Designing Transducers for Compact Active Speakers

AUDIO DESIGN WORKSHOP LIVE

MEET THE EXPERTS - LEARN THEIR SECRETS

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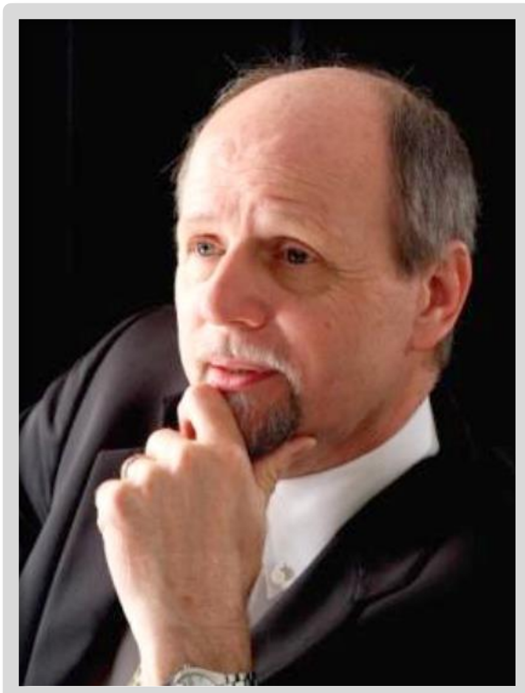
Peter Larsen with these companies from 1974



Peter Larsen
LOUDSOFT

SEAS

vifa

DYNAUDIO
AUTHENTIC FIDELITY

JBL by HARMAN

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The Design Cycle

- Designing Motors for Small Drivers
- Bass Alignments in Box @ High Power
- Cone Designs and Problems
- Crossover Designs in Practice
- Loudspeaker Measurement Examples
- Challenges in Speaker QC Testing

Designing Transducers for Compact Speakers

BBC LS 3/5A Compact Monitor 1974

Designing Transducers for Compact Speakers

Todays Compact Loudspeakers

Table 1. SUMMARY OF LOUDSPEAKER ALIGNMENTS
adapted from Table1, Loudspeakers in Vented Boxes

No.	Type	Ripple (dB)	f_3/f_S	f_B/f_S	C_{AS}/C_{AB}	Q_T	f_{AUX}/f_S
1	QB3	-	2.68	2.00	10.48	0.180	-
2	QB3	-	2.28	1.73	7.48	0.209	-
3	QB3	-	1.77	1.42	4.46	0.259	-
4	QB3	-	1.45	1.23	2.95	0.303	-
5	**BW4**	**-**	**1.000**	**1.000**	**1.414**	**0.383**	**-**
6	CH4	-	0.852	0.927	1.055	0.415	-
7	CH4	0.07	0.724	0.829	0.729	0.466	-
8	CH4	0.25	0.704	0.757	0.559	0.518	-
9	CH4	0.51	0.685	0.716	0.485	0.557	-
10	**BW5**	**-**	**1.000**	**1.000**	**1.000**	**0.447**	**1.00**
11	CH5	-	0.850	0.912	0.583	0.545	1.22
12	CH5	0.25	0.698	0.814	0.273	0.810	1.81
13	CH5	0.5	0.620	0.798	0.227	0.924	[illegible]
14	CH5	1.0	0.554	0.781	0.191	1.102	[illegible]

QB3 ≡ Quasi-Butterworth 3rd order
BW4 ≡ Butterworth 4th order, maximally-flat amplitude response
CH4 ≡ Chebyshev 4th order, equal-ripple amplitude response
BW5 ≡ Butterworth 5th order, maximally-flat amplitude response
CH5 ≡ Chebyshev 5th order, equal-ripple amplitude response

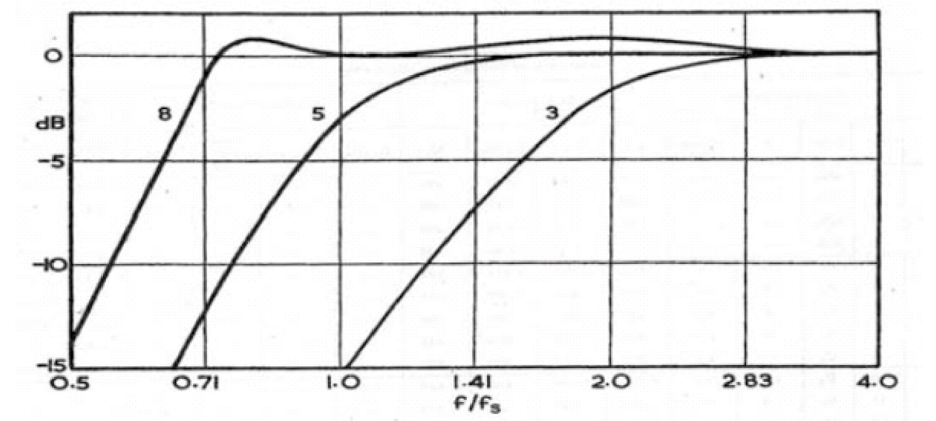
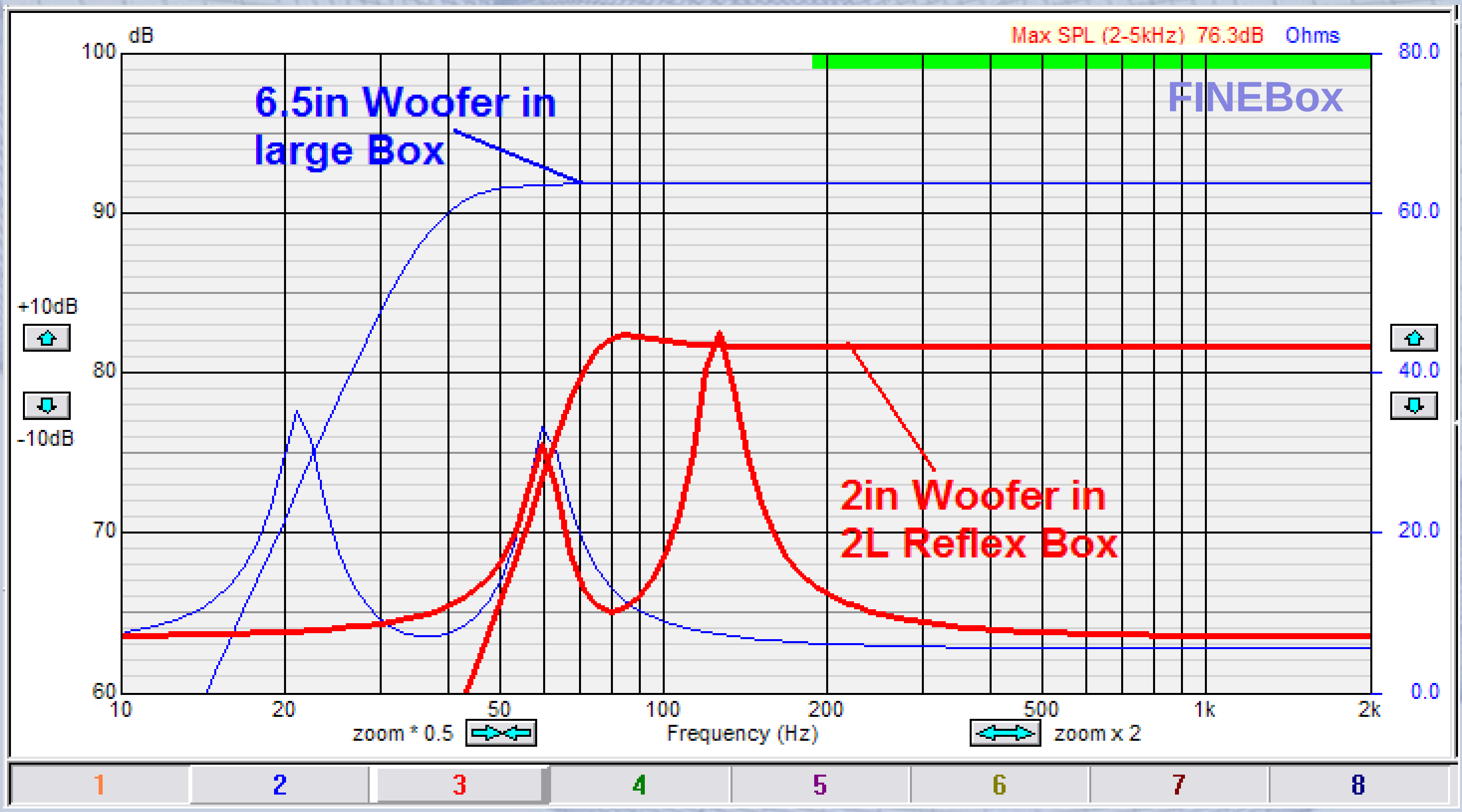


Fig 8 Amplitude Responses of a Vented Box Loudspeaker, with alignments numbered as in Table 1

From Neville Thiele:
"The Loudspeaker Parameters and their Evolution"

Compact speakers require small drivers. These produce less SPL (lower sensitivity)



Initial settings for 6inch example A

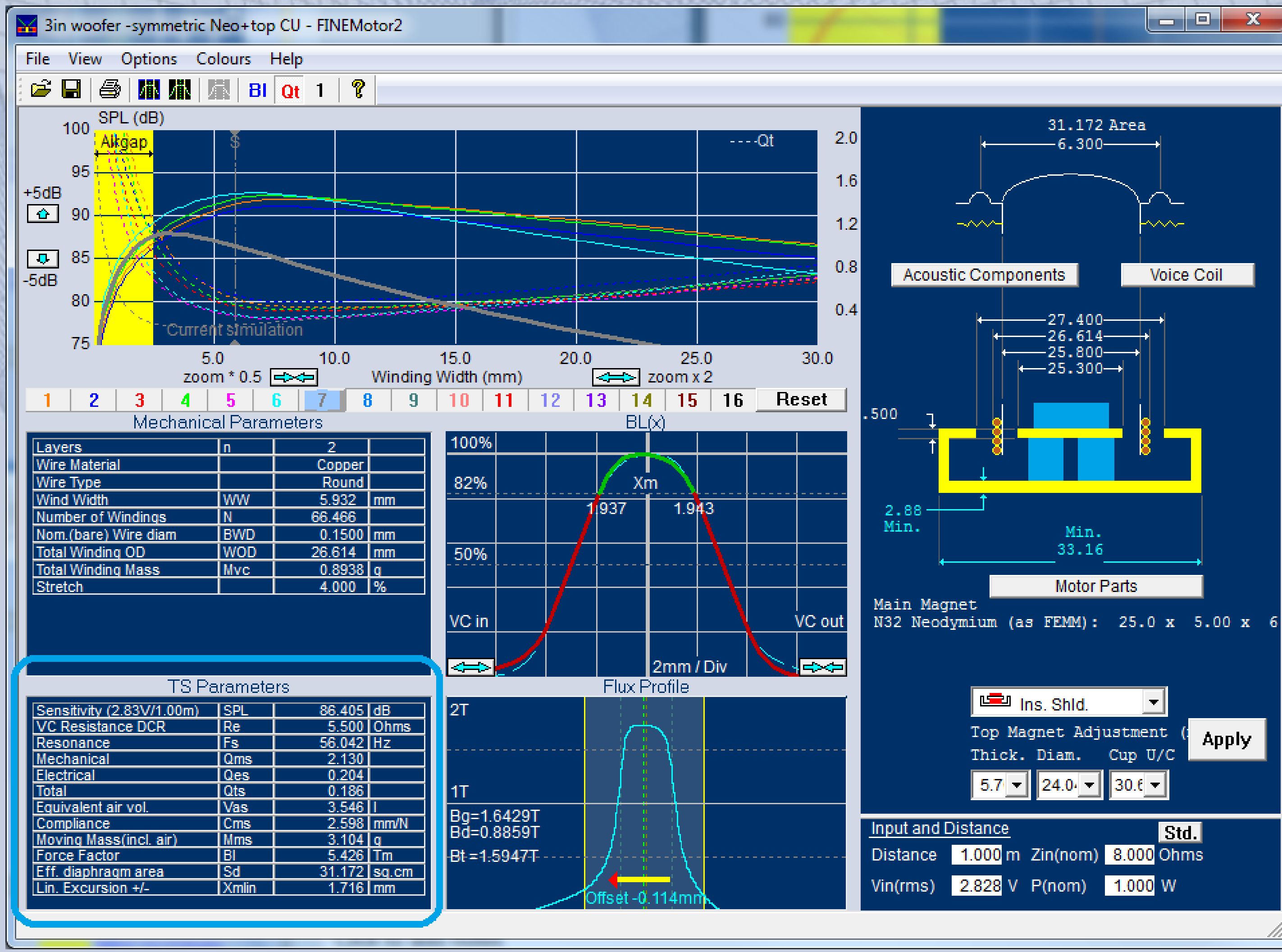
1. Cone Area: 136cm2
2. Cone Mass (incl. ½ surround): 11g
3. DCR: 3.0 R (Nominal impedance: 4 ohms)

Initial settings for 3inch example B

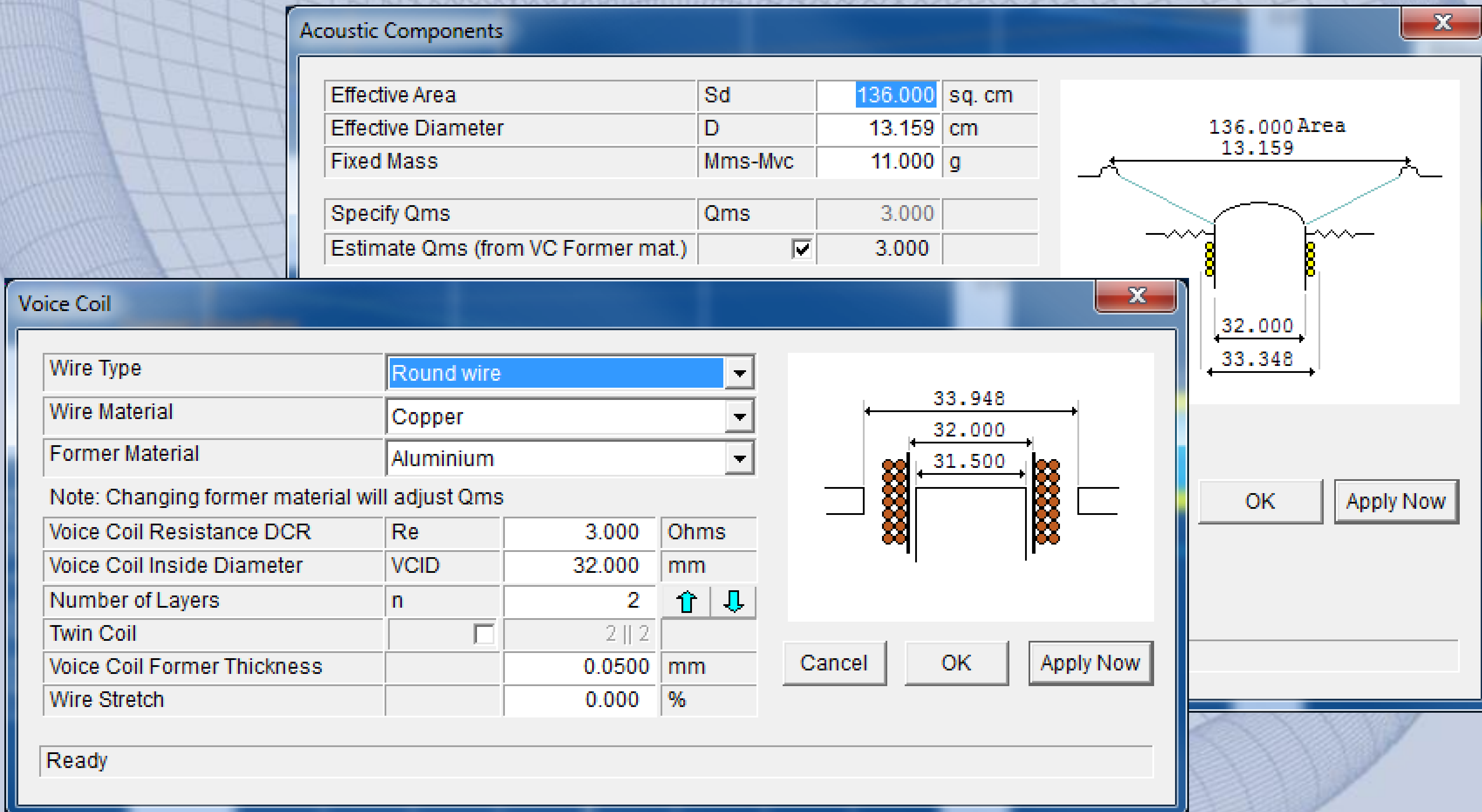
1. Cone Area: 31.2cm2
2. Cone Mass (incl. ½ surround): 2.2g
3. DCR: 5.5 R (Nominal impedance: 8 ohms)

Example A:

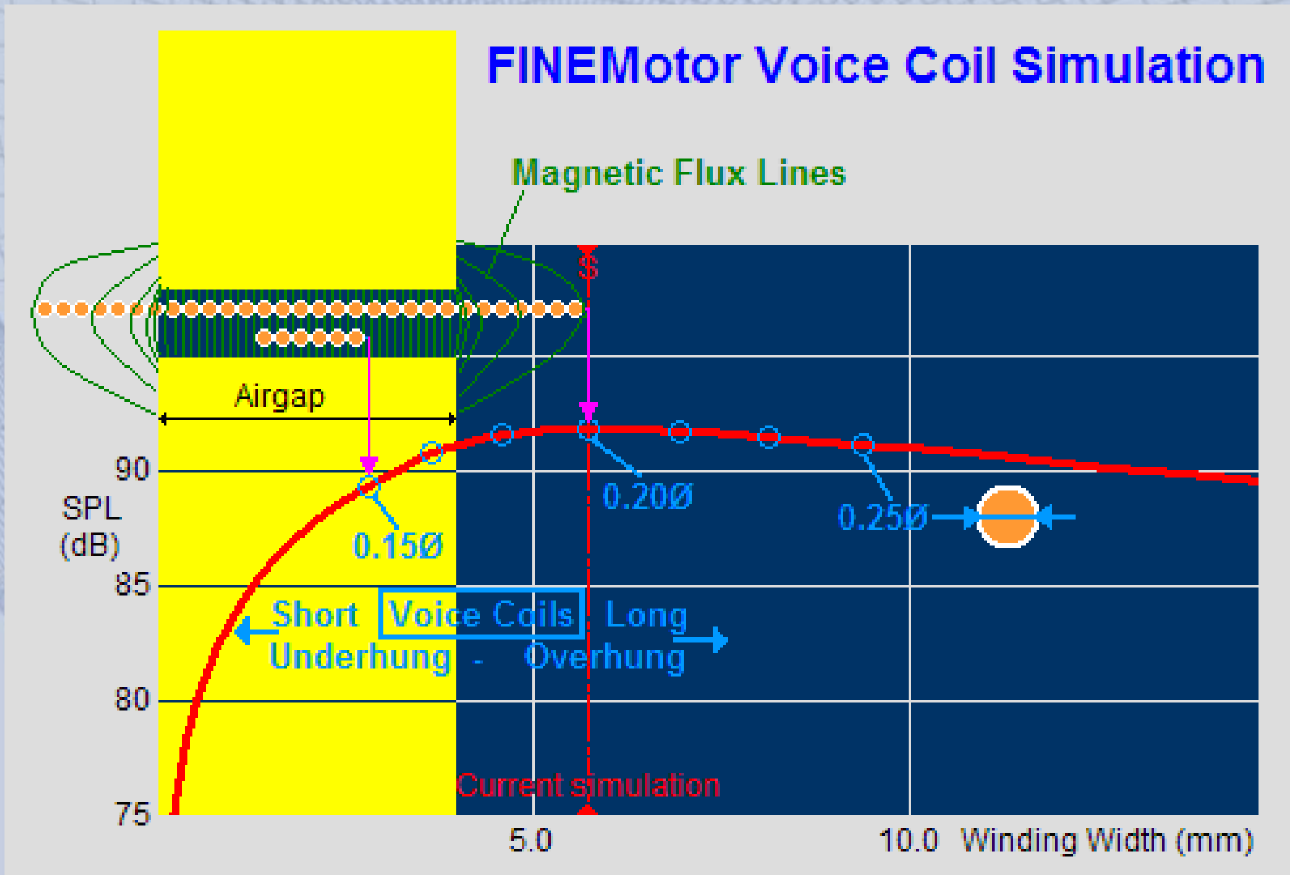
1. Target Xmax ~5mm
2. Optimize TS Parameters (Qts < 0.4)
3. Optimize BL(x) for Low Distortion



Initial input settings for example A

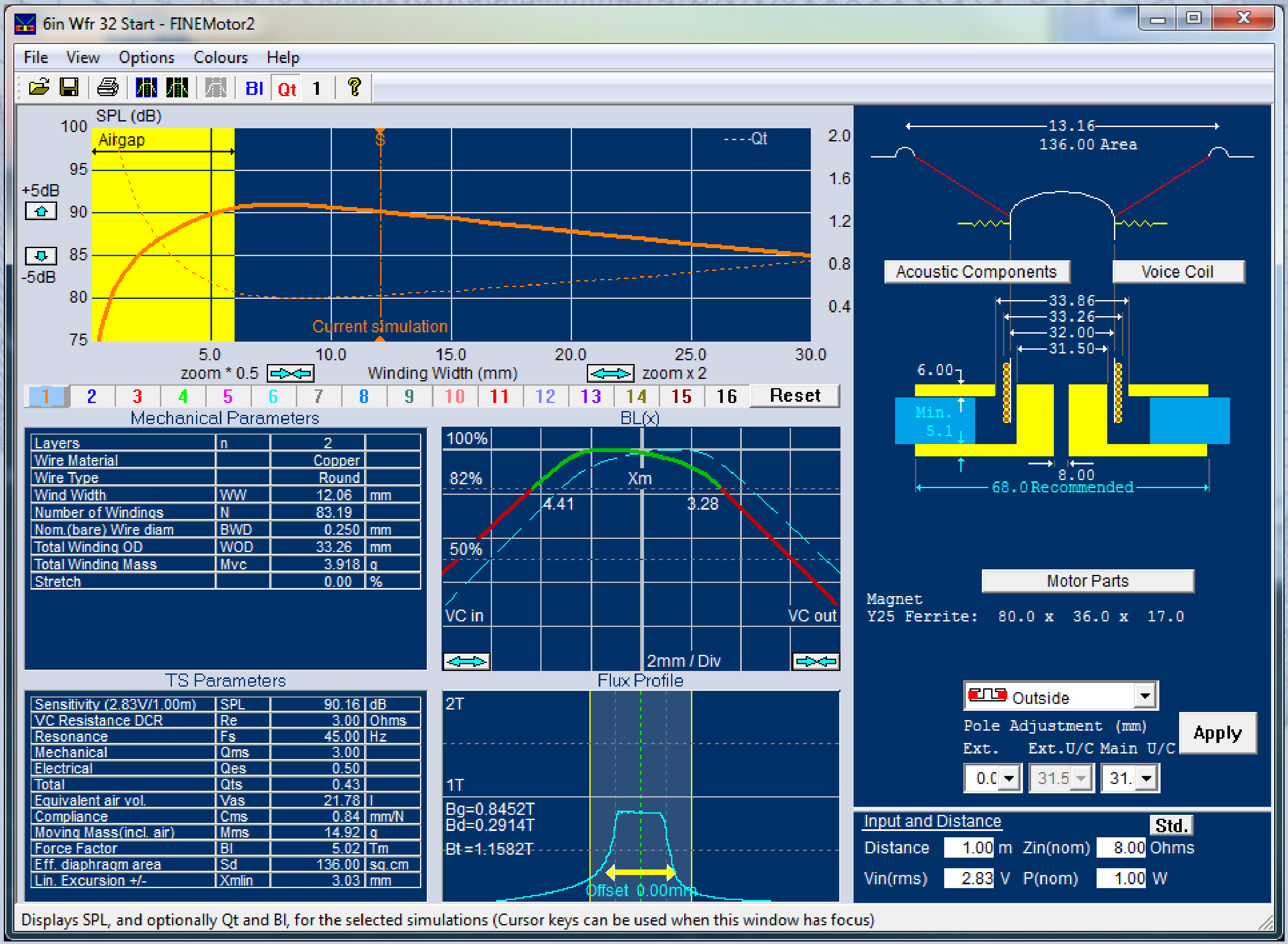


Calculated solutions based on Wire Diameters

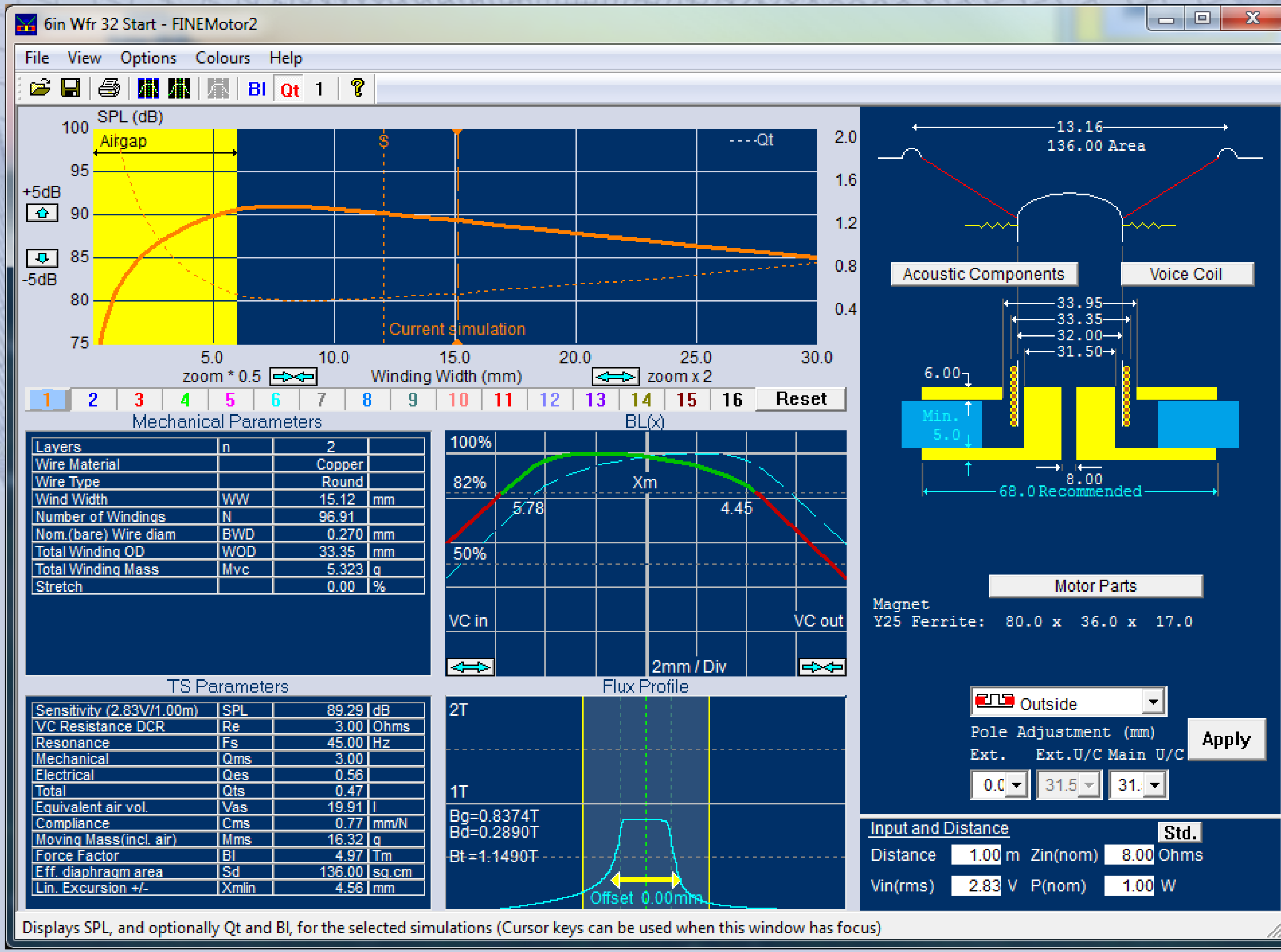


FM

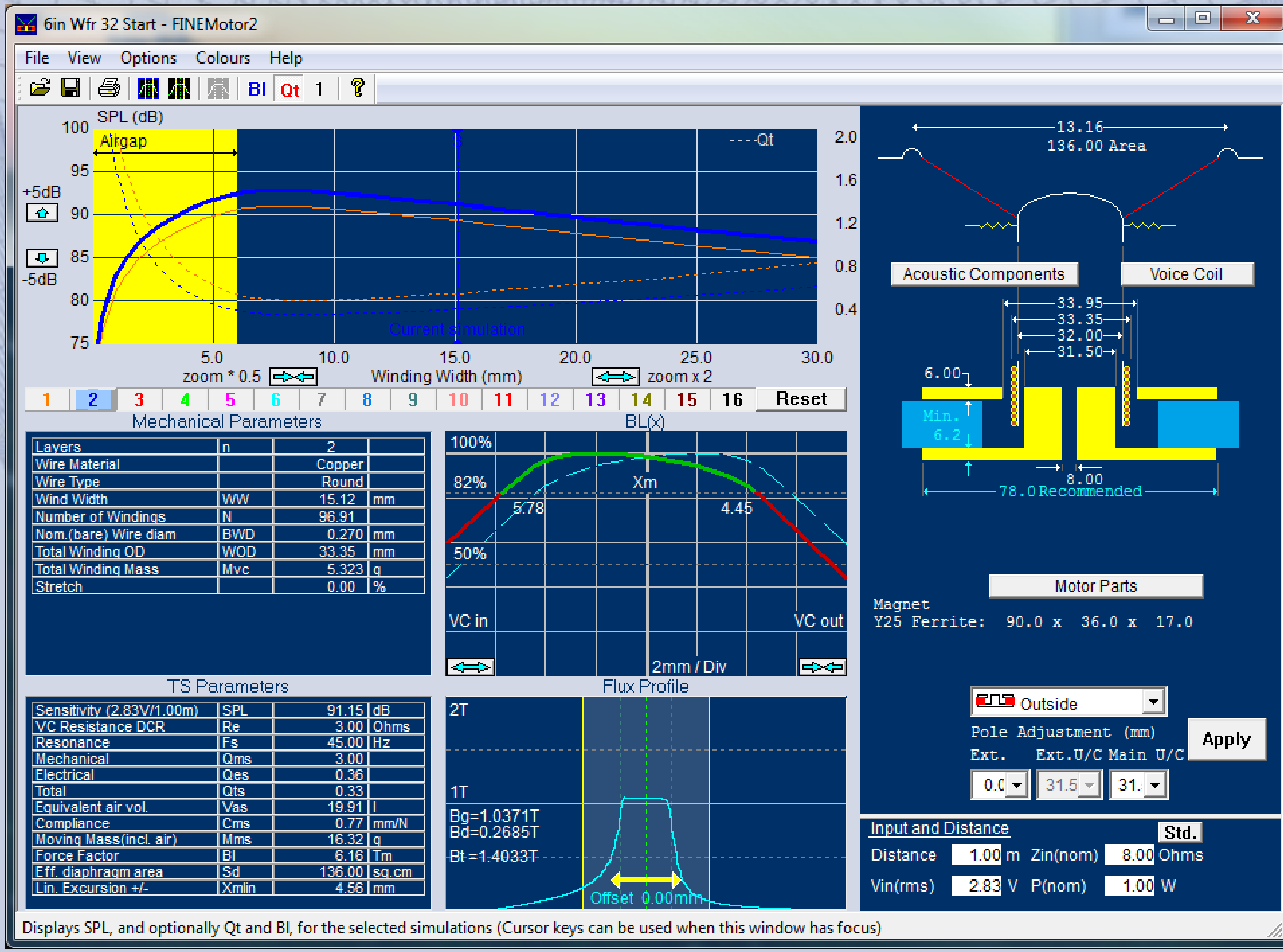
(A) Initial Solution: Xm is only 3mm. Move cursor to the right to find solutions having longer Voice Coils (Xm larger).



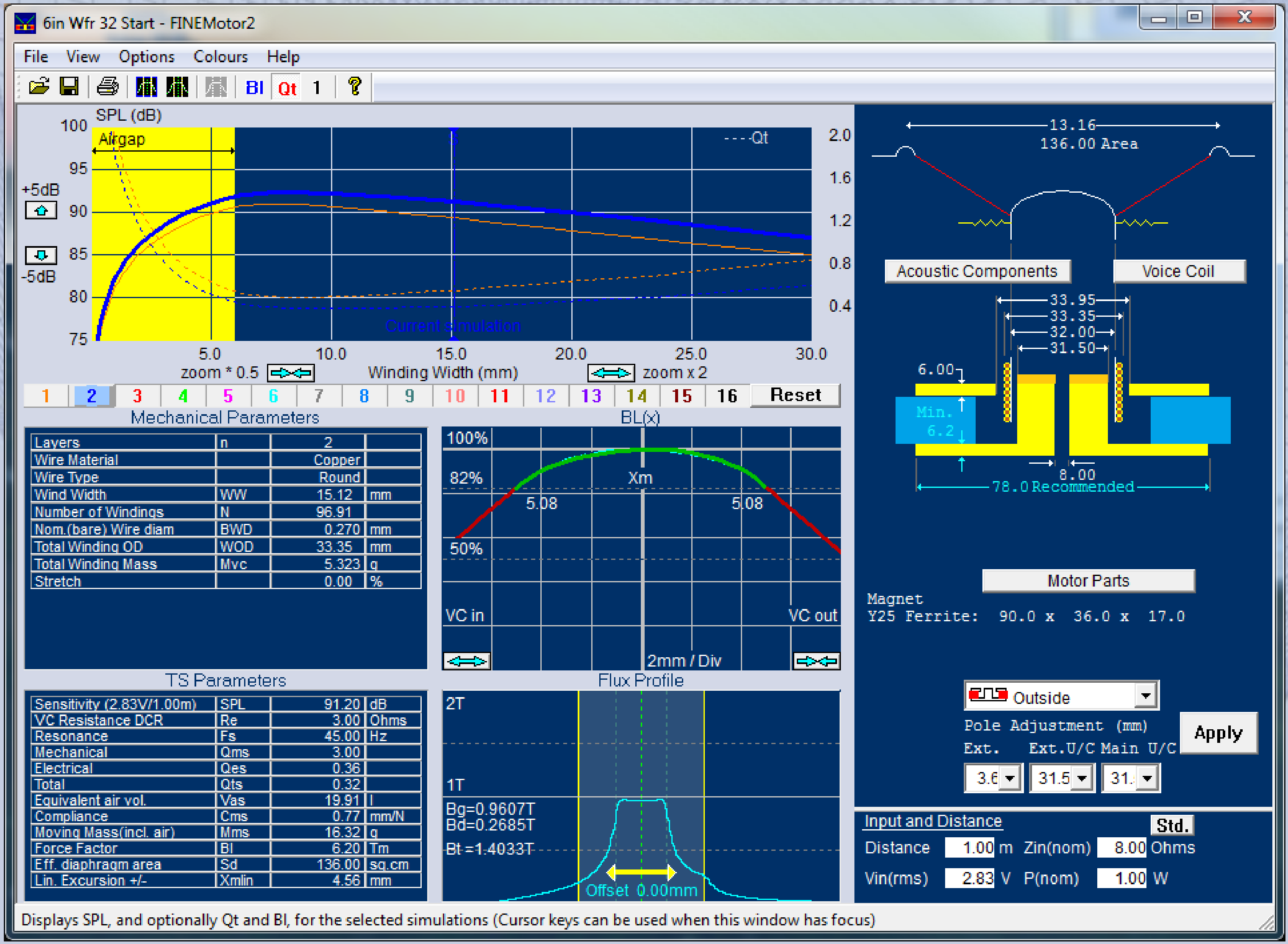
Now Xm is close to 5mm (OK). However Qts=0.47 is too high



A larger 90x36x17 Y25 magnet gave Qts=0.33 ☺
But the BL(x) curve is NOT symmetrical or flat

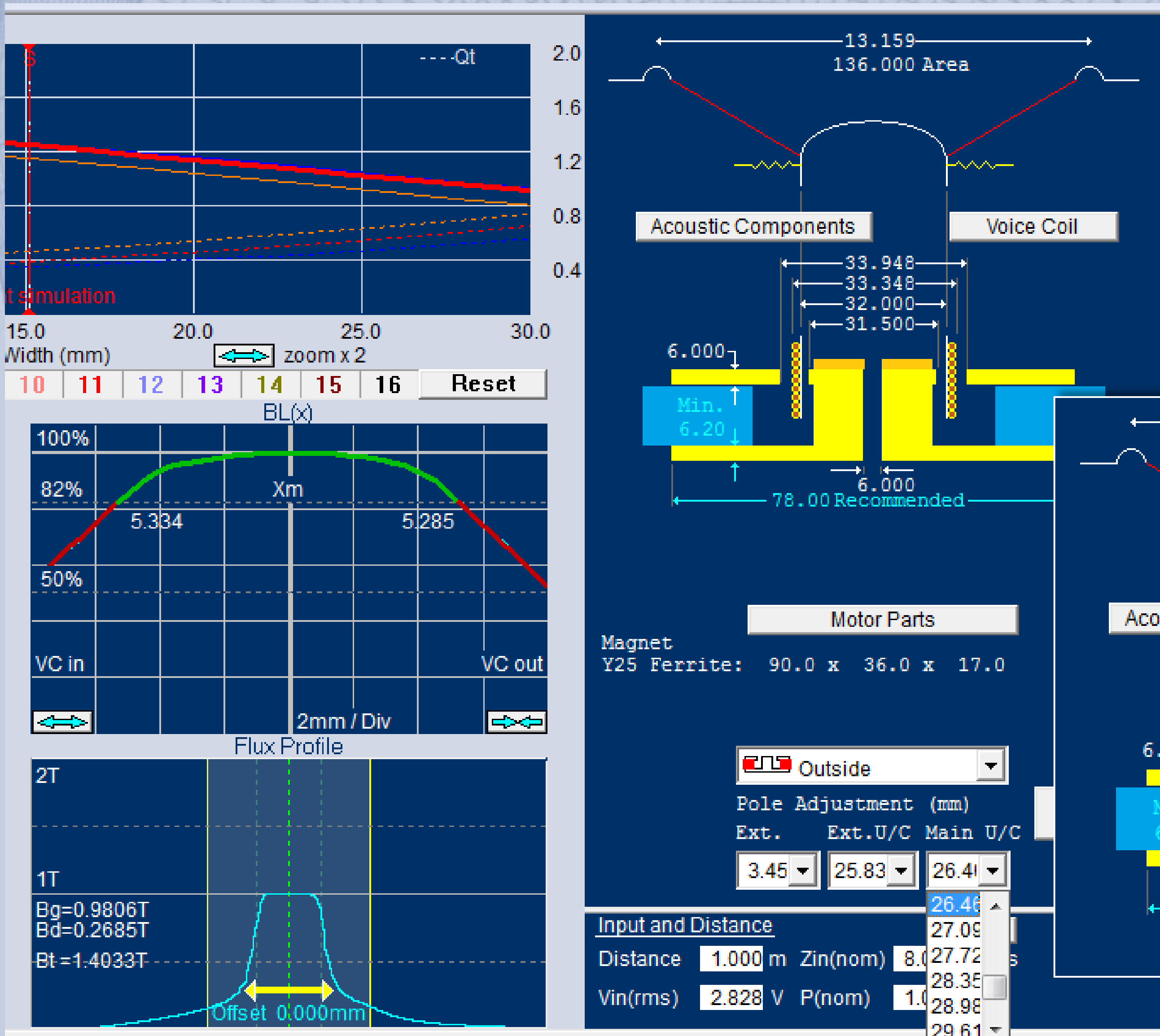


Extending the pole by 3.68mm produces a nice symmetric BL(x) curve, though not flat. But (IM) distortion will be reduced.

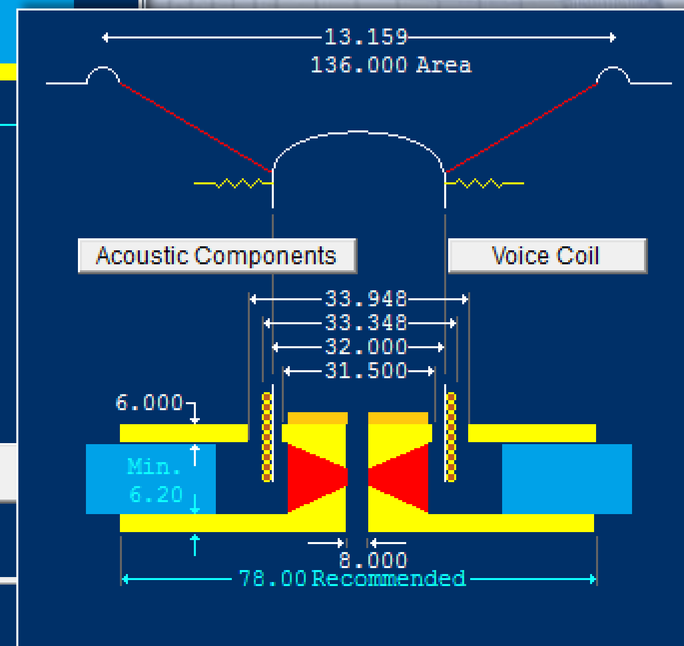


Layers	n	2	
Wire Material		Copper	
Wire Type		Round	
Wind Width	WW	15.12	mm
Number of Windings	N	96.91	
Nom.(bare) Wire diam	BWD	0.270	mm
Total Winding OD	WOD	33.35	mm
Total Winding Mass	Mvc	5.323	g
Stretch		0.00	%

Sensitivity (2.83V/1.00m)	SPL	91.20	dB
VC Resistance DCR	Re	3.00	Ohms
Resonance	Fs	45.00	Hz
Mechanical	Qms	3.00	
Electrical	Qes	0.36	
Total	Qts	0.32	
Equivalent air vol.	Vas	19.91	l
Compliance	Cms	0.77	mm/N
Moving Mass(incl. air)	Mms	16.32	g
Force Factor	Bl	6.20	Tm
Eff. diaphragm area	Sd	136.00	sq.cm
Lin. Excursion +/-	Xmlin	4.56	mm

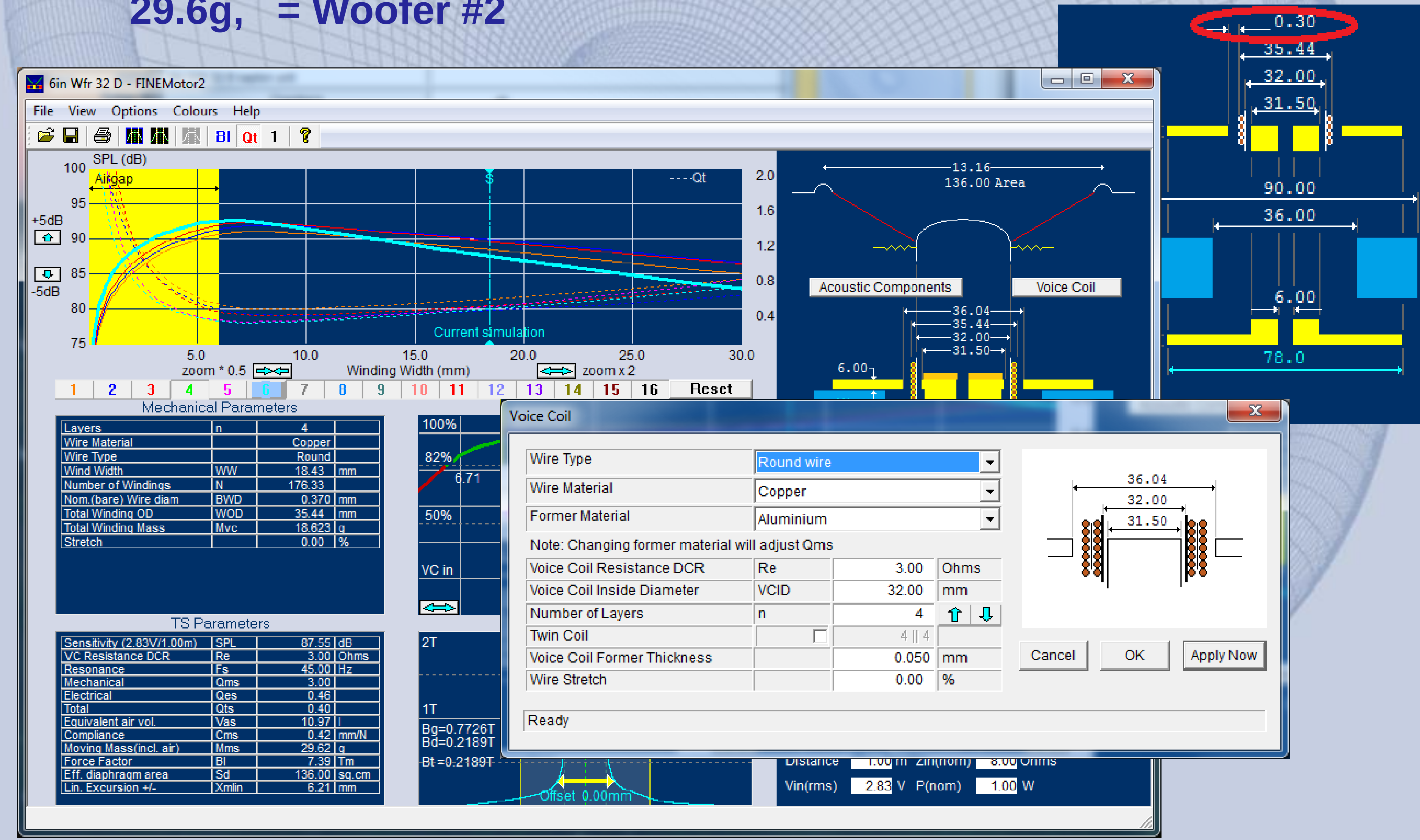


Pole with undercut under and above the air gap gave a flat and symmetric BL(x) curve. =Woofer #1

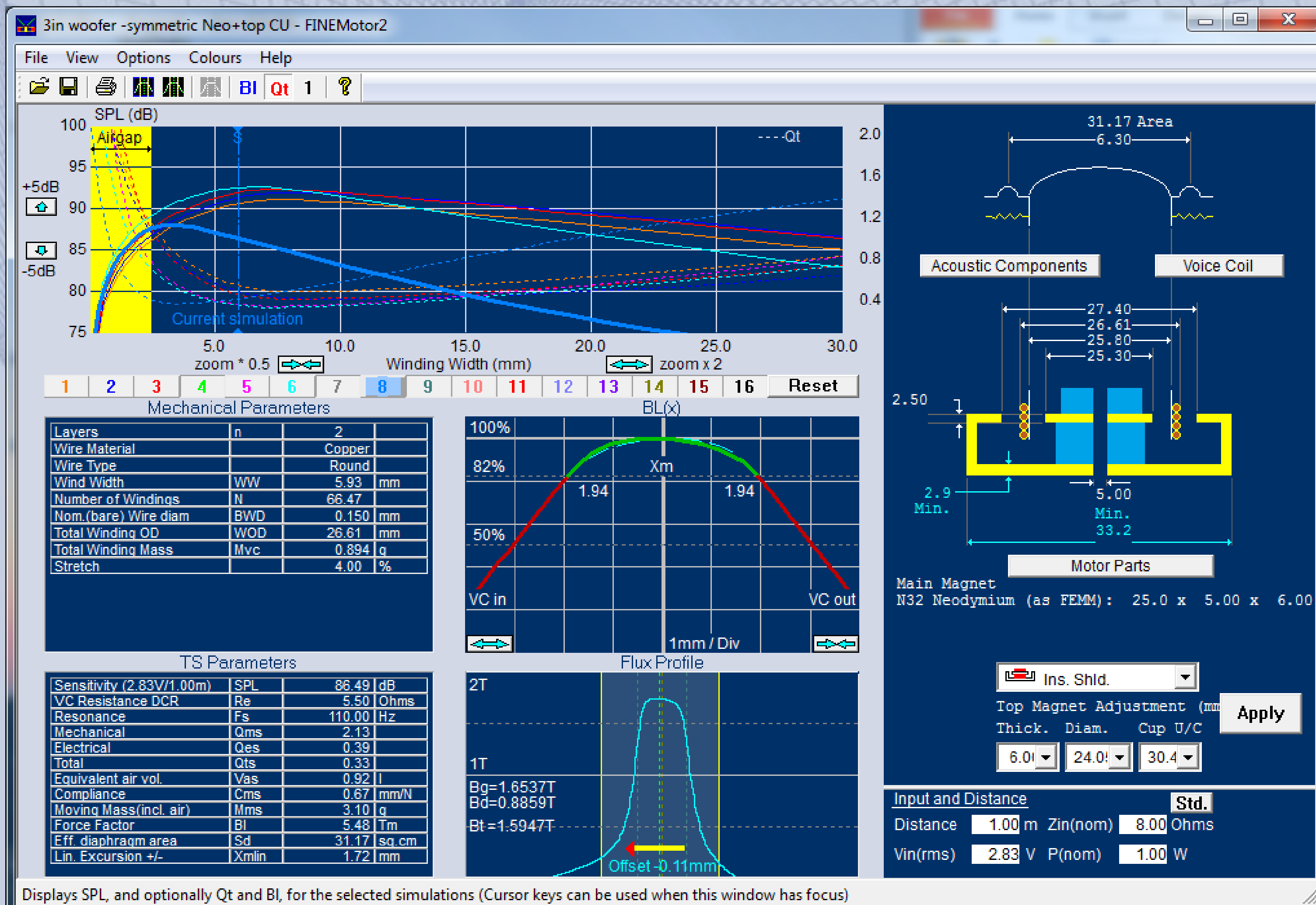


Ø8 hole caused saturation in the pole. Ø6 was used

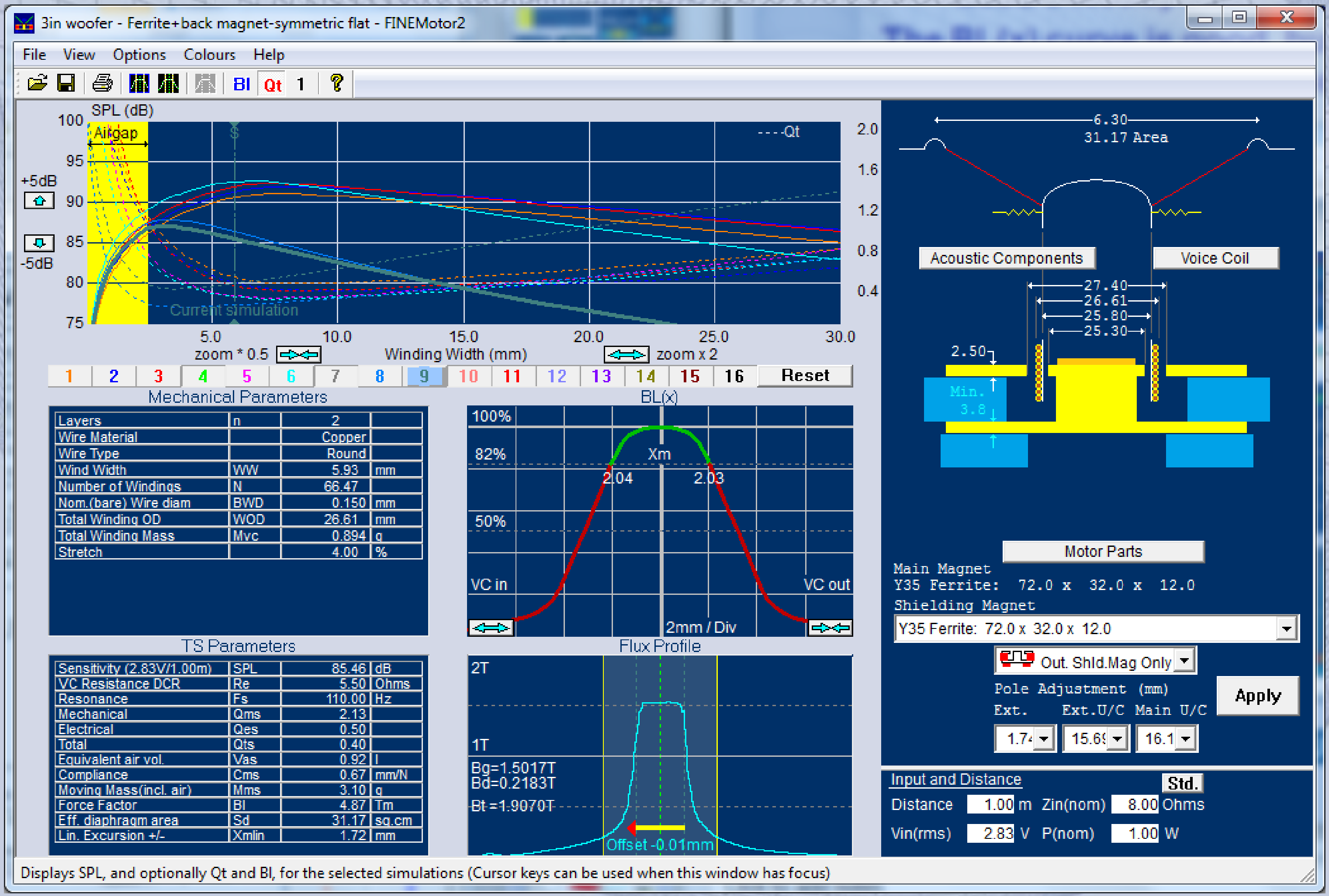
An alternative design using a 4-layer Voice Coil. The air gap OD was auto-adjusted for the larger Voice Coil using a 0.30mm clearance. Xm=+/-6.7mm. Moving Mass Mms up from 16.3 to 29.6g, = Woofer #2



Example B. This small 3inch woofer is designed like before. But this time a Neodymium Magnet + a top Neo magnet was used . The BL(x) curve is good, but sensitivity is low. = Woofer #3



Alternative 3” Ferrite magnet + back magnet solution for low cost. The BL(x) curve is very good. Sensitivity is still low.



Question:

Which parameter influences Qts most?
Mms (Moving mass, Re (DCR) or BL (Force factor)

Feedback from You: Qts

Qts is defined as the total Q (quality factor) at the resonance Fs.

1/Qts= 1/Qms+1/Qes

Qes < Qms (typically 0.4 < 5)

Qes=2pi*Fs*Re*Mms / **BL^2**

Answer is BL

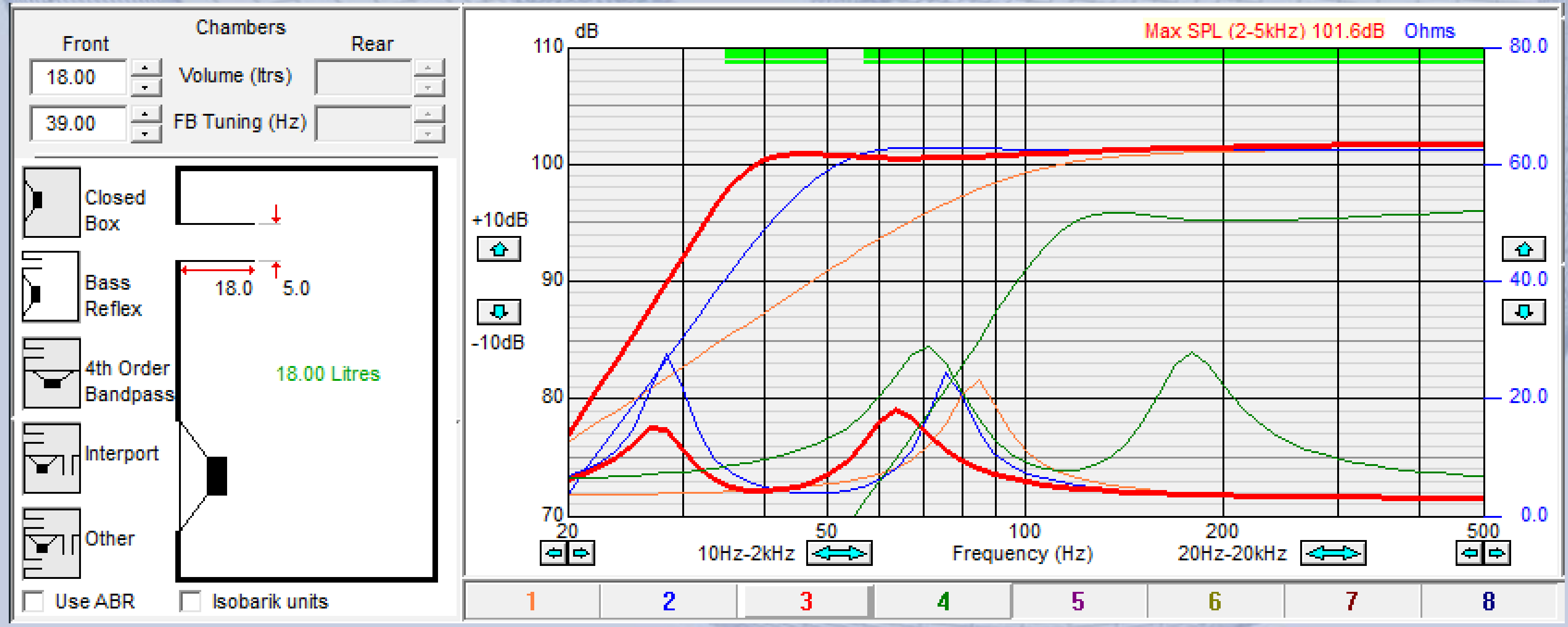
Bass Alignments in Box @ High Power

Next we will study how the designed woofers will behave in cabinets of different sizes and tuning. The effect of high input power will be included.

The 3 example drivers were imported into the FINEBox program:

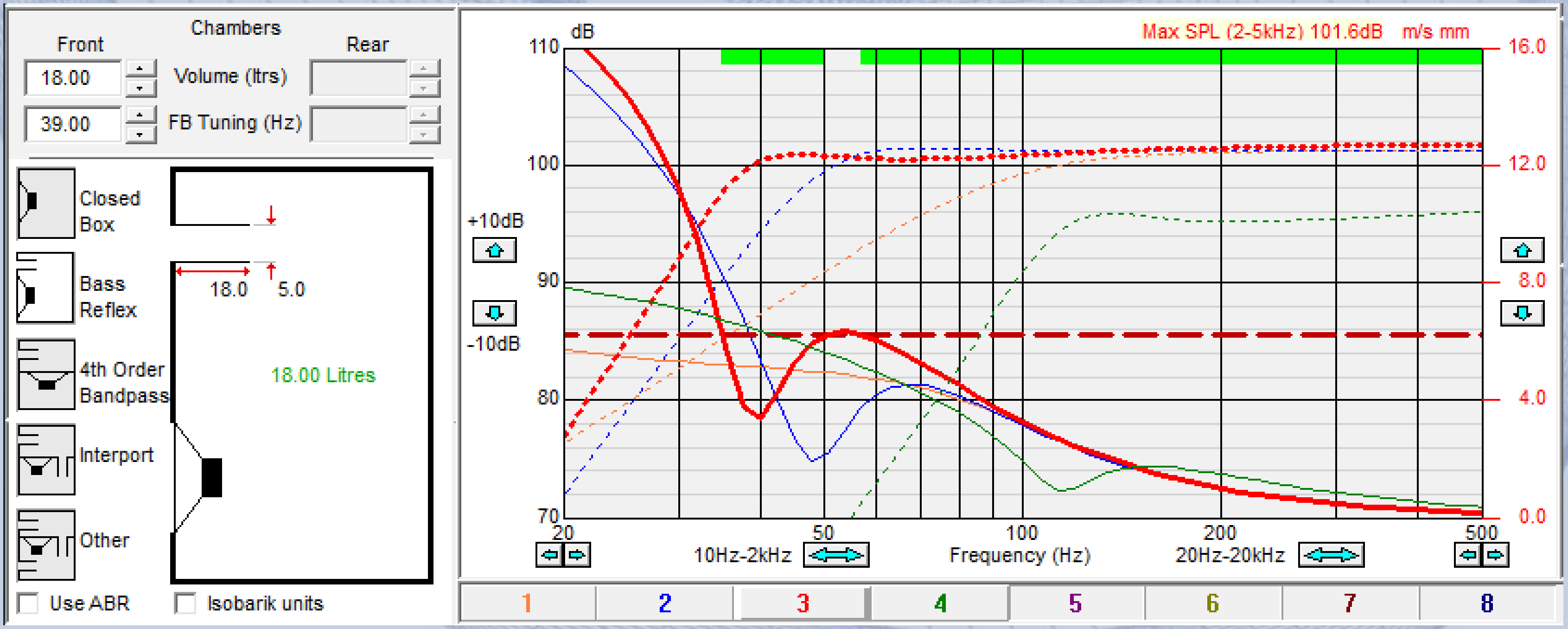
1. Woofer #1 in 8 Ltr. closed box
2. Woofer #1 in 18 ltr. Bass Reflex, tuned to Fb= 48Hz
3. Woofer #2 in 18 ltr. Bass Reflex, tuned to Fb= 39Hz
4. Woofer #3 in 1 ltr. Bass Reflex, tuned to Fb= 115Hz

#3 has more bass extension, due to more mass and BL.

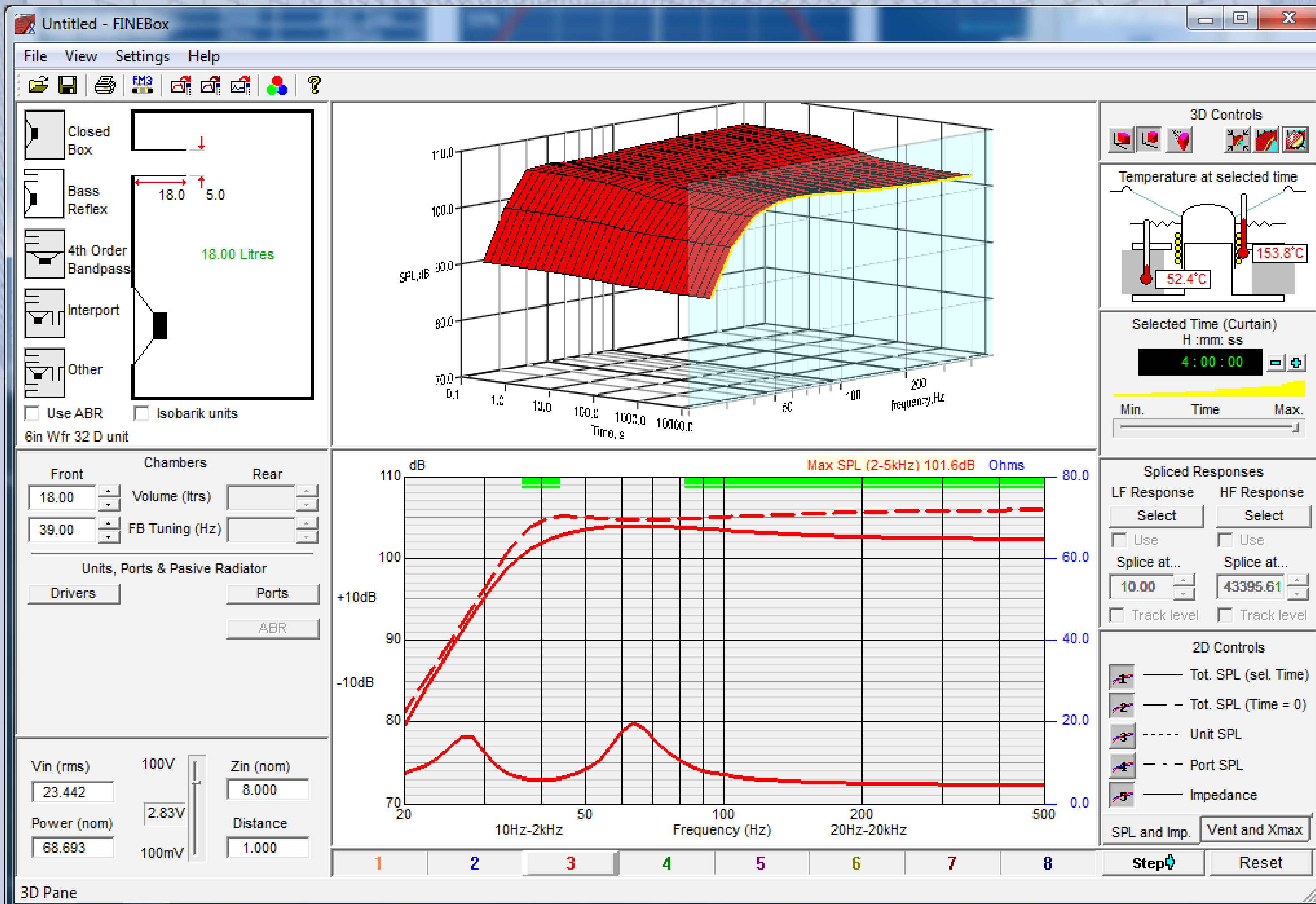


FB

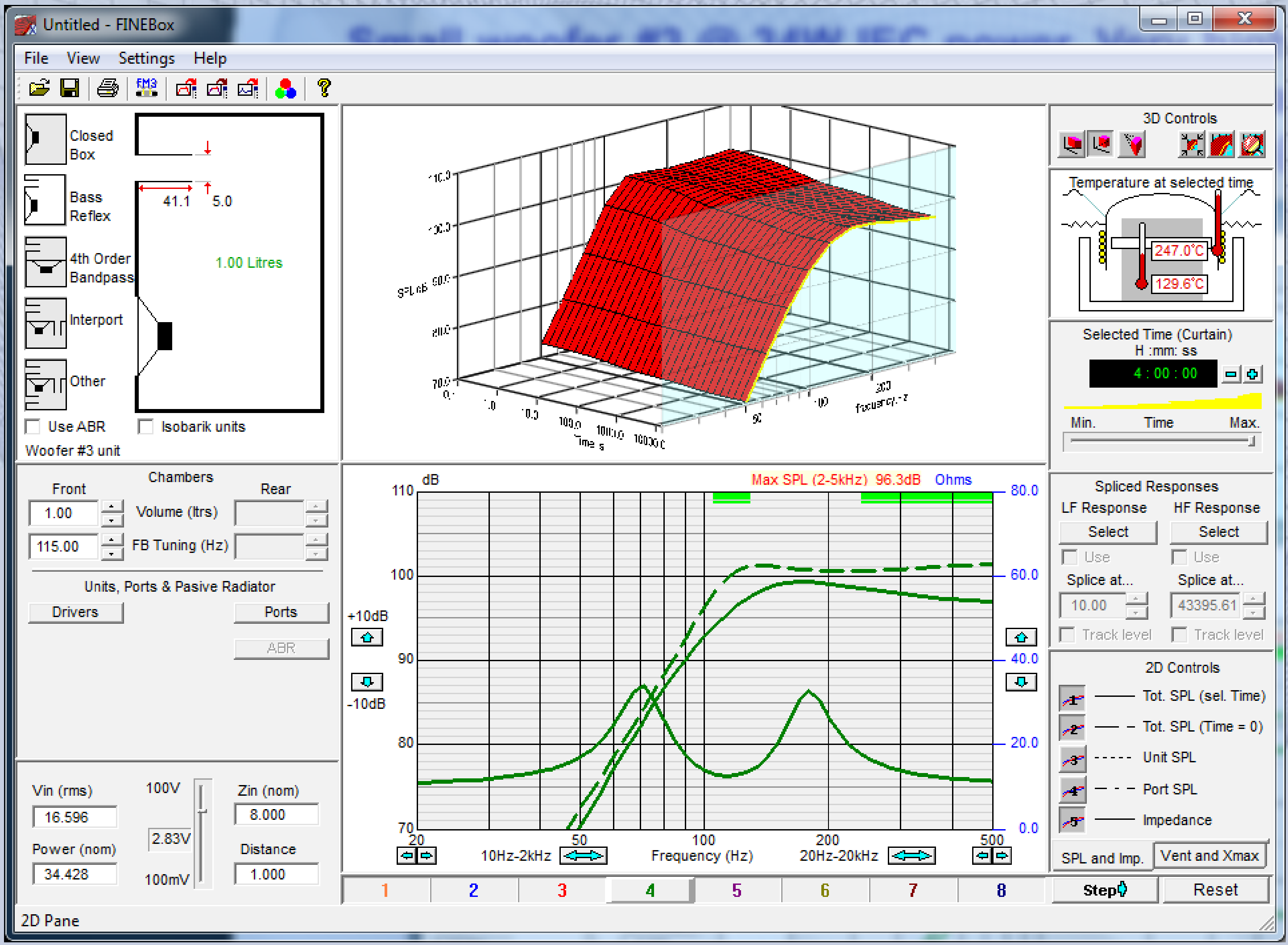
Bass Reflex Woofer Displacement reaching Xmax of woofer #2. LF rise to be filtered.



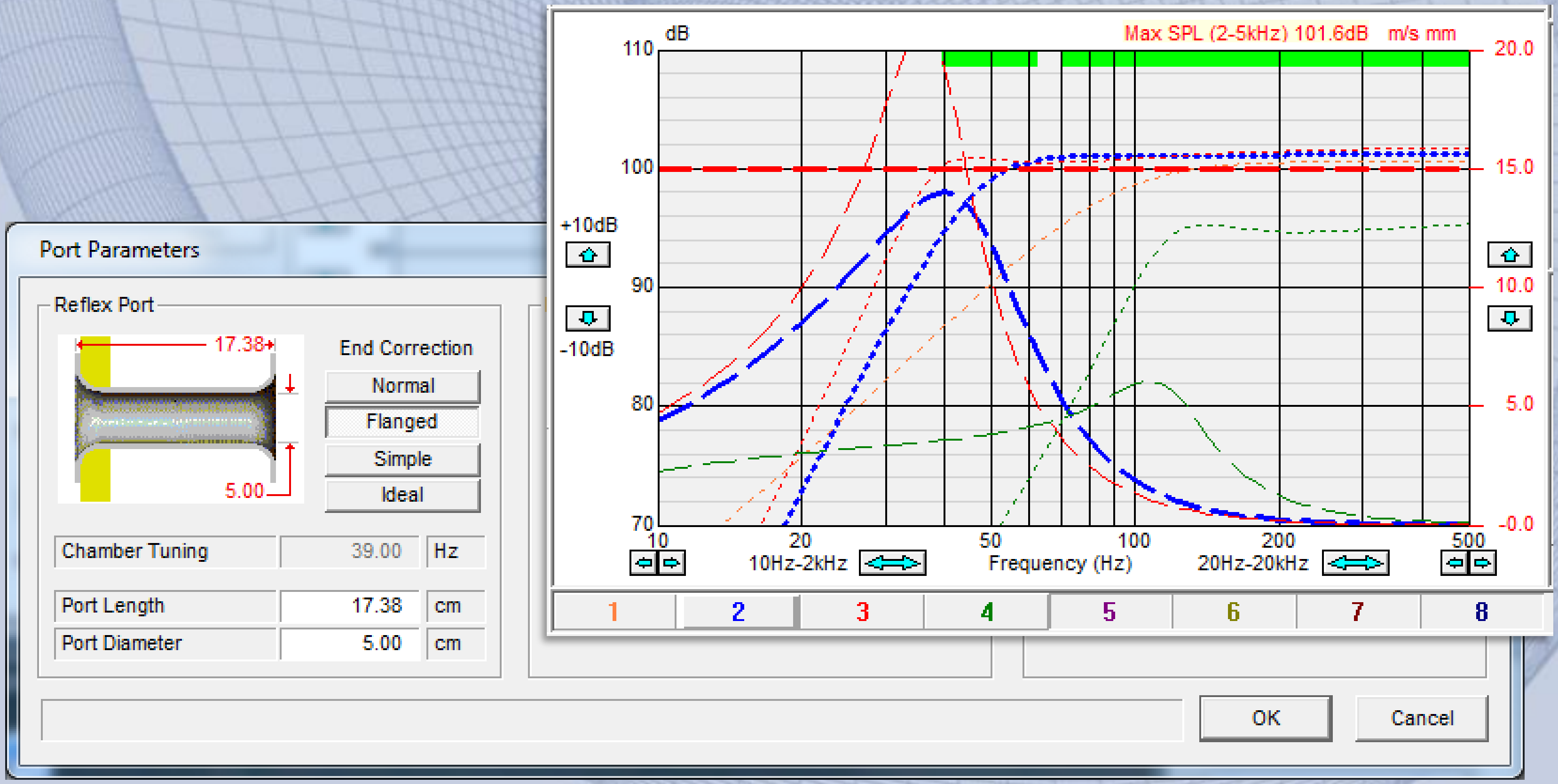
Power Compression of Woofer #2 @ 70W IEC input. The Voice Coil has reached 154 deg. C. The magnet temp is 52.4 deg. C



Small woofer #3 @ 34W IEC power. Very high Power Compression, and the Voice Coil is 247 deg. C = Overload! The neodymium magnet is probably demagnetized @ 129 deg. C



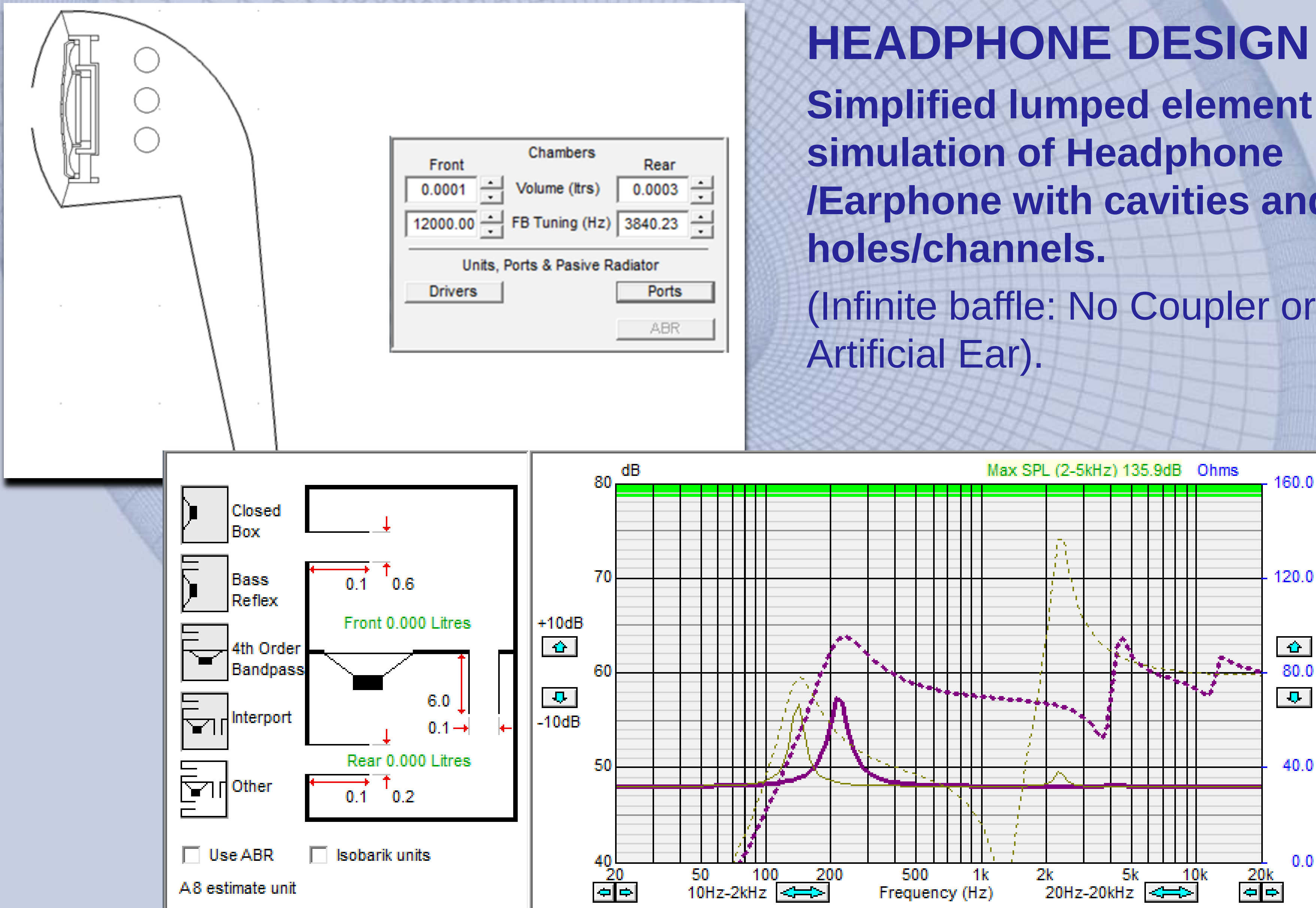
Bass Reflex Port dimensions to avoid air noise due to turbulence for curve No. 2 (Woofer #1)

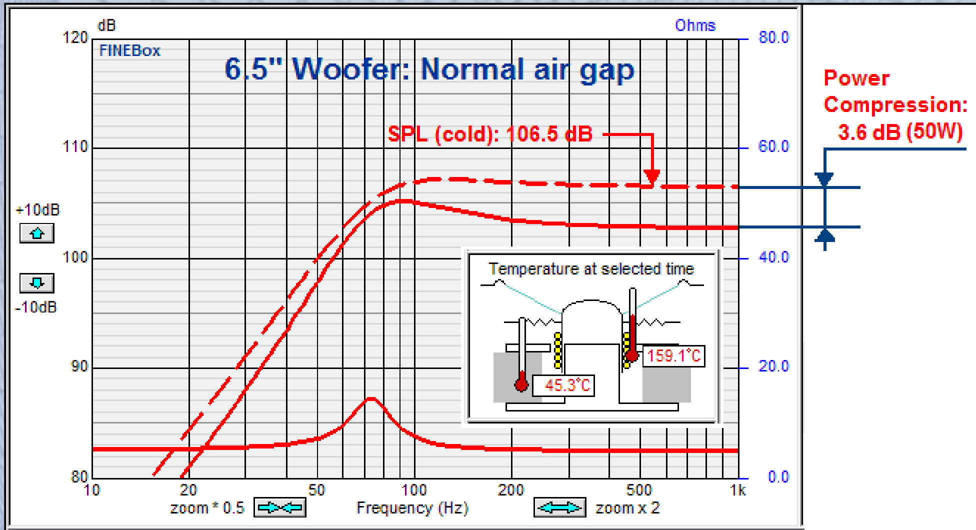


HEADPHONE DESIGN

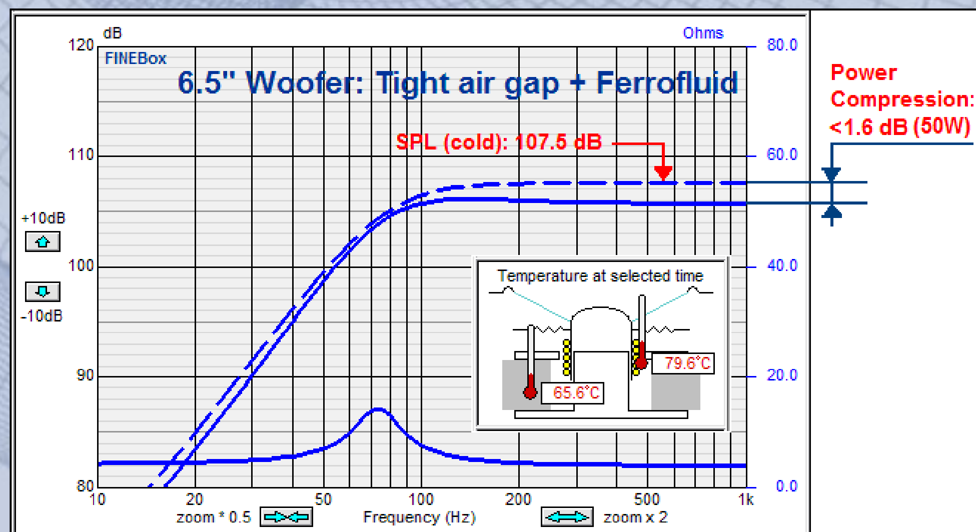
Simplified lumped element simulation of Headphone /Earphone with cavities and holes/channels.

(Infinite baffle: No Coupler or Artificial Ear).



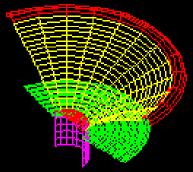


Calculated Compression of 6½" Woofer



Reduced Compression with Ferrofluid + Tighter Air gap

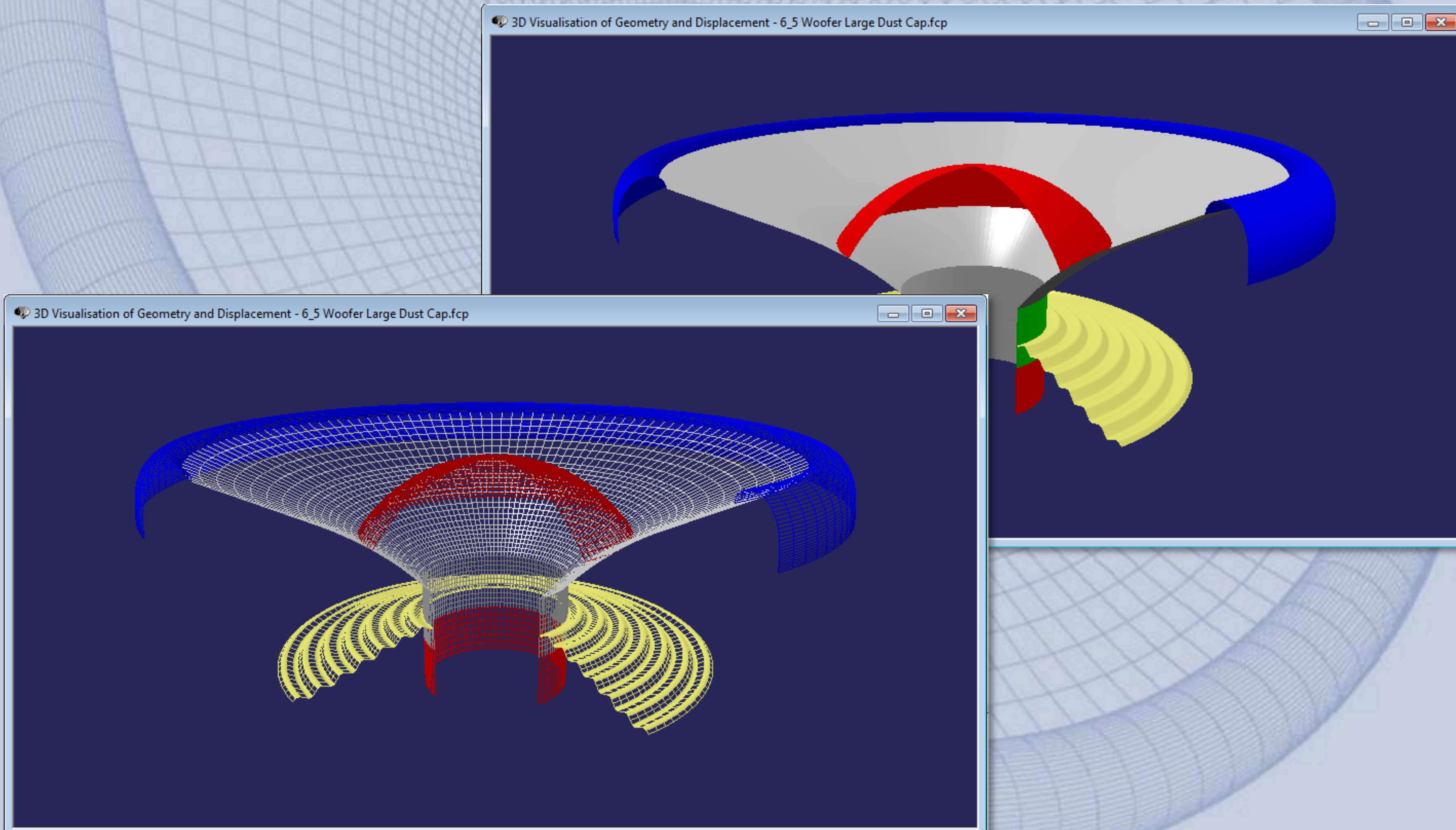
Cone Designs and Problems



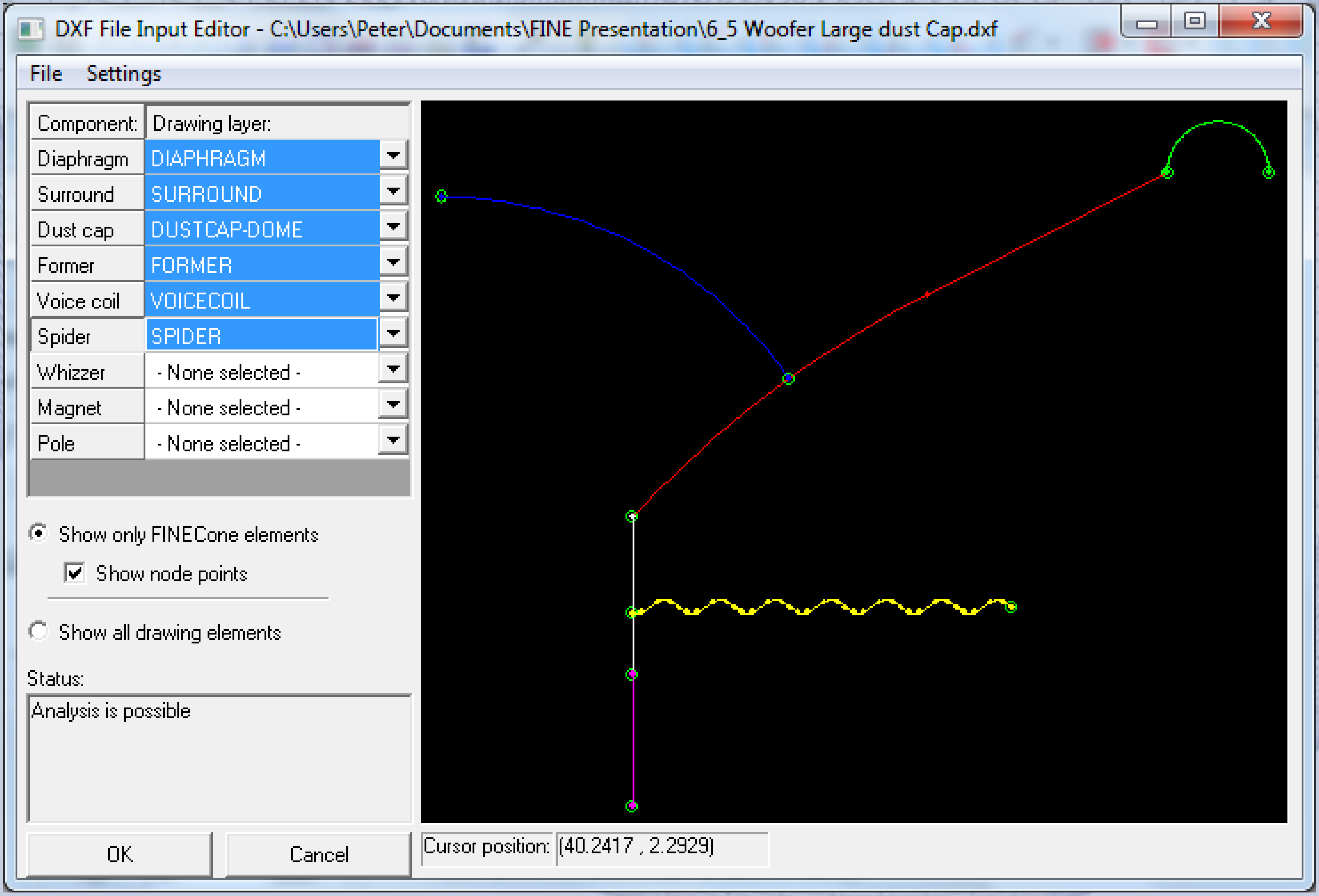
Cone design used to be a challenge based on trial and error.

Today we can quickly simulate with the help of FEM and gain insight into the mechanical and acoustical behavoir of cones and domes of any size

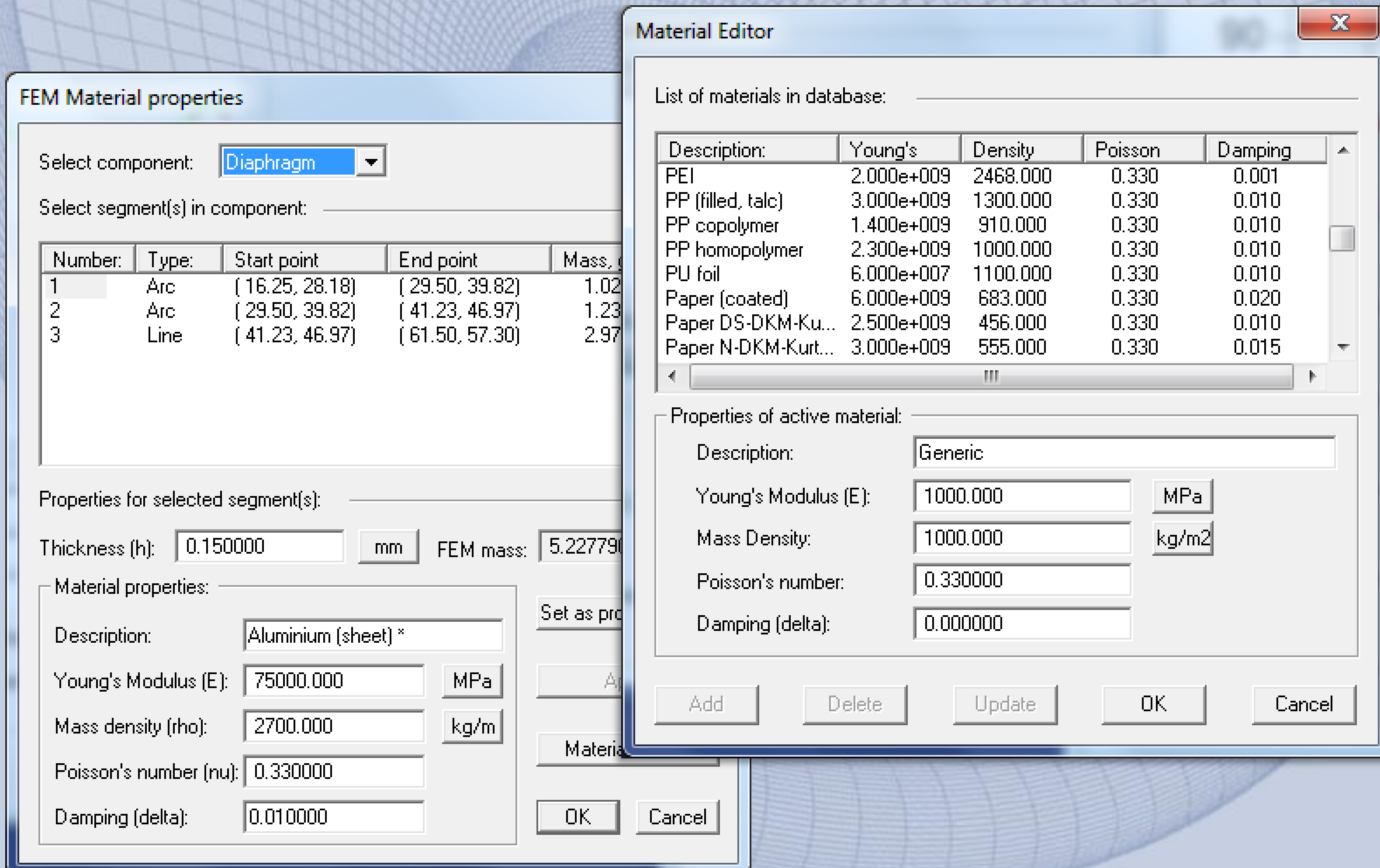
Acoustic Finite-Element (FEM) Simulation examples



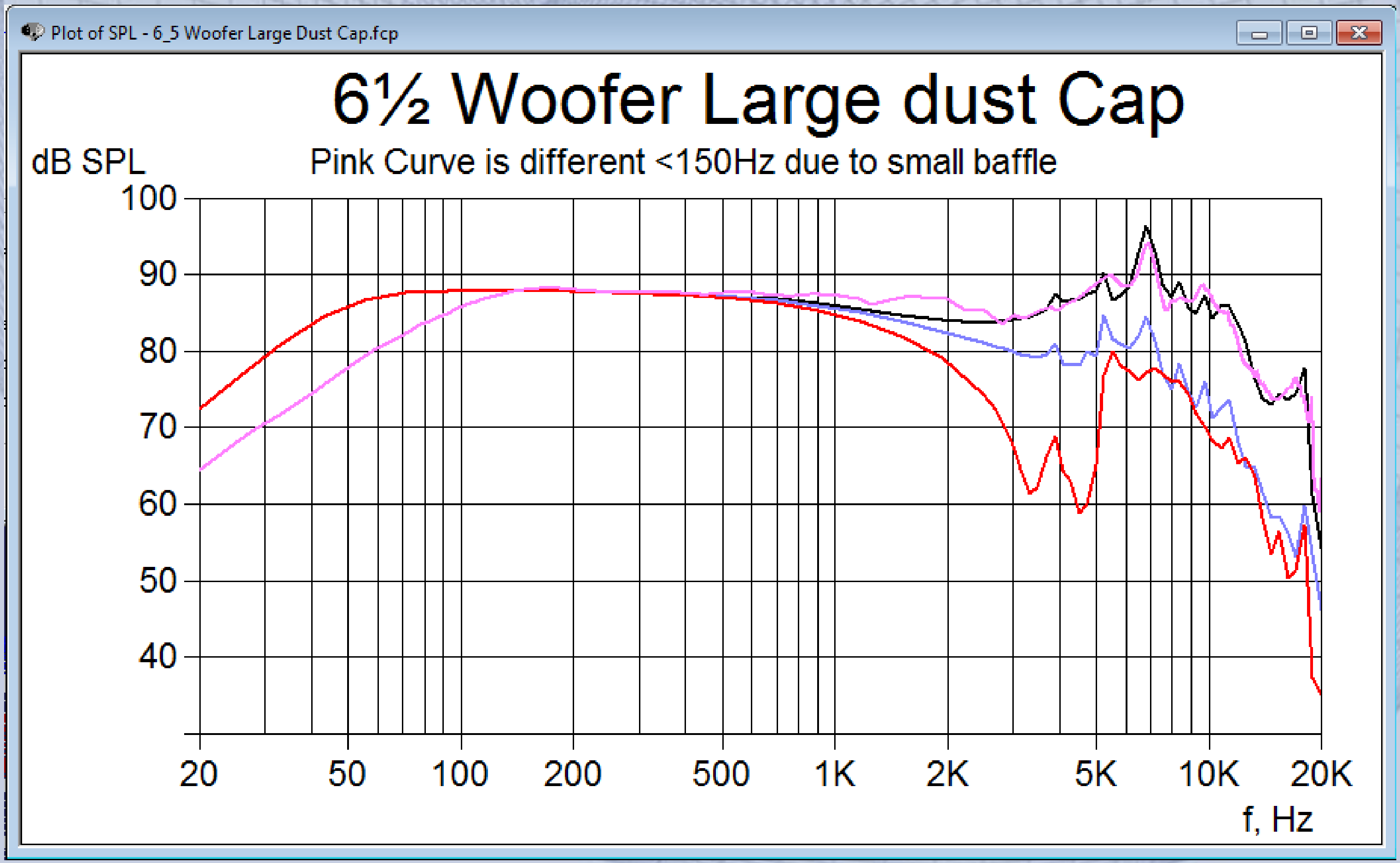
The driver Geometry can be defined as a simple DXF drawing



Each segment is given material parameters from a comprehensive database

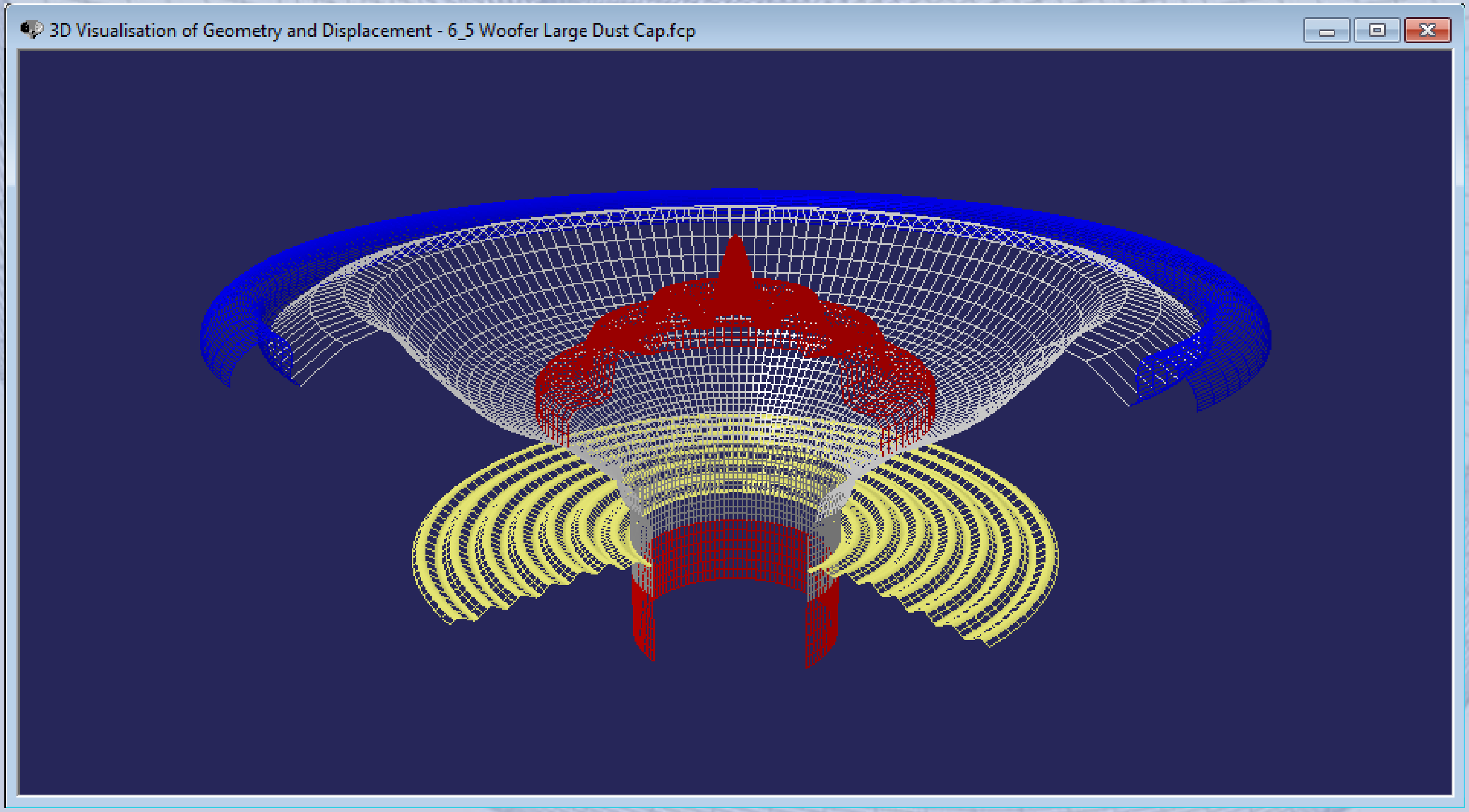


FEM simulated 0__/30__/60__ deg. frequency responses of 6½" Woofer, compared to actual measurement__. The agreement is quite good, especially at high frequencies.

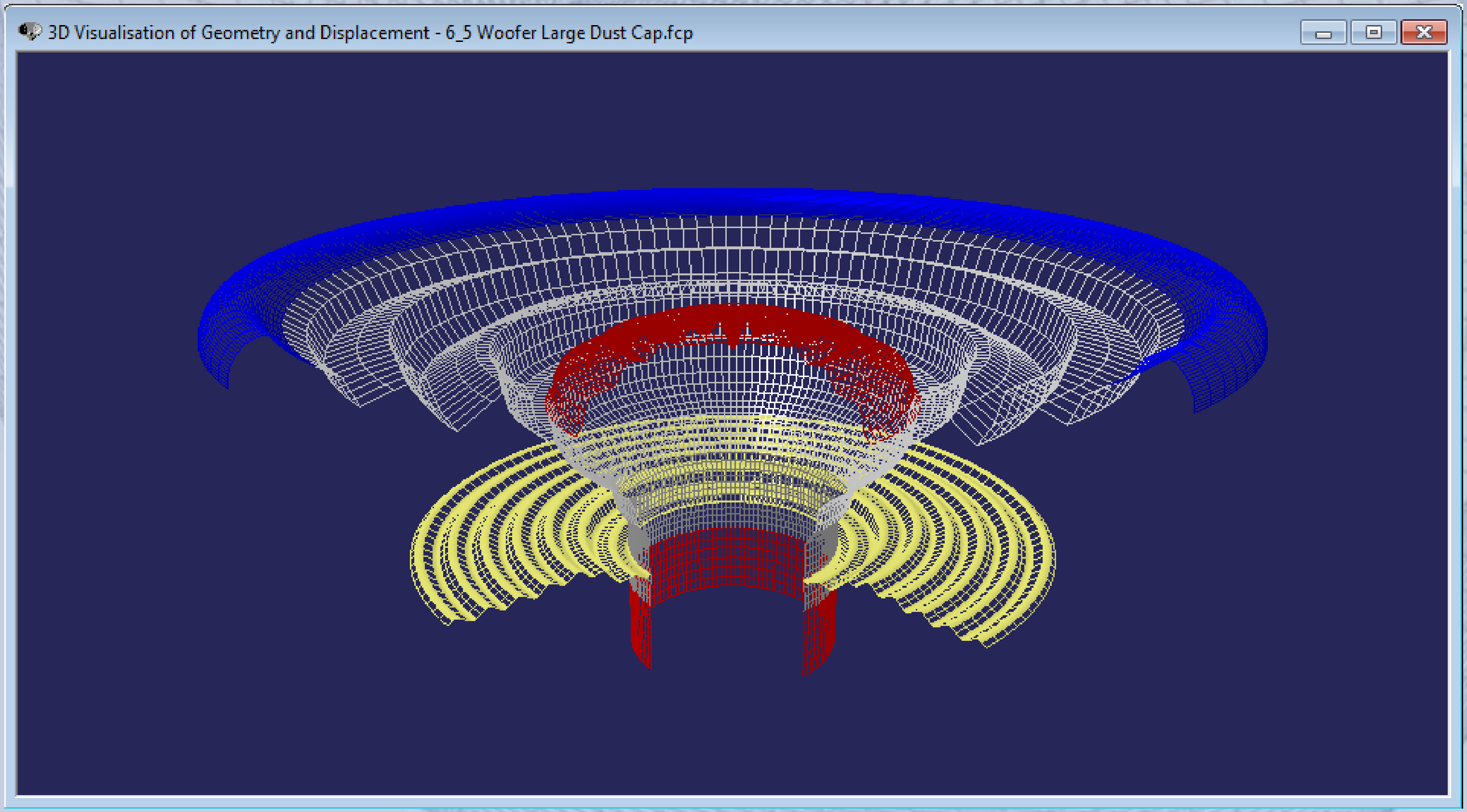


FC

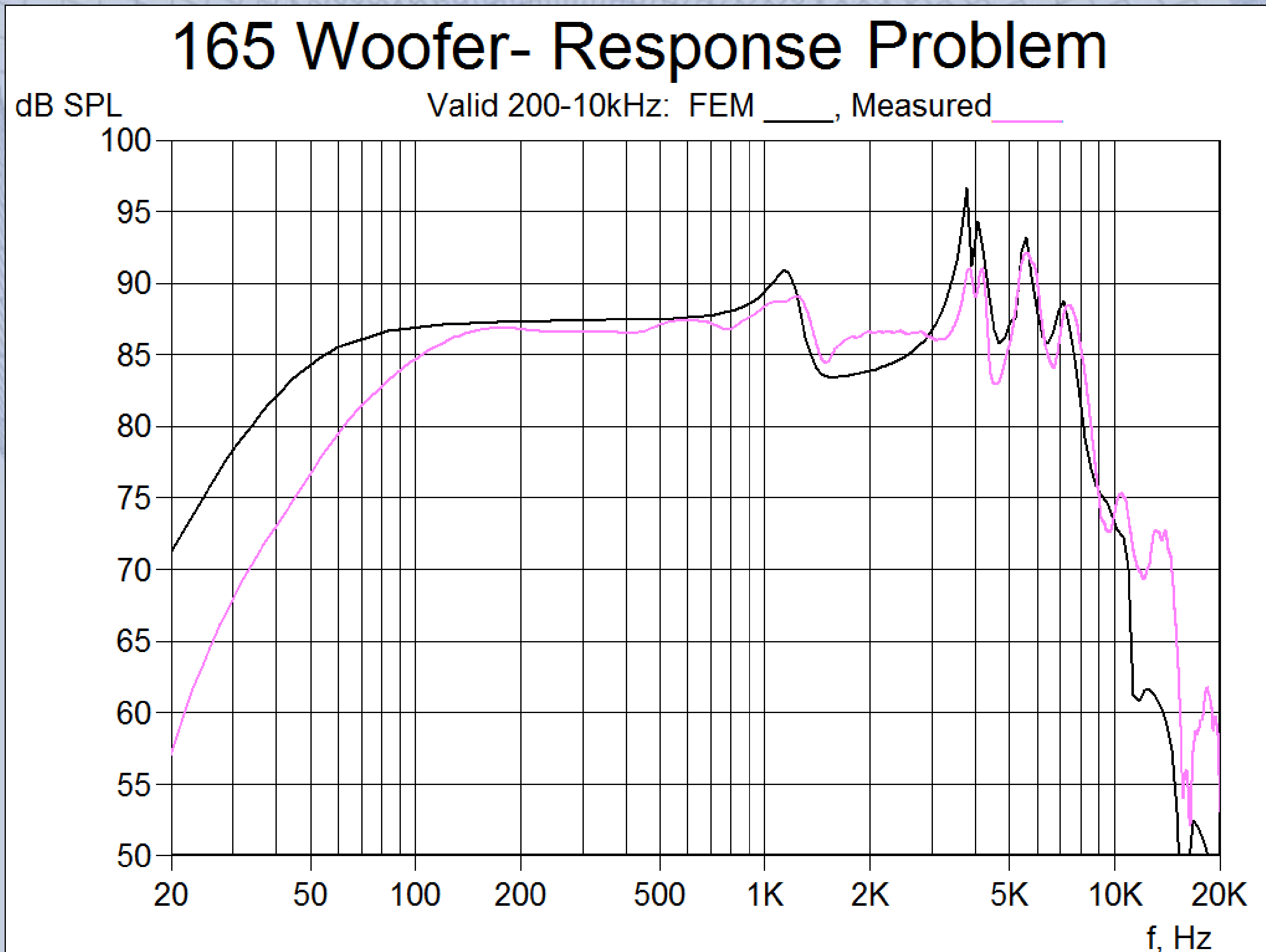
Cone and Dust cap Break-up of 6½" woofer @ 6804 Hz. The outer half of the cone shows the 1st cone mode, and the dust cap has high order break-up



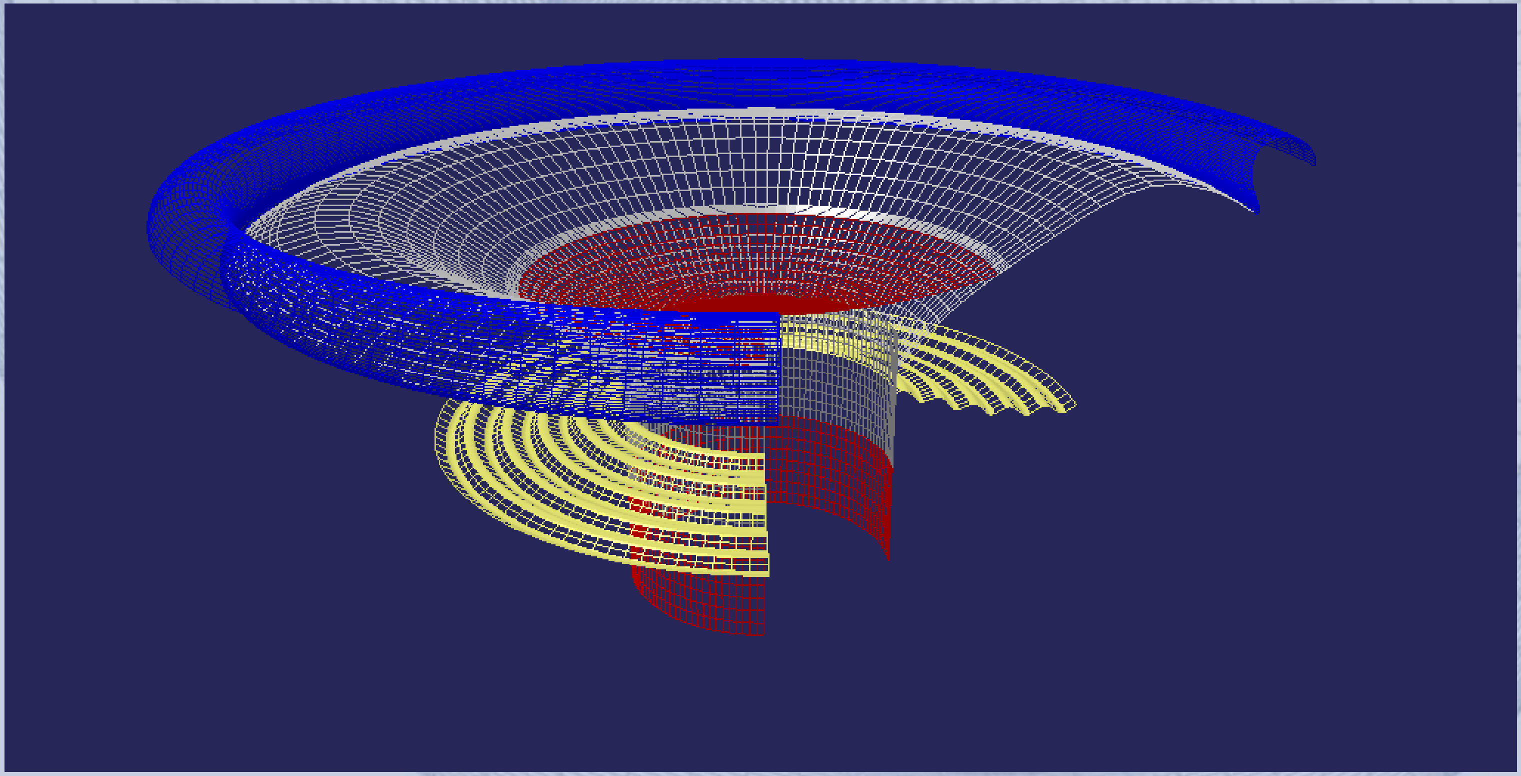
High order break-up of 6½" woofer @ 13623 Hz. The cone break-up has just reached the Voice Coil former.



Example: 165mm/6.5" Woofer with a response problem 1000-1500 Hz

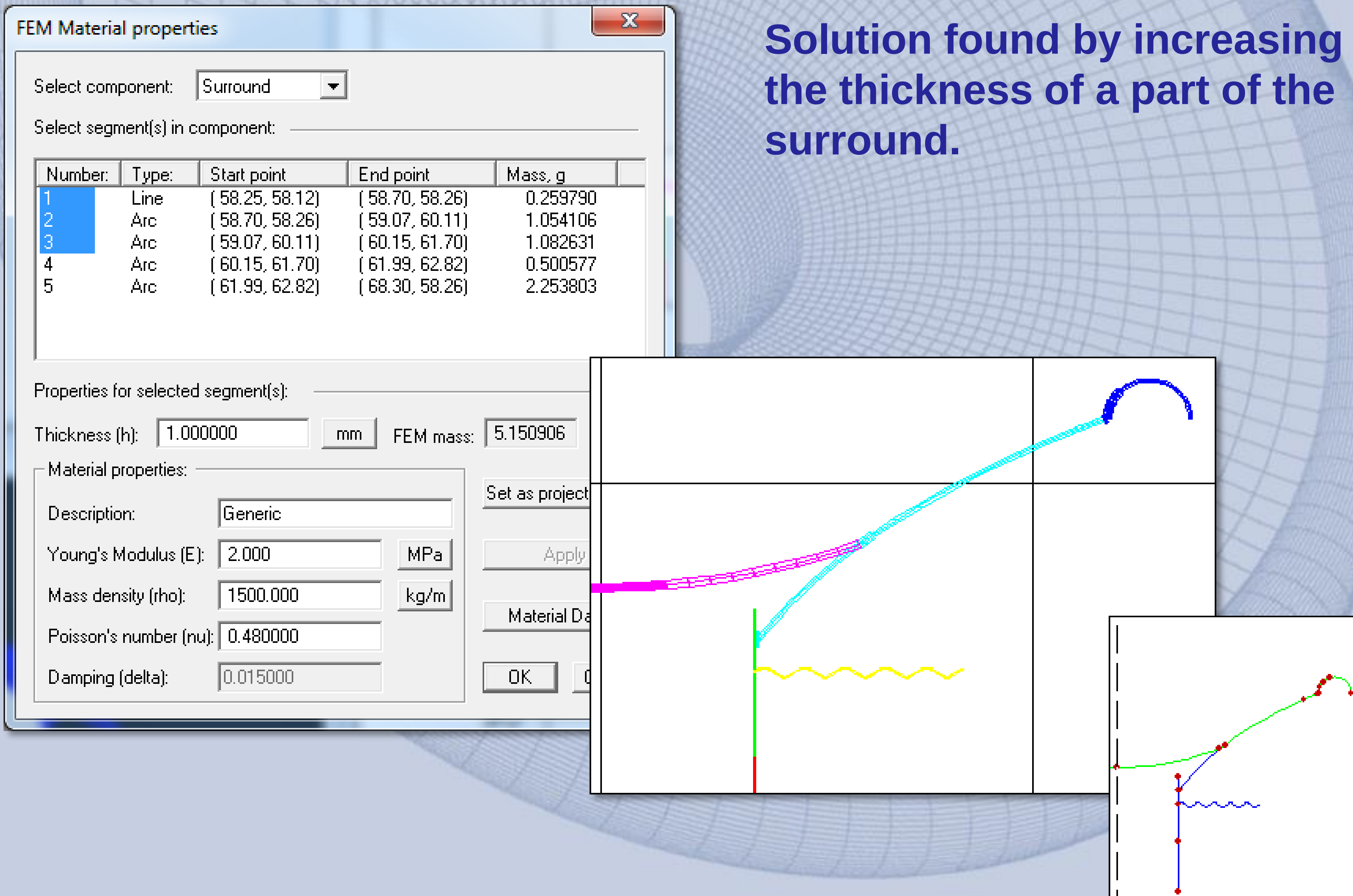


The FEM analysis reveals a strong edge resonance causing the problem around 1355 Hz

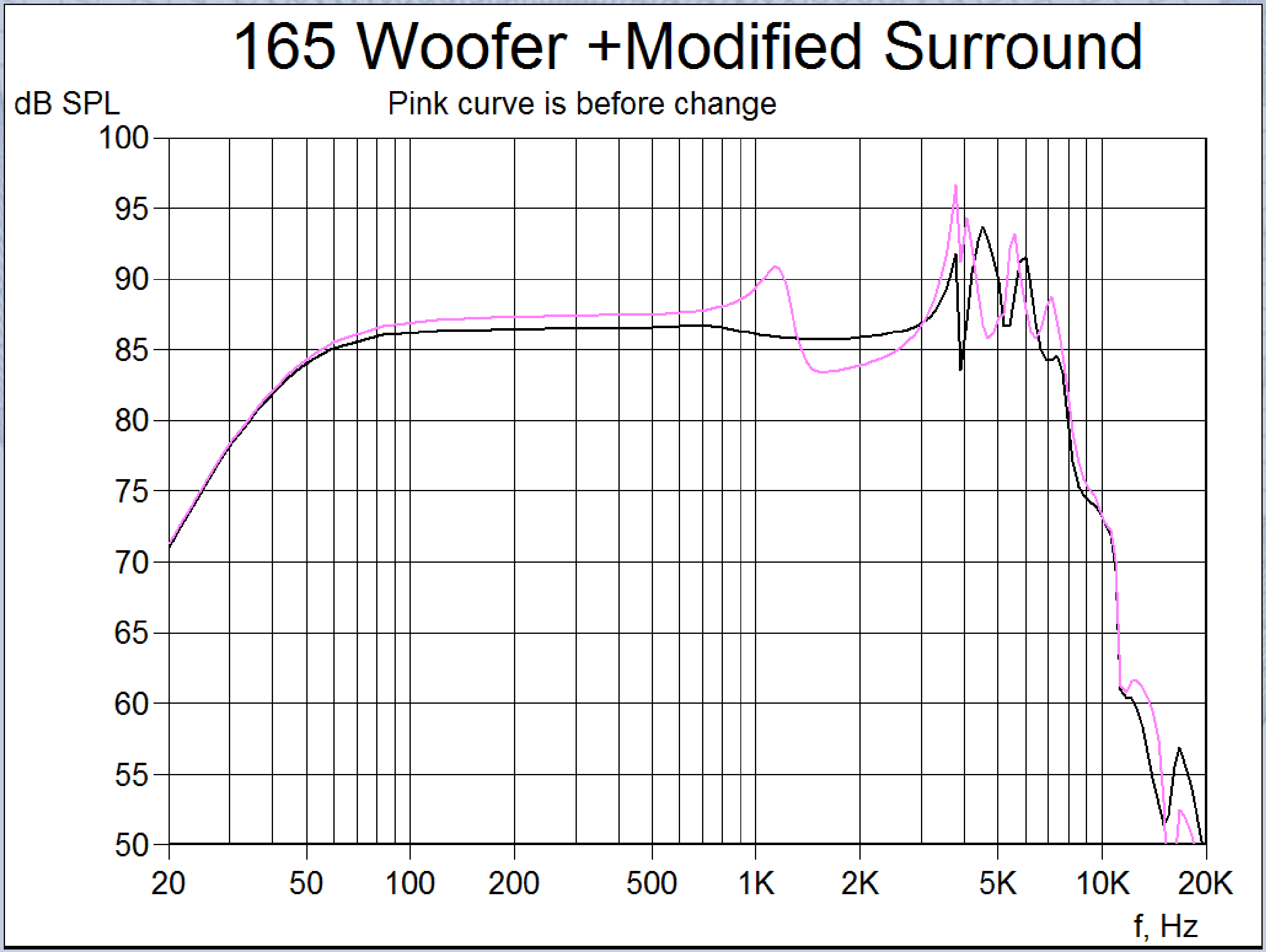


FC

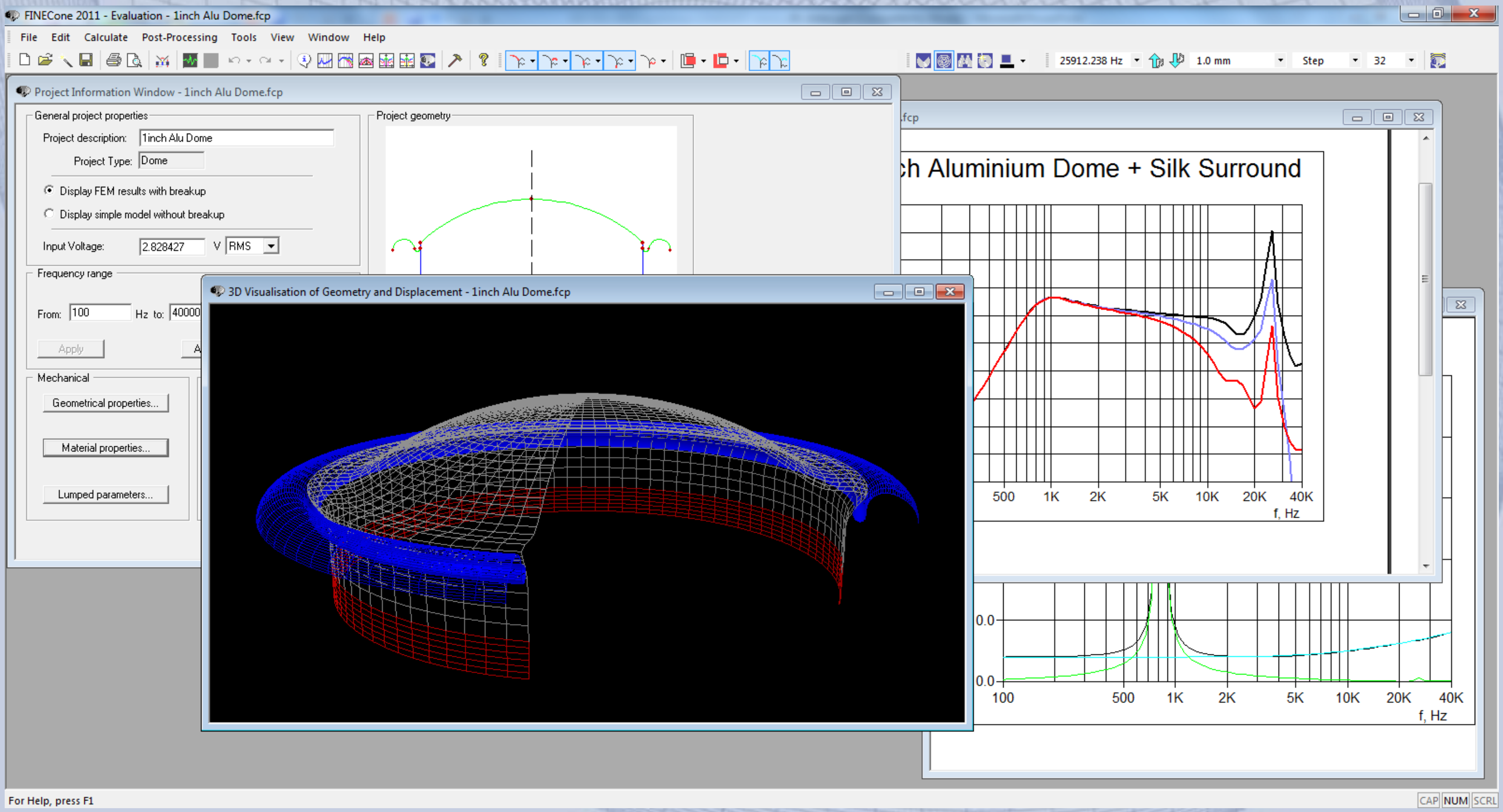
Solution found by increasing the thickness of a part of the surround.



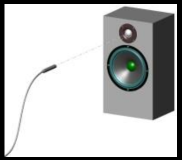
FEM simulated solution___ / before___



FEM simulated 0__/30__/60__ deg. frequency responses of 1" Aluminium Dome Tweeter with break-up @ 25912 Hz.



Crossover Designs in Practice



Crossover design is very simple in theory. In reality many problems makes it difficult and time consuming to design a good cross over circuit without the help of CAD.

Half space/baffle (2Pi) versus Anechoic (4Pi) Loudspeaker response

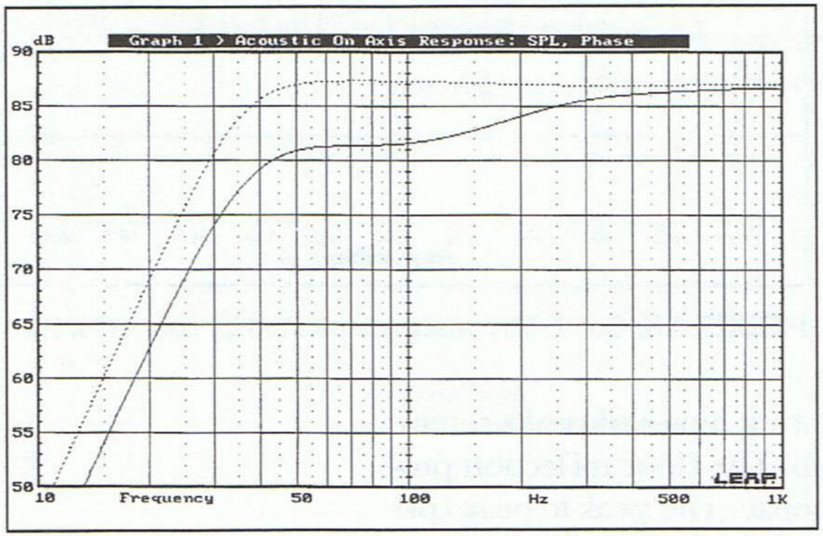


FIGURE 4.11: Half-space versus anechoic response (dotted = half-space, solid = free-standing anechoic).

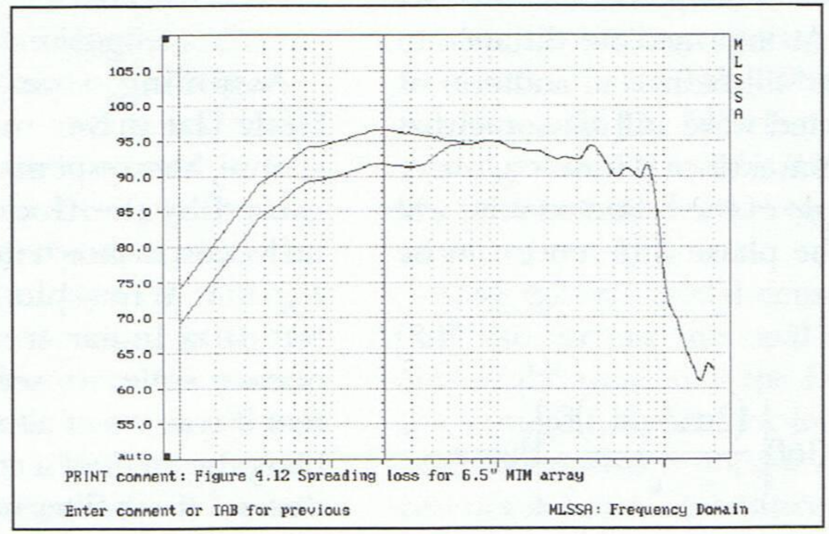


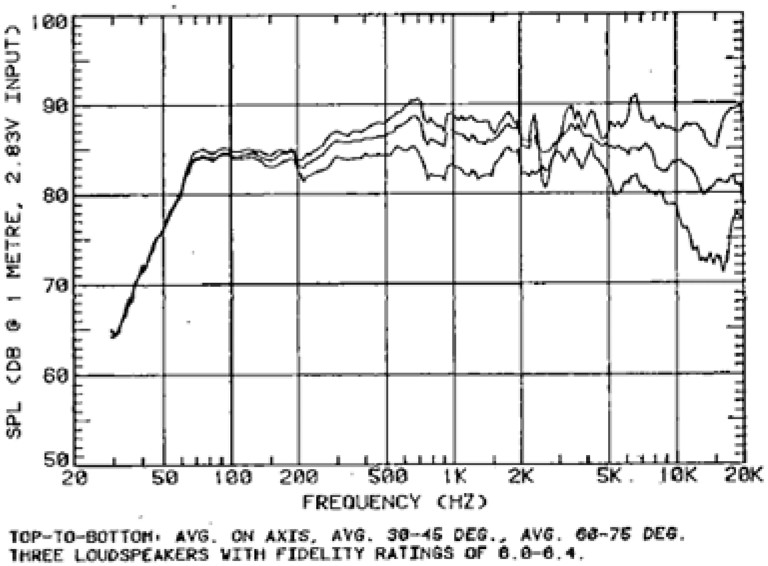
FIGURE 4.12: Spreading loss for 6.5″ MTM array.

From "Testing Loudspeakers"

J. D'Apolito

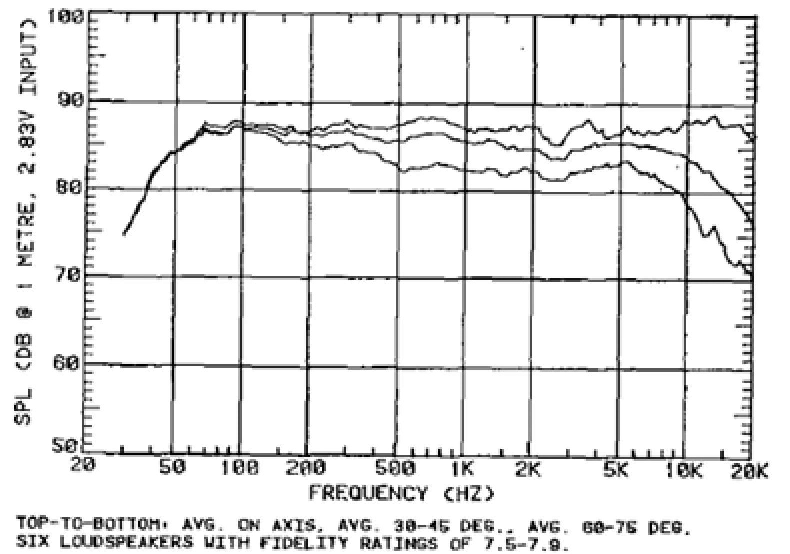
Loudspeaker Measurements and Their Relationships with Listener Preference

Examples from Floyd Tool's article:



(a)

Fig. 7. Amplitude response measurements of loudspeakers with fidelity ratings (a) 6.0–6.4.

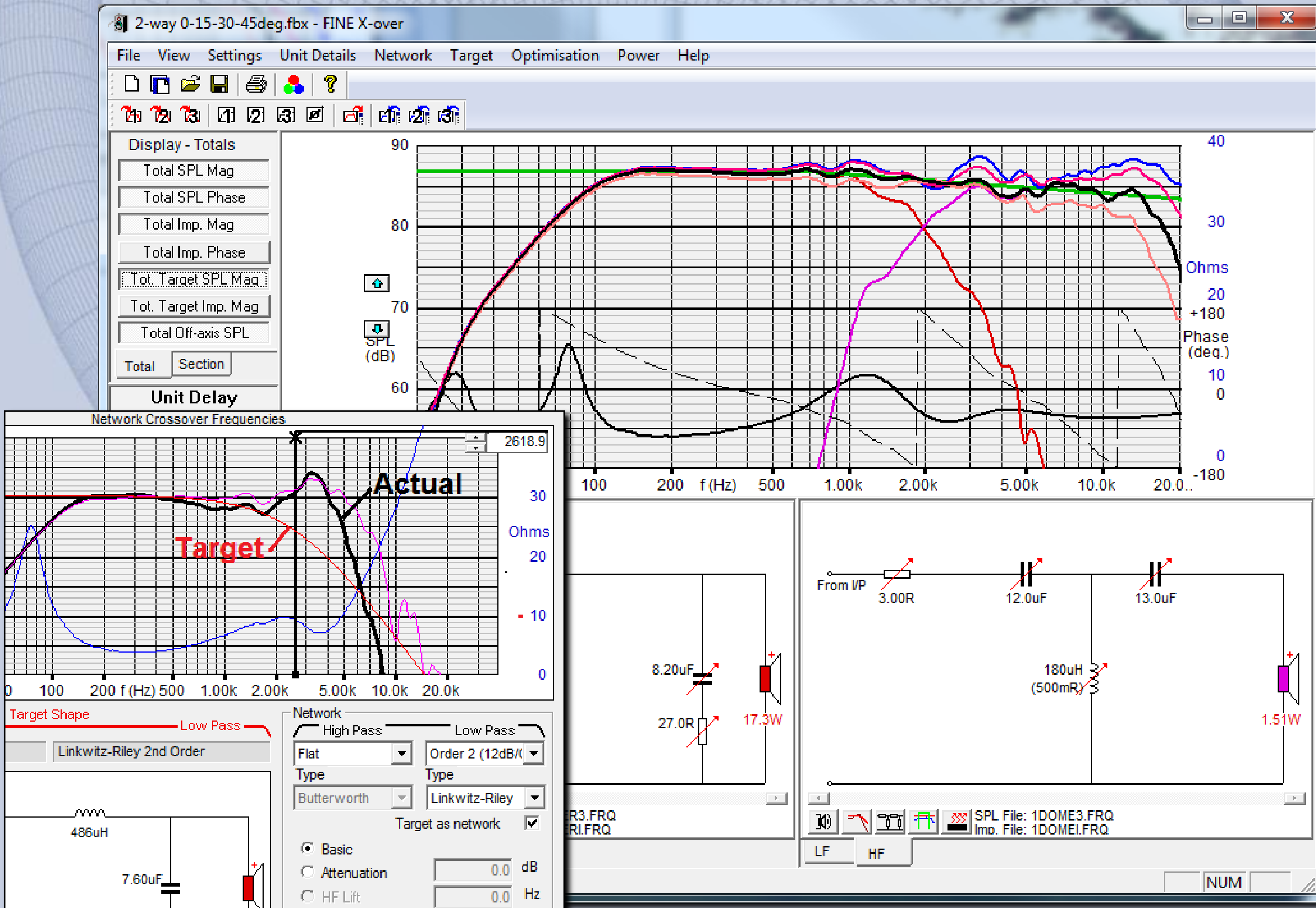


(d)

Fig. 7. Amplitude response measurements of loudspeakers with fidelity ratings (d) 7.5–7.9.

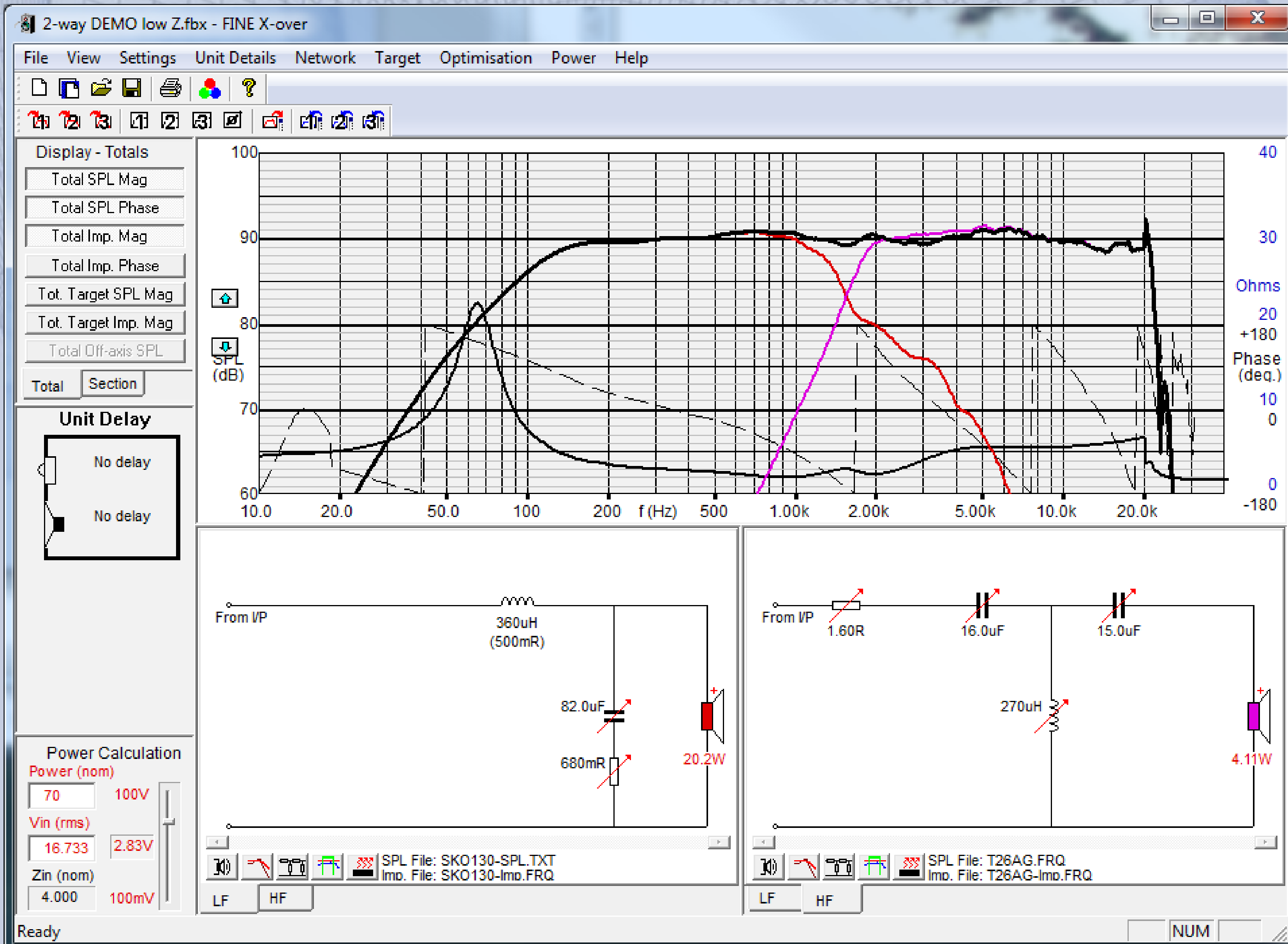
J. Audio Eng. Soc., Vol. 34, No. 5, 1986 May

Example of 2-way cross over circuit with optimized off-axis responses (Controlled power response)

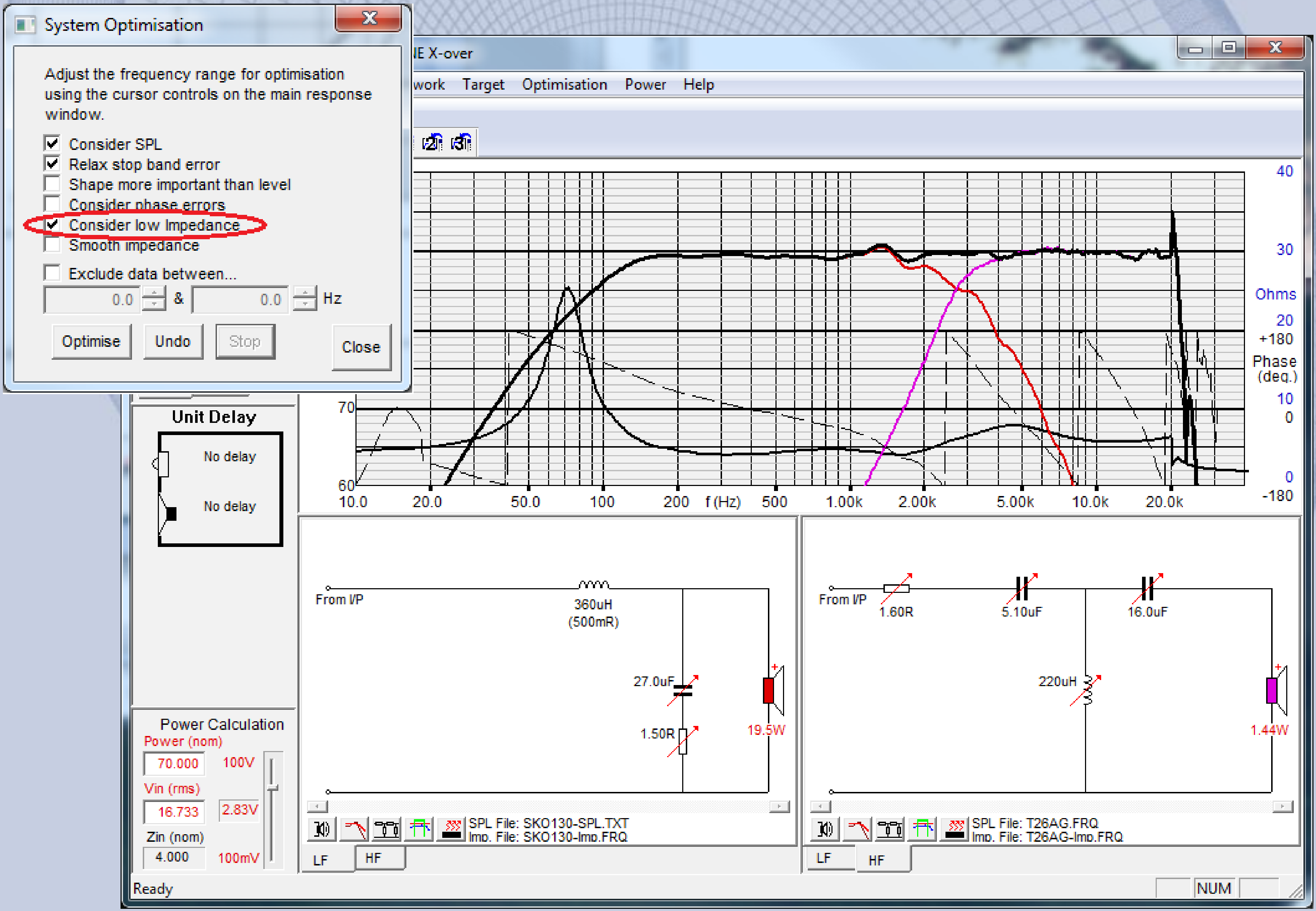


FX

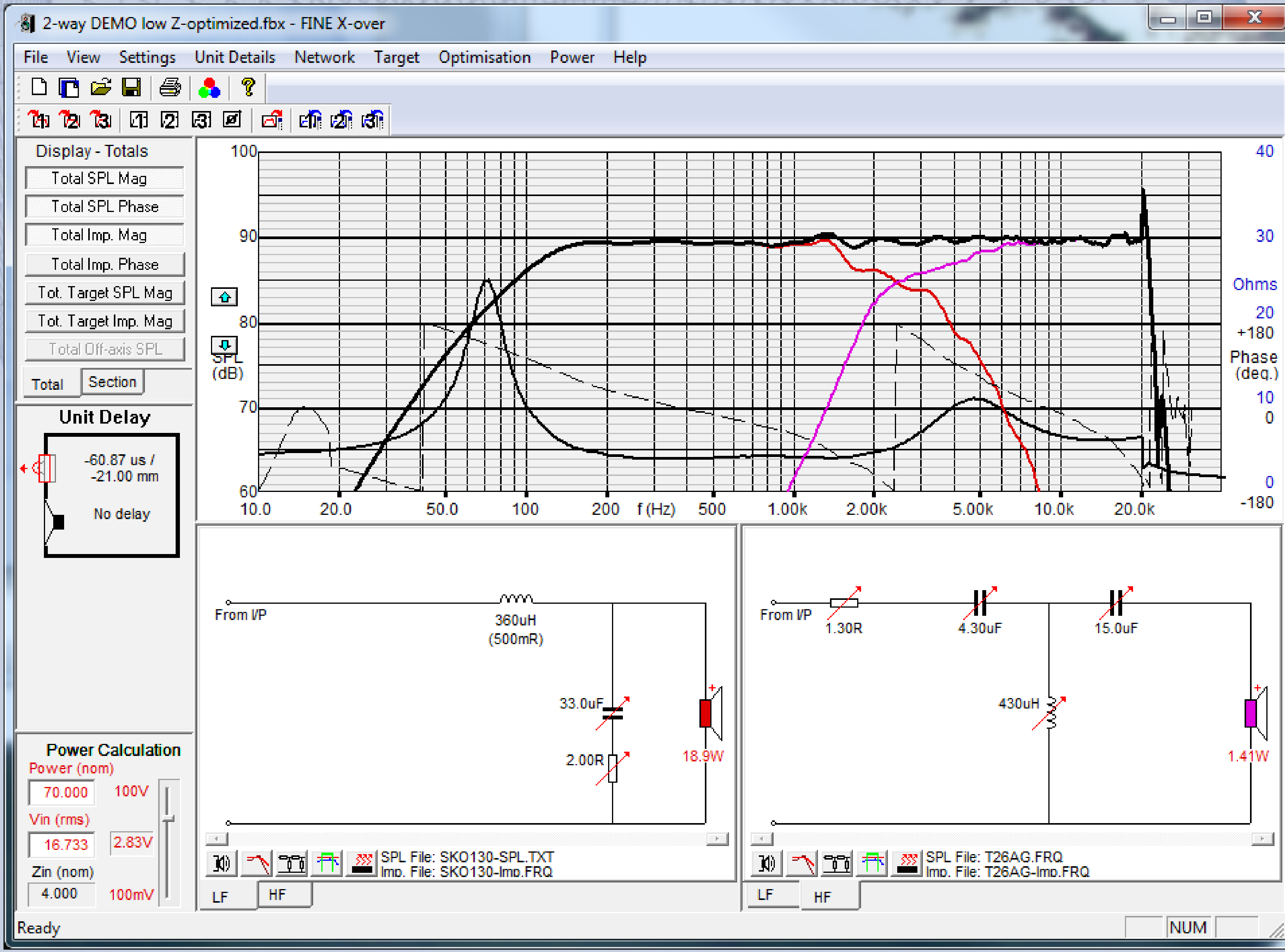
2-way cross over optimized for flat response.
But Impedance is too low! (~2R)



2-way cross over circuit now optimized also for impedance Z



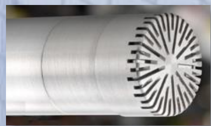
2-way cross over further optimized with unit delay for linear phase



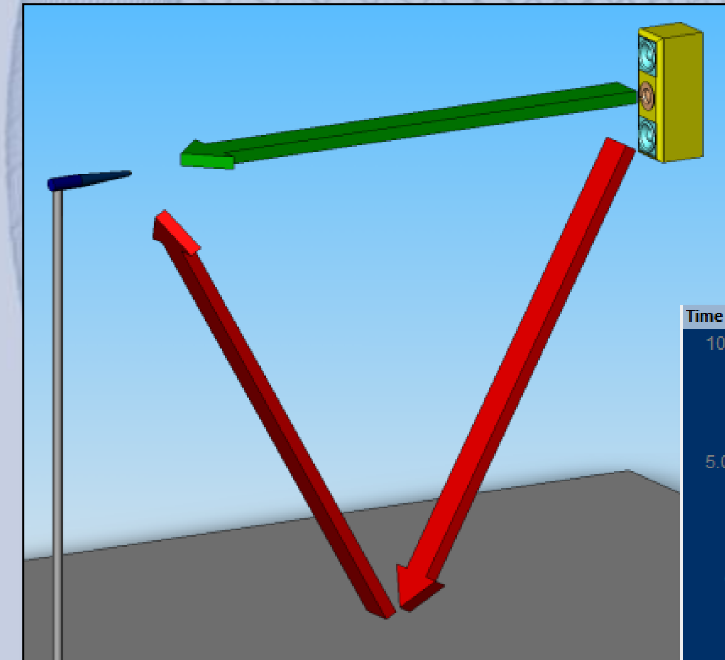
Loudspeaker Measurement Examples

R+D))

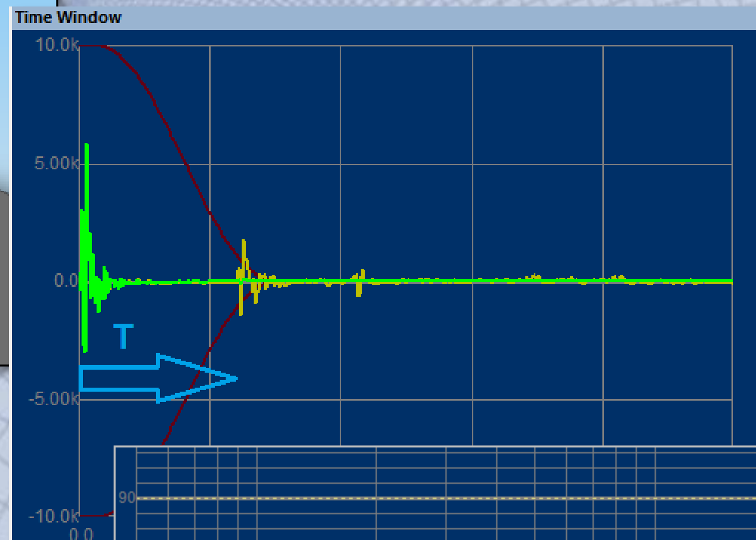
Some examples from using modern measuring methods

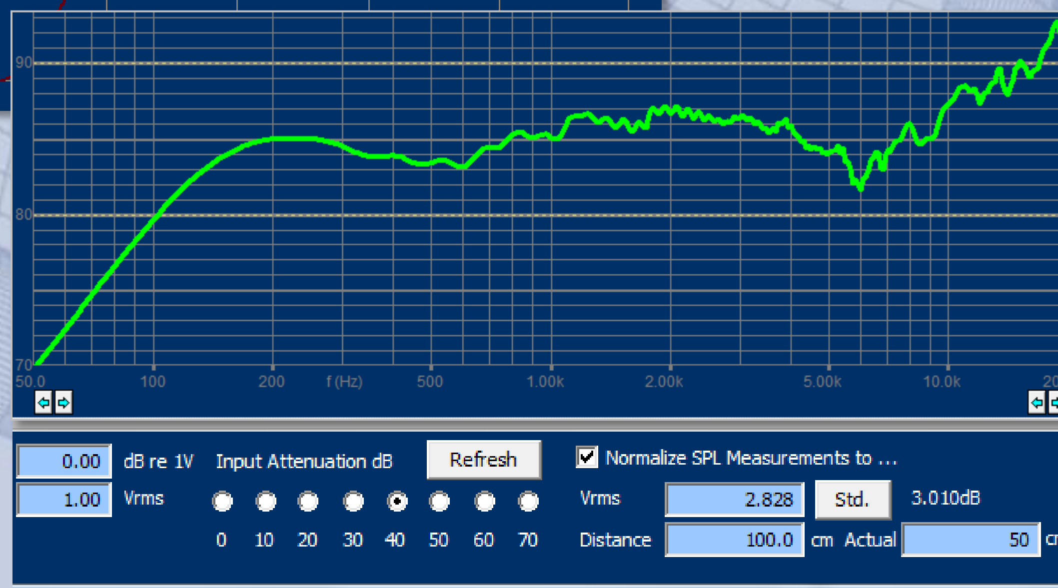


The swept sine / FFT technique makes it simple to get accurate frequency responses in normal rooms



The time difference T between the direct___ and the reflected sound___ must be large in order to measure low frequencies: F min=1/T (Hz)





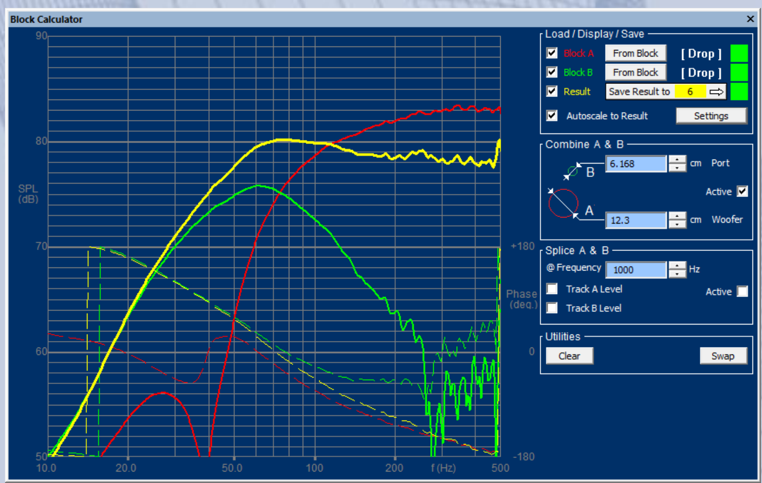
In a small room T can be increased by moving the microphone closer.

This curve measured at 1V/50cm was normalized to 2.83V/1m

(=Industry standard)

LF Near field measurements:

Near field measurements will measure all low frequencies. However since these are really pressure responses it is necessary to compensate for the differences due to distance and piston size.

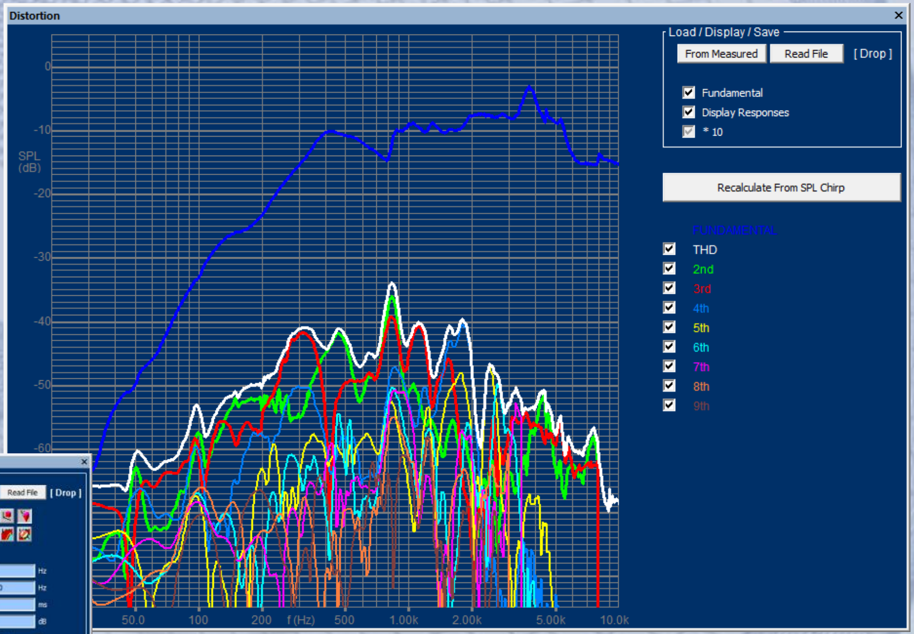


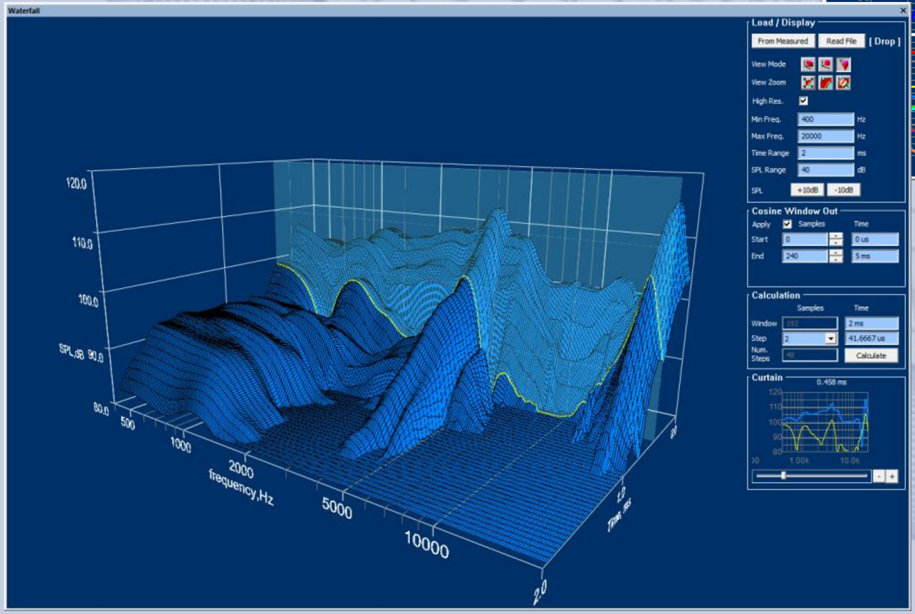
Total response__ , combined by far field__ and near field__ . Spliced @ 473 Hz

Bass reflex response__ , complex addition of woofer__ and port__ . Auto compensated for area differences

Harmonic distortion is useful. However the waterfall provides more information

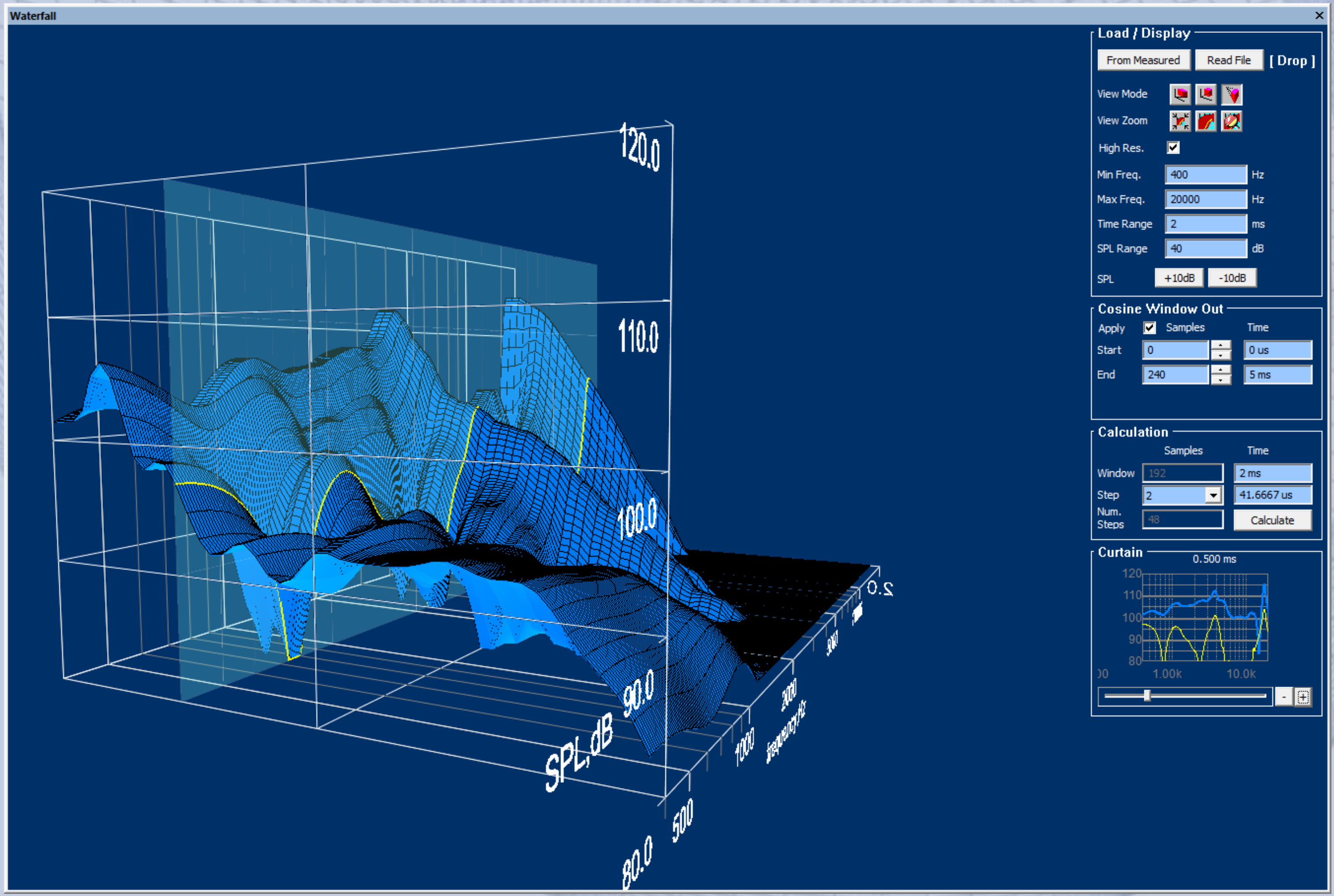
The 1-3rd harmonics are high @ 800 Hz.





The waterfall shows a strong reflection @ 800 Hz and a decaying resonance @ 4 kHz

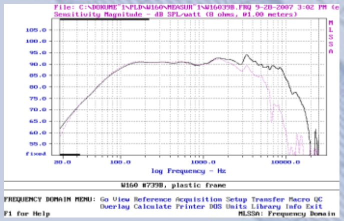
The curtain shows the reflection @ 800 Hz in detail



Replacing old (DOS) Measuring systems

Old System: DOS

No Win 7 or 8 (+ 64bit)



No Amplifier

No Rub & Buzz

New System: (C++)

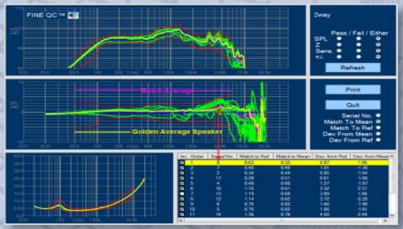
Windows 7 / 8 - 64bit

THD + 2-9th

Test: 1sec

Golden Average

Best Rub & Buzz



USB Hardware

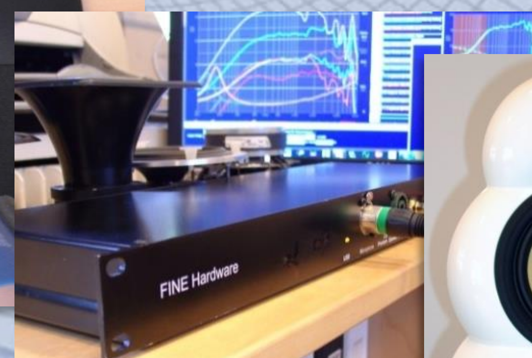
25W Amplifier

SPL+Imp direct

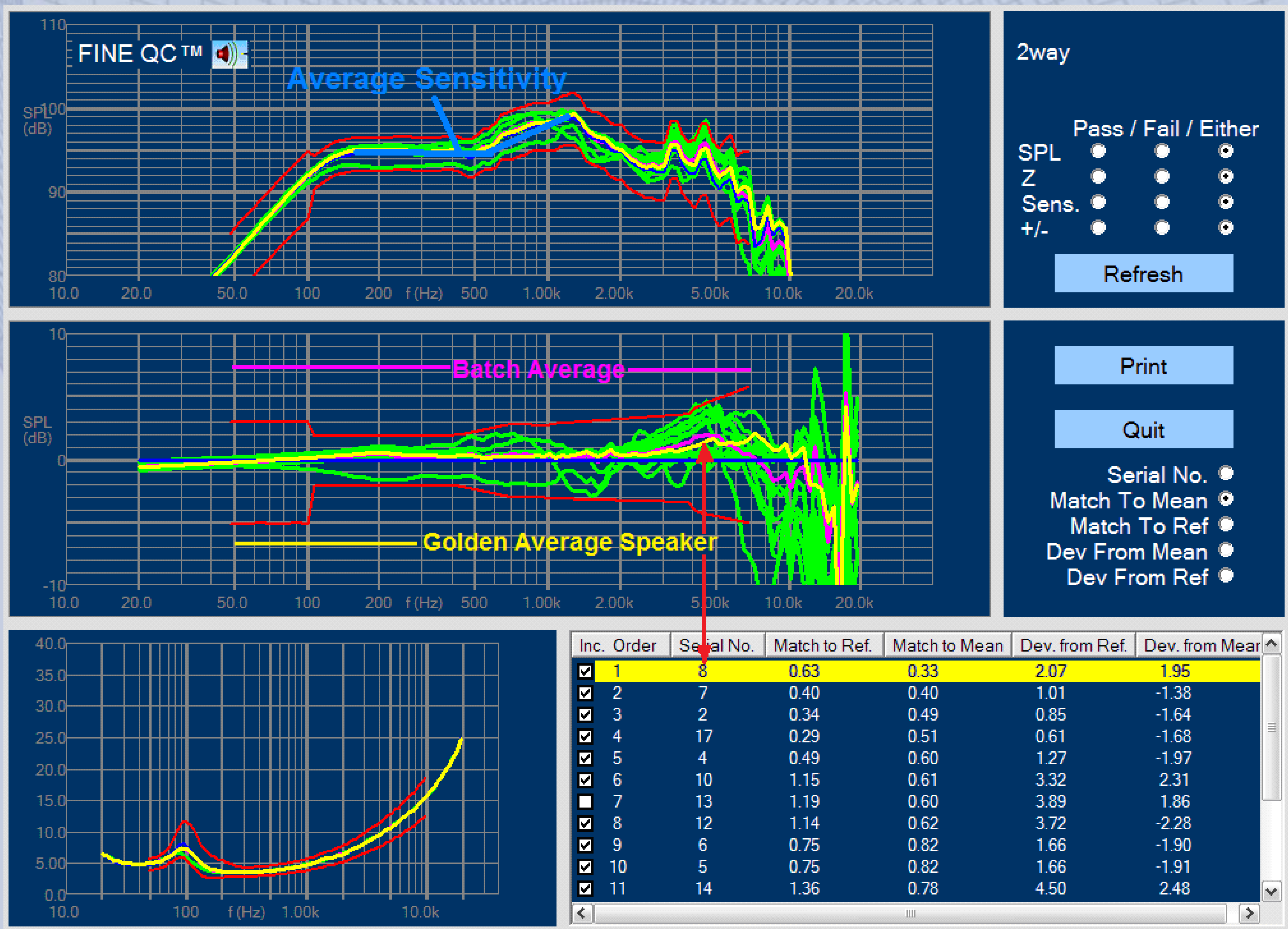
Challenges in Speaker QC Testing

A few notes about Speaker End of Line Quality Control in today's high speed production.

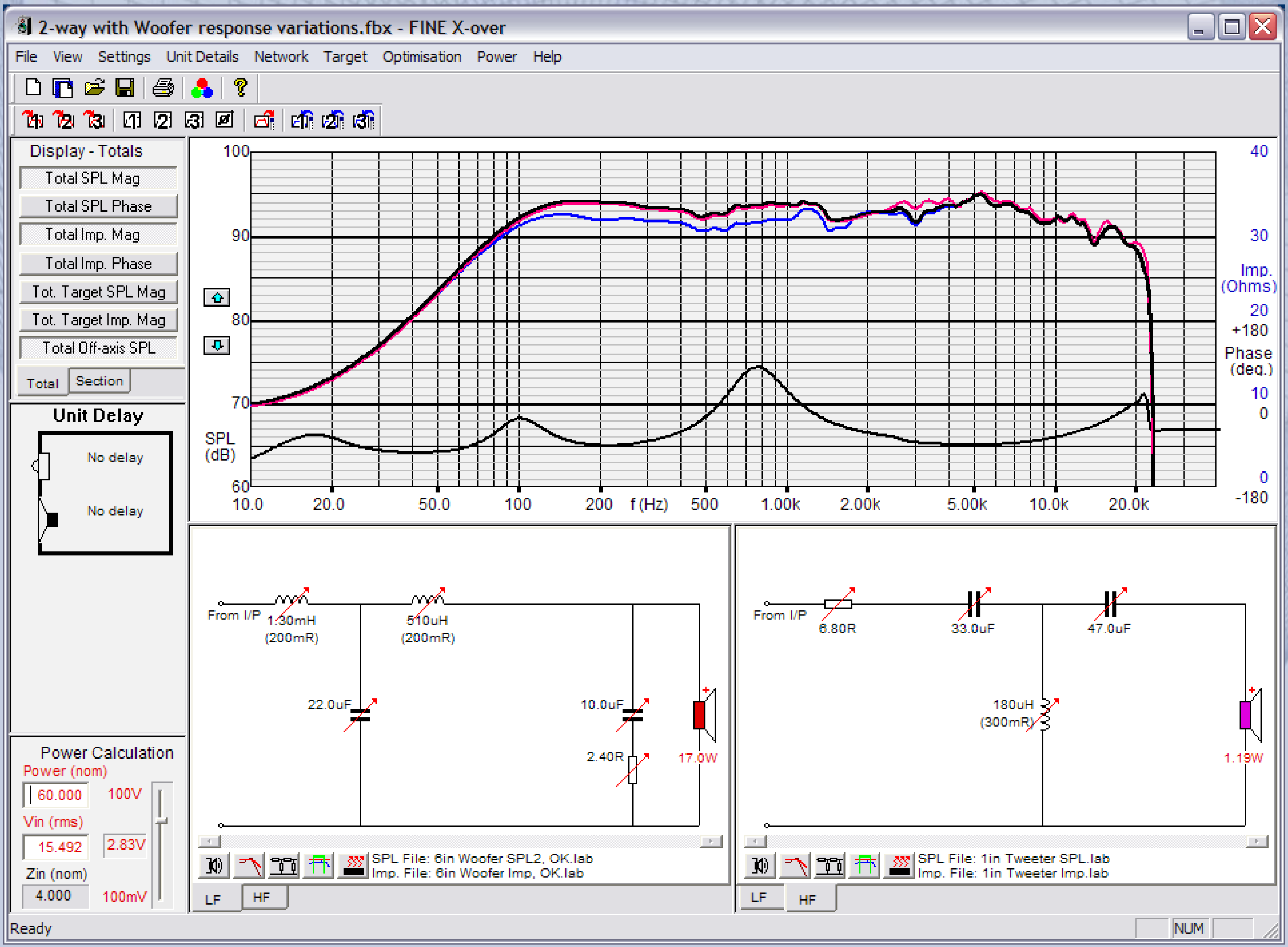
Which parameters should be tested to ensure good speakers and especially micro speakers, in production?



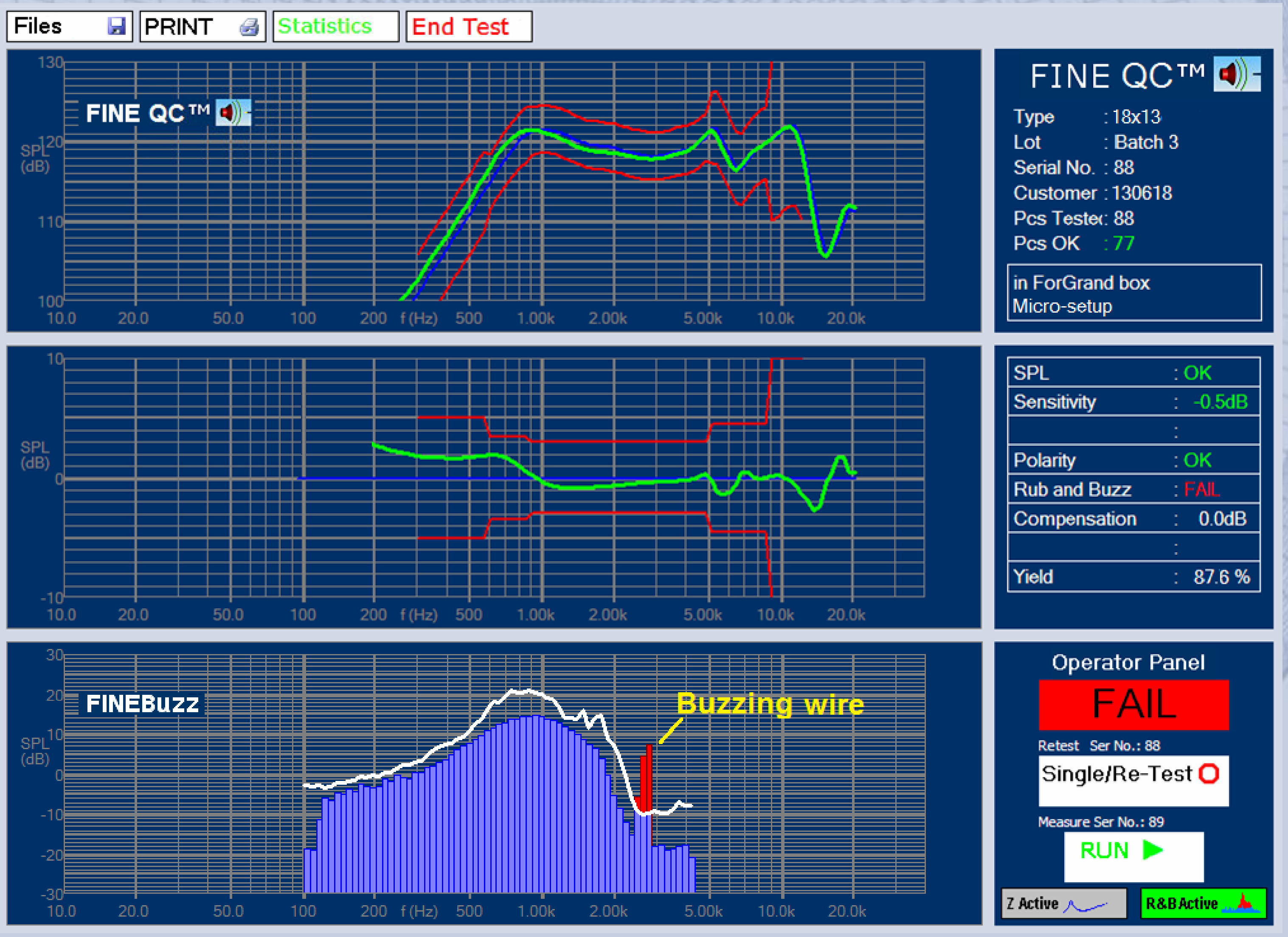
- **Use statistics to find The Golden Average (REF)**
- **Decide response deviations as: Sensitivity and +/- x dB freq. band**



Example: Two rejected woofer responses imported into FINE X-over. Red__ outside frequency tolerance. Blue__ low sensitivity



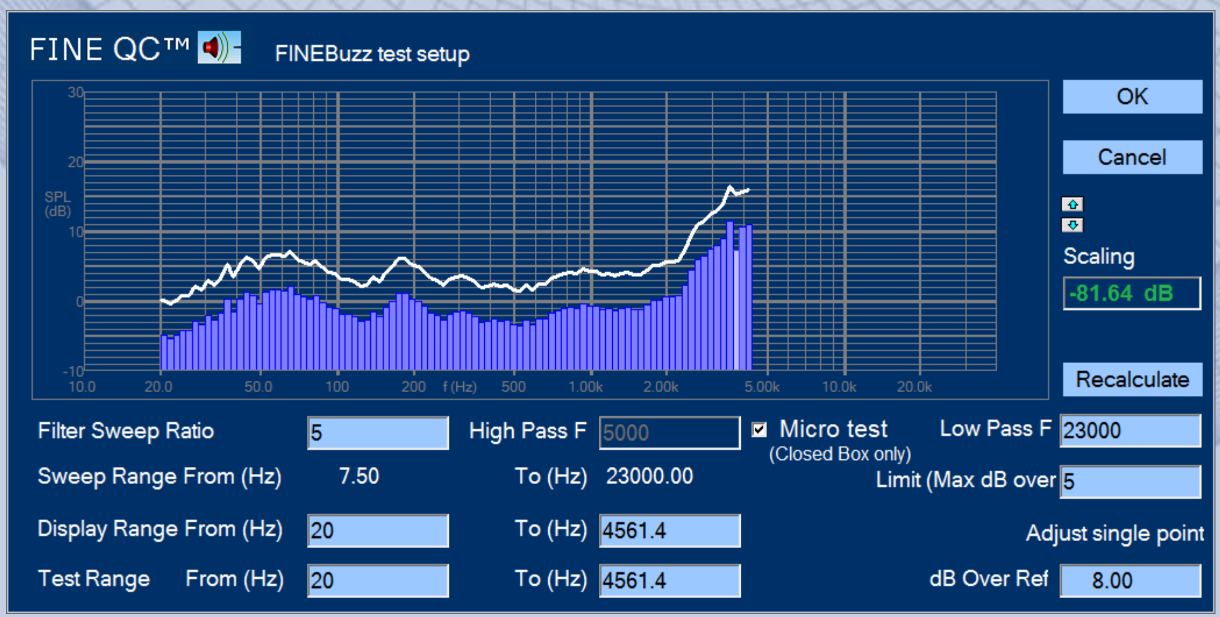
It is vital to find Rub & Buzz especially for micro speakers. This cannot be detected with conventional methods like THD, high harmonics or IM distortion.



How can Rub & Buzz be tested reliably?

Danish F. Leonhard derived in 1993 a new model for auditory perception based on mathematical and physical phenomena that correspond very much to how the human ear perceives sound.

A later detection method based on the Danish research principles uses a completely new protected algorithm to find the annoying sounds, which cannot be detected with conventional methods like THD, high harmonics or IM distortion. Finding fast low level impulses < -80 dB rel. signal is therefore possible.



How Accurate are Speaker Simulations?

Some results from AES 126th Loudspeaker FEA/BEM Workshop

FINEMotor simulated TS parameters versus measured (Klippel)

Measurement in Vacuum

	In air			In vacuum	
Electrical Parameters					
Re	7.13	Ohm	Re	7.04	Ohm
Le	0.046	mH	Le	0.048	mH
L2	0.181	mH	L2	0.198	mH
R2	1.84	Ohm	R2	1.96	Ohm
Cmes	182.02	µF	Cmes	162.01	µF
Lces	5.38	mH	Lces	5.51	mH
Res	21.14	Ohm	Res	16.93	Ohm
fs	160.8	Hz	fs	168.4	Hz
Mechanical Parameters (using laser)					
Mms	1.277	g	Mms	1.095	g
Mmd (Sd)	1.244	g	Mmd (Sd)	1.062	g
Rms	0.332	kg/s	Rms	0.399	kg/s
Cms	0.767	mm/N	Cms	0.815	mm/N
Kms	1.30	N/mm	Kms	1.23	N/mm
Bl	2.649	N/A	Bl	2.600	N/A
Lambda s	0.096		Lambda s	0.094	
Loss factors					
Qtp	0.982		Qtp	0.854	
Qms	3.887		Qms	2.902	
Qes	1.311		Qes	1.207	
Qts	0.981		Qts	0.853	
Vas	0.2443	l	Vas	0.2596	l

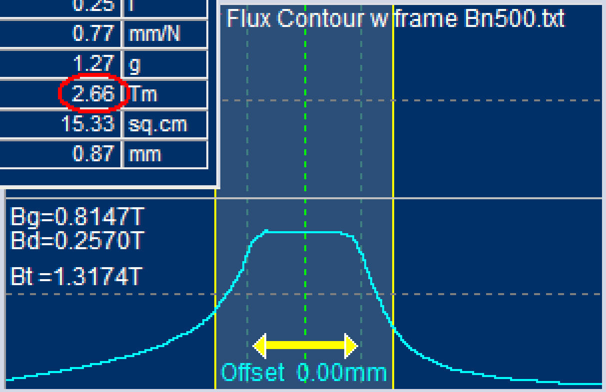
Klippel, Loudspeaker Analysis, Workshop AES 2009, 5

TS Parameters

Sensitivity (2.83V/1.00m)	SPL	79.72	dB
VC Resistance DCR	Re	7.00	Ohms
Resonance	Fs	161.00	Hz
Mechanical	Qms	4.00	
Electrical	Qes	1.27	
Total	Qts	0.96	
Equivalent air vol.	Vas	0.25	l
Compliance	Cms	0.77	mm/N
Moving Mass(incl. air)	Mms	1.27	g
Force Factor	Bl	2.66	Tm
Eff. diaphragm area	Sd	15.33	sq.cm
Lin. Excursion +/-	Xmlin	0.87	mm

FINEMotor Prediction of TS Parameters

Flux Profile

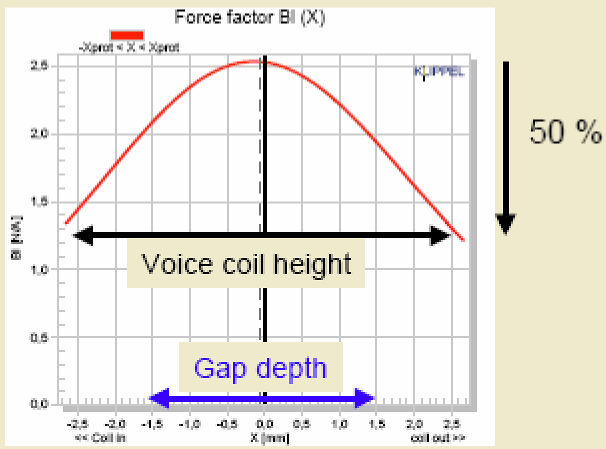


The predicted BL is really close to the Klipper Laser measurement

FINEMotor simulated BL(x) versus measured (Klippel)

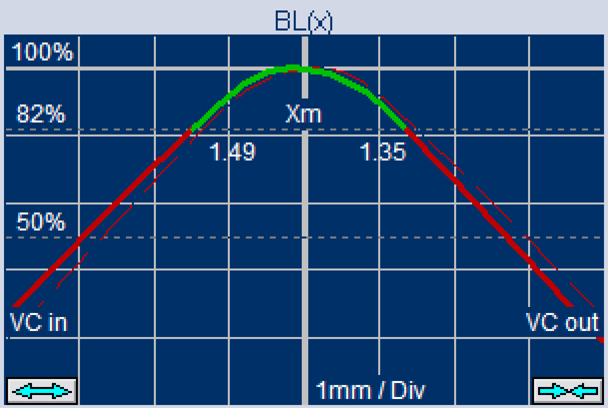
Dominant Nonlinearities: Bl(x)

Measured by using the LSI module



XBl=1.3 mm @ Blmin=82 % (10 % intermodulation distortion in SPL, mainly 3rd-order)

FINEMotor BL(x) Calculation

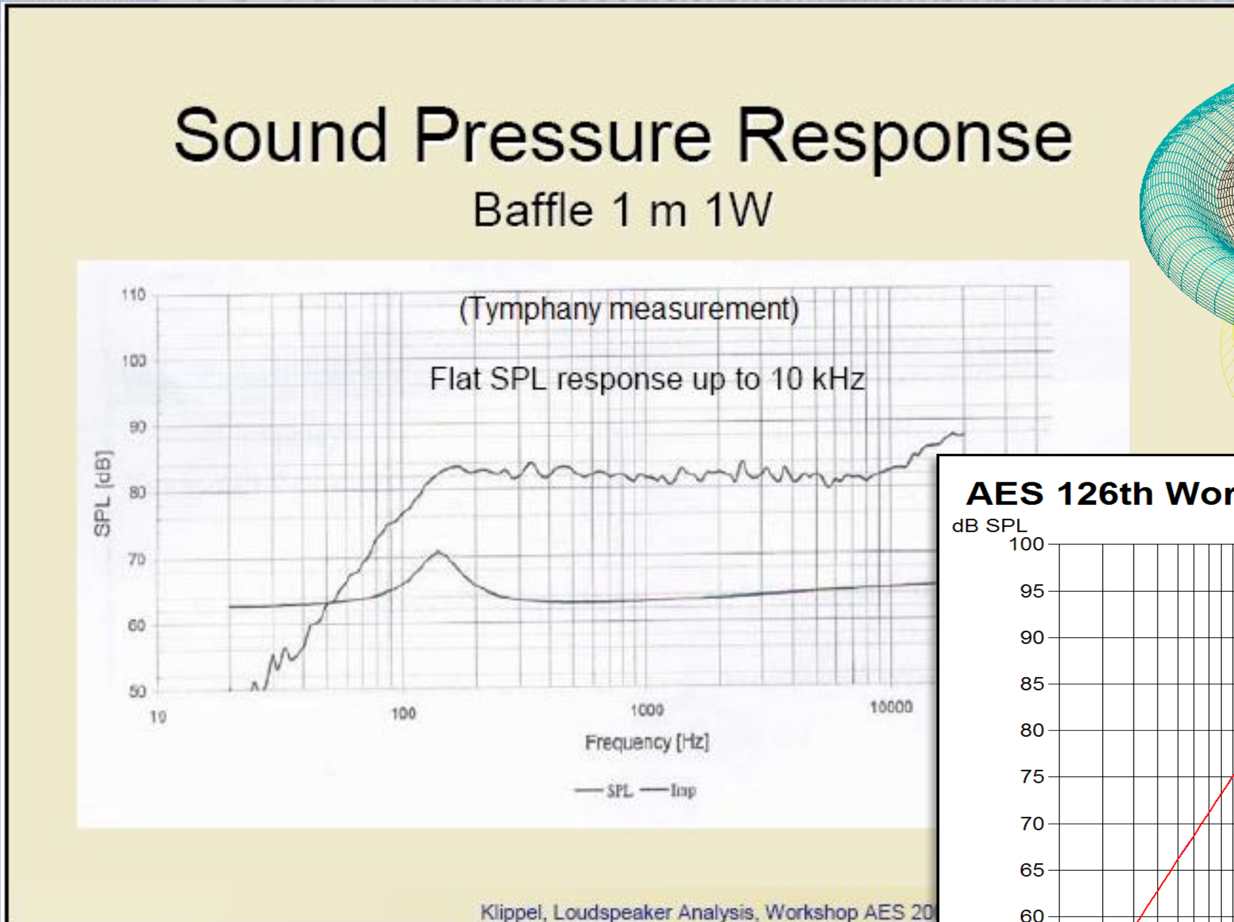


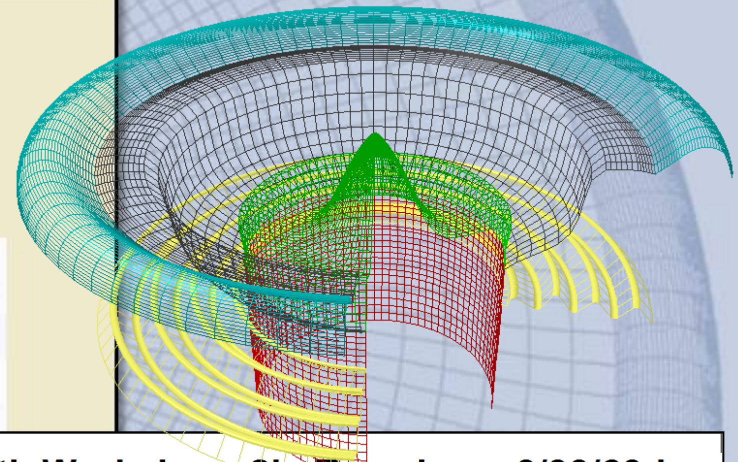
Predicted by FINEMotor:

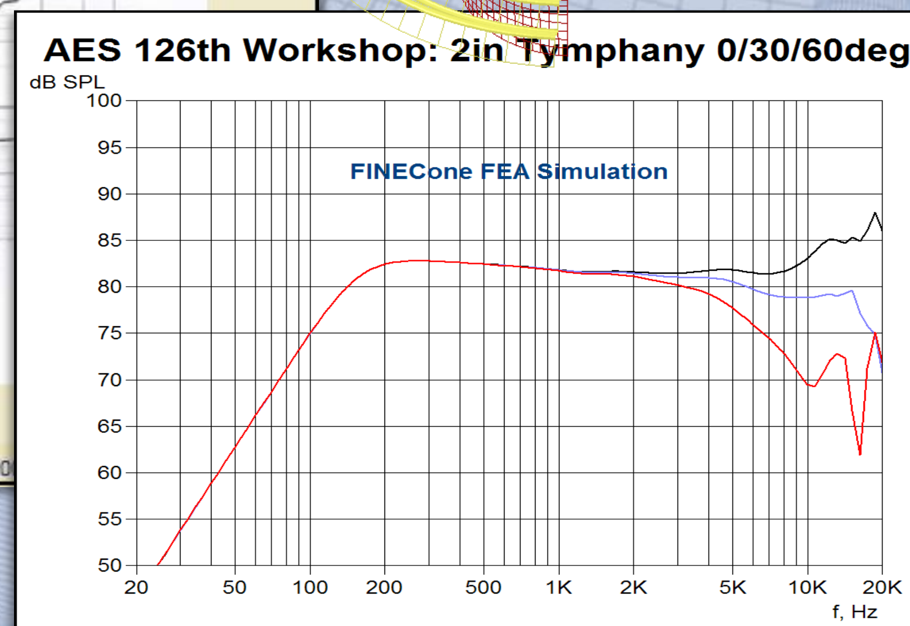
XBL @ 82% BLmin =1.35mm.
The shape and symmetry of the BL(x) curve is extremely close to that measured by Klippel

AES 126th Loudspeaker FEA/BEM Workshop

FINECone FEA versus measured response







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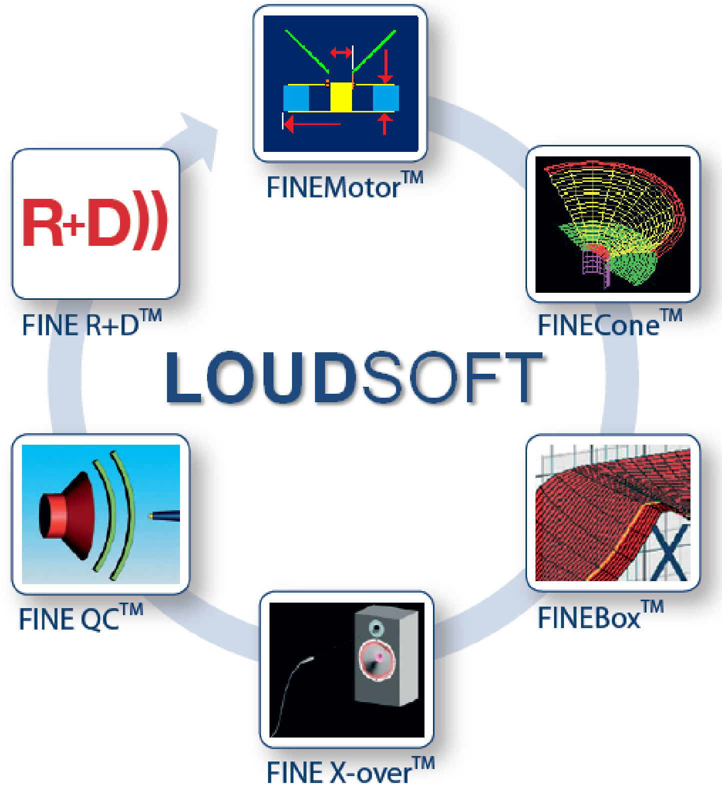
The FINE Circle



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