

Designing Transducers for Compact Active Speakers

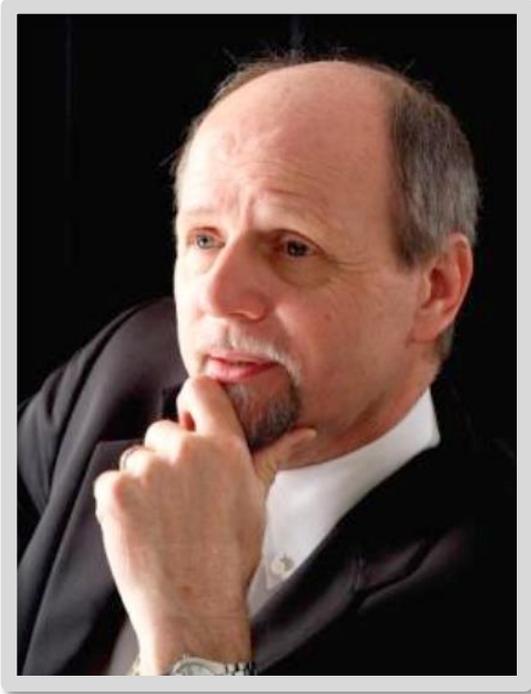


AUDIO DESIGN WORKSHOP **LIVE**

MEET THE EXPERTS - LEARN THEIR SECRETS

LOUDSOFT

Peter Larsen with these companies from 1974



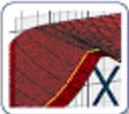
Peter Larsen
LOUDSOFT



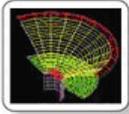
The Design Cycle



Designing Motors for Small Drivers



Bass Alignments in Box @ High Power



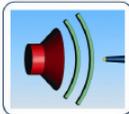
Cone Designs and Problems



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



Today's Compact Loudspeakers

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

No.	Type	Ripple (dB)	f_s/f_s	f_w/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	2.00
14	CH5	1.0	0.554	0.781	0.191	1.102	2.20

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

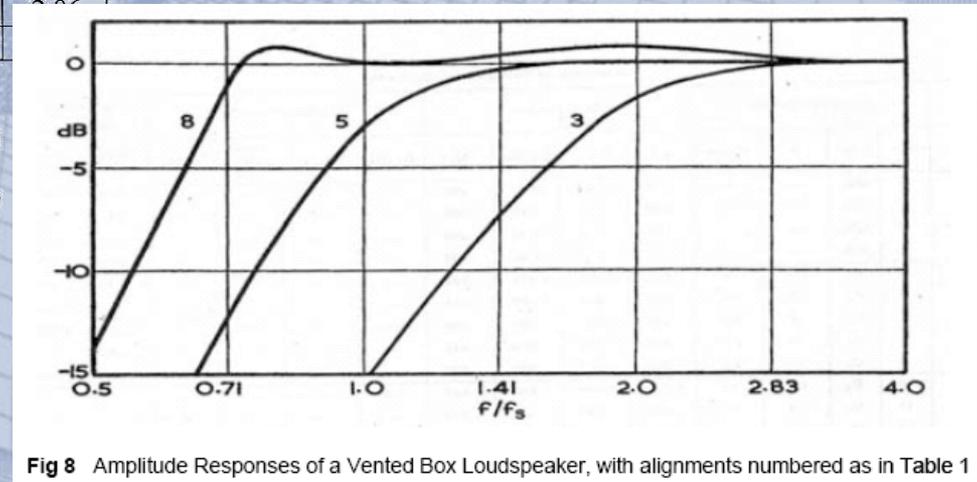
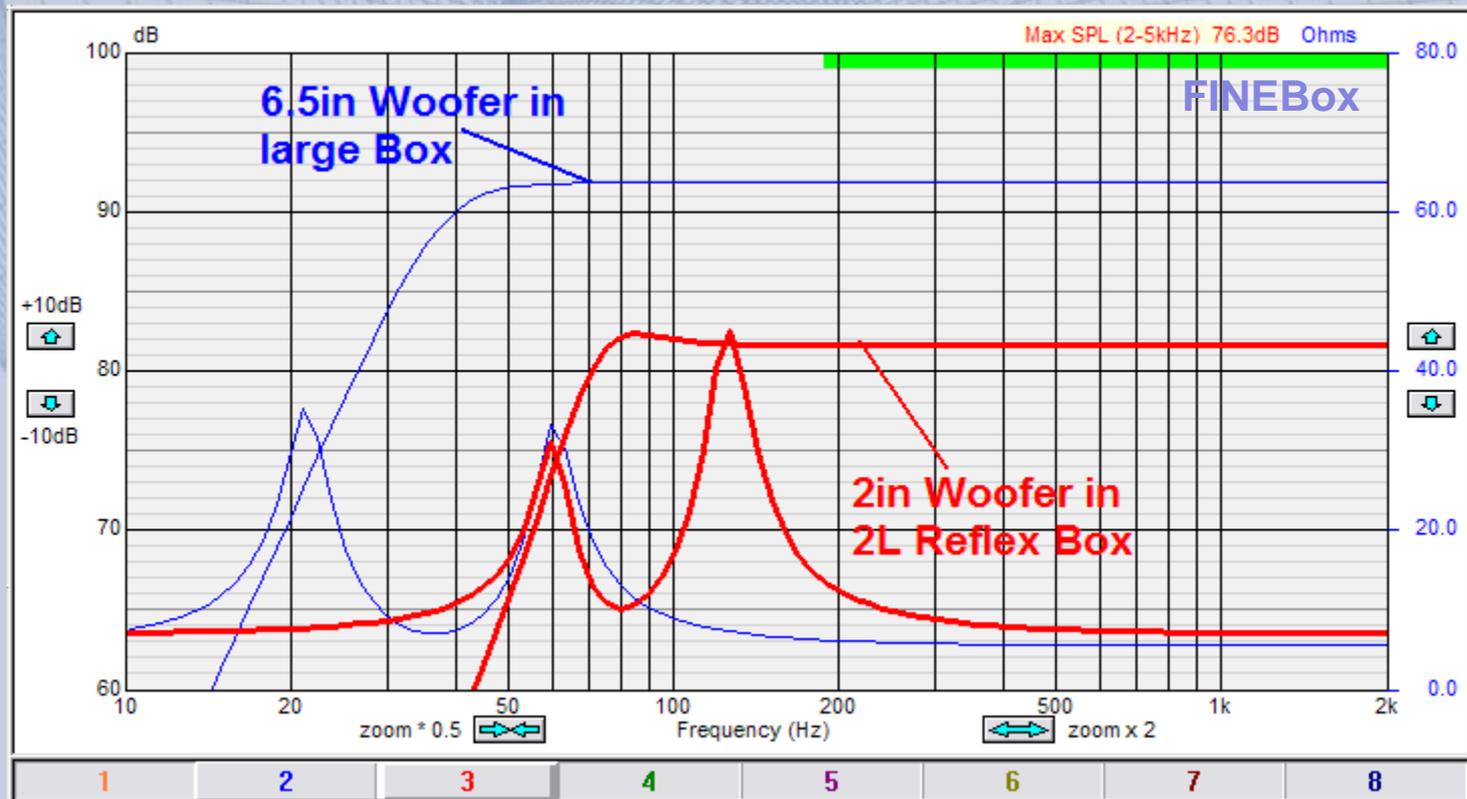
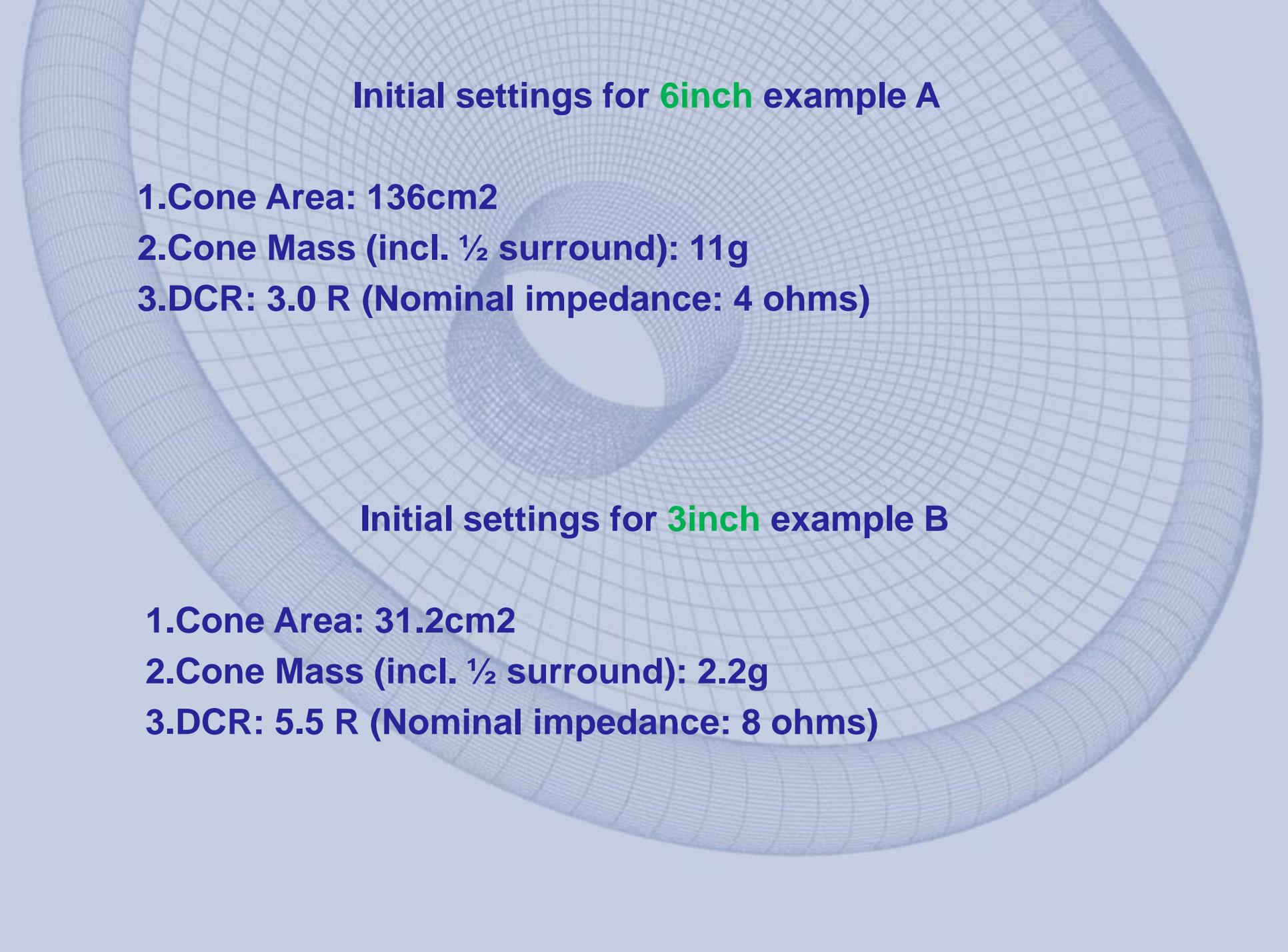


Fig 8 Amplitude Responses of a Vented Box Loudspeaker, with alignments numbered as in Table 1

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

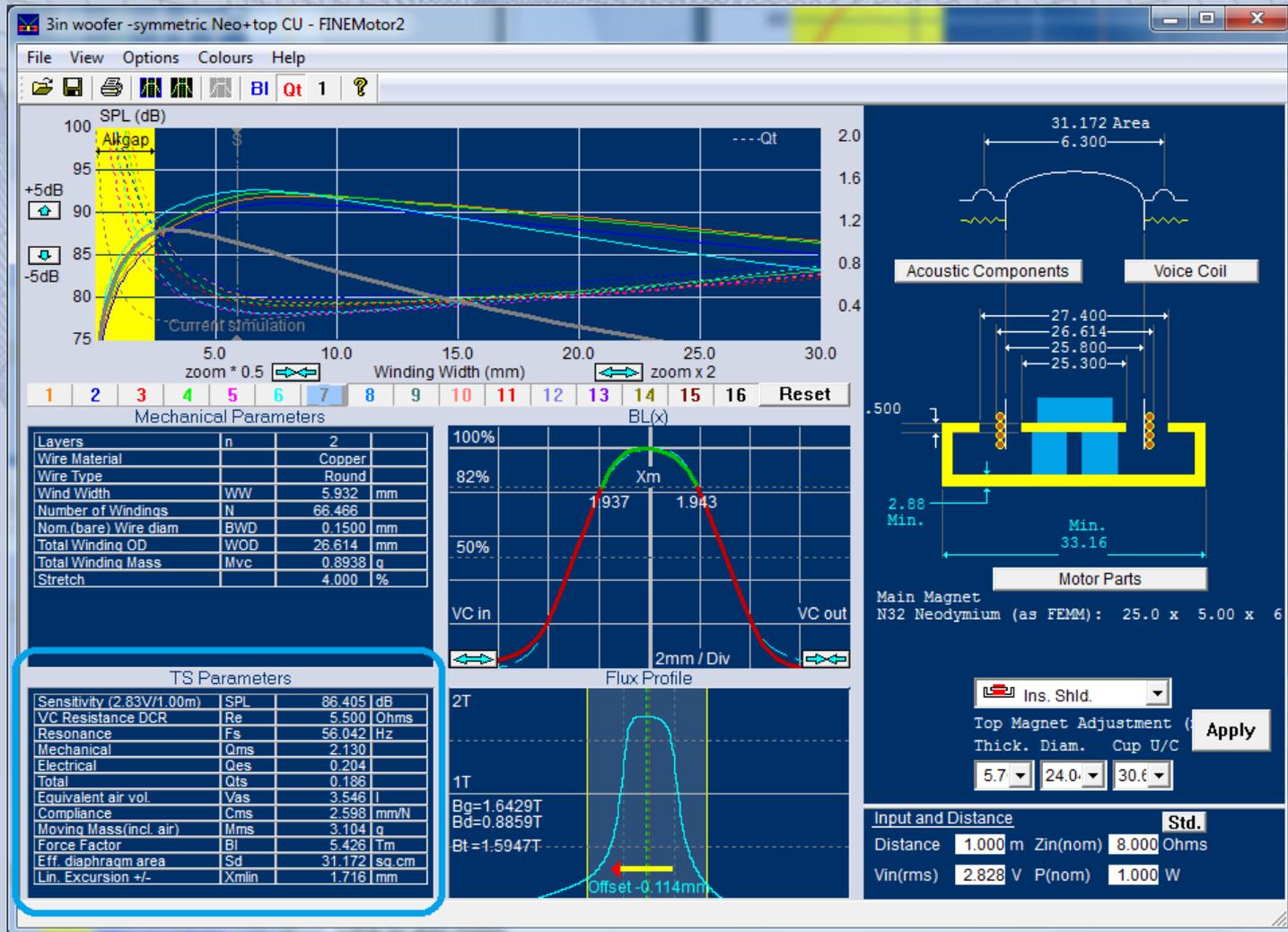
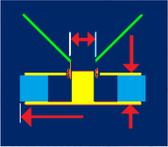
- 1.Cone Area: 136cm²
- 2.Cone Mass (incl. ½ surround): 11g
- 3.DCR: 3.0 R (Nominal impedance: 4 ohms)

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:

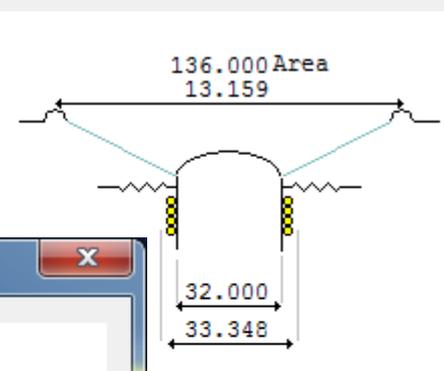
1. Target $X_{max} \sim 5\text{mm}$
2. Optimize TS Parameters ($Q_{ts} < 0.4$)
3. Optimize $BL(x)$ for Low Distortion



Initial input settings for example A

Acoustic Components

Effective Area	Sd	136.000	sq. cm
Effective Diameter	D	13.159	cm
Fixed Mass	Mms-Mvc	11.000	g
Specify Qms	Qms	3.000	
Estimate Qms (from VC Former mat.)	<input checked="" type="checkbox"/>	3.000	



136.000 Area
13.159

32.000
33.348

OK Apply Now

Voice Coil

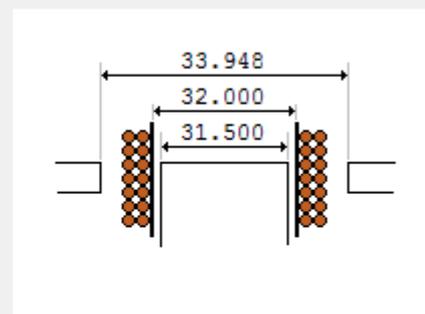
Wire Type: Round wire

Wire Material: Copper

Former Material: Aluminium

Note: Changing former material will adjust Qms

Voice Coil Resistance DCR	Re	3.000	Ohms
Voice Coil Inside Diameter	VCID	32.000	mm
Number of Layers	n	2	<input type="button" value="↑"/> <input type="button" value="↓"/>
Twin Coil	<input type="checkbox"/>	2 2	
Voice Coil Former Thickness		0.0500	mm
Wire Stretch		0.000	%

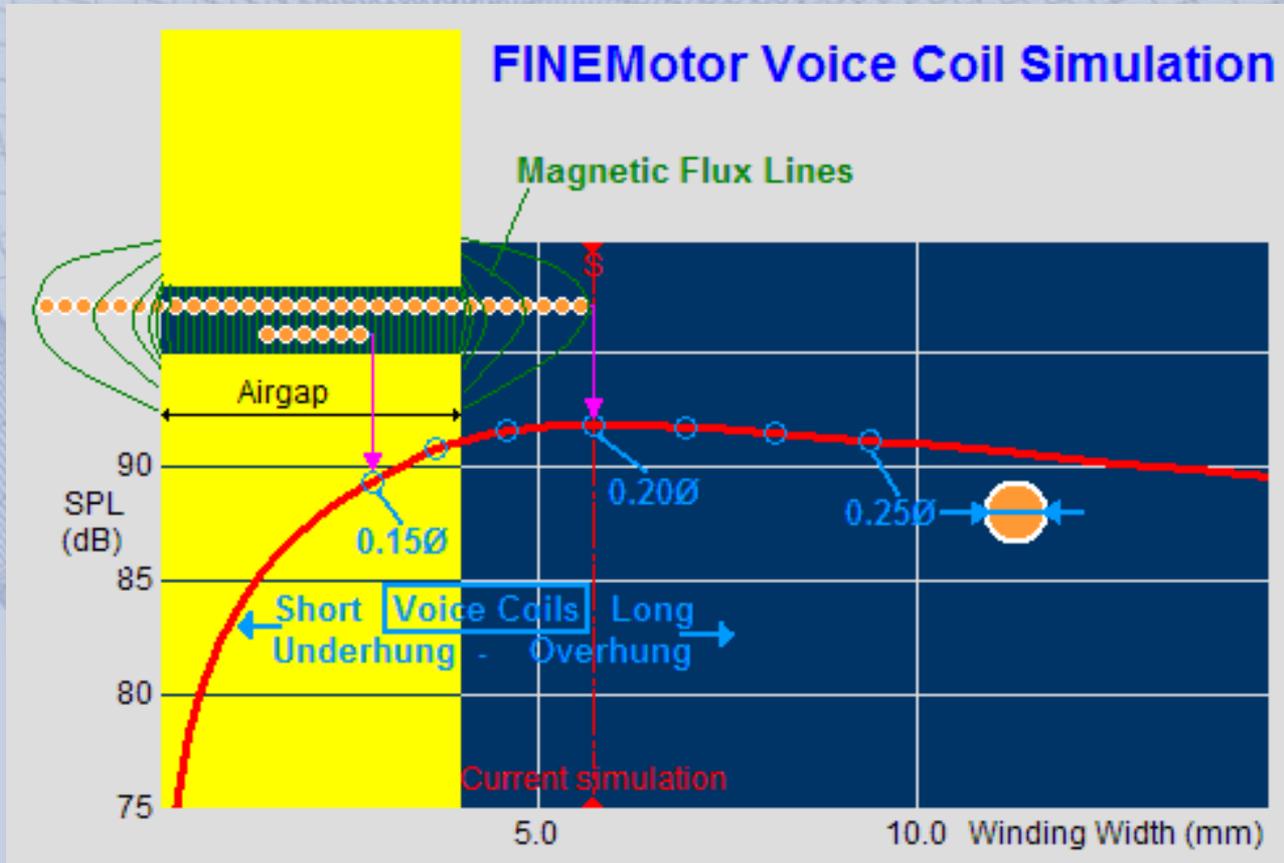


33.948
32.000
31.500

Cancel OK Apply Now

Ready

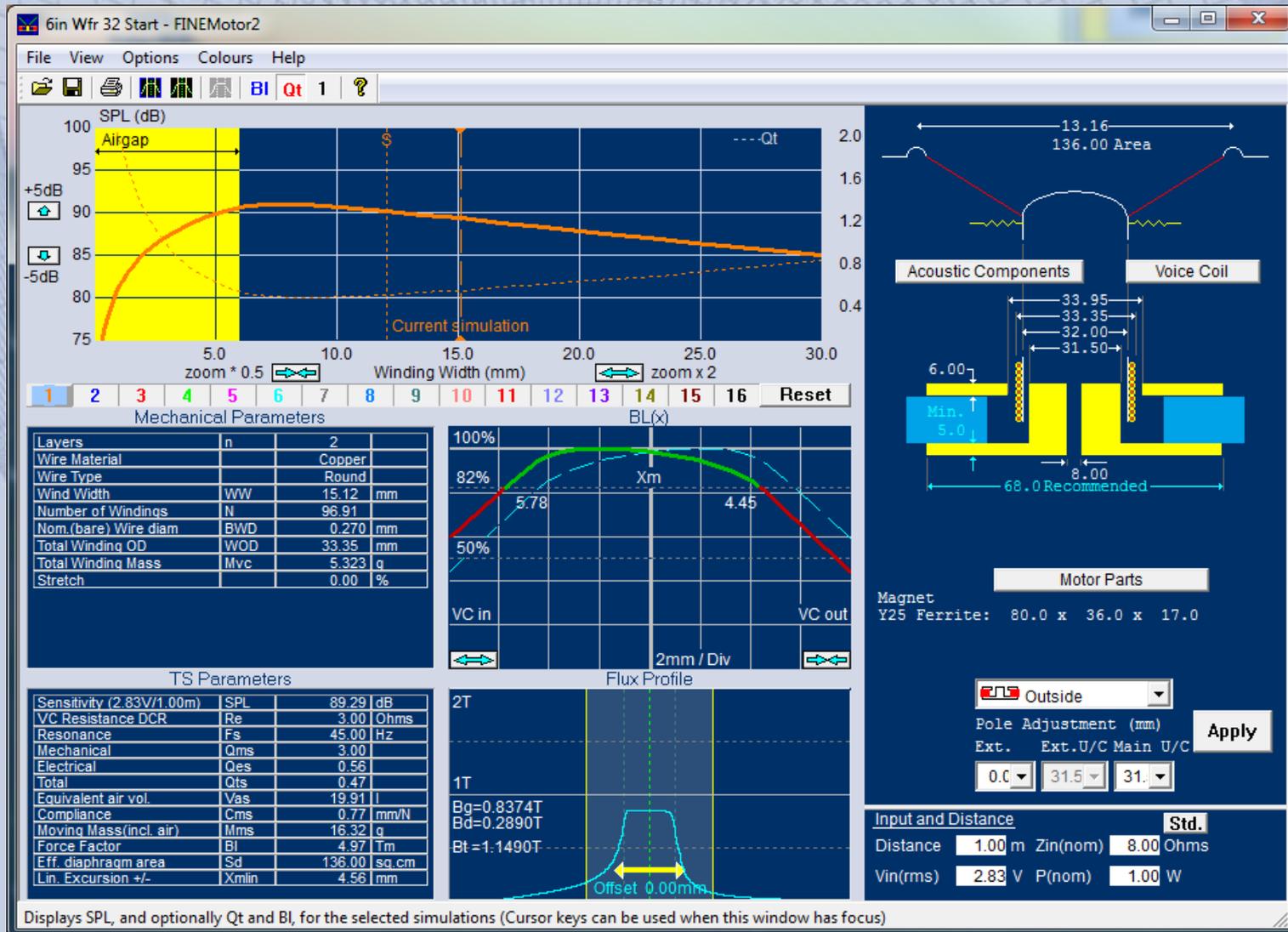
Calculated solutions based on Wire Diameters



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

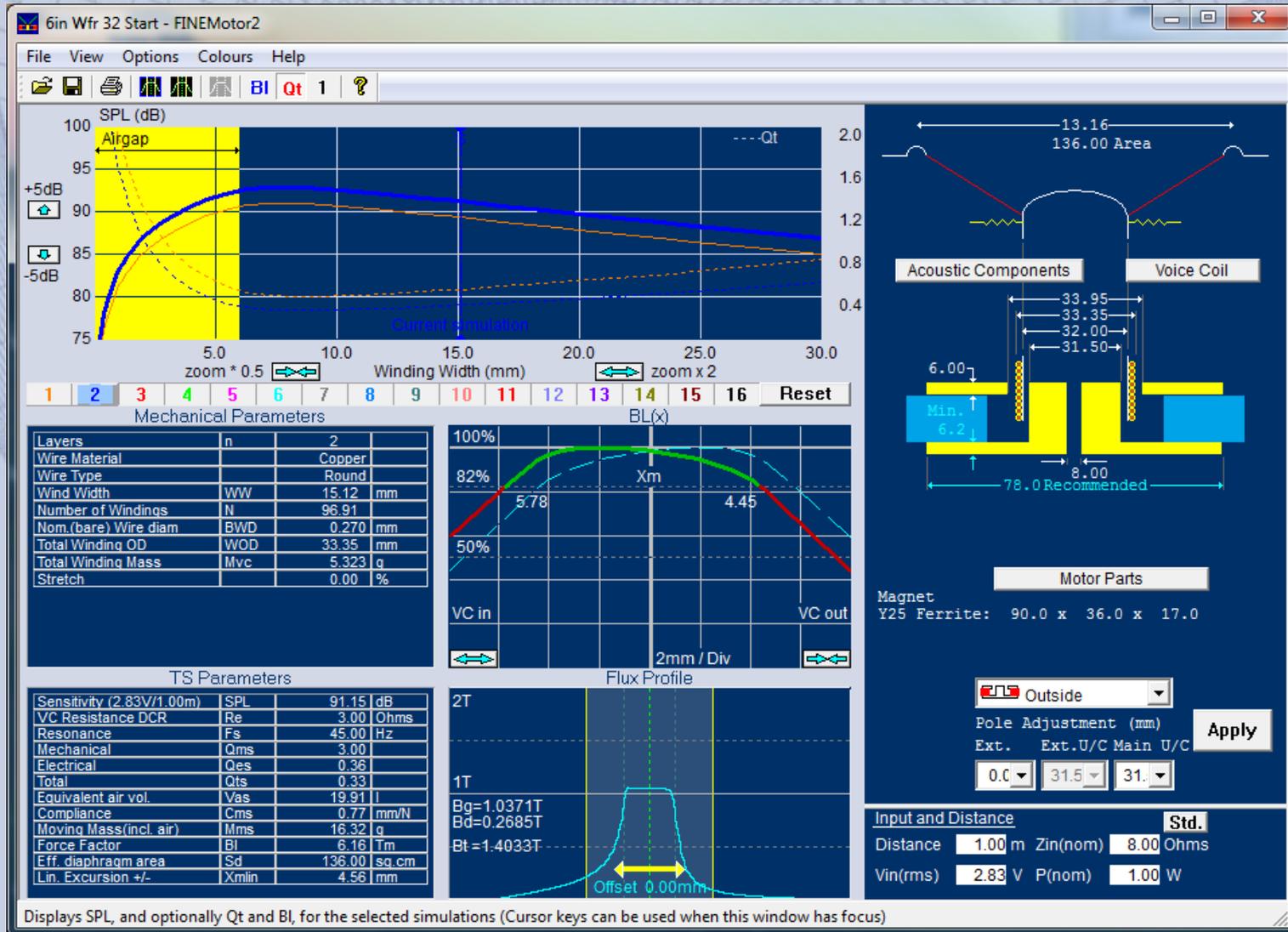


Now X_m is close to 5mm (OK). However $Q_{ts}=0.47$ is too high

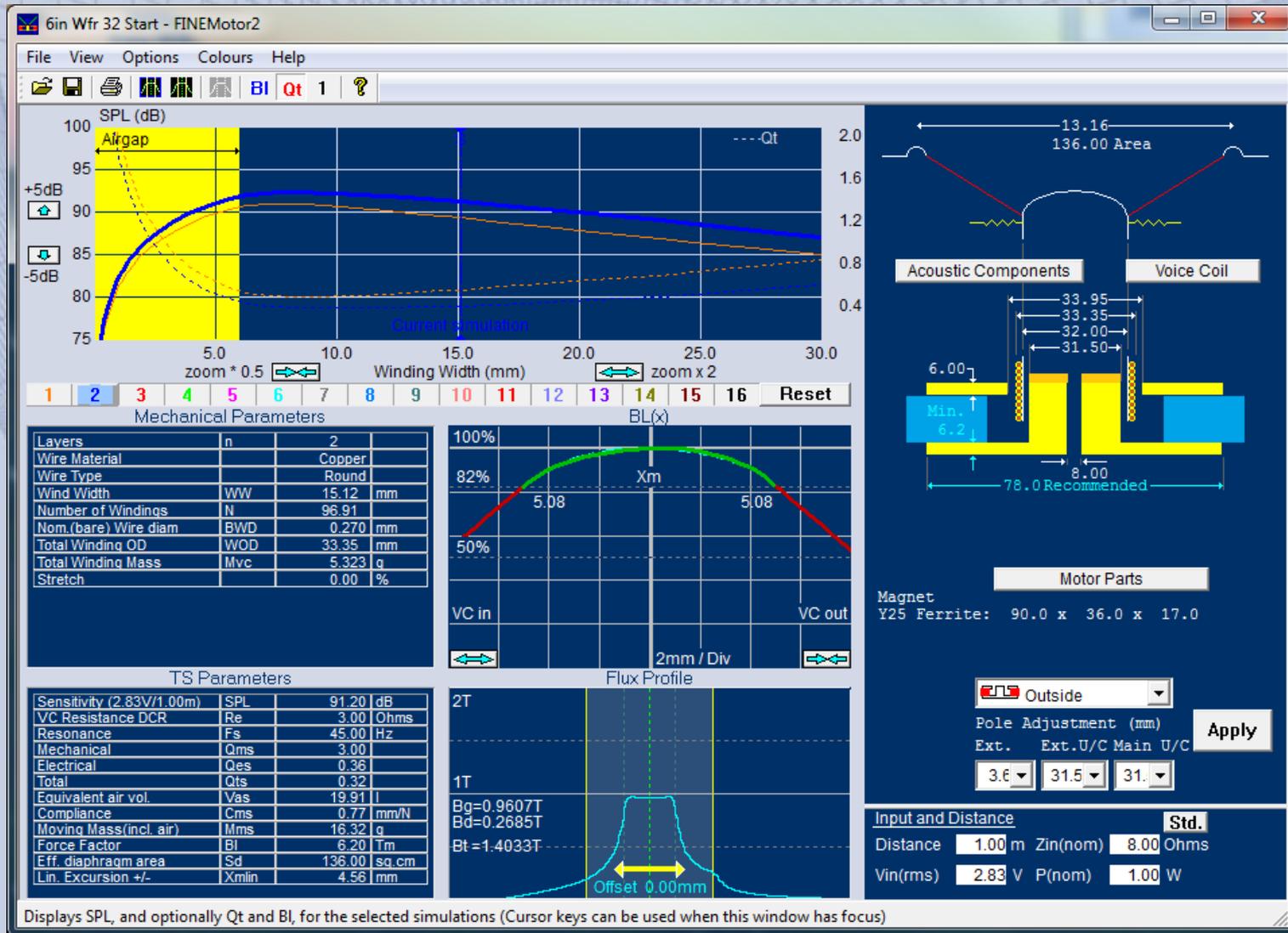


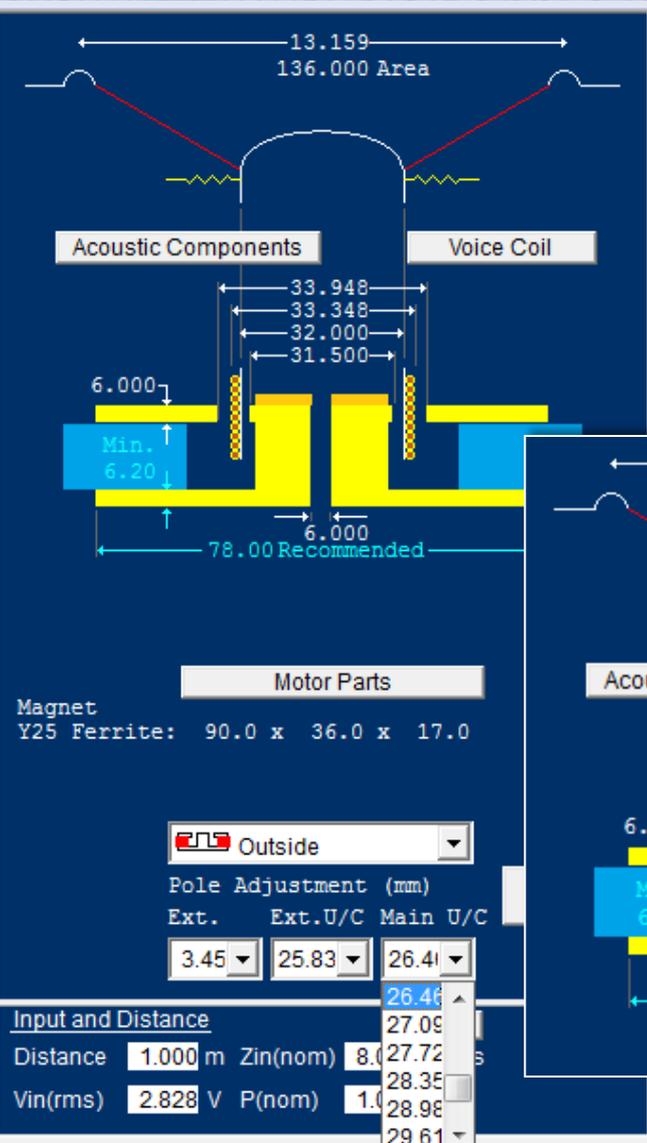
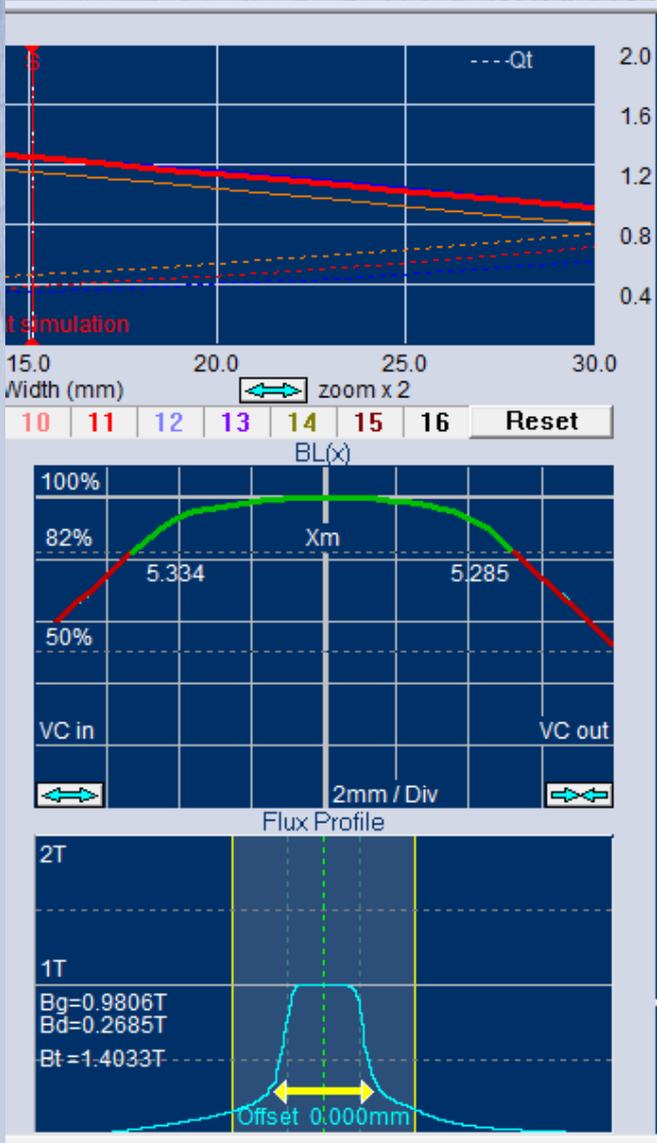
A larger 90x36x17 Y25 magnet gave $Q_{ts}=0.33$ 😊

But the BL(x) curve is NOT symmetrical or flat

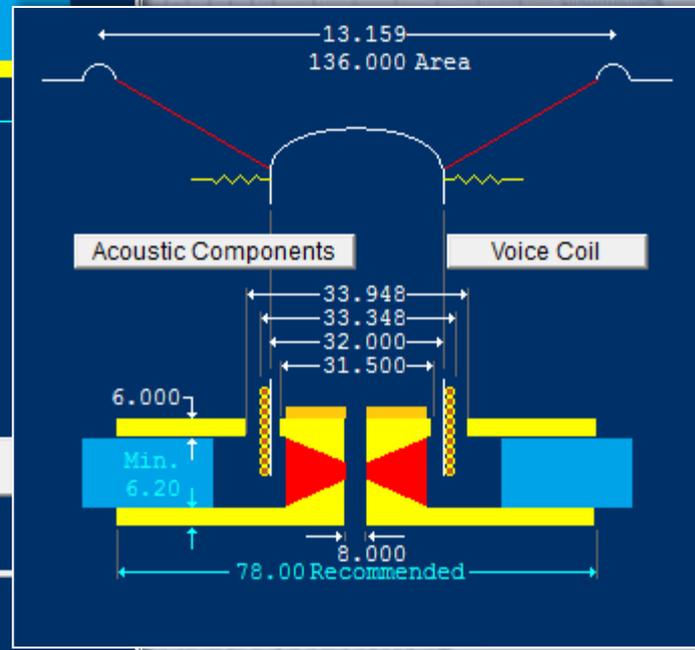


Extending the pole by 3.68mm produces a nice symmetric BL(x) curve, though not flat. But (IM) distortion will be reduced.



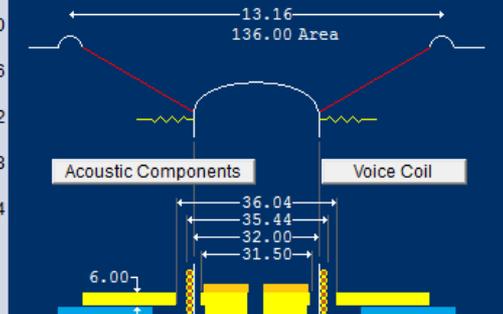
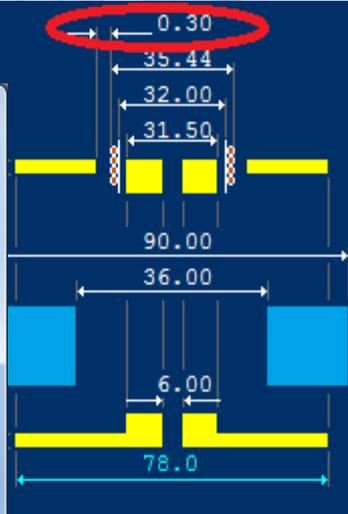
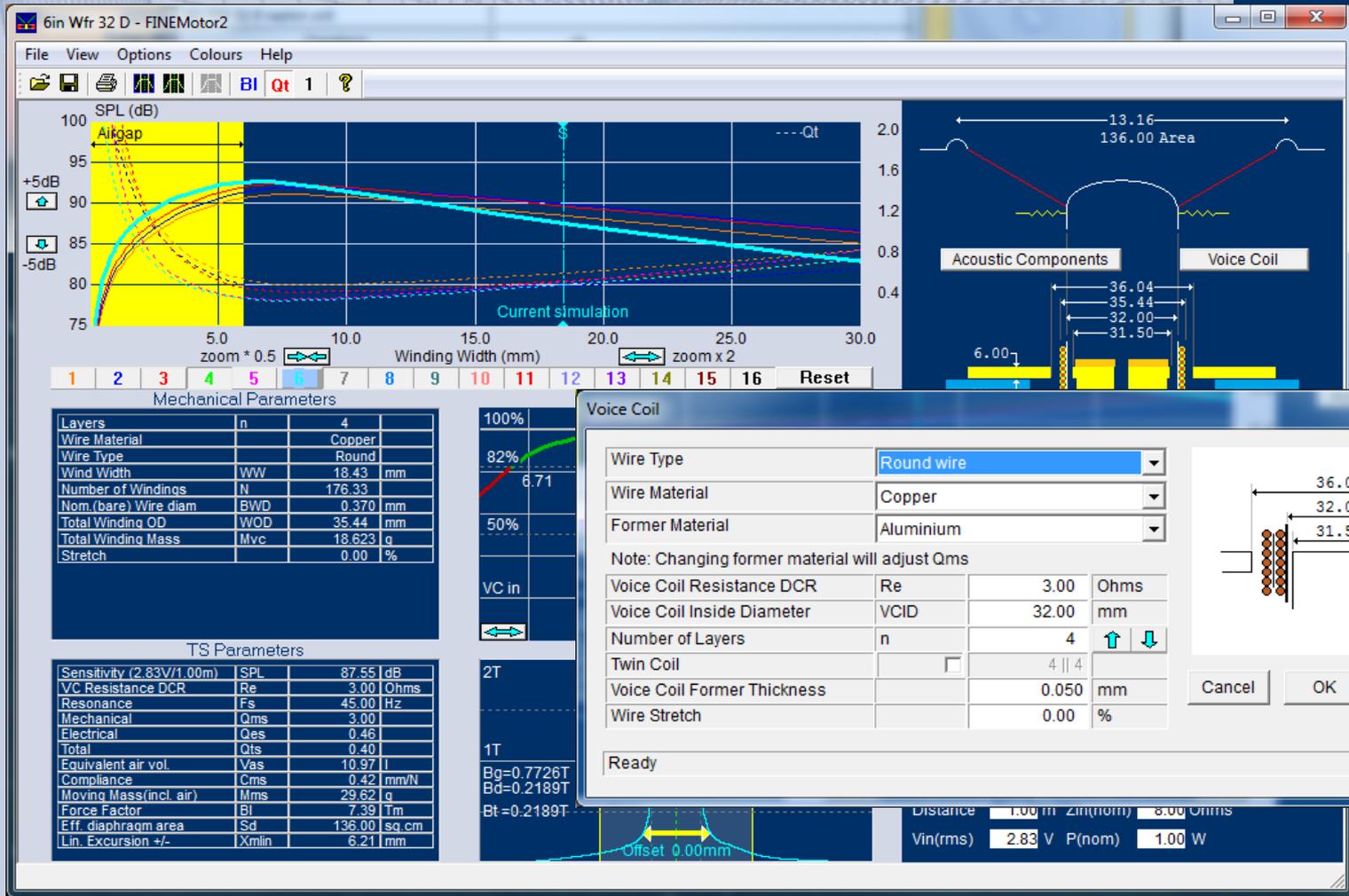


Pole with undercut under and above the air gap gave a flat and symmetric BL(x) curve.
=Woofer #1



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. $X_m = \pm 6.7\text{mm}$. Moving Mass M_{ms} up from 16.3 to 29.6g, = Woofer #2



Voice Coil

Wire Type: Round wire
 Wire Material: Copper
 Former Material: Aluminium

Note: Changing former material will adjust Qms

Voice Coil Resistance DCR	Re	3.00	Ohms
Voice Coil Inside Diameter	VCID	32.00	mm
Number of Layers	n	4	
Twin Coil	<input type="checkbox"/>	4 4	
Voice Coil Former Thickness		0.050	mm
Wire Stretch		0.00	%

Ready

Buttons: Cancel, OK, Apply Now

Distance: 1.00 in Zin(nom): 8.00 Ohms
 Vin(rms): 2.83 V P(nom): 1.00 W

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

3in woofer -symmetric Neo+top CU - FINEMotor2

File View Options Colours Help

BI Qt 1 ?

SPL (dB)

Winding Width (mm)

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 Reset

Mechanical Parameters

Layers	n	2
Wire Material		Copper
Wire Type		Round
Wind Width	WW	5.93 mm
Number of Windings	N	66.47
Nom.(bare) Wire diam	BWD	0.150 mm
Total Winding OD	WOD	26.61 mm
Total Winding Mass	Mvc	0.894 g
Stretch		4.00 %

TS Parameters

Sensitivity (2.83V/1.00m)	SPL	86.49 dB
VC Resistance DCR	Re	5.50 Ohms
Resonance	Fs	110.00 Hz
Mechanical	Qms	2.13
Electrical	Qes	0.39
Total	Qts	0.33
Equivalent air vol.	Vas	0.92 l
Compliance	Cms	0.67 mm/N
Moving Mass(incl. air)	Mms	3.10 g
Force Factor	Bl	5.48 Tm
Eff. diaphragm area	Sd	31.17 sq.cm
Lin. Excursion +/-	Xmlin	1.72 mm

BL(x)

VC in VC out

Flux Profile

2T 1T

Bg=1.6537T
Bd=0.8859T
Bt=1.5947T

Acoustic Components Voice Coil

31.17 Area
6.30

27.40
26.61
25.80
25.30

2.50
2.9 Min.
5.00
33.2 Min.

Motor Parts

Main Magnet
N32 Neodymium (as FEMM): 25.0 x 5.00 x 6.00

Ins. Shld.

Top Magnet Adjustment (mm)

Thick. Diam. Cup U/C

6.0 24.0 30.4

Input and Distance

Distance 1.00 m Zin(nom) 8.00 Ohms

Vin(rms) 2.83 V P(nom) 1.00 W

Displays SPL, and optionally Qt and BI, for the selected simulations (Cursor keys can be used when this window has focus)

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

3in woofer - Ferrite+back magnet-symmetric flat - FINEMotor2

File View Options Colours Help

BI Qt 1 ?

SPL (dB)

Winding Width (mm)

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 Reset

Mechanical Parameters

Layers	n	2
Wire Material		Copper
Wire Type		Round
Wind Width	WW	5.93 mm
Number of Windings	N	66.47
Nom. (bare) Wire diam	BWD	0.150 mm
Total Winding OD	WOD	26.61 mm
Total Winding Mass	Mvc	0.894 g
Stretch		4.00 %

TS Parameters

Sensitivity (2.83V/1.00m)	SPL	85.46 dB
VC Resistance DCR	Re	5.50 Ohms
Resonance	Fs	110.00 Hz
Mechanical	Qms	2.13
Electrical	Qes	0.50
Total	Qts	0.40
Equivalent air vol.	Vas	0.92 l
Compliance	Cms	0.67 mm/N
Moving Mass (incl. air)	Mms	3.10 g
Force Factor	Bl	4.87 Tm
Eff. diaphragm area	Sd	31.17 sq.cm
Lin. Excursion +/-	Xmlin	1.72 mm

BL(x)

VC in VC out

Flux Profile

2T

1T

Bg=1.5017T
Bd=0.2183T
Bt=1.9070T

Acoustic Components

Voice Coil

Motor Parts

Main Magnet: Y35 Ferrite: 72.0 x 32.0 x 12.0

Shielding Magnet: Y35 Ferrite: 72.0 x 32.0 x 12.0

Out. Shld.Mag Only

Pole Adjustment (mm)

Ext. Ext.U/C Main U/C

1.7 15.6 16.1

Apply

Input and Distance

Distance 1.00 m Zin(nom) 8.00 Ohms

Vin(rms) 2.83 V P(nom) 1.00 W

Displays SPL, and optionally Qt and BI, for the selected simulations (Cursor keys can be used when this window has focus)

Question:

Which parameter influences Q_{ts} most?

M_{ms} (Moving mass, R_e (DCR) or BL (Force factor)



Feedback from You: Qts

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

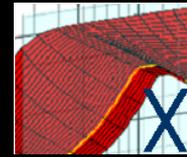
$$1/Qts = 1/Qms + 1/Qes$$

$Qes < Qms$ (typically $0.4 < 5$)

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

Answer is BL

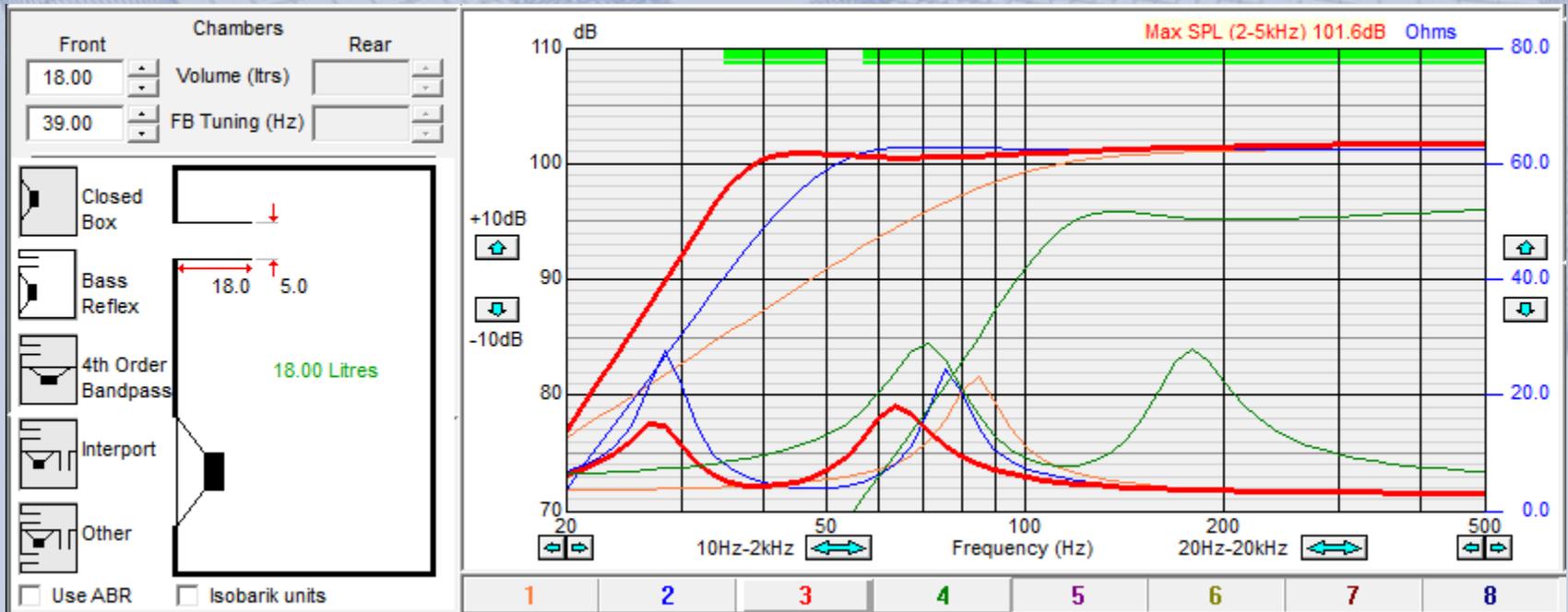
Bass Alignments in Box @ High Power



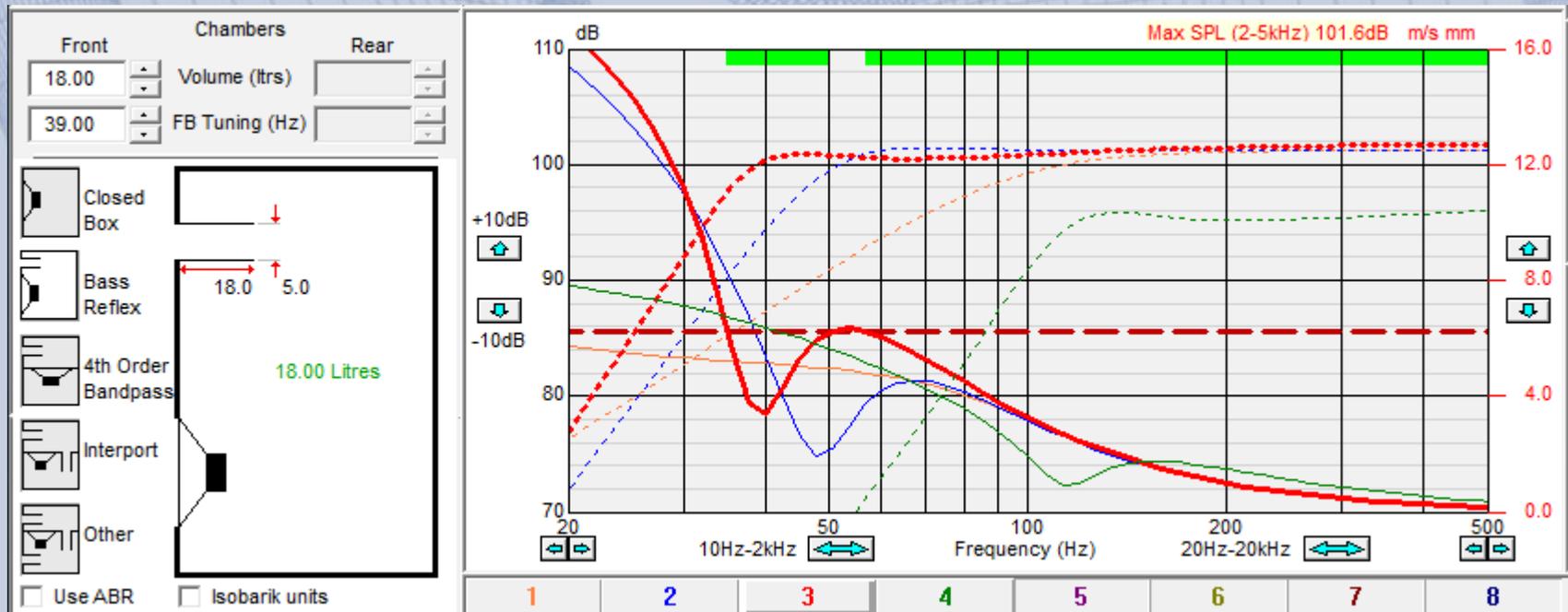
Next we will study how the designed woofers will behave in cabinets of different sizes and tuning. The effect of high input power will be included.

The 3 example drivers were imported into the FINEBox program:

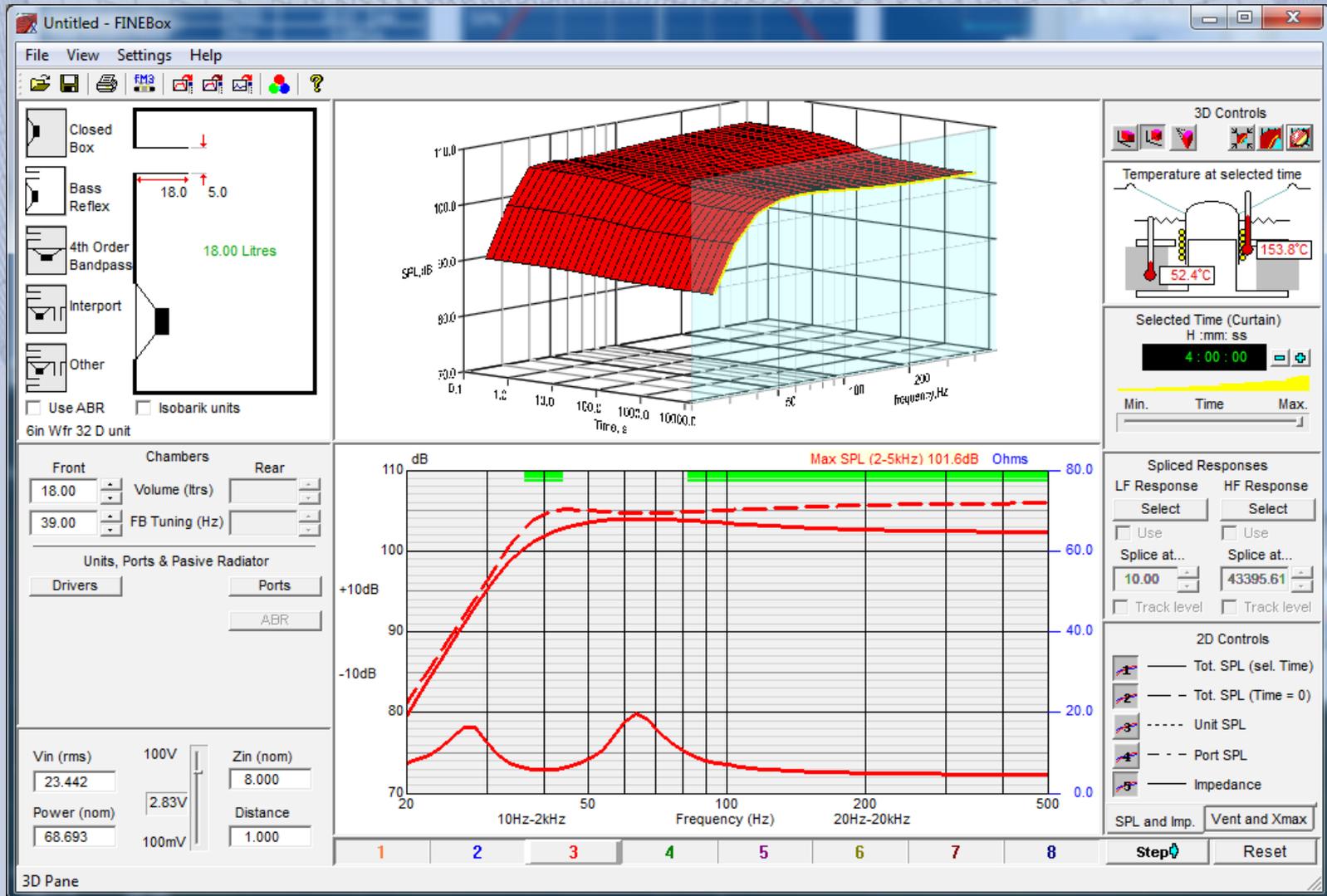
1. Woofer #1 in 8 Ltr. closed box
 2. Woofer #1 in 18 ltr. Bass Reflex, tuned to $F_b = 48\text{Hz}$
 3. Woofer #2 in 18 ltr. Bass Reflex, tuned to $F_b = 39\text{Hz}$
 4. Woofer #3 in 1 ltr. Bass Reflex, tuned to $F_b = 115\text{Hz}$
- #3 has more bass extension, due to more mass and BL.



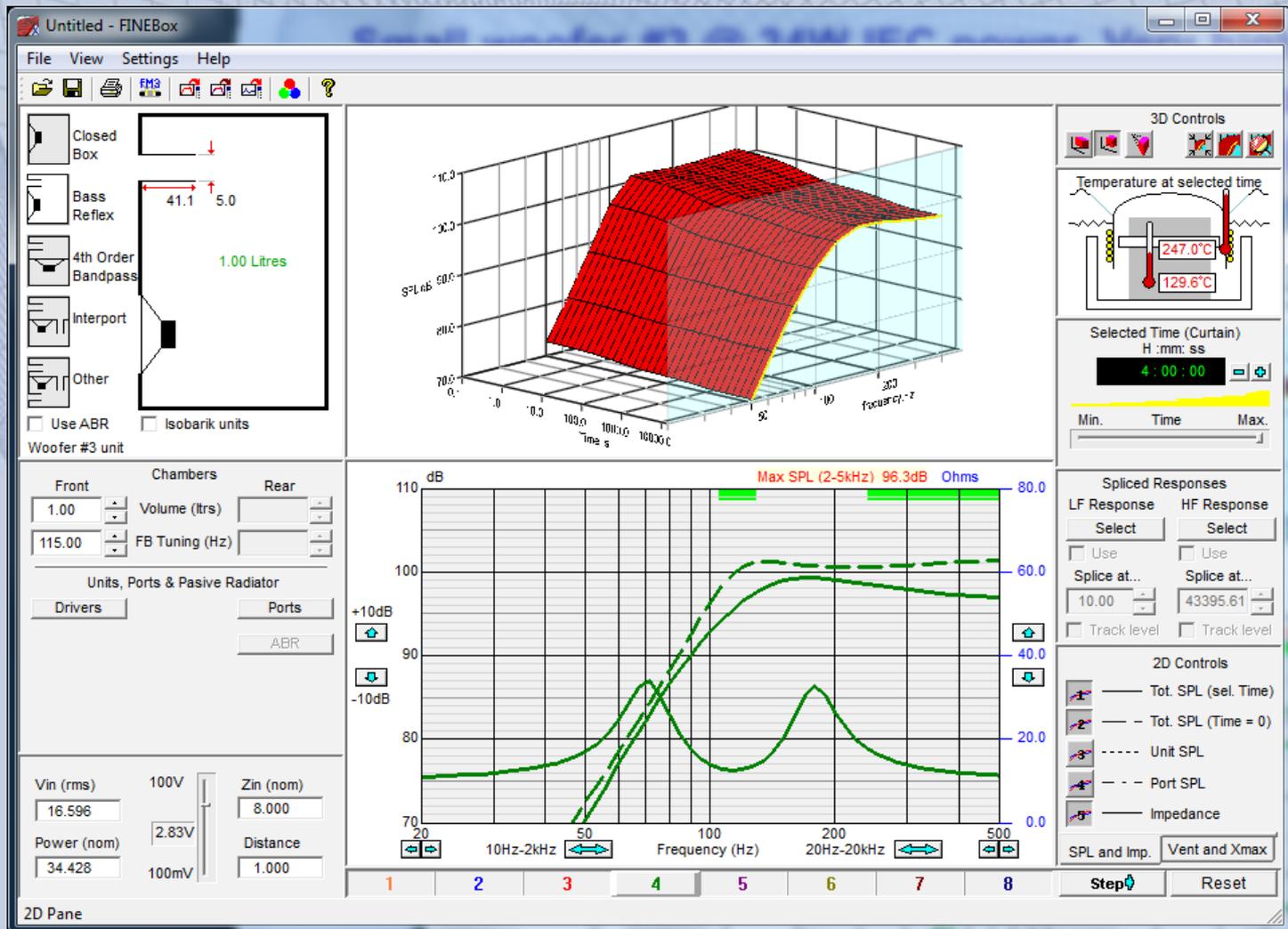
Bass Reflex Woofer Displacement reaching Xmax of woofer #2. LF rise to be filtered.



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



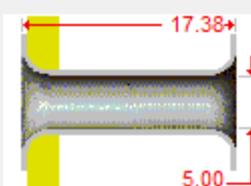
Small woofer #3 @ 34W IEC power. Very high Power Compression, and the Voice Coil is 247 deg. C = Overload! The neodymium magnet is probably demagnetized @ 129 deg. C



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

Port Parameters

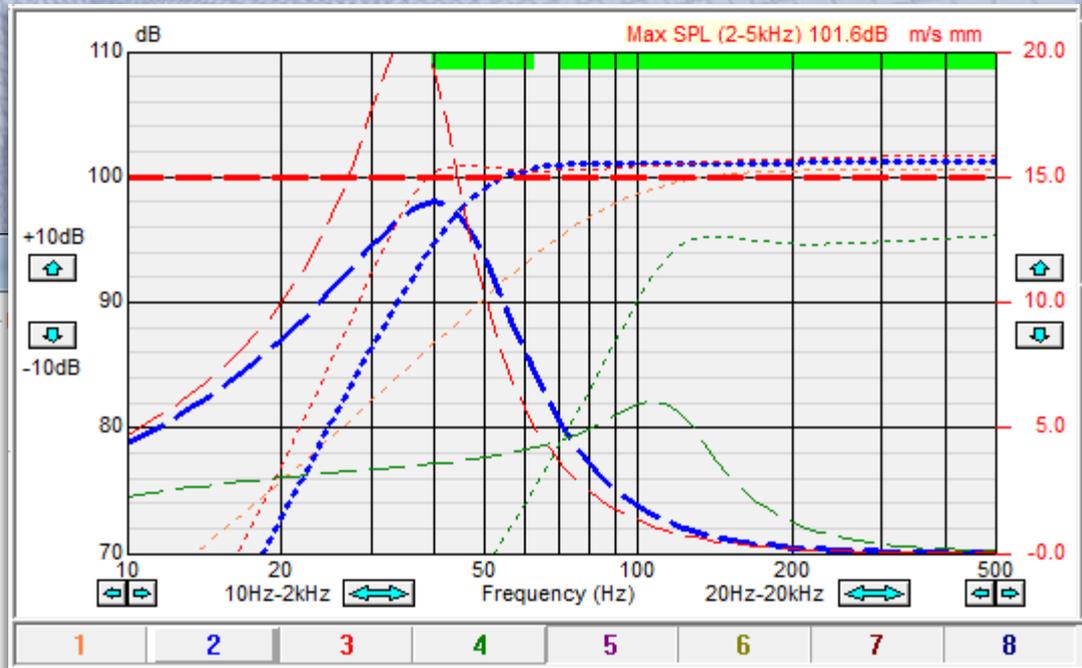
Reflex Port



End Correction

- Normal
- Flanged
- Simple
- Ideal

Chamber Tuning	39.00	Hz
Port Length	17.38	cm
Port Diameter	5.00	cm



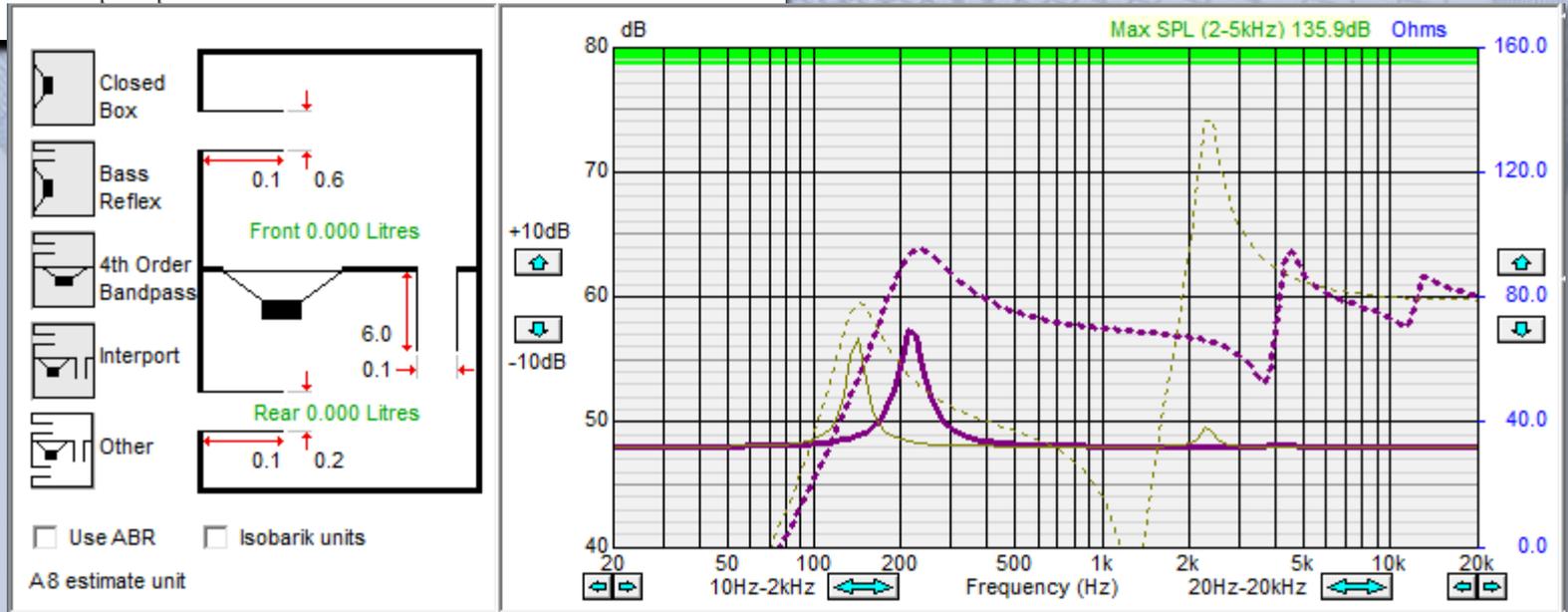
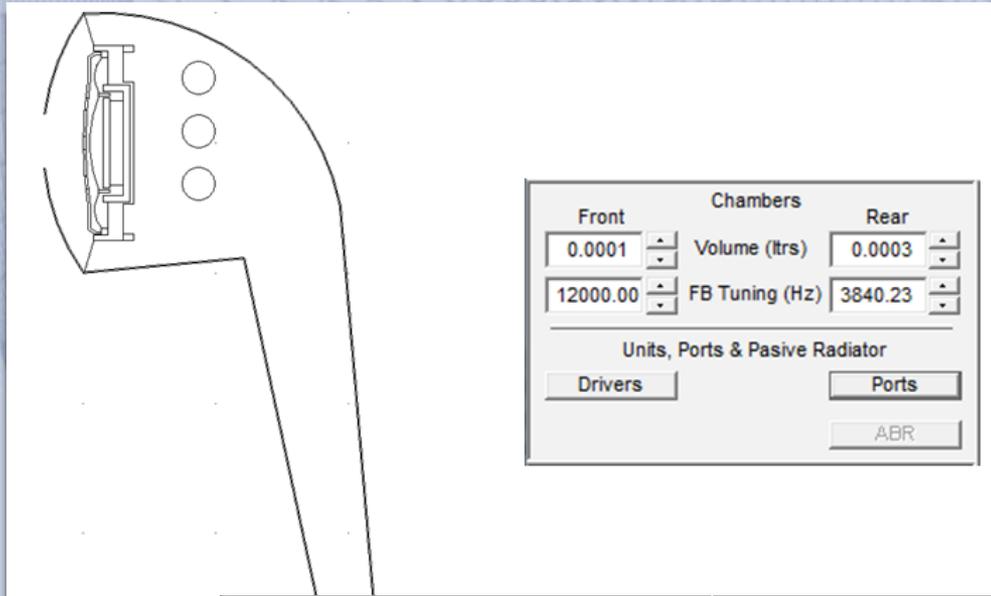
OK

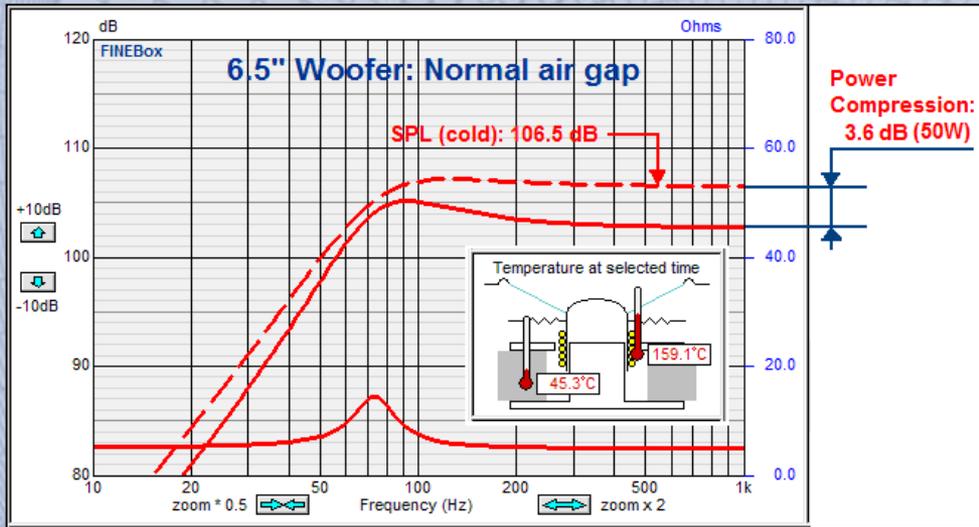
Cancel

HEADPHONE DESIGN

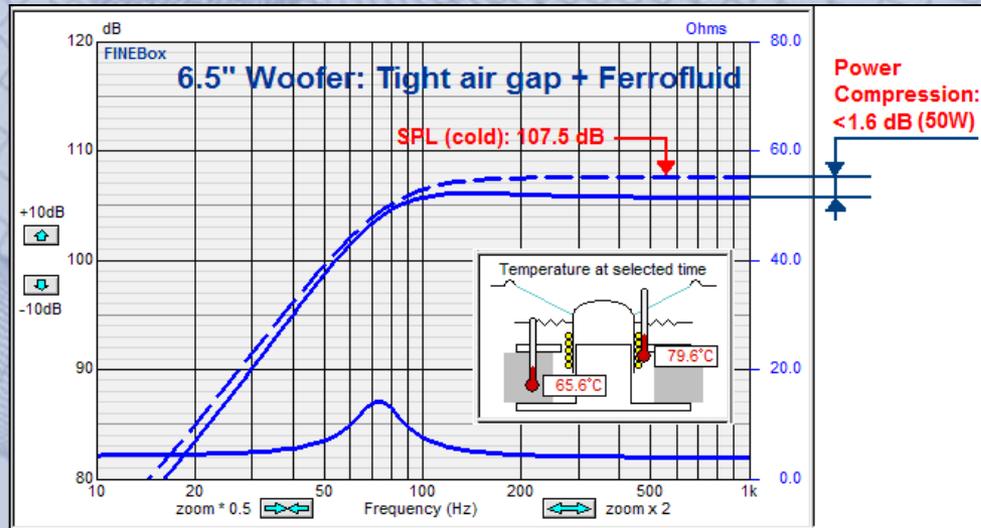
Simplified lumped element simulation of Headphone /Earphone with cavities and holes/channels.

(Infinite baffle: No Coupler or Artificial Ear).



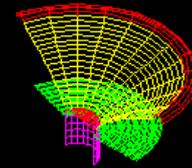


Calculated Compression of 6½" Woofer



Reduced Compression with Ferrofluid + Tighter Air gap

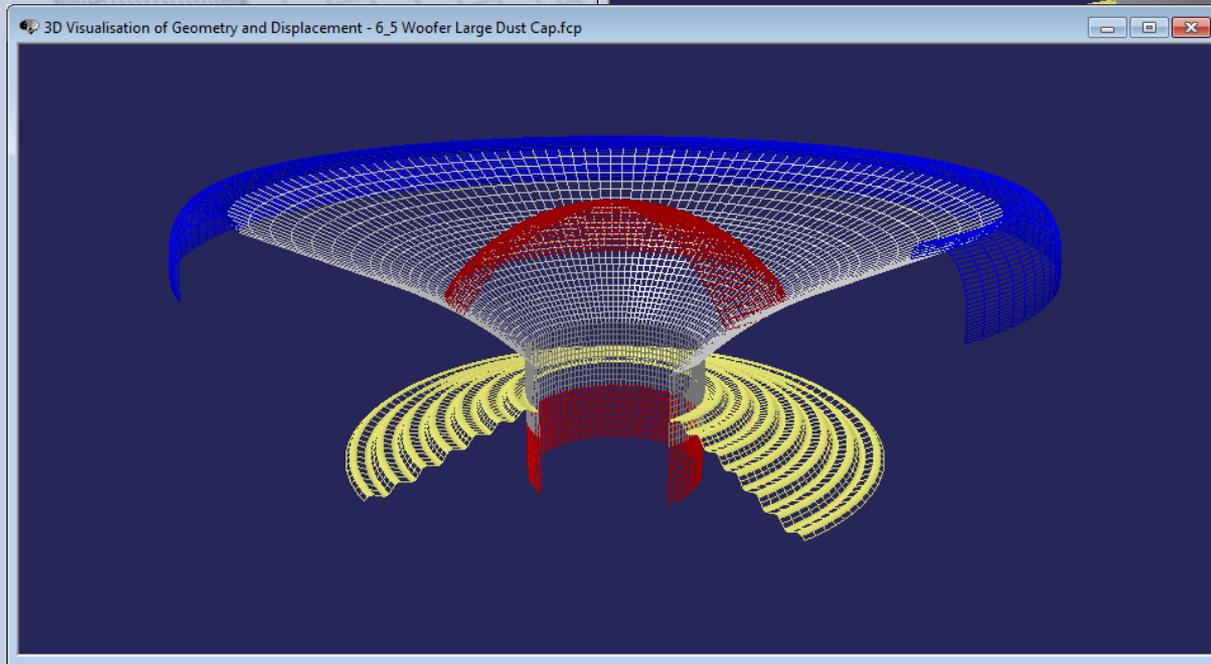
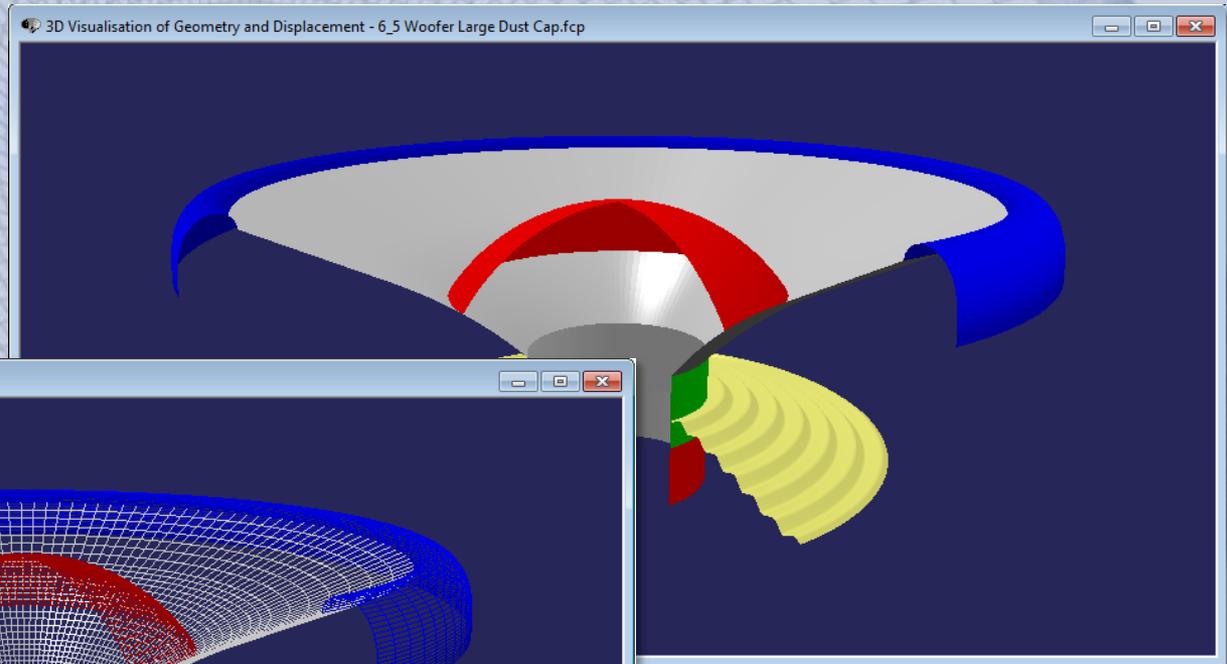
Cone Designs and Problems



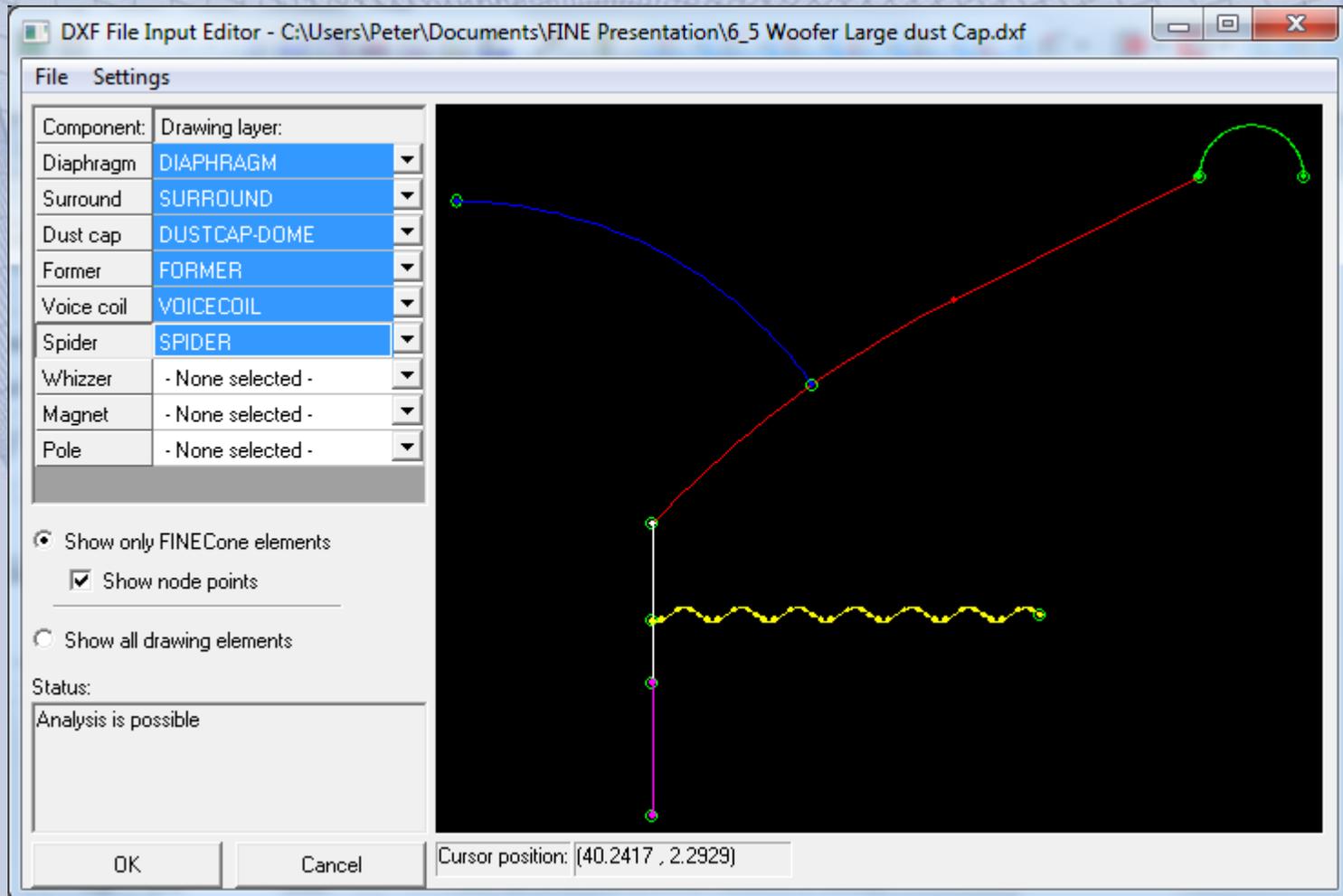
Cone design used to be a challenge based on trial and error.

Today we can quickly simulate with the help of FEM and gain insight into the mechanical and acoustical behaviour 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 Material properties

Select component: **Diaphragm**

Select segment(s) in component:

Number:	Type:	Start point	End point	Mass, g
1	Arc	(16.25, 28.18)	(29.50, 39.82)	1.02
2	Arc	(29.50, 39.82)	(41.23, 46.97)	1.23
3	Line	(41.23, 46.97)	(61.50, 57.30)	2.97

Properties for selected segment(s):

Thickness (h): mm FEM mass:

Material properties:

Description:

Young's Modulus (E): MPa

Mass density (rho): kg/m

Poisson's number (nu):

Damping (delta):

Material Editor

List of materials in database:

Description:	Young's	Density	Poisson	Damping
PEI	2.000e+009	2468.000	0.330	0.001
PP (filled, talc)	3.000e+009	1300.000	0.330	0.010
PP copolymer	1.400e+009	910.000	0.330	0.010
PP homopolymer	2.300e+009	1000.000	0.330	0.010
PU foil	6.000e+007	1100.000	0.330	0.010
Paper (coated)	6.000e+009	683.000	0.330	0.020
Paper DS-DKM-Ku...	2.500e+009	456.000	0.330	0.010
Paper N-DKM-Kurt...	3.000e+009	555.000	0.330	0.015

Properties of active material:

Description:

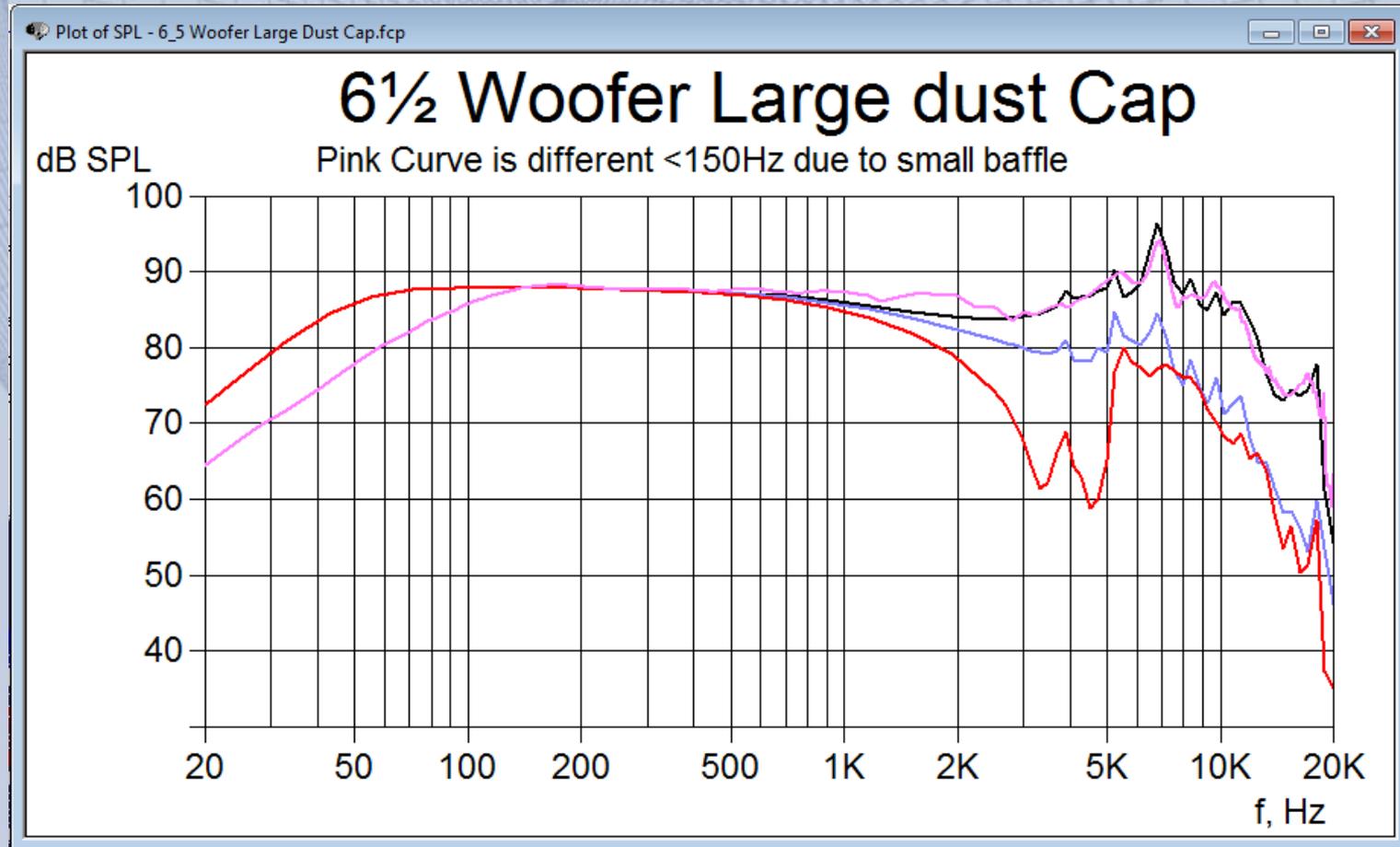
Young's Modulus (E): MPa

Mass Density: kg/m²

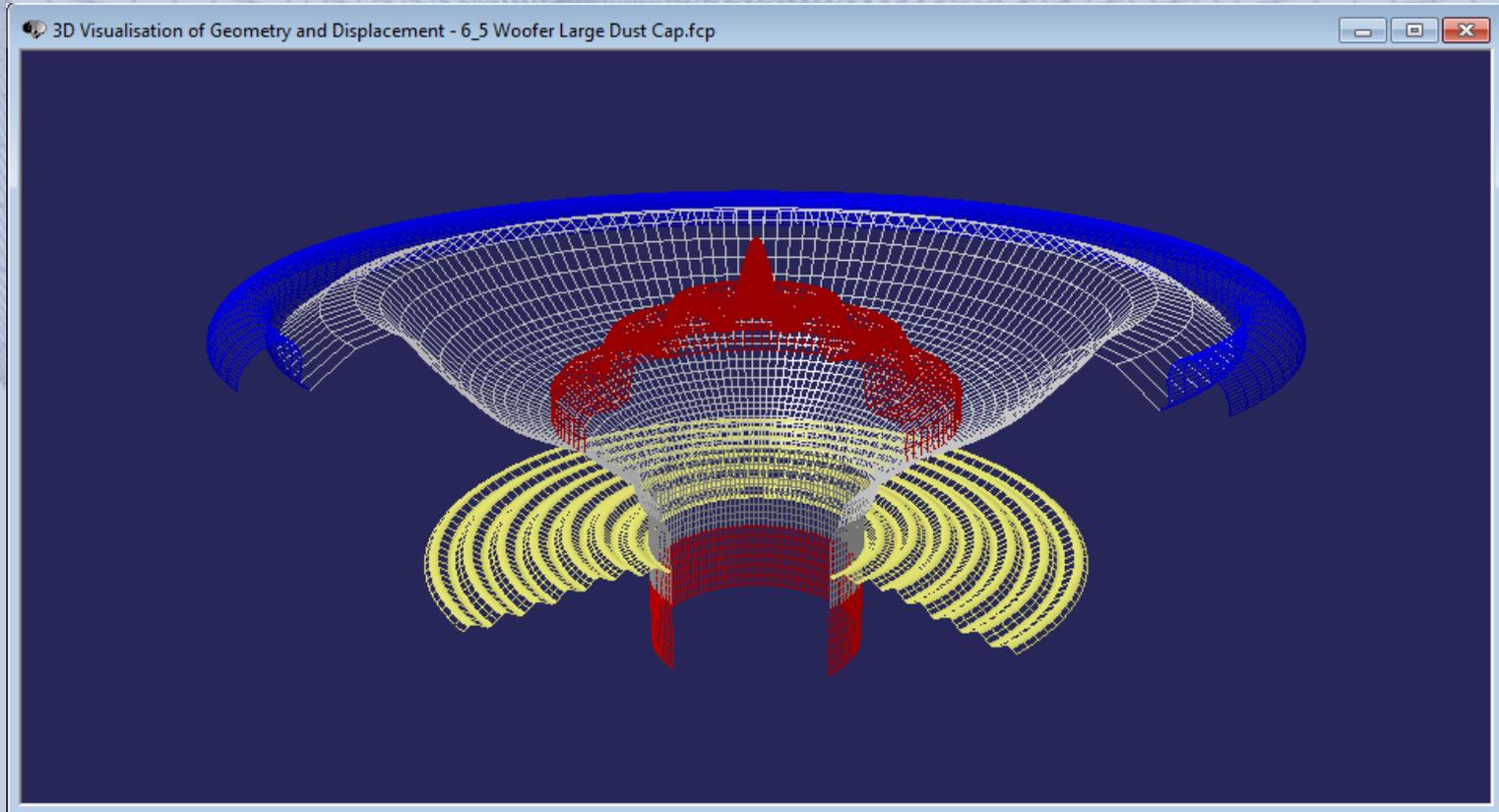
Poisson's number:

Damping (delta):

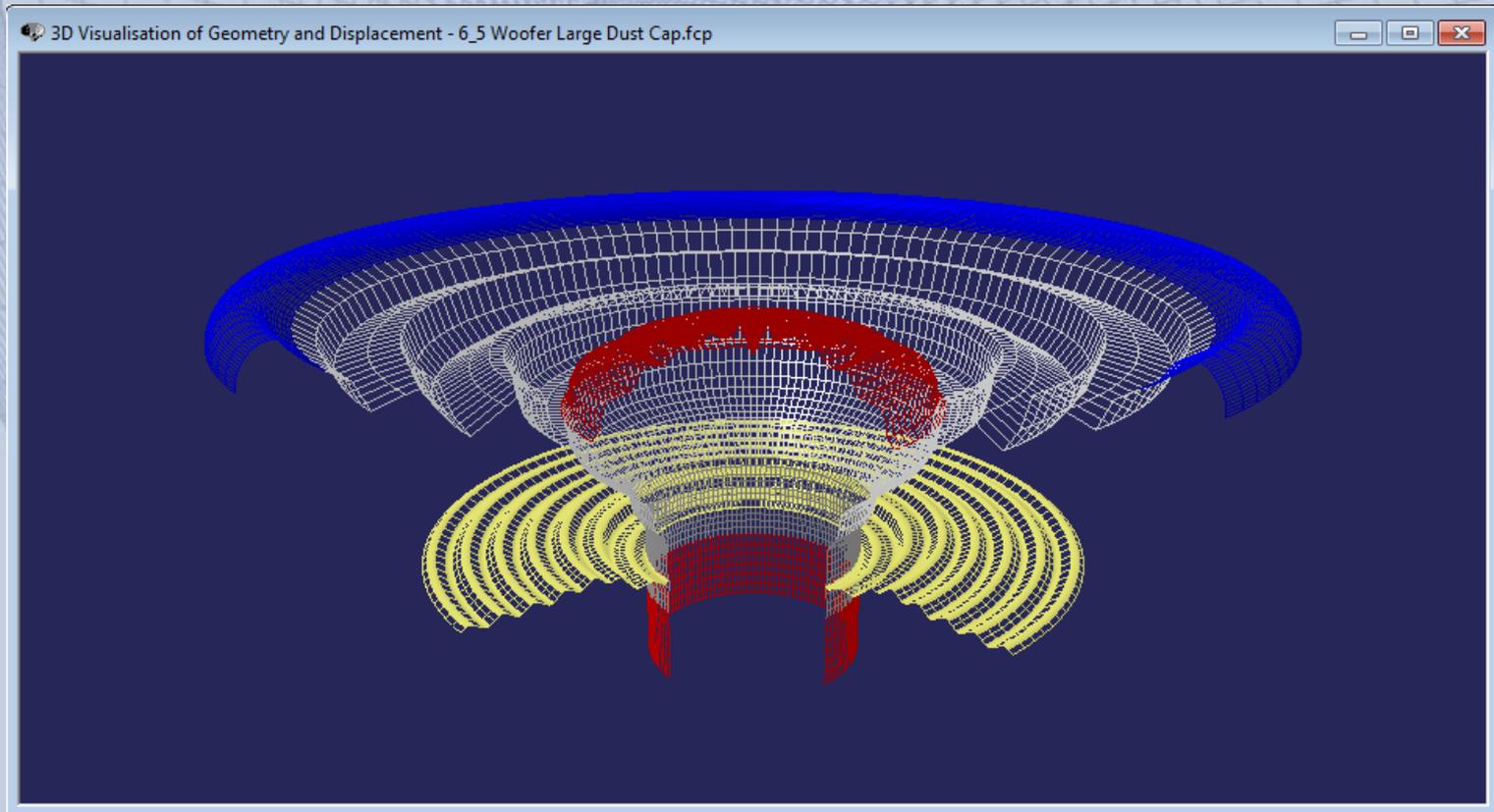
FEM simulated 0 ___ /30 ___ /60 ___ deg. frequency responses of 6½” Woofer, compared to actual measurement ___. The agreement is quite good, especially at high frequencies.



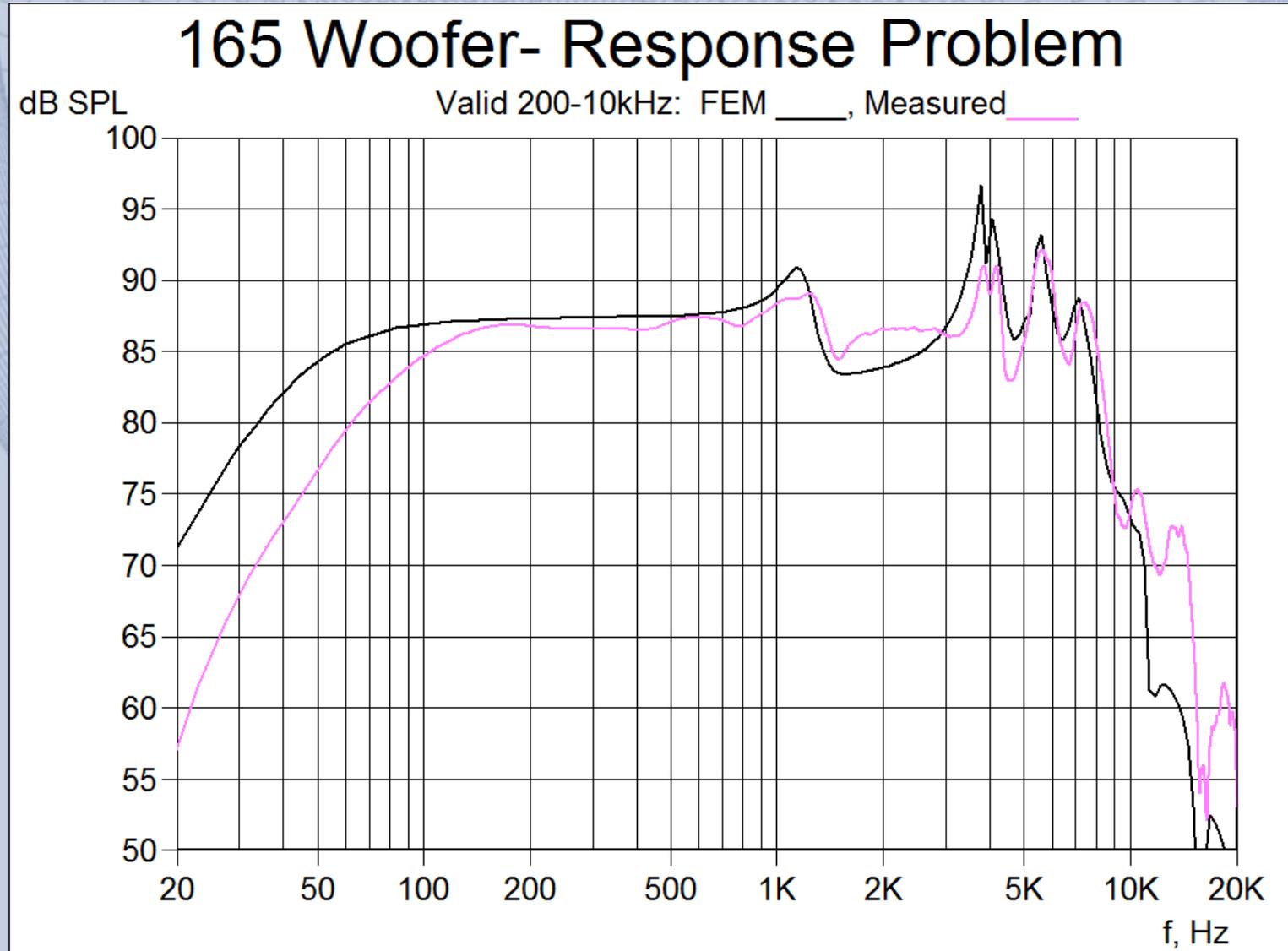
Cone and Dust cap Break-up of 6½" woofer @ 6804 Hz. The outer half of the cone shows the 1st cone mode, and the dust cap has high order break-up



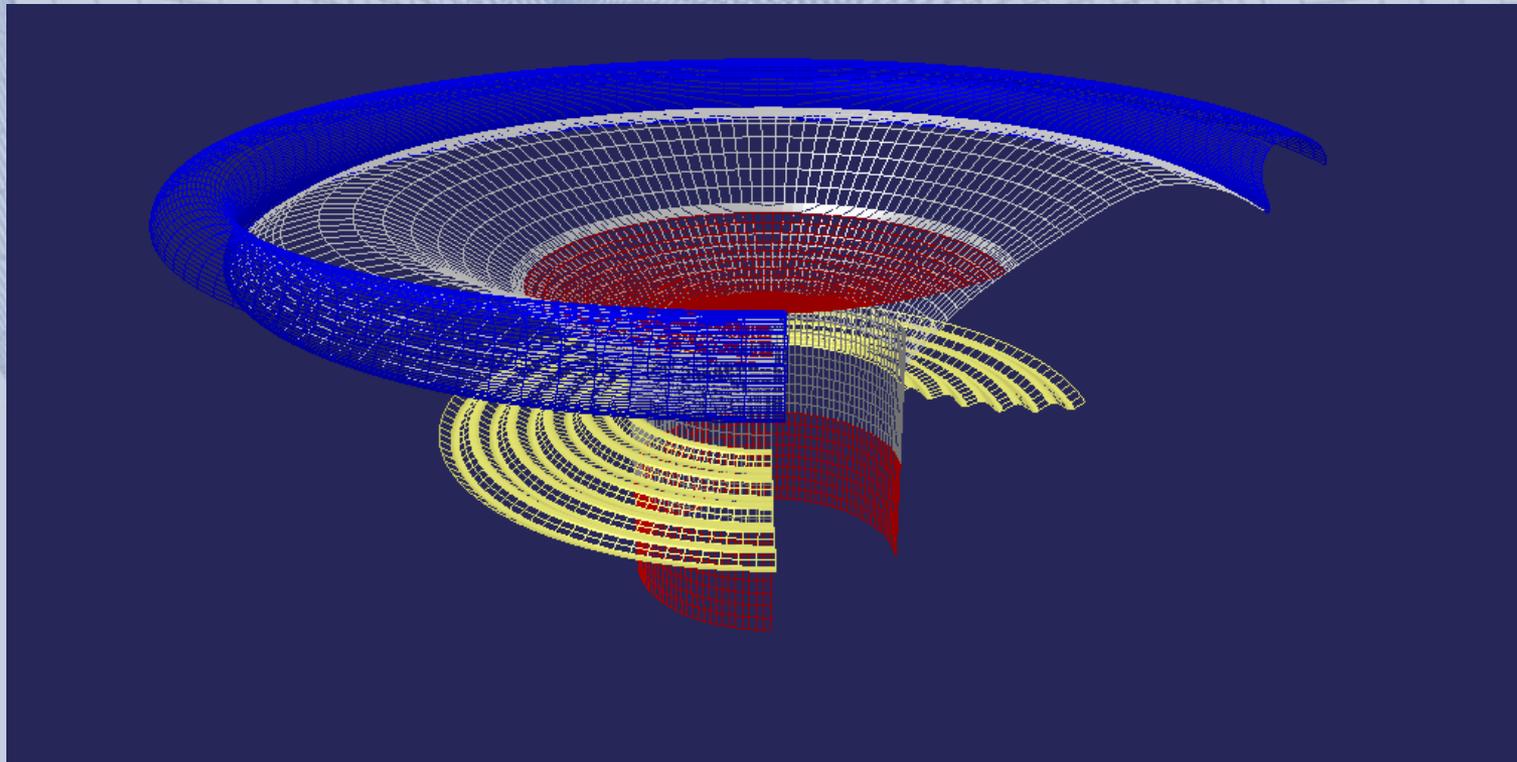
High order break-up of 6½” woofer @ 13623 Hz. The cone break-up has just reached the Voice Coil former.



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



FEM Material properties

Select component: Surround

Select segment(s) in component: _____

Number:	Type:	Start point	End point	Mass, g
1	Line	(58.25, 58.12)	(58.70, 58.26)	0.259790
2	Arc	(58.70, 58.26)	(59.07, 60.11)	1.054106
3	Arc	(59.07, 60.11)	(60.15, 61.70)	1.082631
4	Arc	(60.15, 61.70)	(61.99, 62.82)	0.500577
5	Arc	(61.99, 62.82)	(68.30, 58.26)	2.253803

Properties for selected segment(s): _____

Thickness (h): 1.000000 mm FEM mass: 5.150906

Material properties:

Description: Generic

Young's Modulus (E): 2.000 MPa

Mass density (rho): 1500.000 kg/m

Poisson's number (nu): 0.480000

Damping (delta): 0.015000

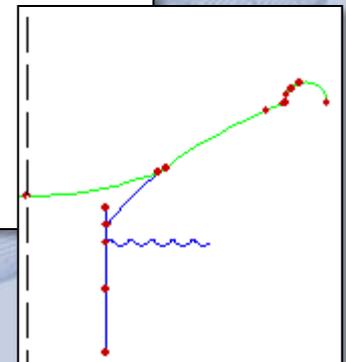
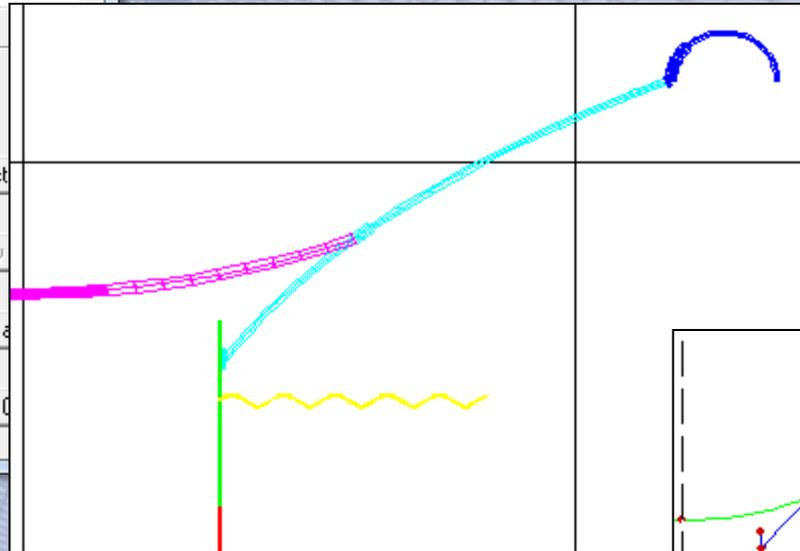
Set as project

Apply

Material De

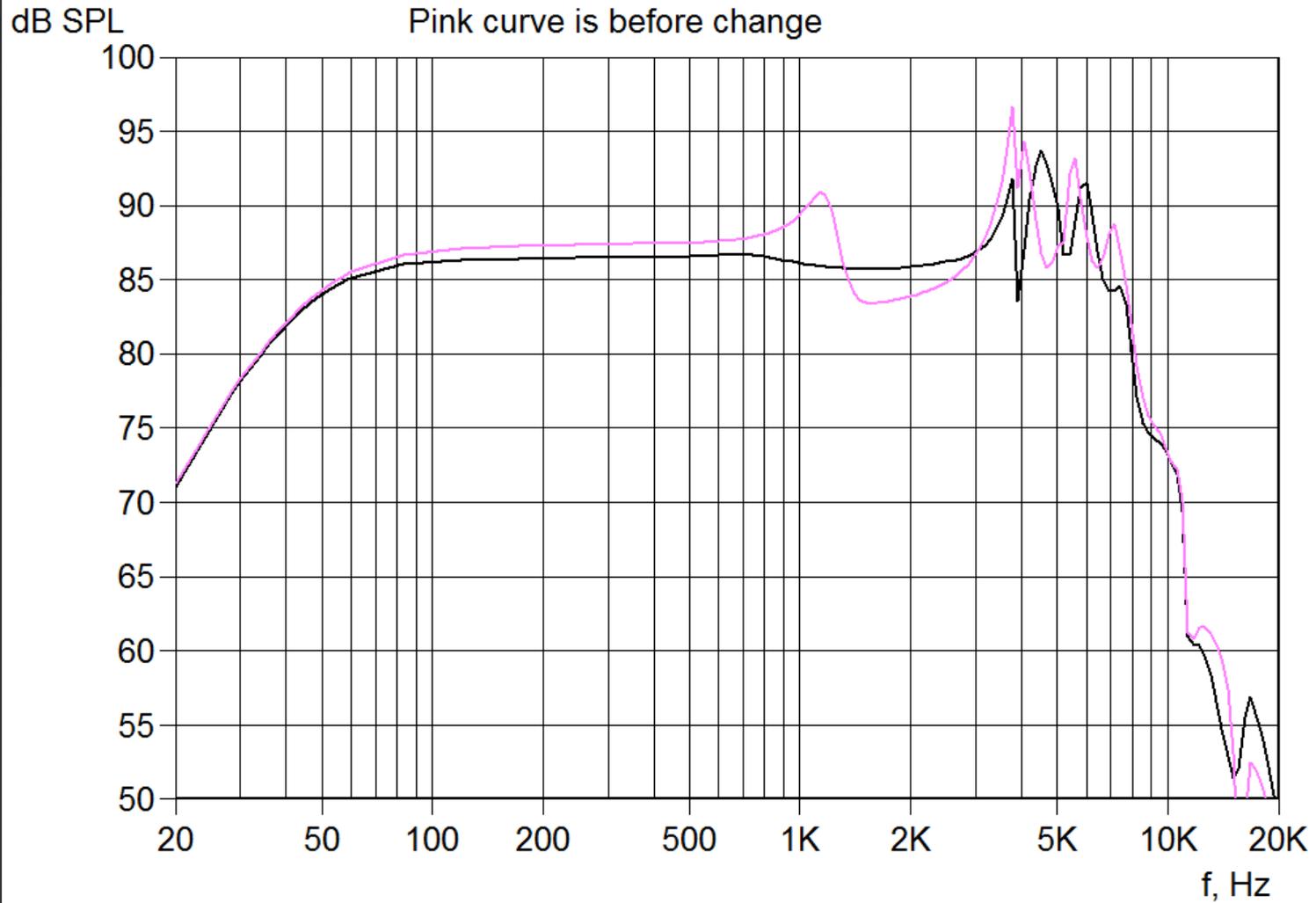
OK

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

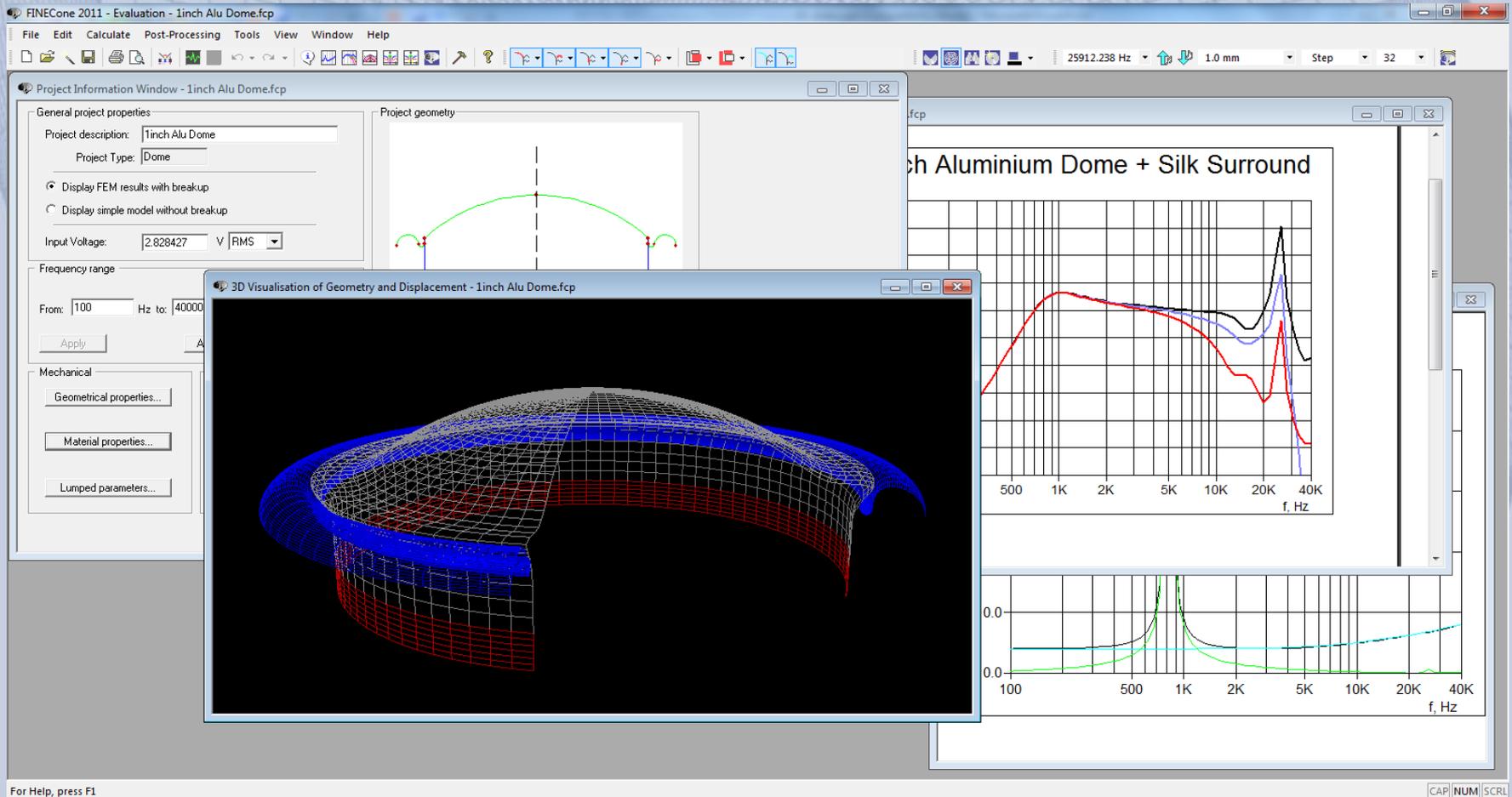


FEM simulated solution _____ / before _____

165 Woofer + Modified Surround



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 (2π) versus Anechoic (4π) Loudspeaker response

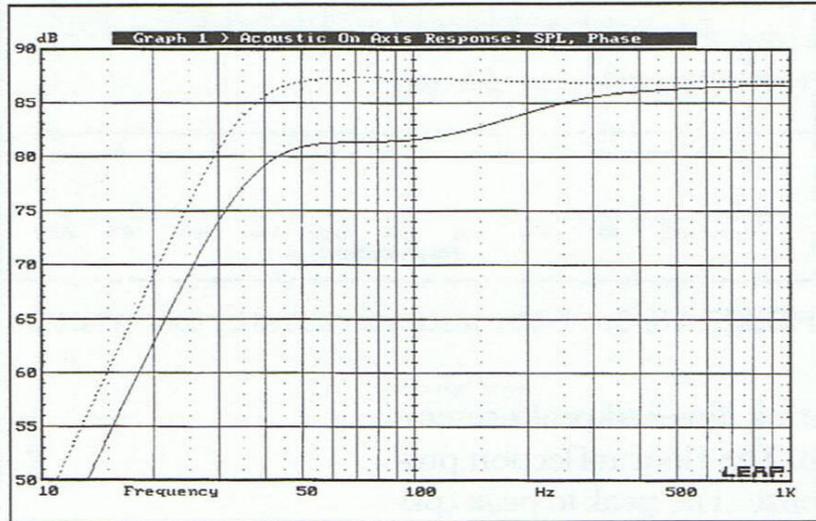


FIGURE 4.11: Half-space versus anechoic response (dotted = half-space, solid = free-standing anechoic).

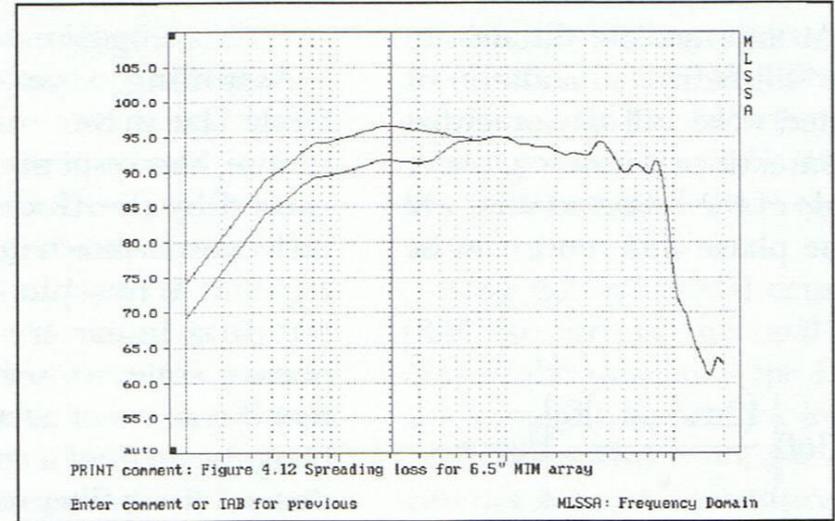


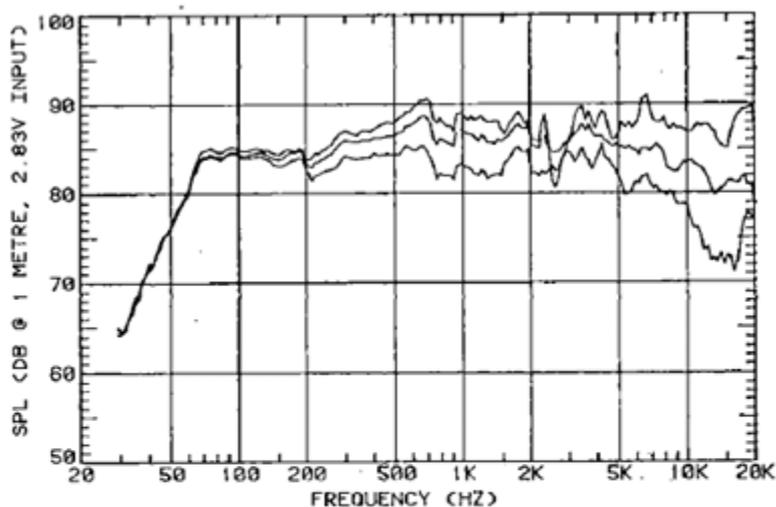
FIGURE 4.12: Spreading loss for 6.5" MTM array.

*From "Testing
Loudspeakers"*

J. D'Apollito

Loudspeaker Measurements and Their Relationships with Listener Preference

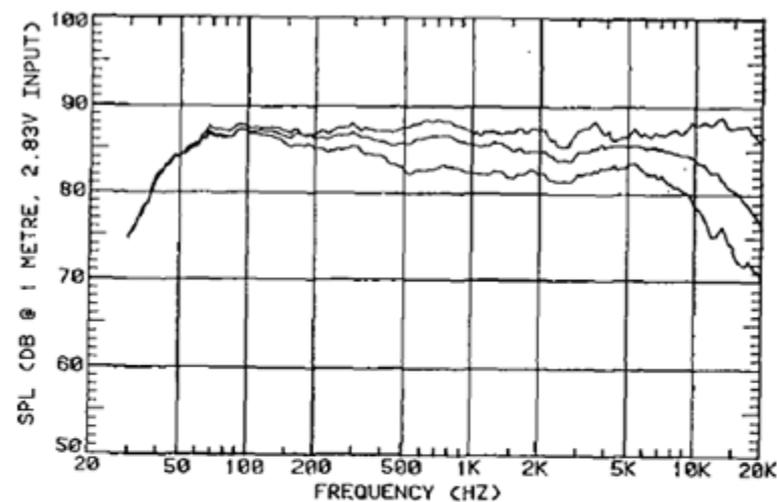
Examples from Floyd Tool's article:



TOP-TO-BOTTOM: AVG. ON AXIS, AVG. 30-45 DEG., AVG. 60-75 DEG.
THREE LOUDSPEAKERS WITH FIDELITY RATINGS OF 6.0-6.4.

(a)

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

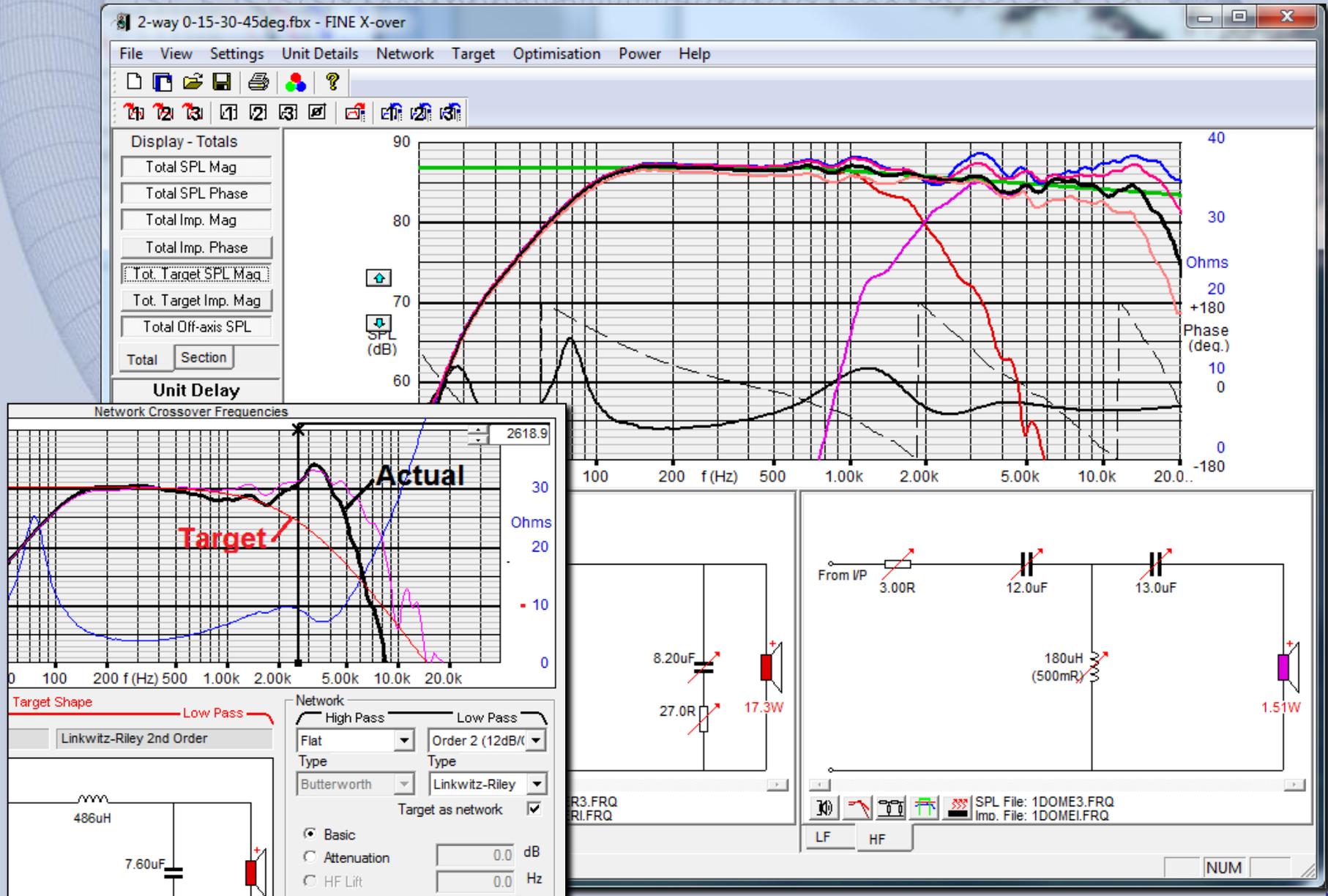


TOP-TO-BOTTOM: AVG. ON AXIS, AVG. 30-45 DEG., AVG. 60-75 DEG.
SIX LOUDSPEAKERS WITH FIDELITY RATINGS OF 7.5-7.9.

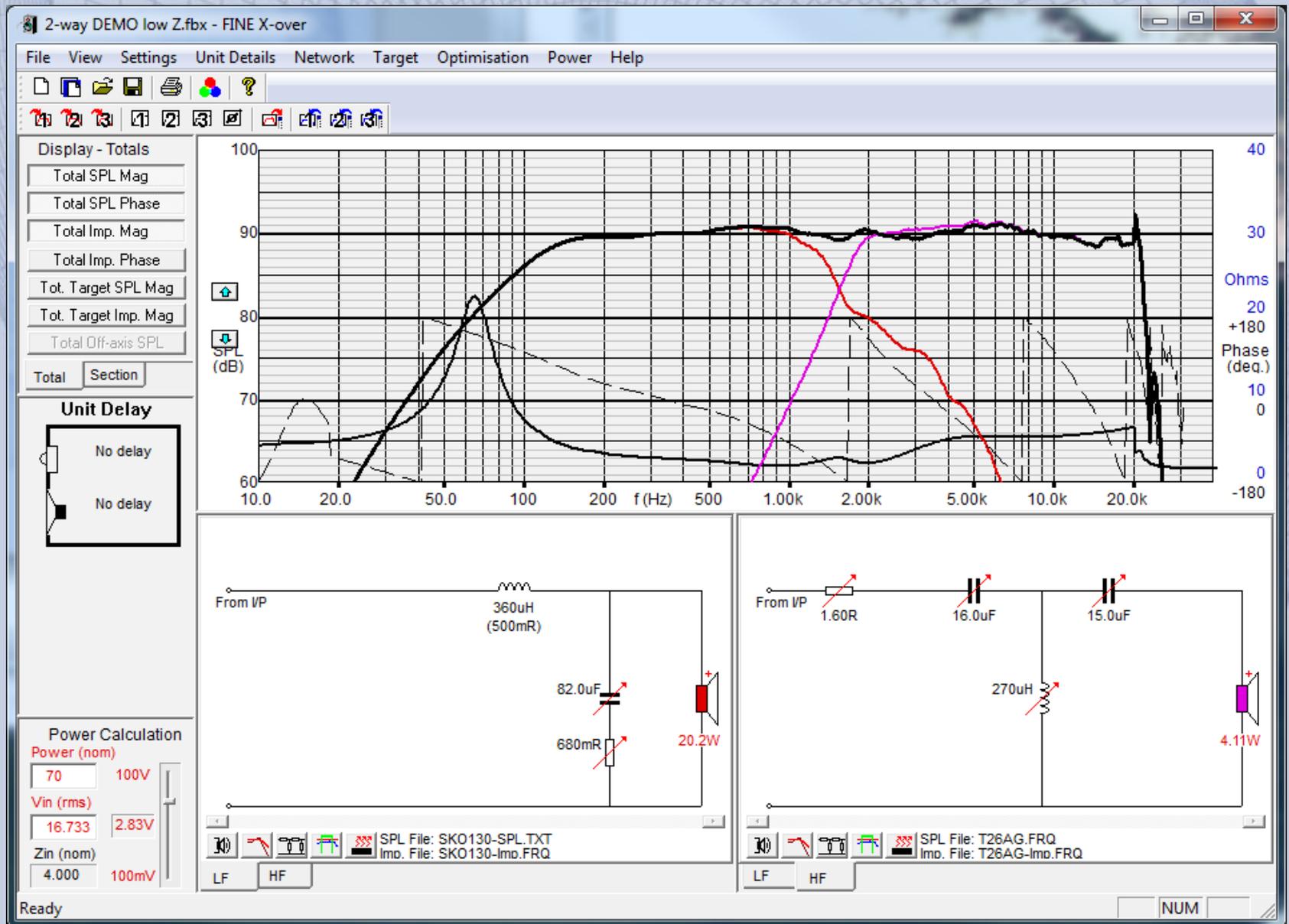
(d)

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

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



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

System Optimisation

Adjust the frequency range for optimisation using the cursor controls on the main response window.

- Consider SPL
- Relax stop band error
- Shape more important than level
- Consider phase errors
- Consider low Impedance
- Smooth impedance
- Exclude data between...
0.0 & 0.0 Hz

Optimise Undo Stop Close

IE X-over

work Target Optimisation Power Help

40
30
Ohms
+180
Phase (deg.)
10
0
-180

70
60
10.0 20.0 50.0 100 200 f (Hz) 500 1.00k 2.00k 5.00k 10.0k 20.0k

Unit Delay

No delay
No delay

Power Calculation

Power (nom)
70.000 100V

Vin (rms)
16.733 2.83V

Zin (nom)
4.000 100mV

From VP

360uH (500mR)

27.0uF

1.50R

19.5W

SPL File: SKO130-SPL.TXT
Imp. File: SKO130-Imp.FRQ

LF HF

From VP

1.60R

5.10uF

16.0uF

220uH

1.44W

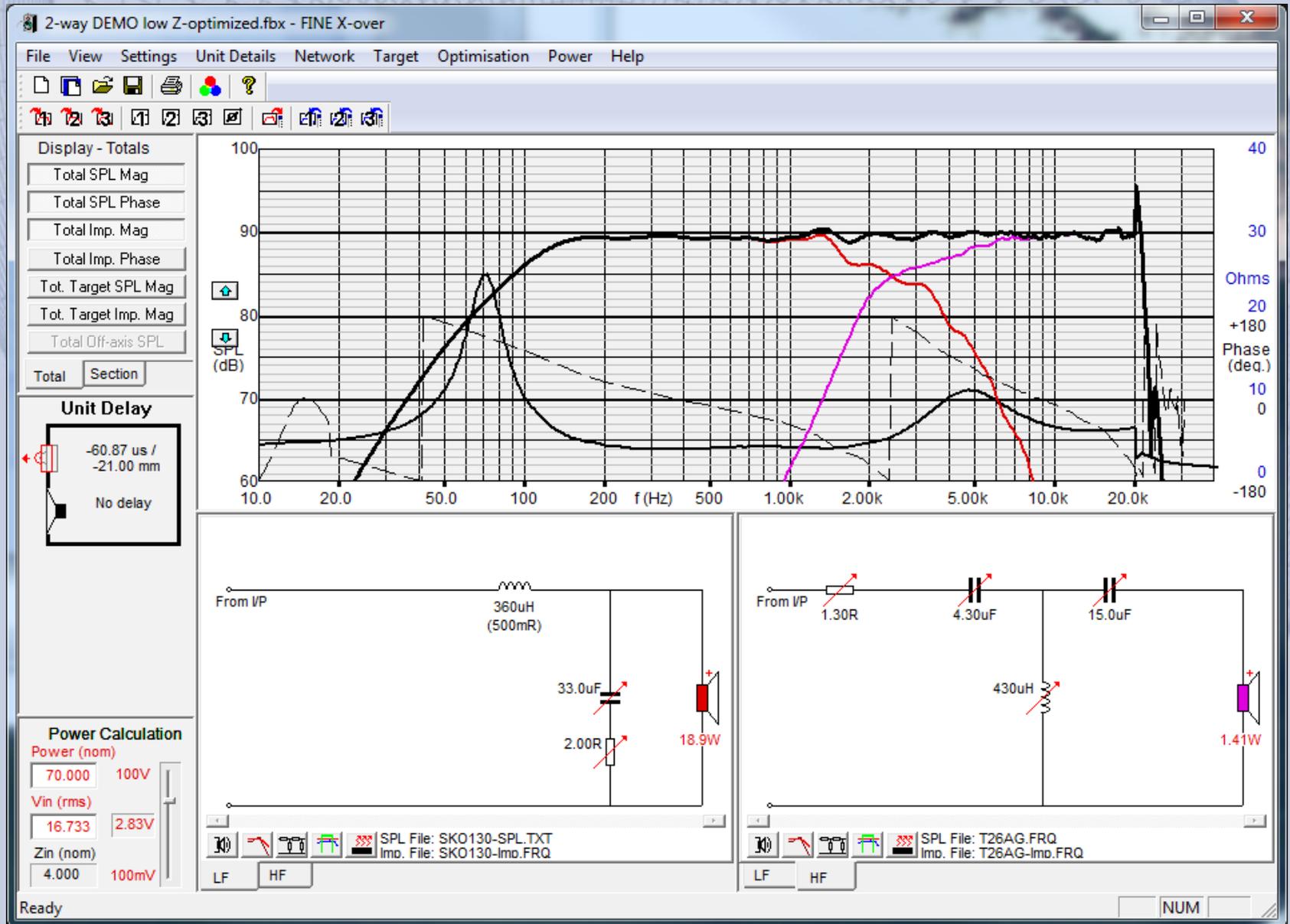
SPL File: T26AG.FRQ
Imp. File: T26AG-Imp.FRQ

LF HF

Ready

NUM

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



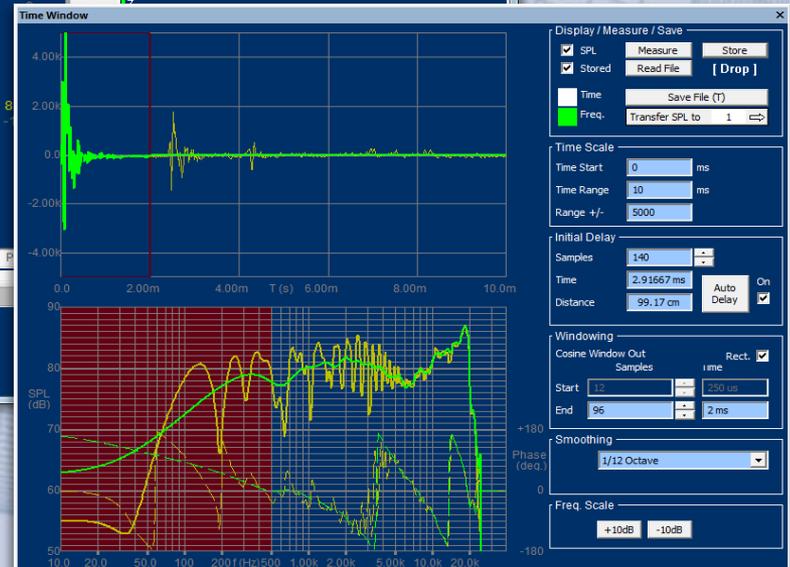
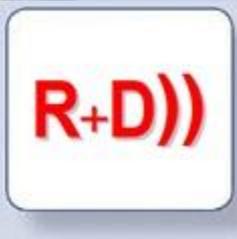
Loudspeaker Measurement Examples

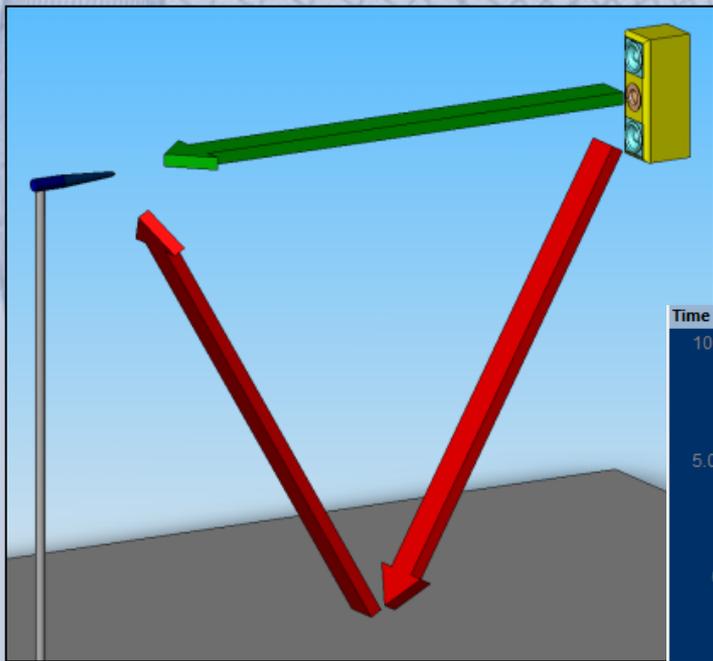
R+D))

**Some examples from using modern
measuring methods**



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



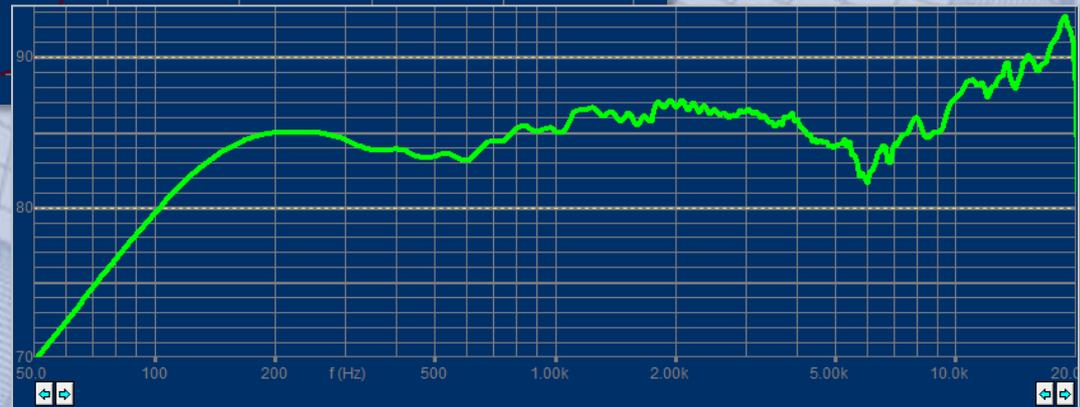
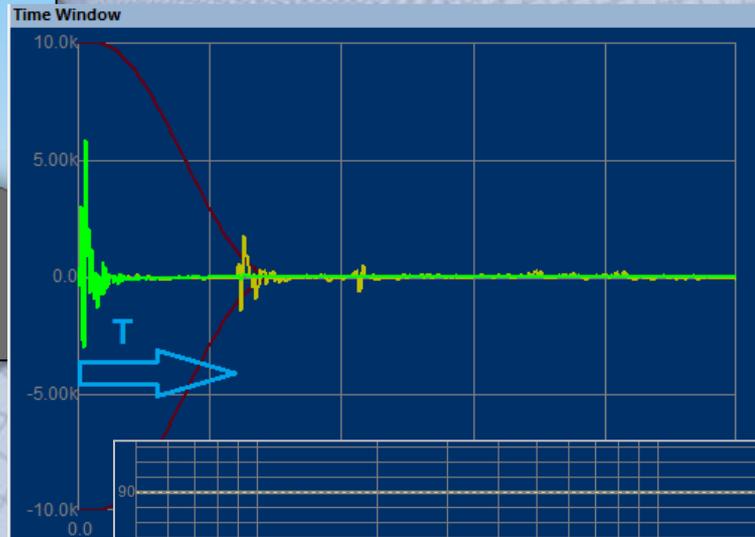


The time difference T between the direct ___ and the reflected sound ___ must be large in order to measure low frequencies: $F_{min} = 1/T$ (Hz)

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)



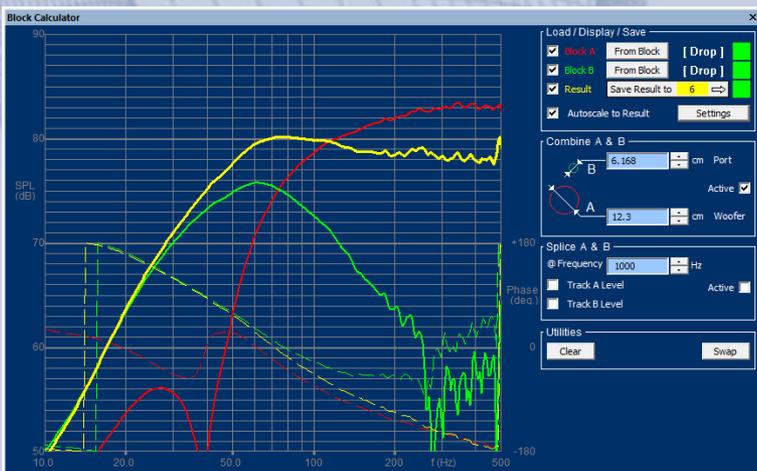
0.00 dB re 1V Input Attenuation dB Refresh Normalize SPL Measurements to ...

1.00 Vrms 0 10 20 30 40 50 60 70 Vrms 2.828 Std. 3.010dB

Distance 100.0 cm Actual 50 cm

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.



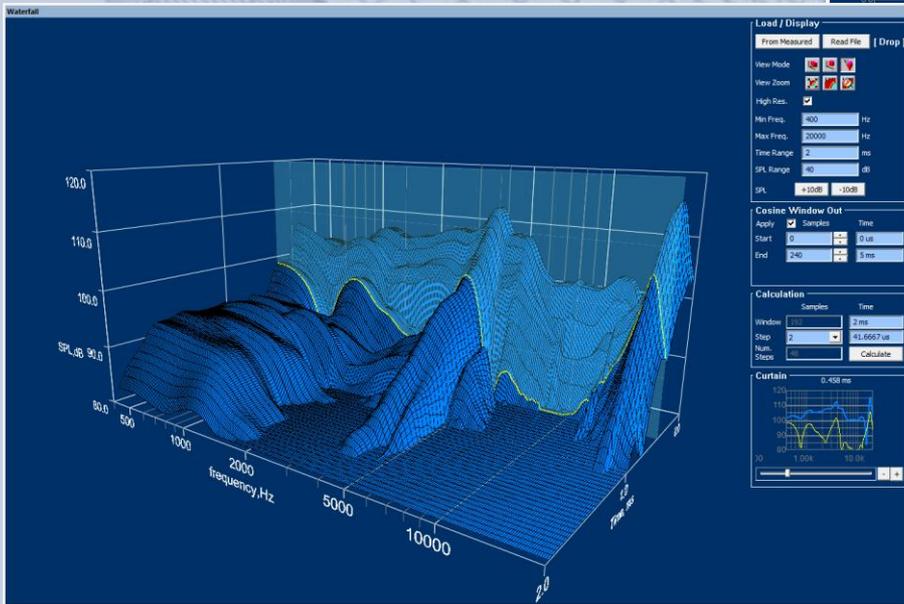
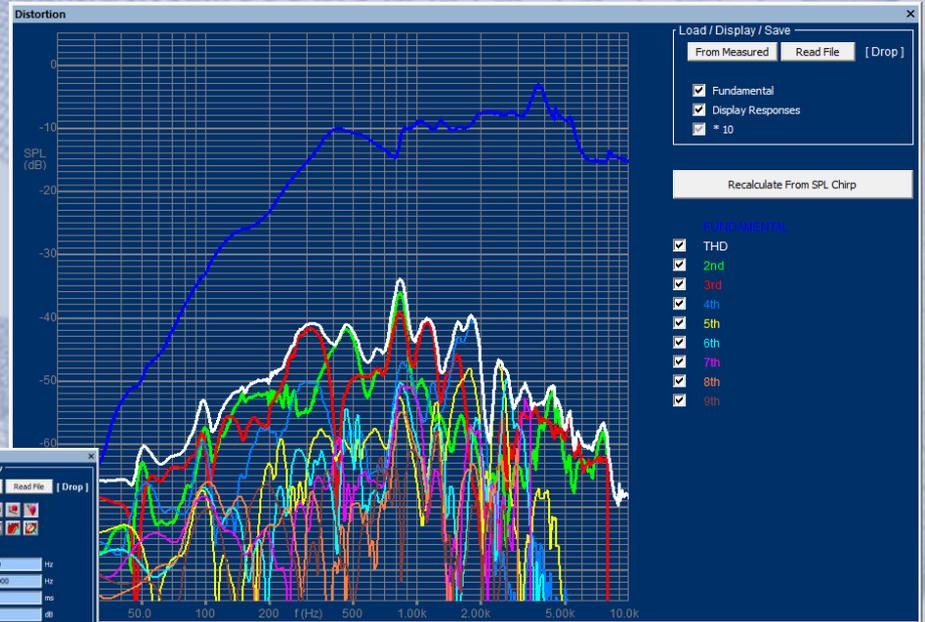
Total response , combined by far field and near field . Spliced @ 473 Hz

Bass reflex response , complex addition of woofer and port . Auto compensated for area differences



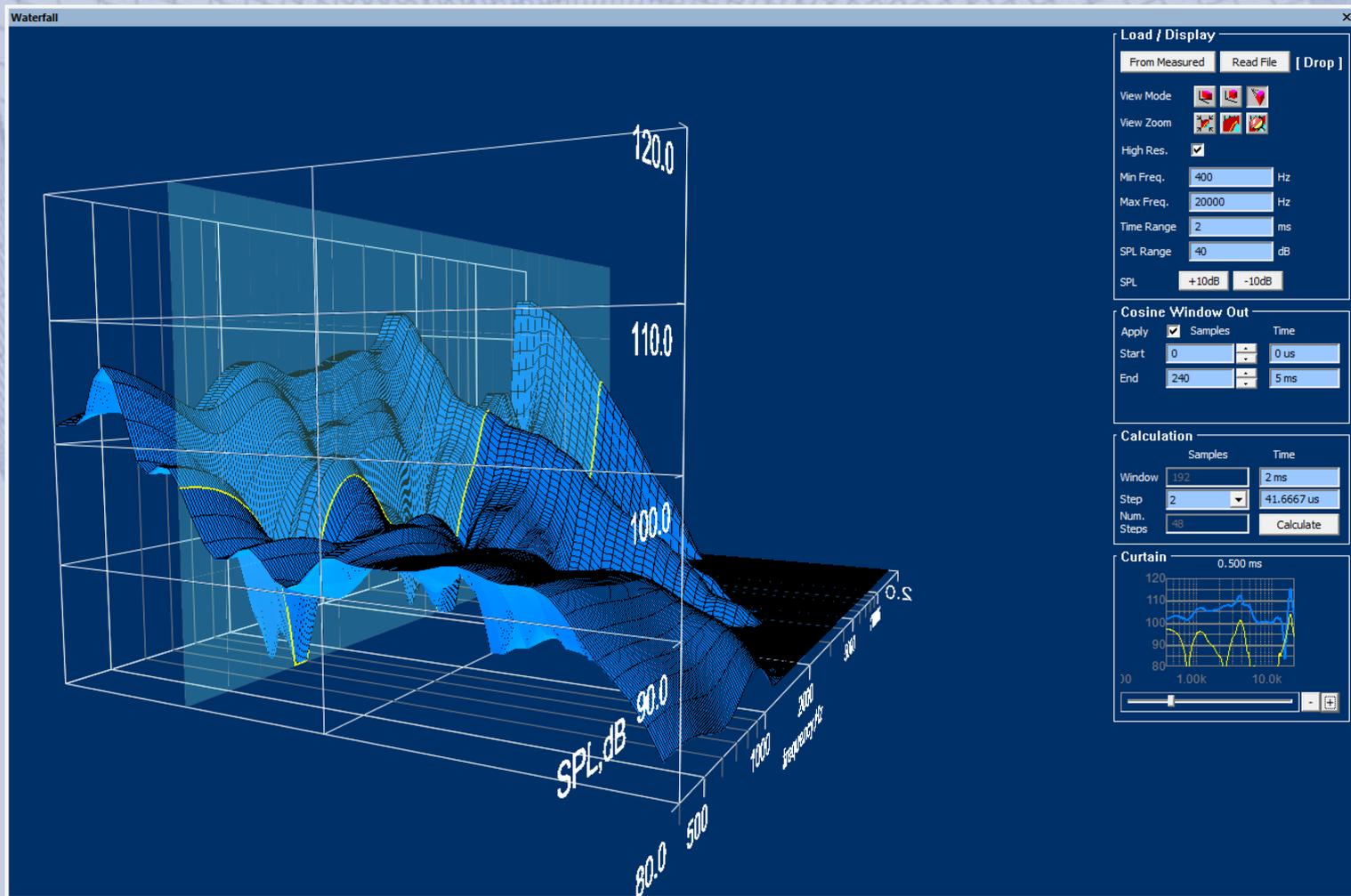
Harmonic distortion is useful. However the waterfall provides more information

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)



FREQUENCY DOMAIN MENU: Go View Reference Acquisition Setup Transfer Macro DC Overlap Calculate Printer PSD Units Library Info Soft F1 for Help
RLSSA: Frequency Domain

No Amplifier
No Rub & Buzz

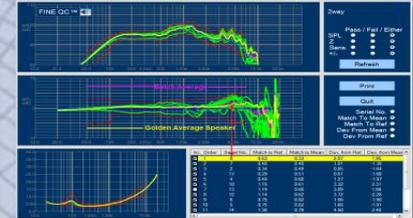


New System: **(C++)**



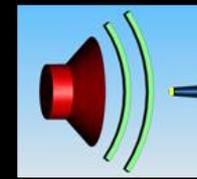
Windows 7 / 8 -
64bit
THD + 2-9th

Test: 1sec
Golden Average
Best Rub & Buzz



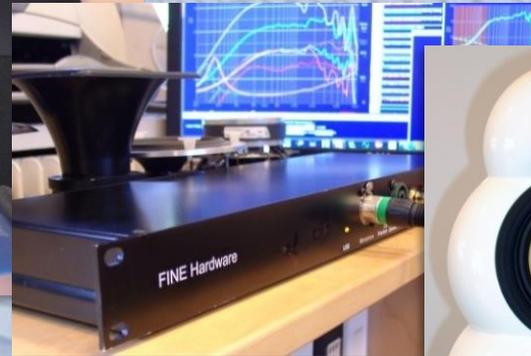
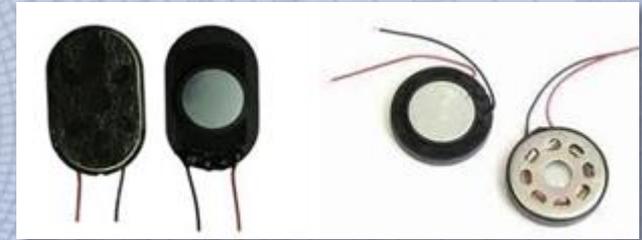
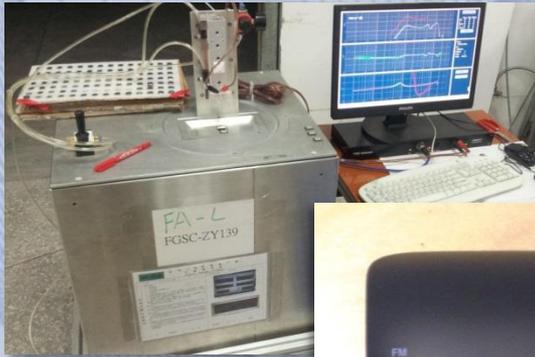
USB Hardware
25W Amplifier
SPL+Imp direct

Challenges in Speaker QC Testing

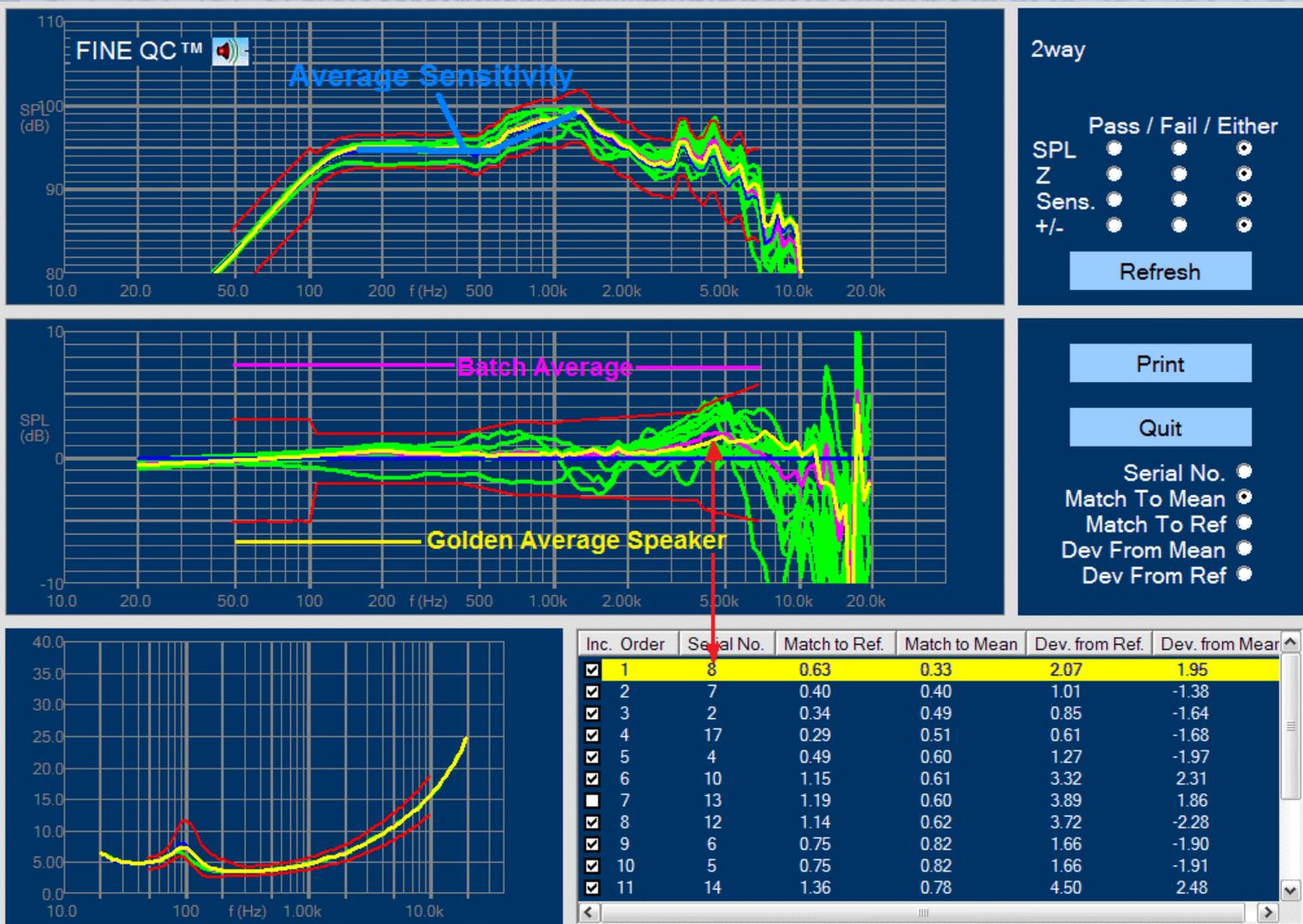


**A few notes about Speaker End of Line
Quality Control in today's high speed
production.**

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

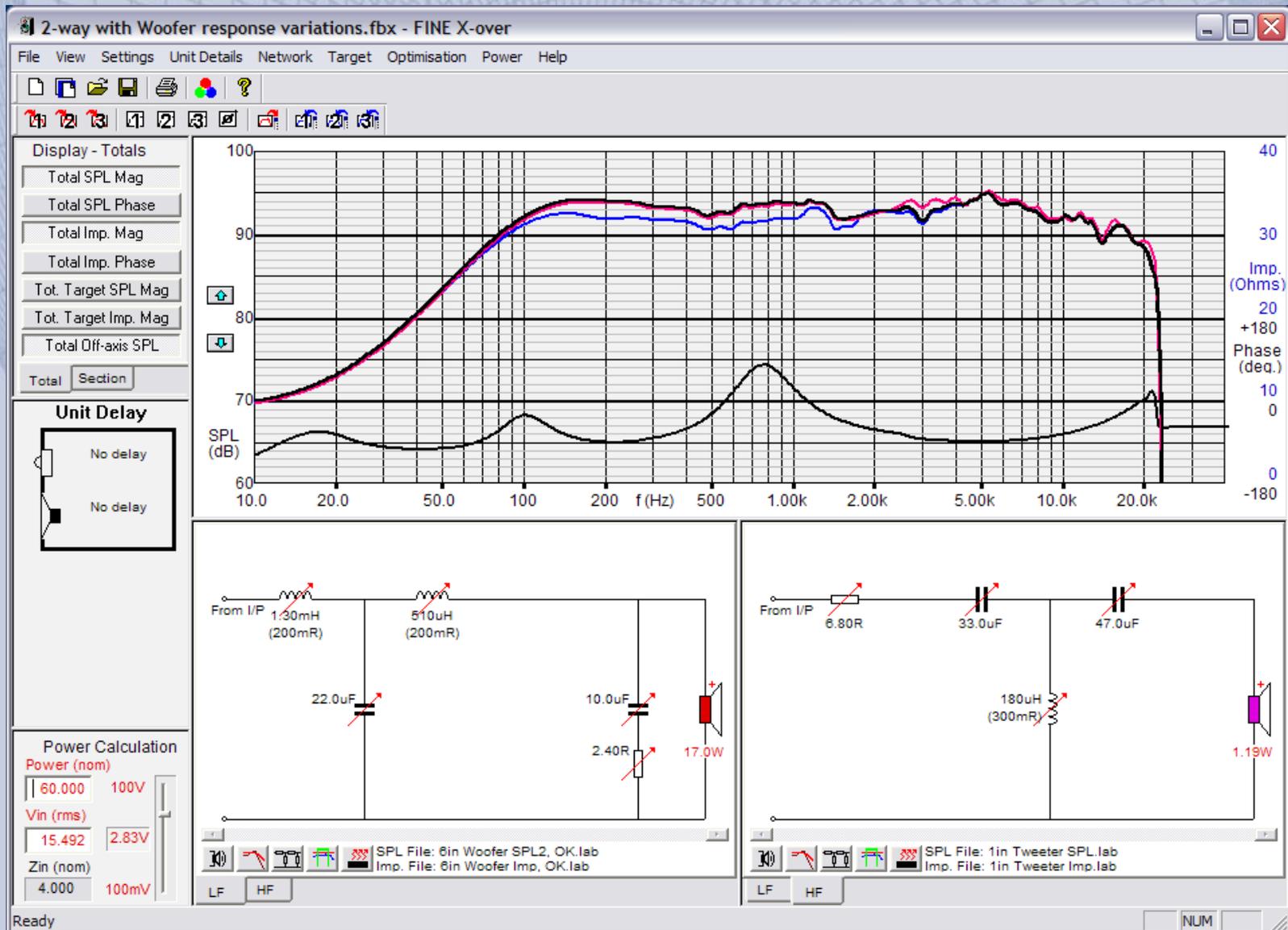


- Use statistics to find The Golden Average (REF)
- Decide response deviations as: Sensitivity and +/- x dB freq. band



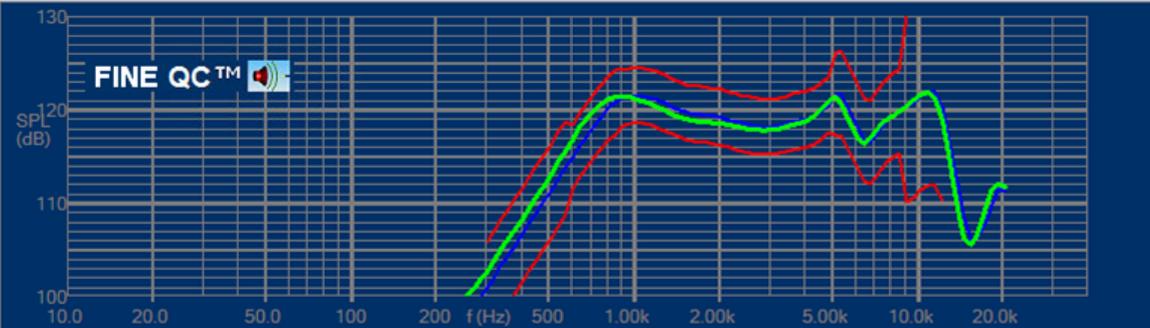
Example: Two rejected woofer responses imported into FINE X-over.

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.

Files
PRINT
Statistics
End Test

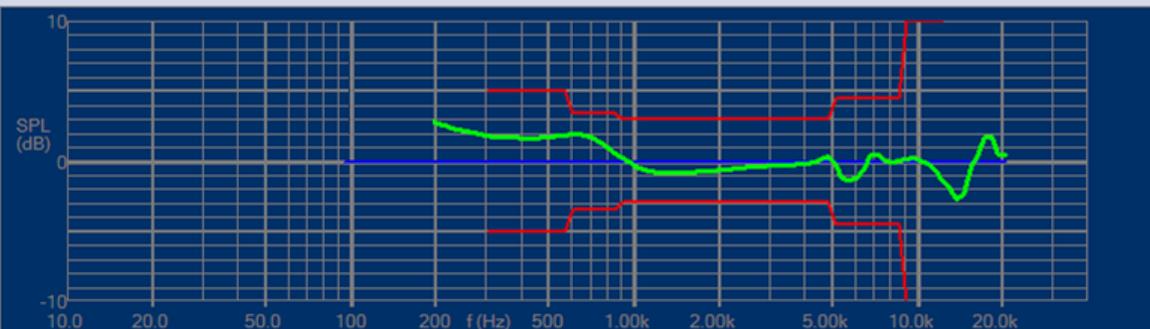


FINE QC™

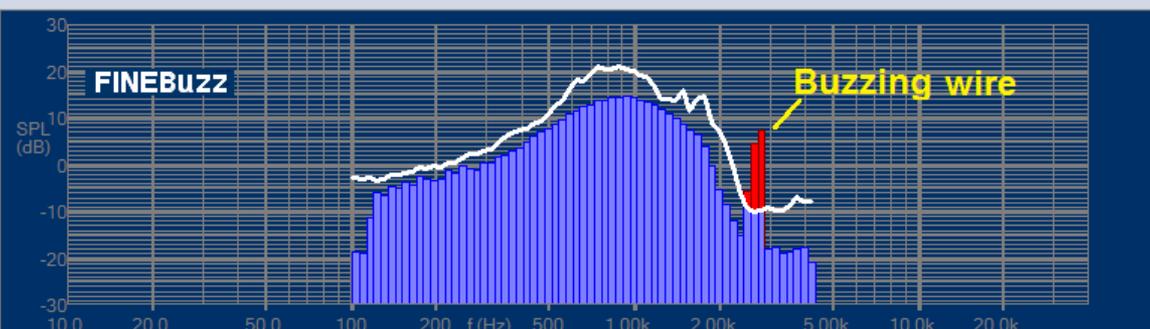
FINE QC™

Type : 18x13
 Lot : Batch 3
 Serial No. : 88
 Customer : 130618
 Pcs Tester: 88
 Pcs OK : 77

in ForGrand box
 Micro-setup



SPL	: OK
Sensitivity	: -0.5dB
:	
Polarity	: OK
Rub and Buzz	: FAIL
Compensation	: 0.0dB
:	
Yield	: 87.6 %



FINEBUZZ

Buzzing wire

Operator Panel

FAIL

Retest Ser No.: 88

Single/Re-Test ○

Measure Ser No.: 89

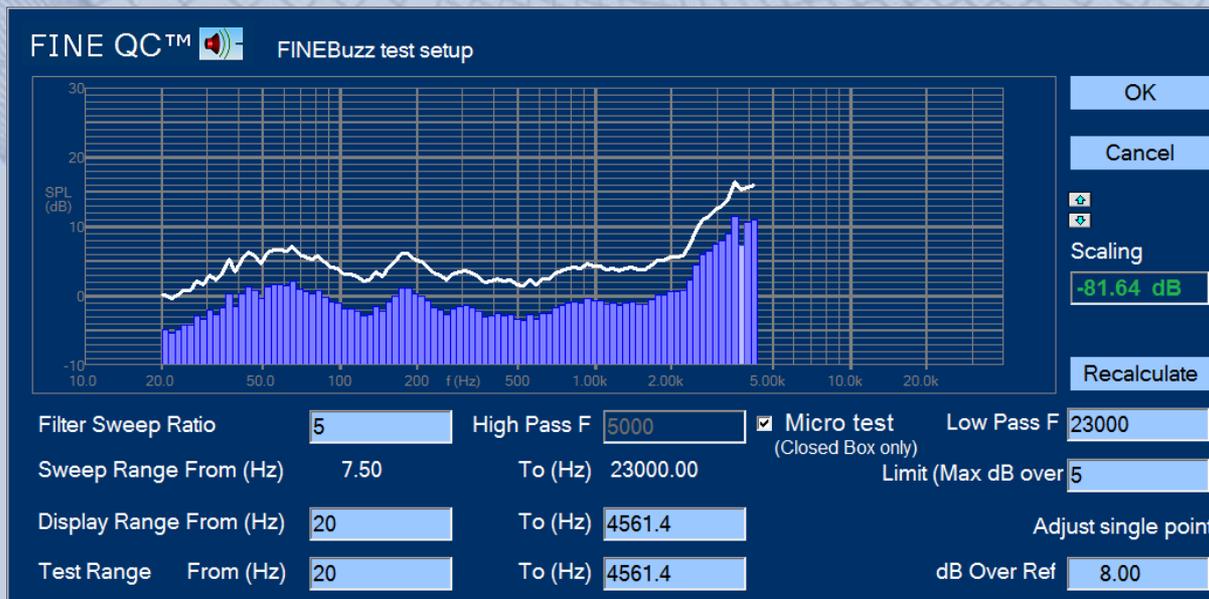
RUN ▶

Z Active
R & B Active

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			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)			Mechanical Parameters (using laser)		
Mms	1.277	g	Mms	1.095	g
Mind (3d)	1.244	g	Mind (3d)	1.602	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			Loss factors		
Qtp	0.982		Qtp	0.854	
Qms	3.687		Qms	2.902	
Qes	1.311		Qes	1.207	
Qts	0.981		Qts	0.853	
Vas	0.2443	l	Vas	0.2596	l

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
Flux Contour w/ frame Bn500.txt

Bg=0.8147T
Bd=0.2570T
Bt=1.3174T

Offset 0.00mm

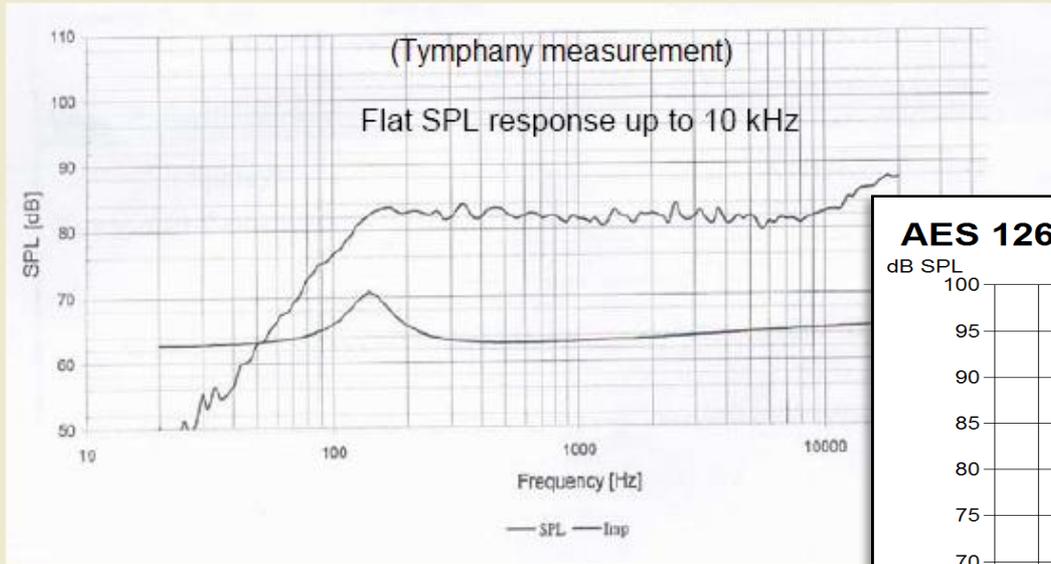
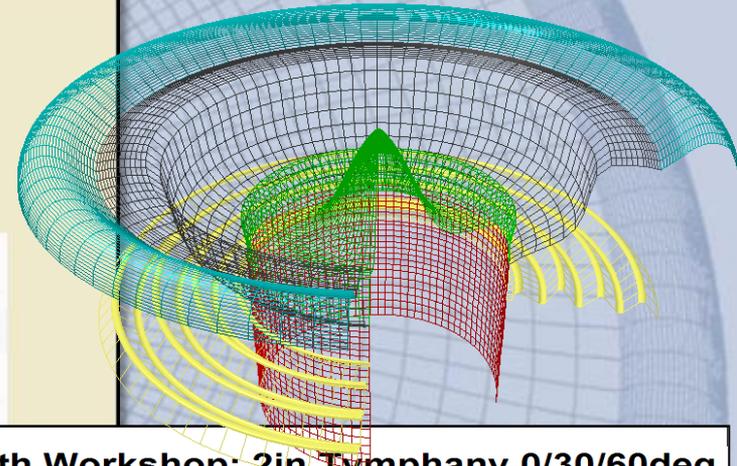
The predicted BL is really close to the Klipper Laser measurement

AES 126th Loudspeaker FEA/BEM Workshop

FINECone FEA versus measured response

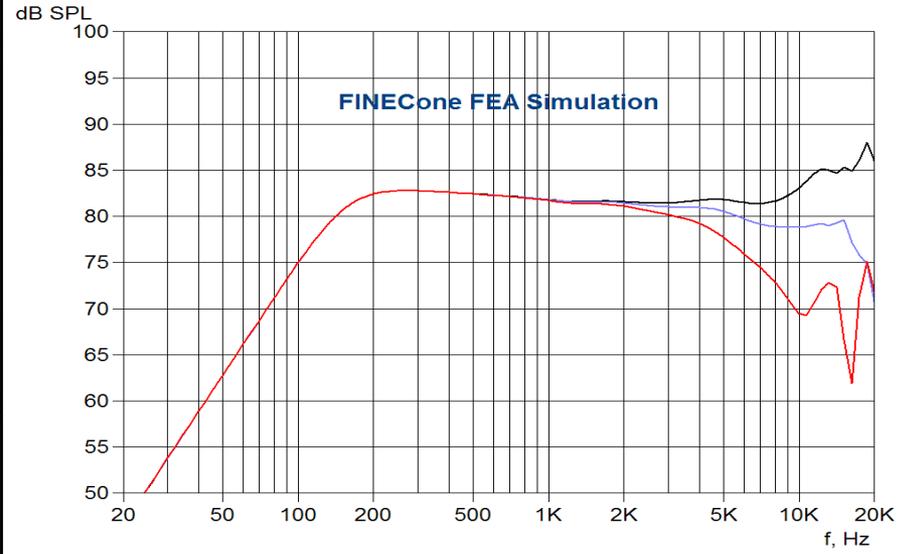
Sound Pressure Response

Baffle 1 m 1W

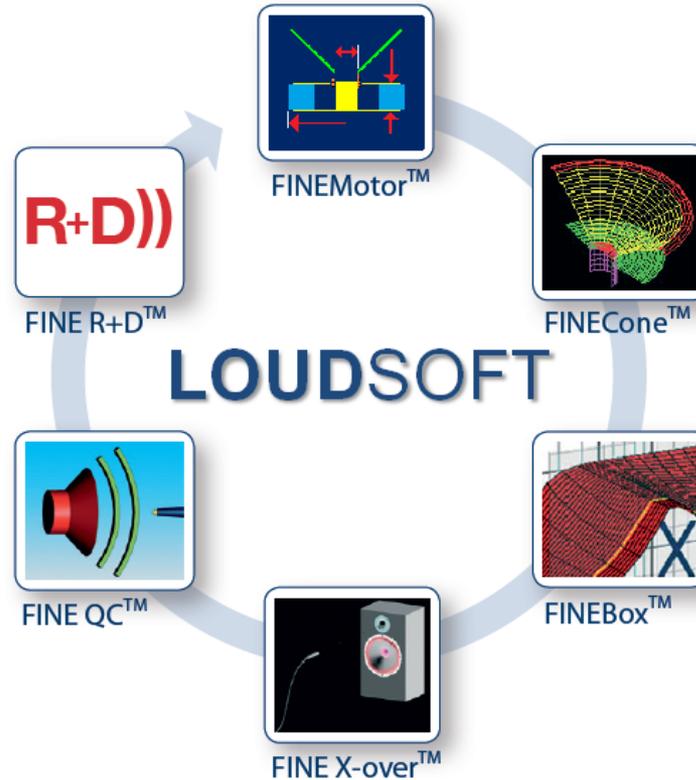


Klippel, Loudspeaker Analysis, Workshop AES 20

AES 126th Workshop: 2in Tymphany 0/30/60deg



The FINE Circle



www.loudsoft.com