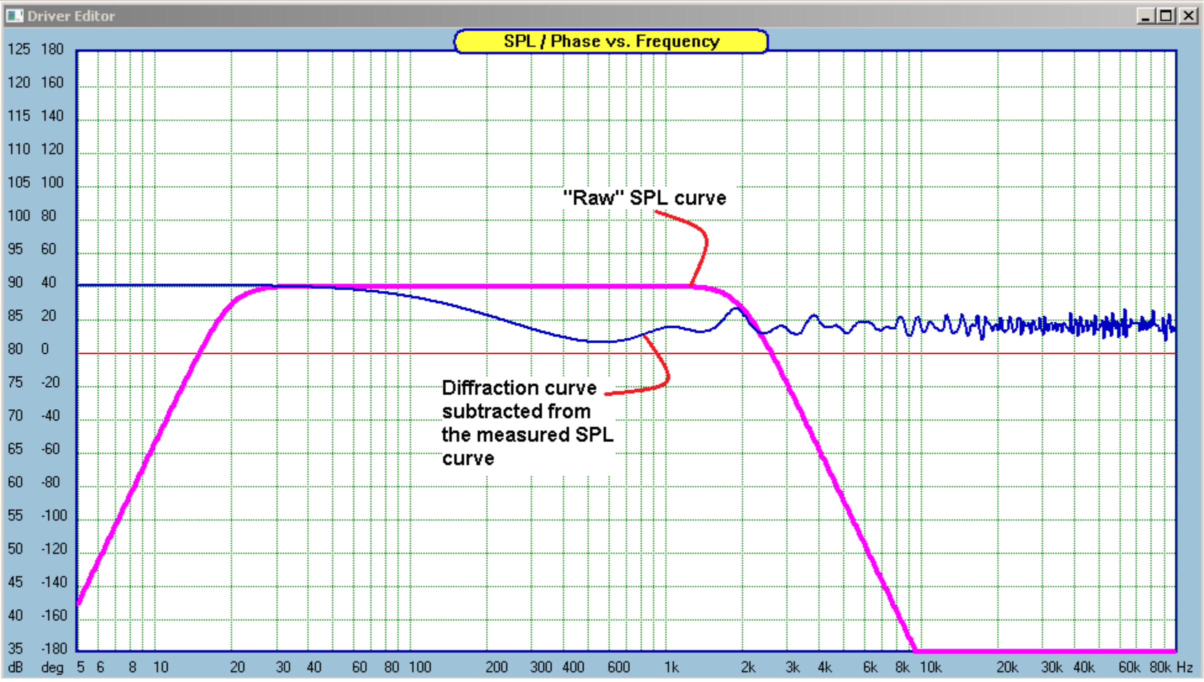


Example of measured SPL curve in free-field, at 1W/1m conditions.
Baffle is a rectangular, 30cm x 60cm, Free-field efficiency = 90dB.

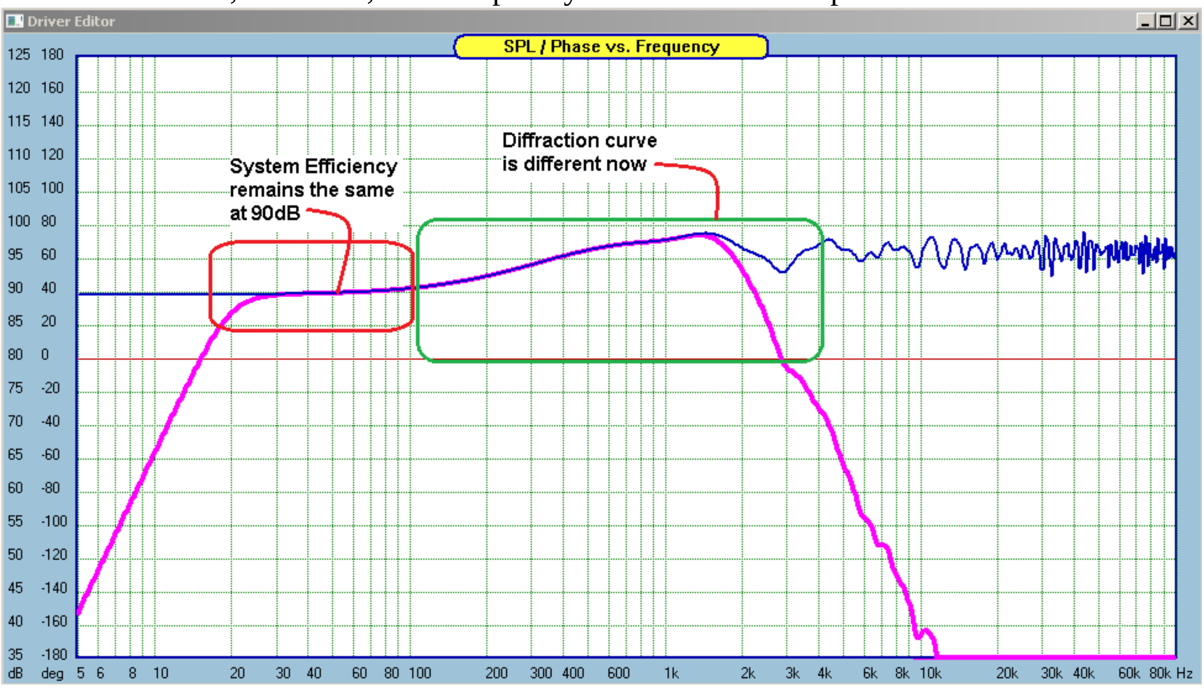
2. The method of dealing with the diffraction effect is now clear. Diffraction increases SPL over the free-field level, therefore it will be possible to apply the opposite and supress it by incorporating a simple passive circuit reducing SPL over the diffraction determined frequency range – see below.



3. Using anechoic chamber, or any of the quasi-anechoic methods, we can measure loudspeaker's SPL curve at 1m/1w conditions. We can then set up SoundEasy to calculate diffraction curve (blue on picture below) for the same geometry as the measured system. After subtracting the diffraction curve from the measured SPL curve, we have stripped the "diffraction point sources" for the given front baffle. What's left?. Call it "raw" SPL curve or 4PI-SPL curve for lack of a better description.



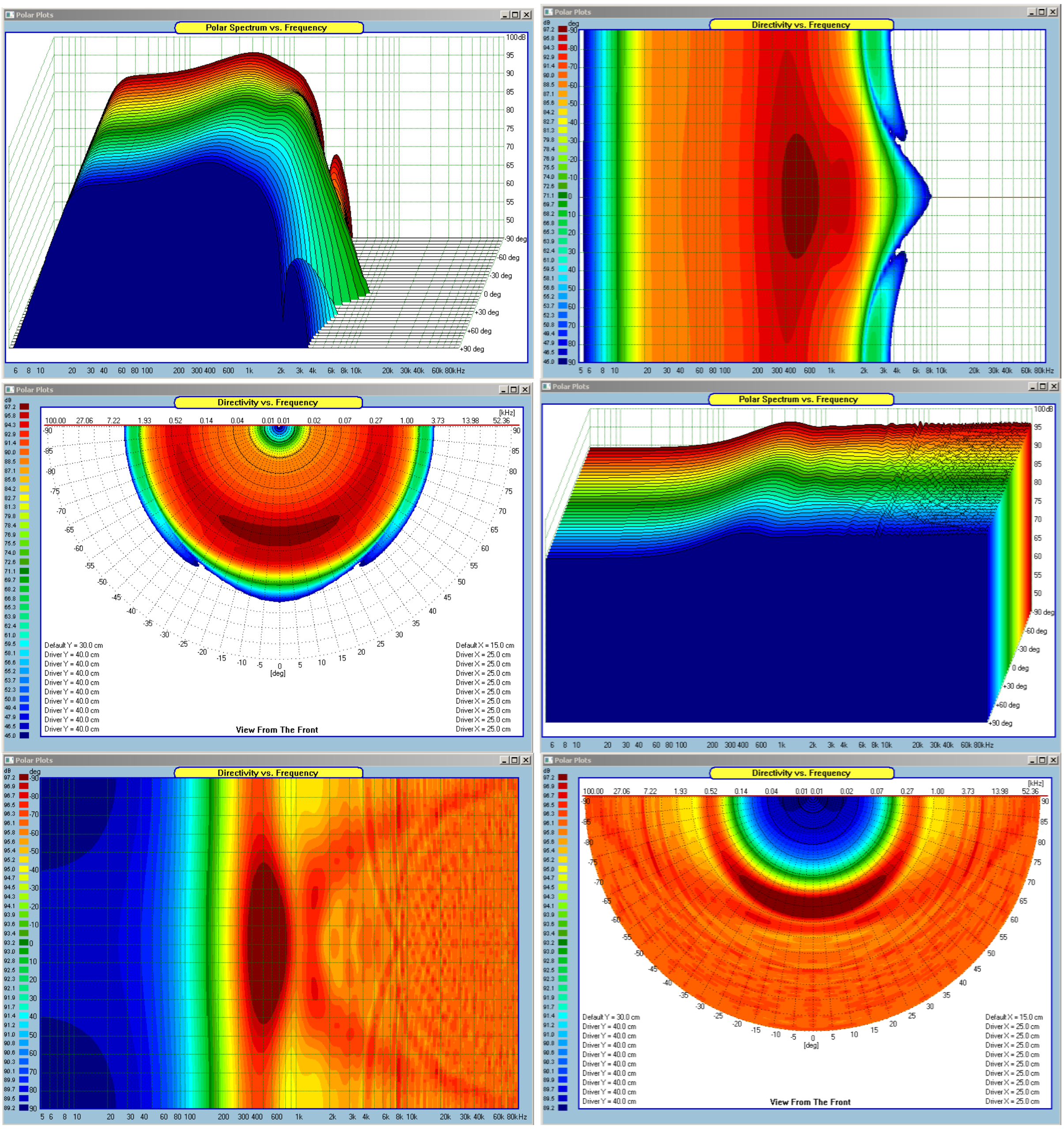
We can now design a different baffle, calculate it's diffraction curve and add this new curve to the "raw" SPL curve. We have just created a valid loudspeaker performance SPL curve, for a new, and completely different baffle shape or box.



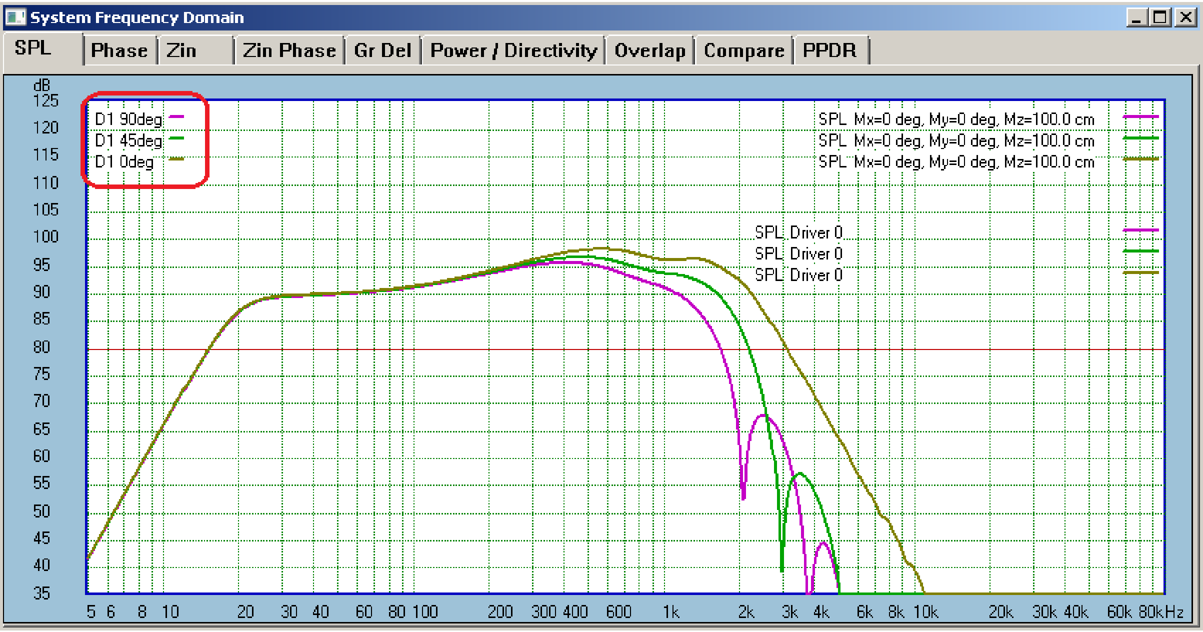
New baffle is 20cm x 40cm, and driver is in different location. Efficiency remains at 90dB level.

This is a simple way of sharing measurement results between loudspeaker designers. All you need is driver's free-field measured transfer function (SPL/Phase), driver size/location on the baffle and baffle size to re-create SLP/Phase between different designs.

4. Using single, "raw" SPL curve as a starting set of data, we can simulate a complete set of of-axis SPL performance at -90….+90deg set of angles.



Shown above, are examples of modelled SPL and diffraction alone at -90….+90deg set of angles. All were based on a single "raw" or 4PI SPL measurement. The SPL plots were created by selecting "Off-axis SPL + Diff" option and pressing Generate H-Polar Plots button. The off-axis simulations are now stored under the "Measured SPL + Filt" plotting option and can be used as if they were actually measured SPL results. See examples below for 0deg, 45deg and 90deg angles.



Presented above are several examples, that illustrate usefulness of the implemented diffraction modelling scheme. A single measurement of a driver's SPL/Phase leads to complete characterization of on-axis and off-axis performance at -90….+90deg set of angles. Not only that – you can move the "raw" SPL curve between designs, and still maintain a good modelling accuracy.

IEC 268-5 Testing Baffle

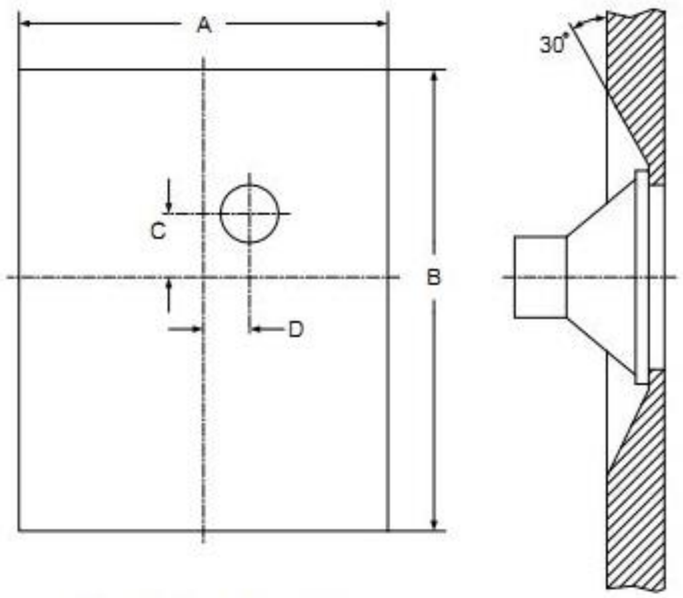
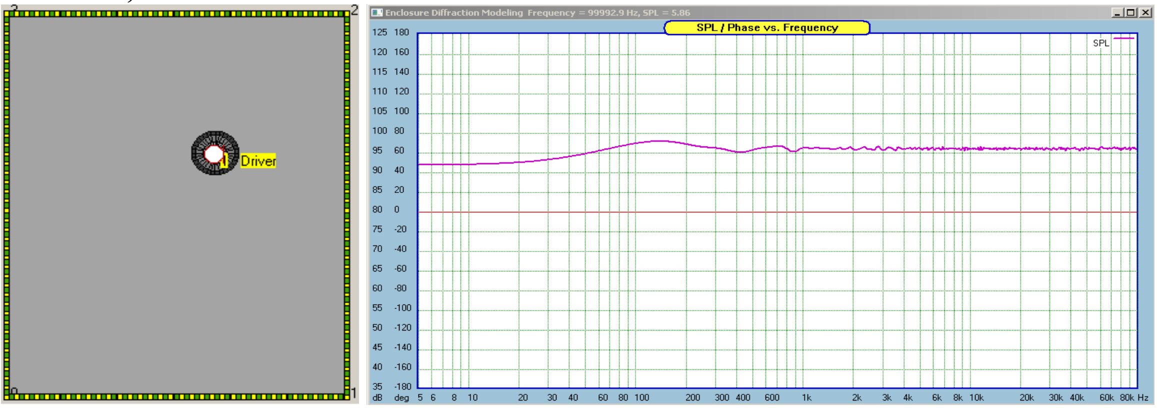


Fig. B1. Standard baffle dimensions for low-frequency driver measurements.

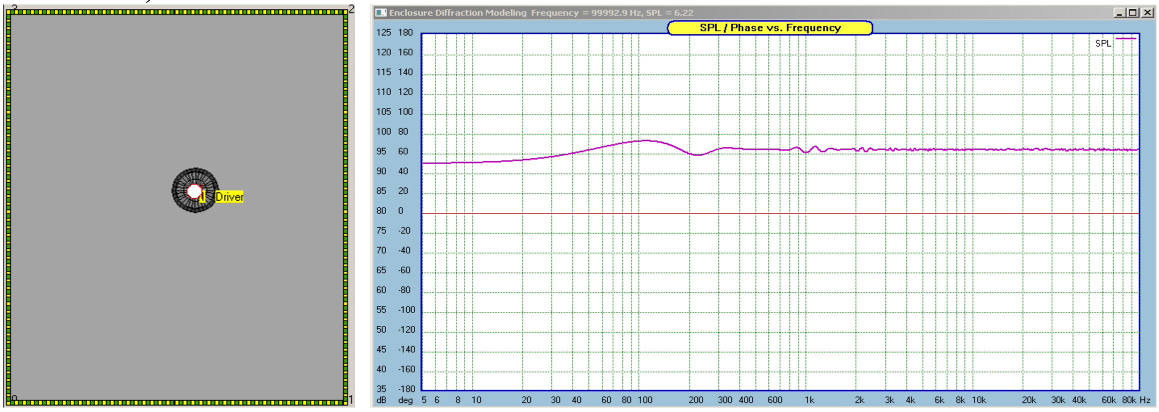
Table B 1. Preferred baffle dimensions for lf loudspeaker

Nominal Loudspeaker Size	Baffle Dimensions			
	A	B	C	D
200 mm (8 in)	1350 mm	1650 mm	225 mm	150 mm
250 mm (10 in)	1690 mm	2065 mm	280 mm	190 mm
315 mm (12 in)	2025 mm	2475 mm	340 mm	225 mm
400 mm (15 in)	2530 mm	3090 mm	420 mm	280 mm
500 mm (18 in)	3040 mm	3715 mm	505 mm	340 mm

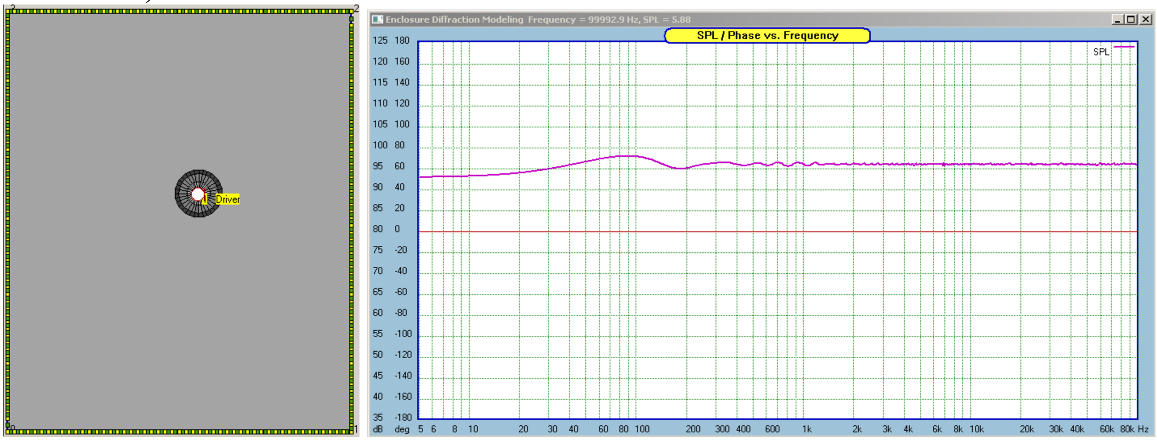
8” driver, 1350 x 1650 mm baffle



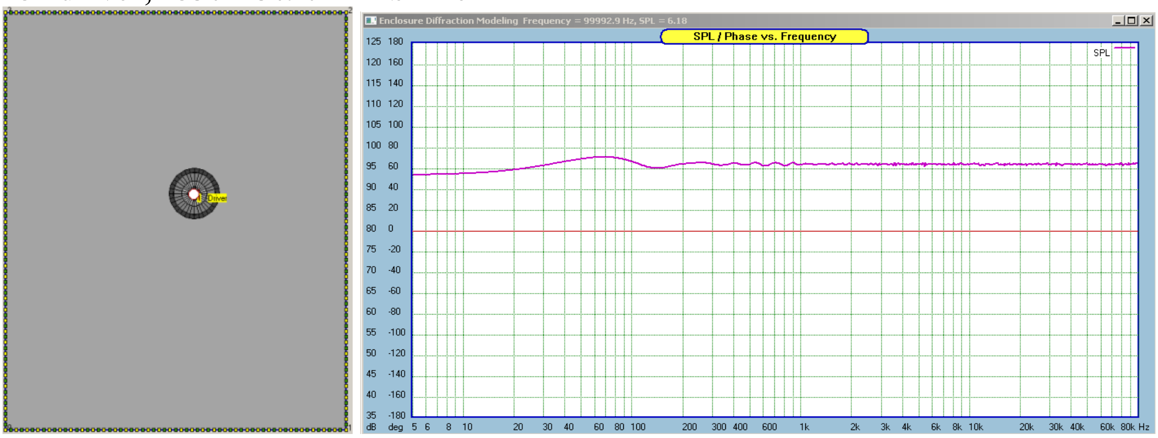
10” driver, 1690 x 2065 mm baffle



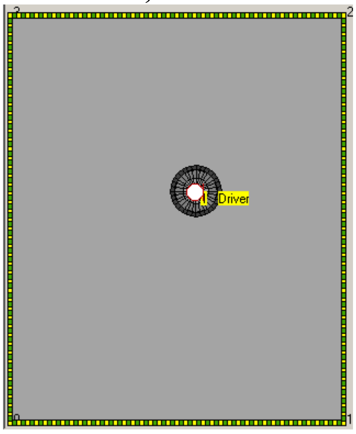
12” driver, 2025 x 2475 mm baffle

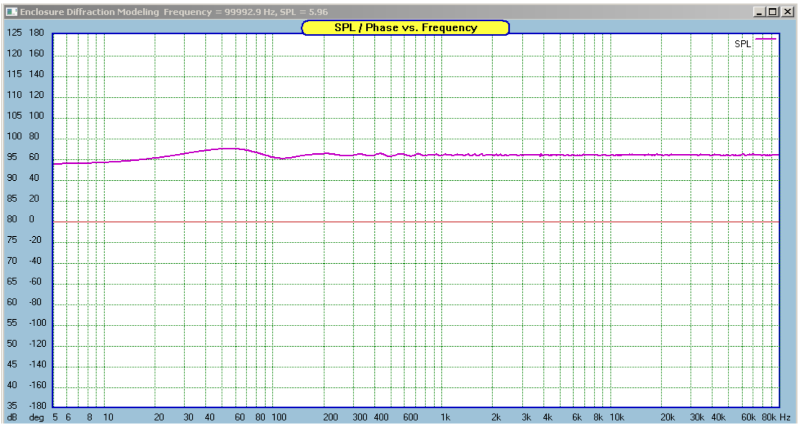


15” driver, 2530 x 3090 mm baffle



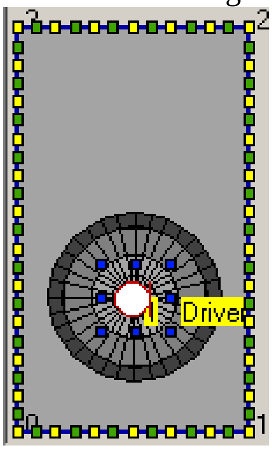
18” driver, 3040 x 3715 mm baffle

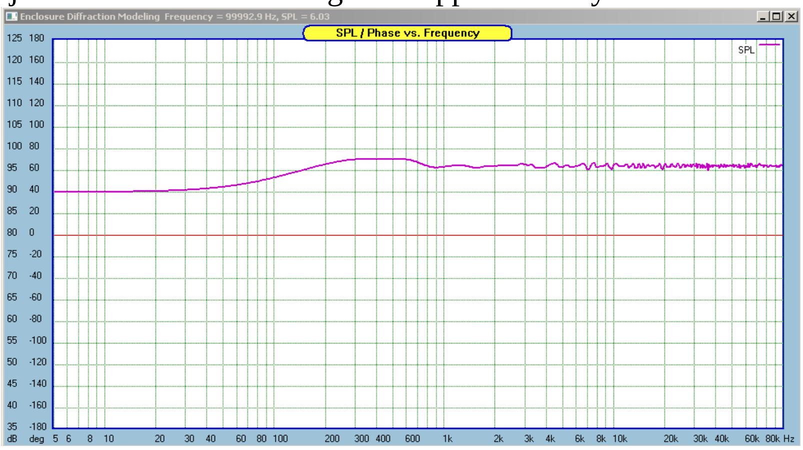




Presented above are diffraction curves for all 5 IEC 268-5 testing baffles and 5 corresponding driver sizes. It is observable, that each baffle provides corresponding driver with almost half-space (2PI) radiating conditions. Obviously assuming, that there are no other reflecting objects around the testing baffle. For instance, the 15” driver would be presented with half-space radiating conditions from about 30Hz onwards, with only +/-1.5dB diffraction ripple.

But this driver could easily be mounted in a commercial loudspeaker with front baffle, size of 50 x 90 cm thus being subjected to diffraction rising from approximately 60Hz.





The manufacturer needs to determine what is the declared efficiency for this driver. And this can be tricky too. Here is an example of a commercial woofer.

Example of Commercial driver

The driver is 6.5” woofer, Wavecor WF166TU02.

Examining the specification, two things can be observed.

1. Driver’s sensitivity is measured on infinite baffle, and is quoted as 91dB at 2.83V/1m testing conditions. However, this is not 1W/1m testing condition. This is because the driver has 4ohm impedance (not 8ohm). So, the power delivered to the driver is:

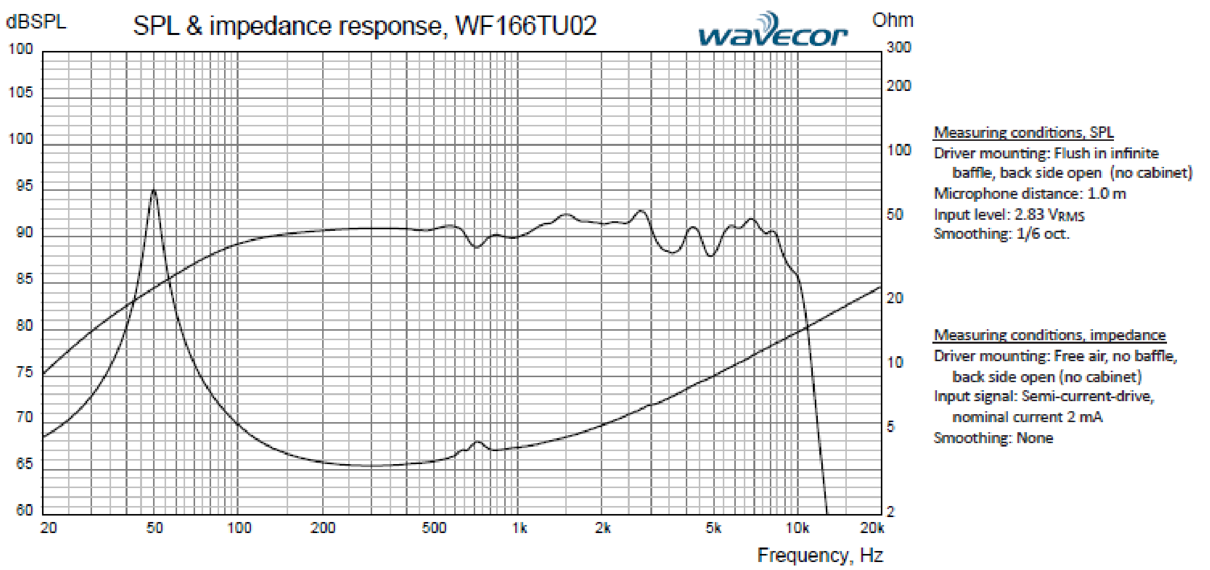
$$Pin = (2.83*2.83)/4 = 2Watt$$

Based on the specification provided, if the 1watt was to be used in this test, the SPL curve would be 3dB lower. This would be 88dB at 1w/1m condition.

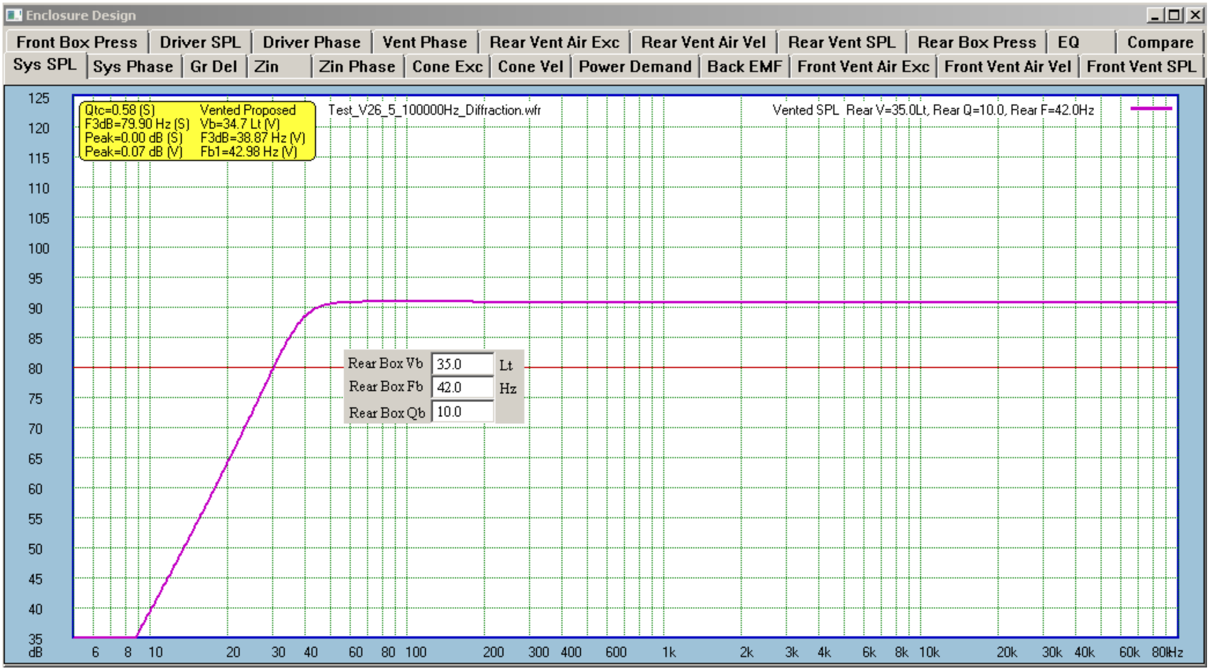
2. When placed on it's designated baffle, for example 24cm x 45cm, and measured in anechoic chamber, the 4PI radiation mode (below frequency where the diffraction effect kicks in) will result in final efficiency of 88dB – 6dB = 82dB. This is explained in details next.

Notes	Parameter	Before burn-in	After burn-in	Unit
	Nominal size	6½		[inch.]
	Nominal impedance	4		[ohm]
	Recommended max. upper frequency limit	3.5		[kHz]
1, 5	Sensitivity, 2.83V/1m (average SPL in range 300 - 1,000 Hz)	91		[dB]
2	Power handling, short term, IEC 268-5, no additional filtering			[W]
2	Power handling, long term, IEC 268-5, no additional filtering			[W]
2	Power handling, continuous, IEC 268-5, no additional filtering	60		[W]
	Effective radiating area, S_d	139		[cm²]
3, 5, 7	Resonance frequency (free air, no baffle), F_s	50		[Hz]
	Moving mass, incl. air (free air, no baffle), M_{ms}	12.5		[g]
3	Force factor, Bxl	5.0		[N/A]
3, 5, 7	Suspension compliance, C_{ms}	0.81		[mm/N]
3, 5, 7	Equivalent air volume, V_{as}	22.3		[lit.]
3, 5, 7	Mechanical resistance, R_{ms}	0.40		[Ns/m]
3, 5, 7	Mechanical Q, Q_{ms}	9.8		[-]
3, 5, 7	Electrical Q, Q_{es}	0.50		[-]
3, 5, 7	Total Q, Q_{ts}	0.48		[-]
4	Voice coil resistance, R_{DC}	3.2		[ohm]
6	Voice coil inductance, L_e (measured at 10 kHz)	0.23		[mH]
	Voice coil inside diameter	32		[mm]
	Voice coil winding height	11		[mm]
	Air gap height	5		[mm]
	Magnet weight (dual neodymium)	400		[g]
	Total unit net weight excl. packaging	1.15		[kg]
3, 6	K_{rm}	109		[µohm]
3, 6	E_{rm}	0.97		[-]
3, 6	K_{xm}	2.04		[mH]
3, 6	E_{xm}	0.79		[-]

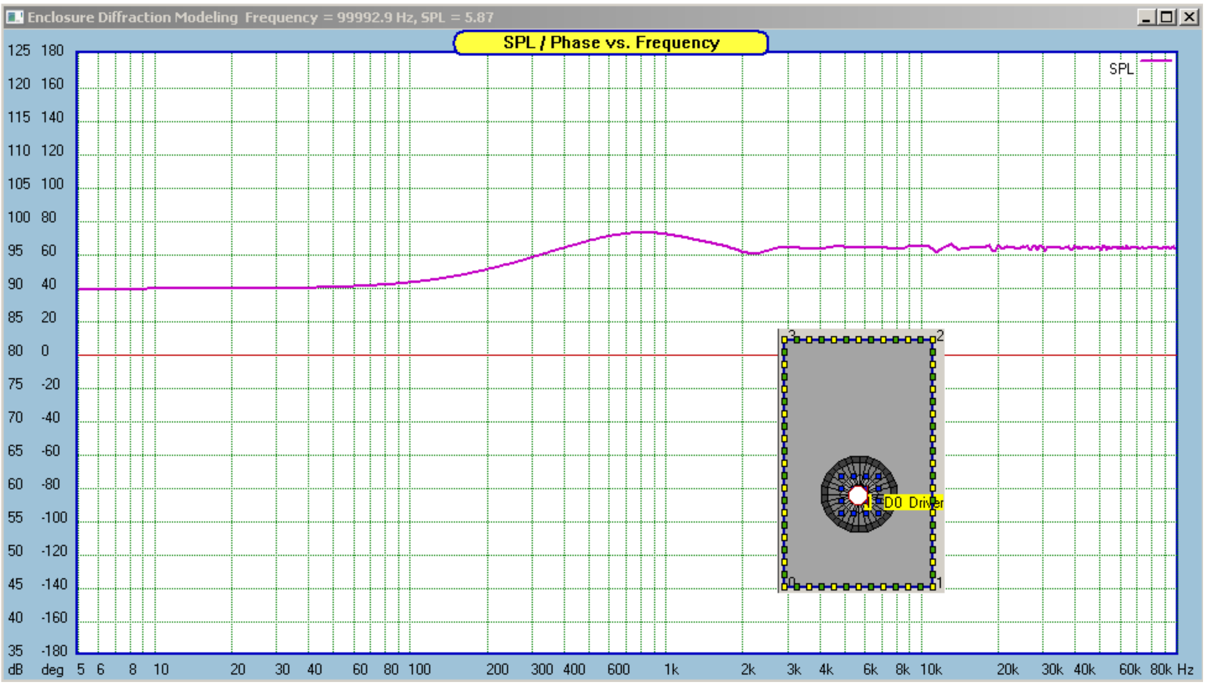
Note 1 Measured in infinite baffle.



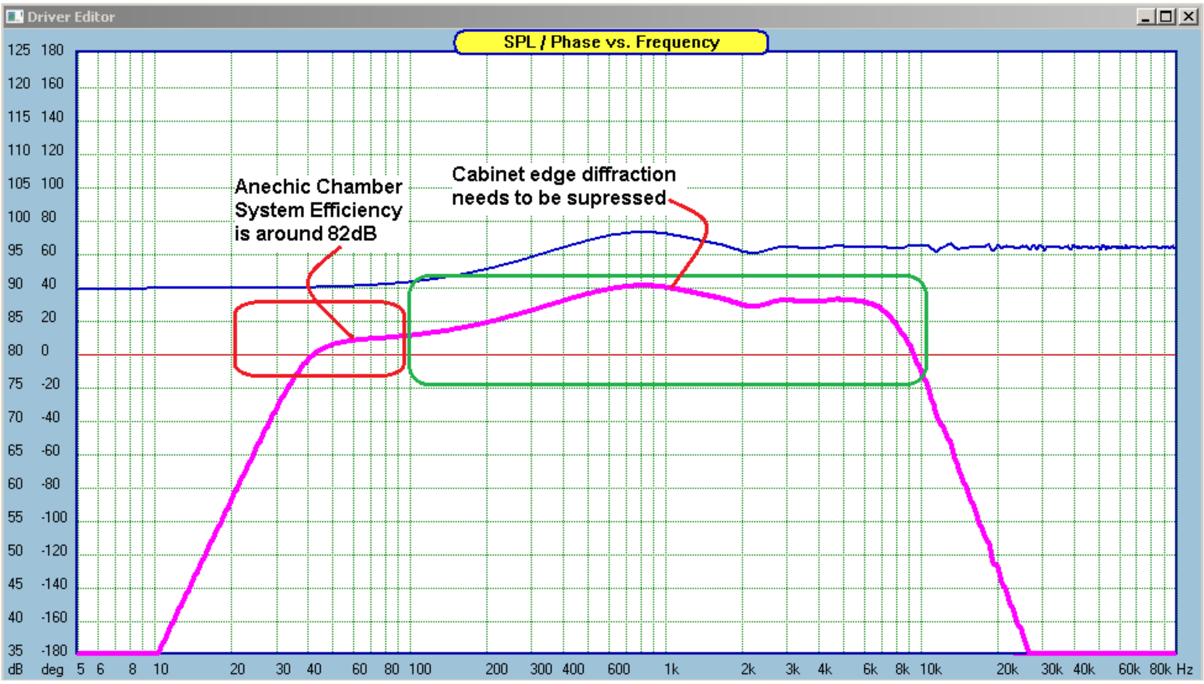
T/S parameters indicate, that this driver would be able to deliver low-frequency cut-off 3dB point at 40Hz. The vented enclosure of 35Lt would be tuned to 42Hz. Please examine the picture below.



Front baffle is 24cm x 45cm (just an example). Diffraction curve calculated for this baffle is shown below.



If the loudspeaker is placed for final compliance testing in an anechoic chamber, its free-field frequency response would look like the one shown below.



Driver's SPL tested in free-field conditions.

Please note, the system efficiency is 82dB and the SPL increase due to diffraction needs to be supressed with a simple LR network, as explained earlier.

We are now at the modelling stage, where we can subtract the diffraction and create the 4PI SPL or “raw SPL” curve. From there we can proceed to accomplish all types of simulations explained already above.

In general, CAD models are just that – models. The attempt is being made to create models, that approximate real-life measurement and design conditions as closely as possible. Sometimes a model falls short of duplicating real phenomenon with 100% accuracy. Therefore, work is being done on improving modelling capabilities as much as possible. This process will continue with every SoundEasy release.

Thank you for reading.

Bohdan