

## Loudsoft Design Tutorial, Part 1

*At the January ALMA Symposium, I asked Loudsoft's Peter Larson to put together a short tutorial for the design of a woofer and then incorporate the woofer in a two-way system using the suite of Loudsoft speaker design programs: FINEMotor, FINECone, FINEBox, and FINE Xover. What follows is the result. In this section, Part 1 of a two-part series (Part 2 will appear in the May issue of **Voice Coil**), FINEMotor, FINEBox, and FINECone are used to produce a complete BOM for a 6.5" woofer – Vance Dickason.*

### **By Peter Larsen**

Target specifications for the woofer in the exercise are  $8\Omega$  nominal impedance, with a magnetically shielded motor with a  $Q_{ts}$  of 0.33-0.36, a resonance of 40-50Hz, a physical  $X_{max}$  of 5mm, a 70W RMS power handling capacity, and the ability to produce a suitable low frequency response in a 12-Ltr enclosure. From experience, I will stipulate that this new woofer uses the following existing parts:

- Voice coil - 35.50mm ID, WW=12.75mm, DCR ( $R_e$ ) =3.2 ohms, 0.05 mm Aluminum VC former (bobbin), CU Wire=0.26mm.
- Cone – a 6.5" polypropylene cone + surround = 13.1cm diameter with a cone  $F_o$ =26 Hz, (Cone + dust cap +  $\frac{1}{2}$ surround +  $\frac{1}{2}$ spider =14g)
- Spider (damper) - stiffness= 0.70mm (deflection) with 50g load
- Motor top plate: OD= 80mm, ID= 37.50mm, thickness= 5mm

**FINEMotor Simulation** – You begin the simulation in FINEMotor by pressing the button "Acoustic Components" on the left side of the FINEMotor main menu (**Fig. 1**) and bringing up the Acoustic components menu shown in **Fig. 2**. Here you input the effective cone diameter of 13.0cm, which includes half of the surround as indicated by the sketch. The next input is the fixed mass of the moving components, which includes half of the surround and half of the spider plus the combination of the cone, dust cap, and glue. All of these components have a total weight of 14 grams.  $Q_{ms}$  is then estimated to be 3.00, a typical value for an aluminum former.

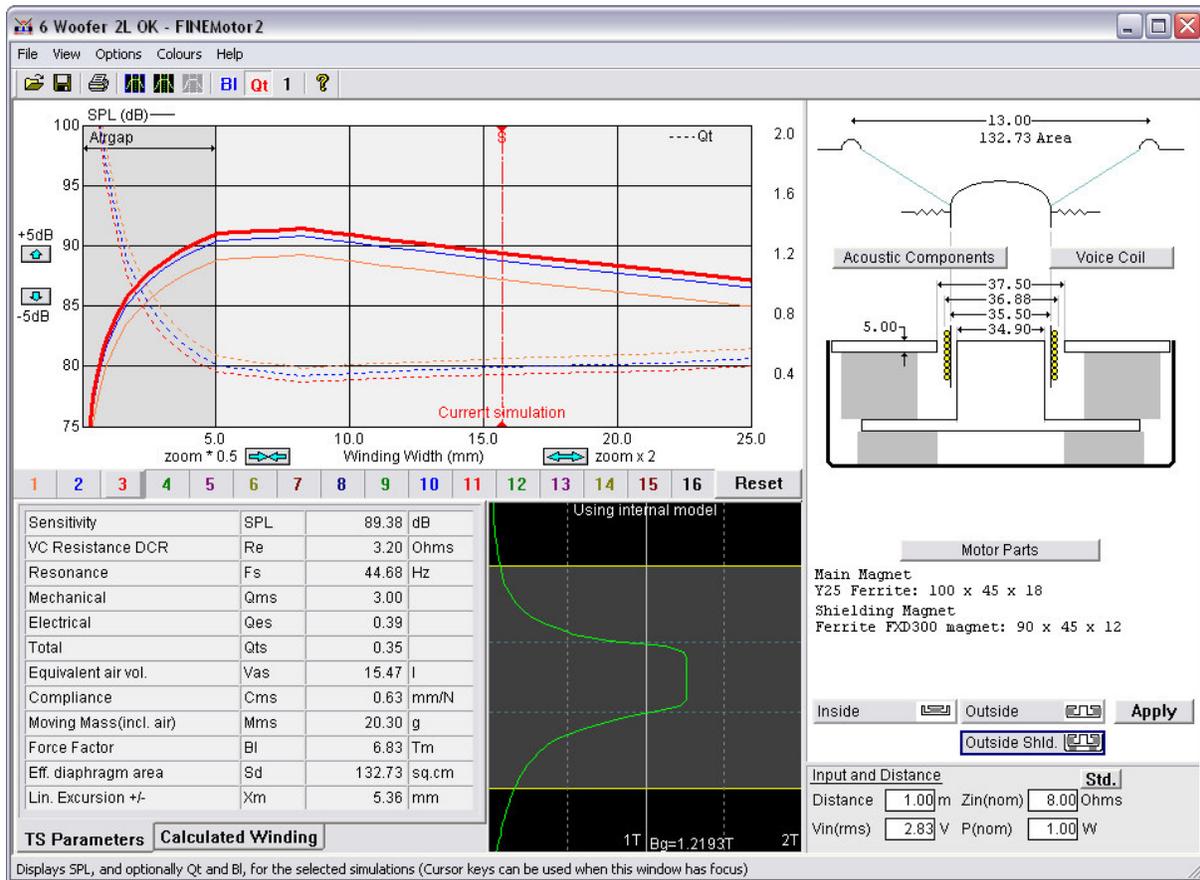


FIGURE 1: FINEMotor Main Screen

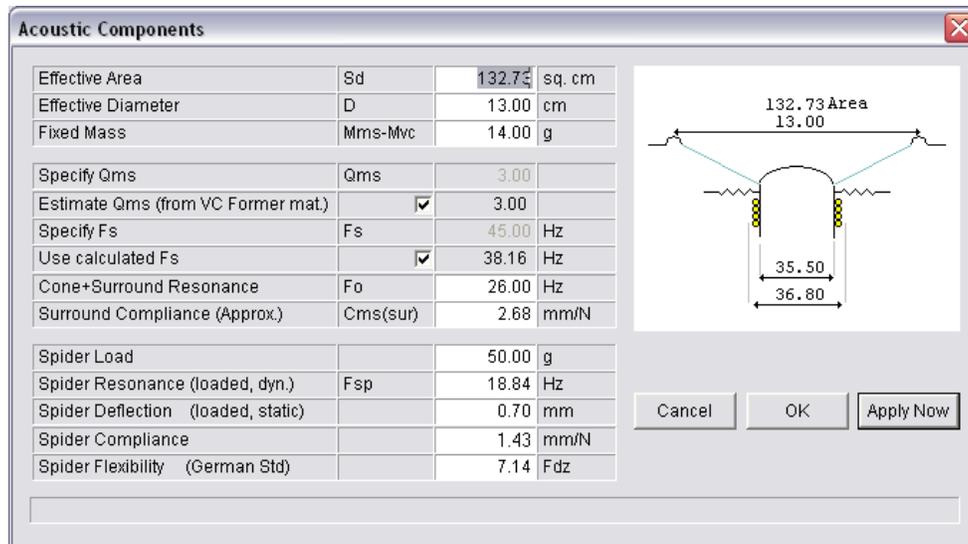


FIGURE 2: FINEMotor acoustic components

Next, check the “Use calculated Fs” box, and type the Cone Fo (26Hz) and spider stiffness (0.70mm deflection for 50g) into the appropriate fields. This will cause the program to automatically calculate the resonance frequency Fs, 38.2Hz. With this accomplished, pressing the Voice Coil button brings up the Voice Coil menu given in **Fig. 3**. After inputting Re= 3.2Ω, voice coil ID = 35.50mm, and selecting a two-layer voice coil using round copper wire and an aluminum former with a 0.05mm thickness, depress the “OK” button.

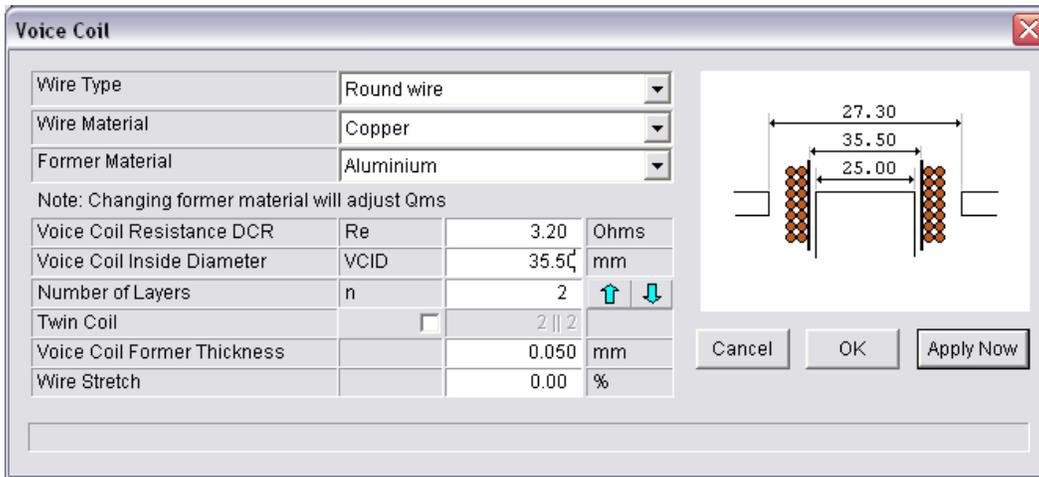


FIGURE 3: FINEMotor Voice Coil Input

At the main menu (*Fig. 1*), hitting the "Motor Parts" button brings up the Motor Parts menu depicted in *Fig.4*. Here you reset the Top Plate thickness to 5mm, and Top Plate ID to 37.50mm with a 34.90mm pole diameter. Once you type these values into the menu, the magnet material is selected, in this case (and again using experience) a standard Chinese 90x42x17mm Y25 ferrite magnet to keep costs down. Last, when you check the Steel Frame box, the software automatically calculates the magnetic loss when incorporating a steel frame.

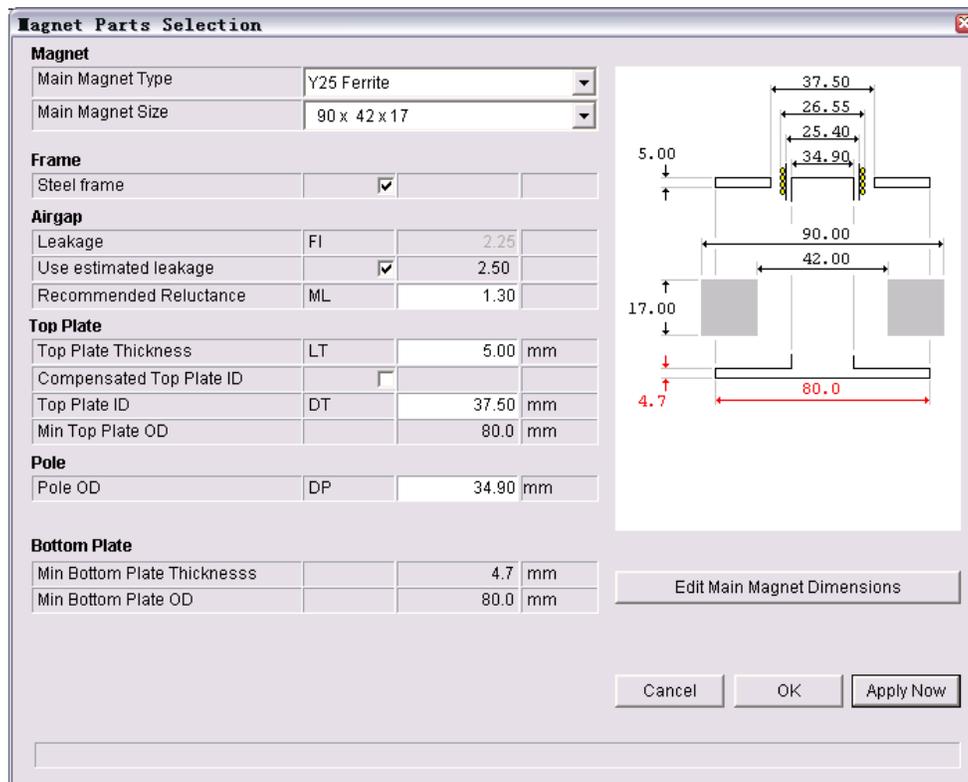


FIGURE 4: FINEMotor magnet parts menu.

Looking again at the main screen graph *Fig. 1*, you can see curves showing a variety of solutions to input data. The graph shows SPL for various voice coils Winding Widths

ranging from 0-25mm horizontal. Short Voice Coils are depicted to the left and longer coils are to the right. (Here the current curve is Red = Button 3.) Clicking with the left mouse around 13mm gives the simulation of the actual voice coil.

Clicking on the “Calculated Winding” button on the lower left of the main screen brings up the Calculated Winding menu illustrated in **Fig. 5**. The simulation has found the correct wire (0.26mm) and calculated the winding width (height) to equal 13.08mm. The actual voice coil is slightly shorter, probably due to the wire being stretched during winding. FINEMotor can simulate this by applying a stretch percent in VC input. A 3% stretch gives WW=12.68mm, which is quite close to the actual coil (WW=12.75mm).

Layers	n	2	
Wire Material		Copper	
Wire Type		Round	
Wind Width	WW	12.68	mm
Number of Windings	N	84.87	
Nom.(bare) Wire diam	BWD	0.260	mm
Total Winding OD	WOD	36.80	mm
Total Winding Mass	Mvc	4.692	g
Stretch		3.00	%

TS Parameters    **Calculated Winding**

**FIGURE 5: FINEMotor calculated winding**

Clicking on the “TS Parameters” tab on the lower left side of the main screen will cause all the parameters to be calculated. Both Fs (38.16Hz) and Qts (0.43) are close to the target, but Xmax is too short, indicating that our existing voice coil is not long enough. You need a longer Voice Coil (VC), which is determined by clicking on the display curve. If you hold down the left mouse button while moving to the right, you see several possible designs. At just above 15mm, the program indicates an Xmax=5.36mm that is more than close enough to the desired target.

However Qts and Fs are still not correct. You can change Fs by opening “Acoustic Components” menu again (**Fig. 2**). As is readily apparent, the surround compliance is 2.68mm/N with a spider compliance of only 1.43mm/N, which means that the surround is softer than the spider. However it is easier to choose a stiffer spider by changing the spider deflection input to 0.40mm, which automatically changes Fs to about 45Hz.

A Qts of 0.53 is still too high, which means that a higher BL is required. It is possible to select a non-steel frame, but this change is not sufficient, thus a larger magnet is necessary. Calling back the “Magnet Parts” menu, you simply select the next magnet size 100x45x18 from the pulldown list. Qts has now been recalculated to 0.35 and all TS parameters are within the target!

Because the original specification required the driver to be magnetically shielded, it is necessary to press the Outside Shielded button located on the lower side of the main screen. This will produce a shielded specification that will yield the same T/S parameters you had prior to the shielding. The shielding (rear) bucking magnet is 90x44x12mm out of the same Y25 material. This design iteration is labeled Woofer #1.

There are several other methods you can use to achieve a higher BL. Using a multi-layer or a flat wire voice coil are two other possibilities. For example, you can simulate a four-layer VC by simply clicking on one of the arrow keys located adjacent to the layer section in “Voice Coil” menu (**Fig. 3**). Unfortunately this VC OD is too large for our air-gap. Clicking on “Compensated Top Plate ID” in Motor Parts and specifying a 0.3mm clearance between the voice coil and the top plate will automatically correct this problem.

Selecting a winding width just below 15mm, you get close to 5mm  $X_{max}$ , and you can see that the magnet gap is automatically increased, reducing the gap flux  $B_g$  from 1.22 T (two-layer gap) to 0.83 T (four-layer gap). That is also indicated by the green curve in **Fig. 1** (main program screen), which is the air gap flux profile taken down through the actual air gap. Looking at the T/S parameters, BL is now 9.14Tm due to the increased number of winding turns. As a result,  $Q_{ts}$  is reduced to 0.25, which is too low.

At the previous magnet size of 90x42x17mm, Y25 gives a  $Q_{ts}$  of 0.33, which is also within the target! With shielding selected, this iteration is labeled as Woofer #2. Note that SPL has dropped from 89.38 to 87.17 dB and the increased inductance of the four-layer voice coil may likely increase IM distortion. However, if this is deemed acceptable, the resulting woofer will have a lower cost than previous iterations.

For that last woofer design iteration, you can go to the extreme and select a one-Layer CCAW (Copper Clad Aluminum Wire) edge wound wire (flat aluminum wire) in order to reduce the inductance and mass. Selecting this will cause the air gap to automatically change and apply the 0.3mm clearance to the one-layer VC. Clicking in the vicinity of WW=15mm gives  $Q_{ts}$ =0.35 using 0.11x1.0mm CCAW wire, while still keeping the 90x42x17mm Y25 magnet, and when shielding is selected you have a third version that will satisfy the target parameters. This is labeled as Woofer #3. The next step in this design exercise is to simulate these three different woofers in an enclosure using FINEBox.

**FINEBox Low-Frequency Simulation** – transferring files from FINEMotor to FINEBox is easily accomplished by pressing the FM2 button at the top right side of the FINEBox main menu screen shown in **Fig.6**. **Fig. 7** depicts a series of curves for both sealed and vented box designs. Curve 1 (brown) shows the woofer #1 in a 12 ltr closed box, where curve no. 2 (blue) shows the same driver in a more suitable 12 ltr bass reflex box tuned to 50 Hz, giving much extended bass response.

Woofer #3 (one-layer CCAW version) gives almost the same response in a vented box, but is not shown in order to avoid too many over-plots.

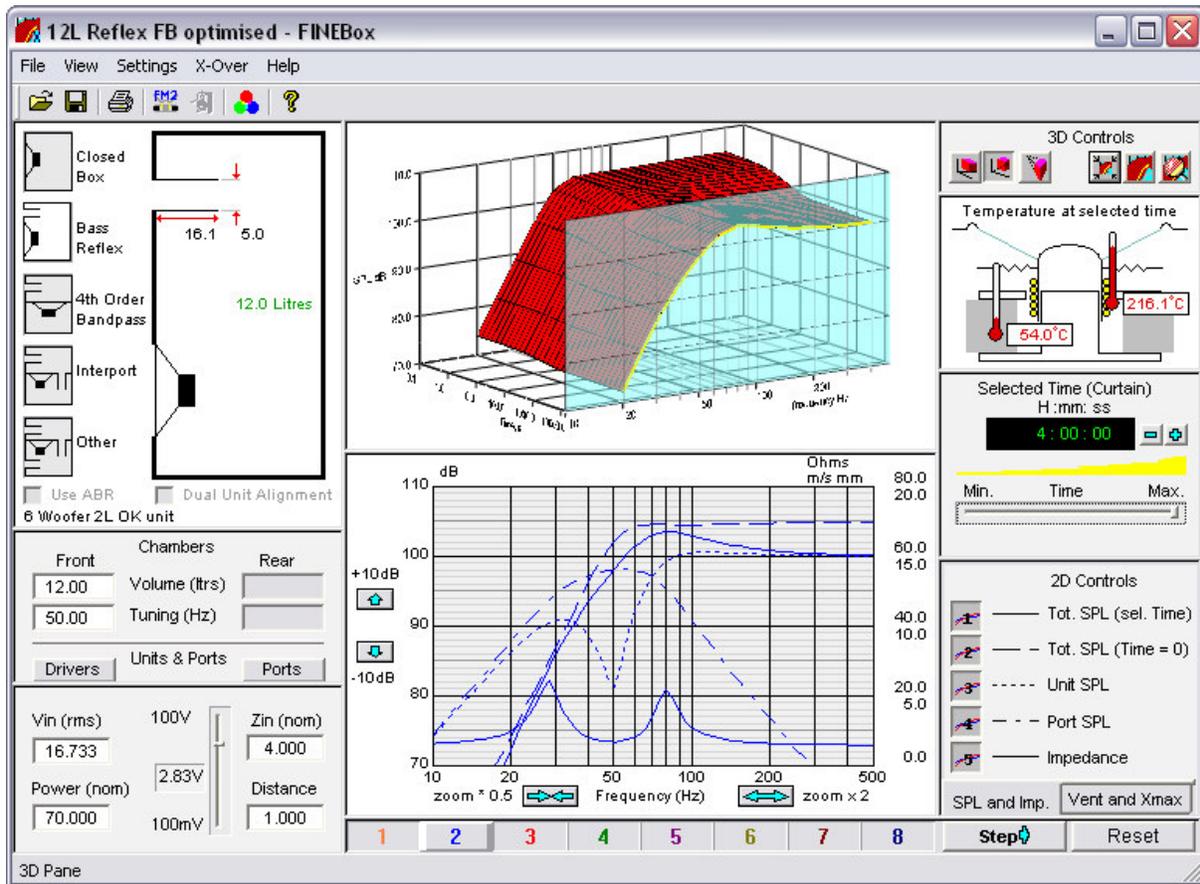


FIGURE 6: FINEBox Main display

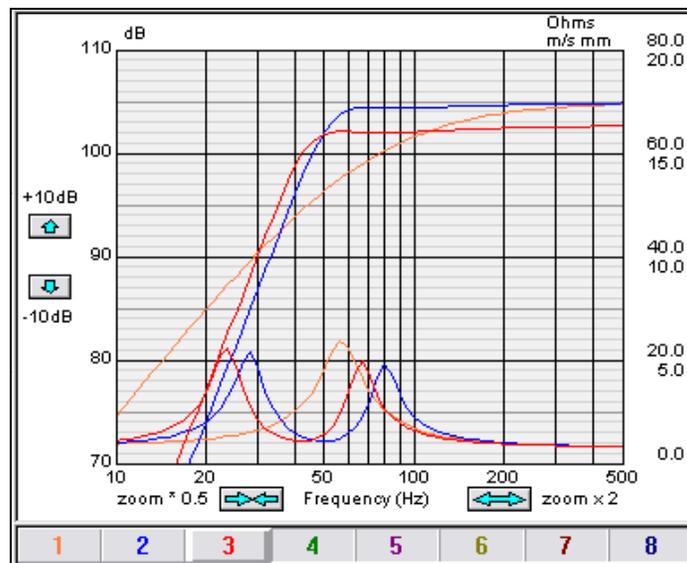
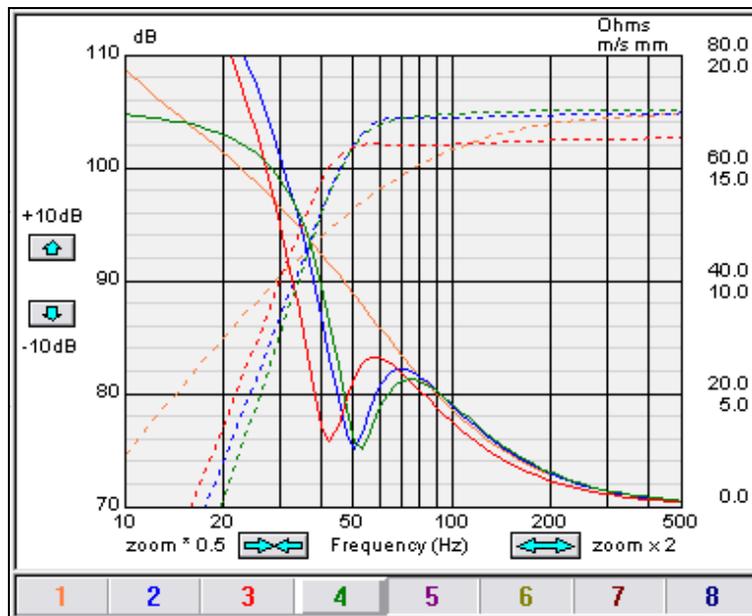


FIGURE 7: FINEBox Closed and Bass reflex Simulation

The next step using FINEBox is to simulate how the previous designs will function at higher power levels. Setting the Power input to 70 W RMS Continuous for the 12-ltr reflex box with Woofer #1, you get the lower curve (solid blue), **Fig. 6**. The previous blue curve is now dashed. The SPL has dropped 5 dB due to *Power Compression*, and the response is no longer flat. The display shows a quite high *Voice Coil Temperature* (216 °C) simulated with Kapton voice coil former (magnet temp 54 °C). A new simulation using aluminum

voice coil former will decrease the voice coil temperature to 164 °C, because the aluminum former becomes an effective heatsink.

High power cone excursion curves are shown in **Fig. 8** (The right scale is using the 0-20mm excursion scale). From the blue curve the excursion for the two-layer voice coil is 6mm above 50Hz, corresponding to  $X_{max} +20\%$ , which should be adequate if you assume that large amplitudes below 50Hz are normally attenuated in many music styles. However the green curve shows an improved woofer with high  $F_s$  at about 60Hz, which results in decreased amplitude below 50Hz, but almost same (pass-band) response as before. When you select the Reflex Port Velocity (air speed) button, the calculated curve depicts  $>20\text{m/s}$  velocity (not shown for clarity). Changing the port diameter to 7cm reduces the port speed to 15m/s, which will prevent whistling, especially with the flanged option (**Fig. 8**).



**FIGURE 8: FINEBox Woofer excursion**

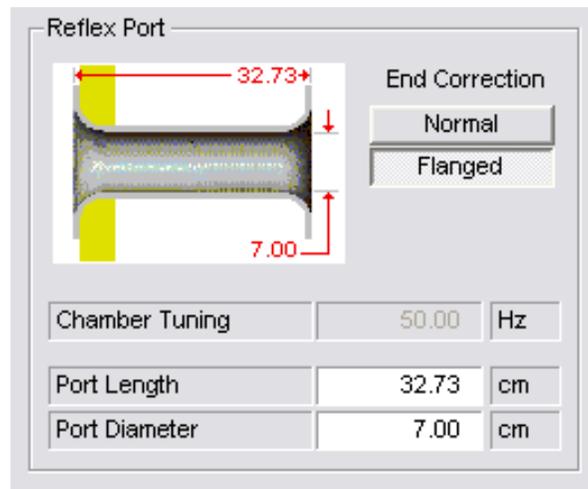


FIGURE 9: FINEBox Bass Reflex Tube

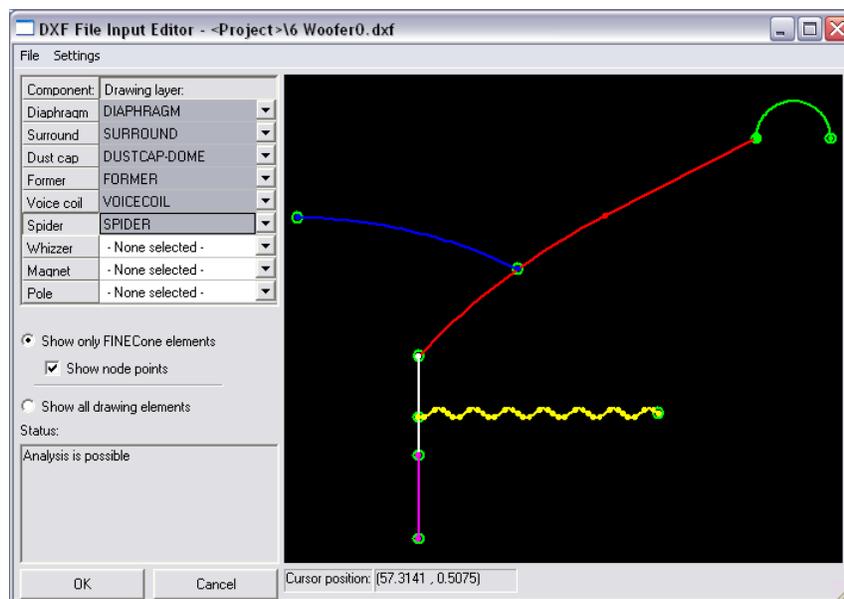
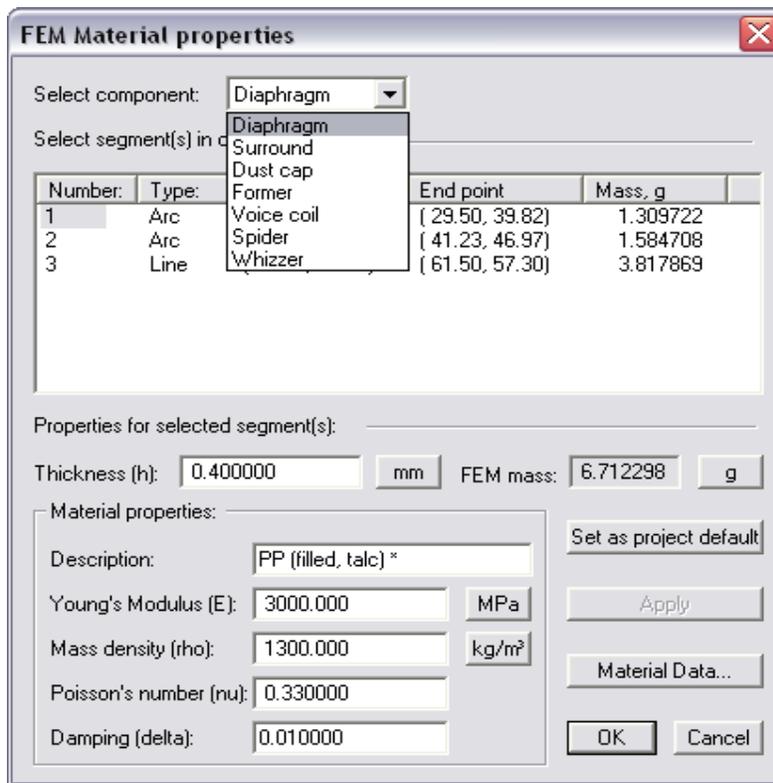


FIGURE 10: FINECone DXF Geometry input

**FINECone Acoustic Simulation** – The last part of the design process for Part 1 of this exercise is to optimize the cone and suspension system with regard to the overall frequency response. This begins with drawing a deep curvilinear cone in AutoCAD (virtually any CAD program can be used for this drawing) using simple lines. **Fig. 9** shows this file imported into FINECone. Note that the DXF Input Editor will automatically check the DXF geometry file. If some lines are not connected, these lines and endpoints will be highlighted in red.



**FIGURE 11: FINECone Material Parameter input**

If the drawing is acceptable, FINECone displays an “Analysis is possible” message on the screen. Next, TS parameters from FINEMotor are imported by hitting the “import” button (see the upper menu in **Fig. 14**). Once this is accomplished, you can then specify the thickness and mass of the main components in “Material Parameters” menu depicted in **Fig. 11**. To save time, start with known materials from the Material Database that includes a Talc filled polypropylene cone (with damping set to a more realistic 0.01), rubber (NBR) for the surround, aluminum for VC former plus a poly dust cap and the FINECone defaults selected for the remaining parameters.

For a good frequency response simulation it is necessary to make a good estimate for the rising slope of the impedance curve. That is done by adjusting (manually iterating) the impedance parameters ( $Le_1$ ,  $le_2$  and  $R_p$ ) using a similar driver for comparison (a better solution would be to import a measured impedance curve). The first simulation is shown as the black curve response in **Fig. 12**. This response is dominated by two peaks with one peak above 3 kHz that is quite large.

To find out what is causing this SPL anomaly, FINECone will produce a 3D animation of the cone. Setting the frequency to 3294 Hz (**Fig. 13**) makes it possible to observe a very strong dust cap breakup mode, despite the fact that you have specified the use of a rather stiff aluminum material. This dust cap mode is also causing the cone to bend simultaneously.

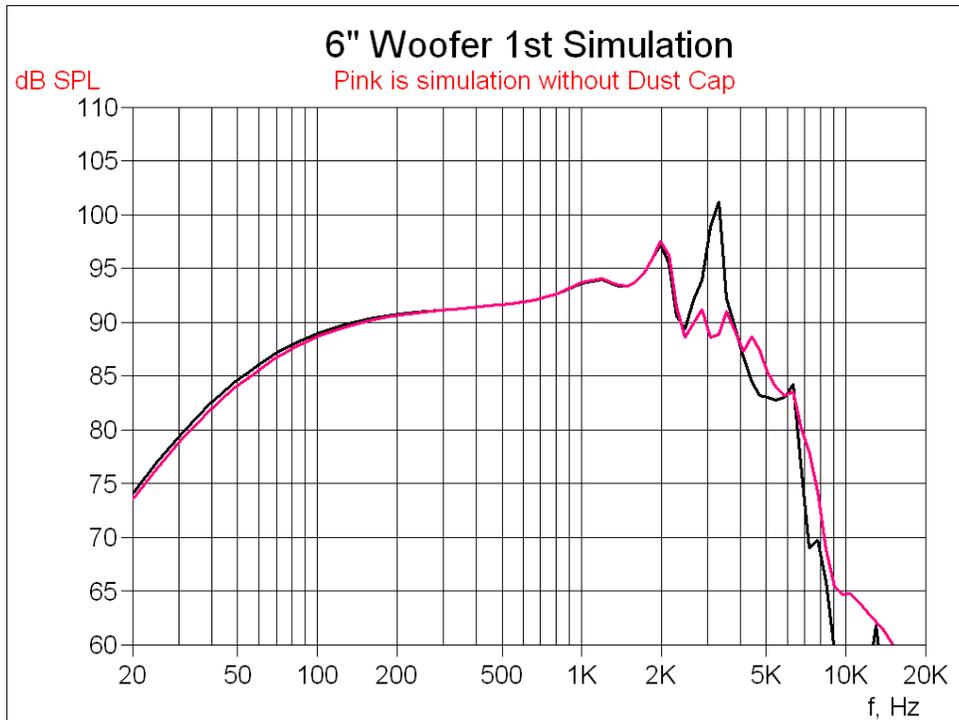


FIGURE 12: FINECone 1<sup>st</sup> FEM model

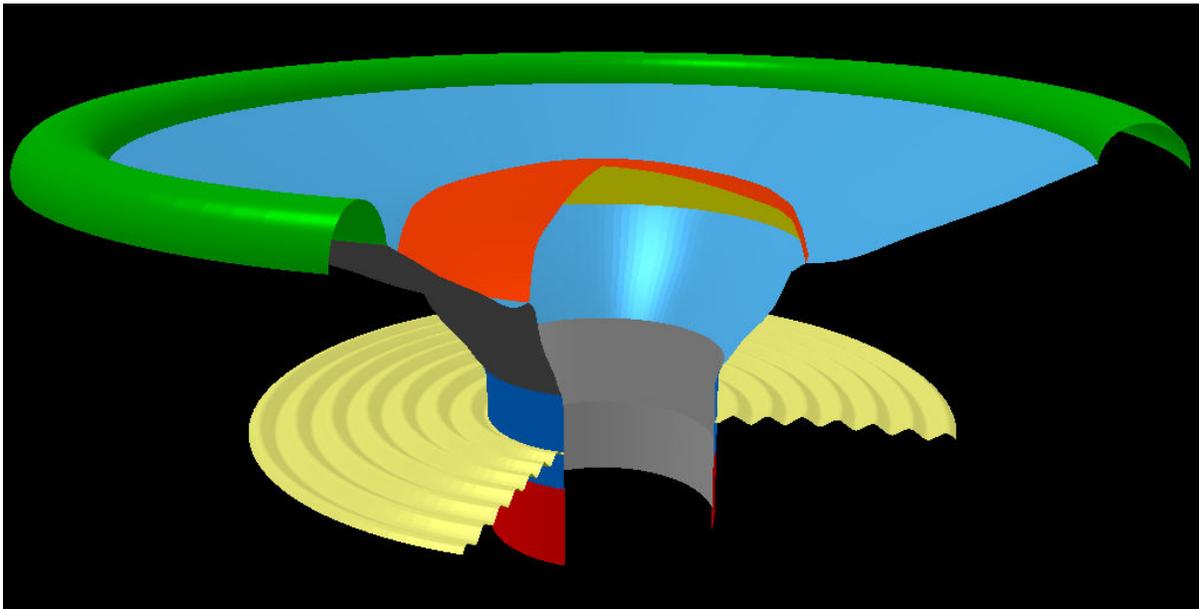
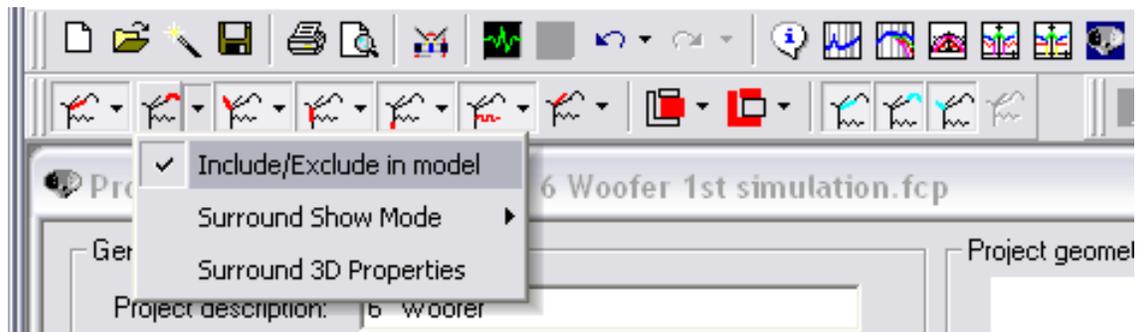


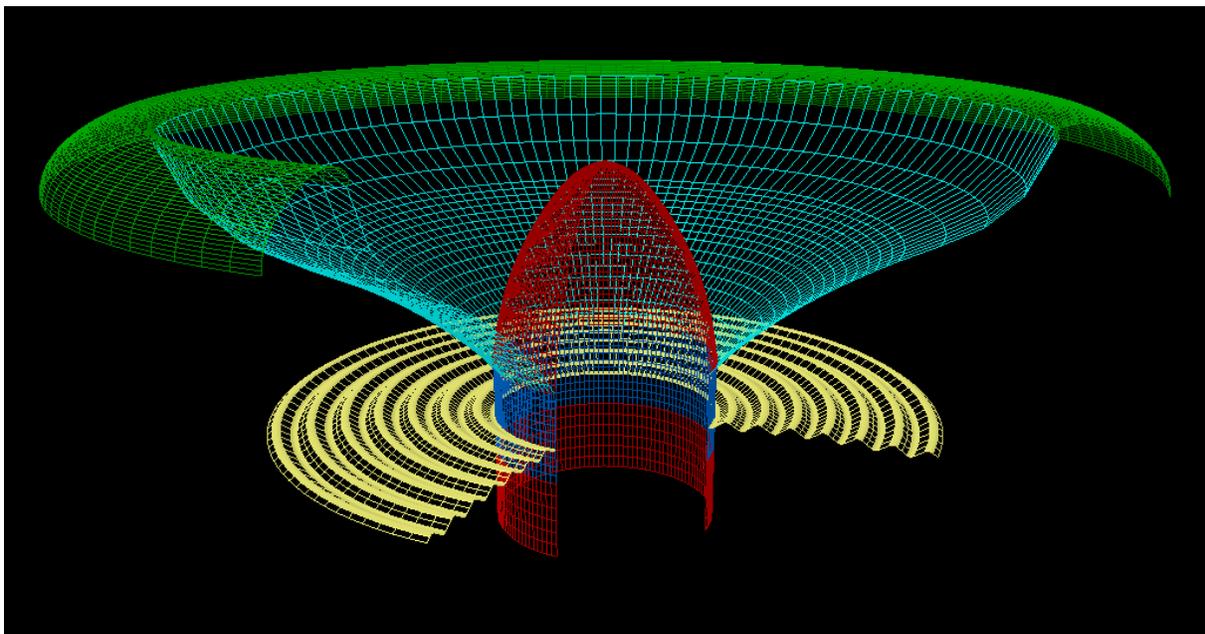
FIGURE 13: FINECone Break-up mode @ 3294Hz in Dust Cap

To further investigate the effect of the dust cap, you can easily exclude it from the FEM calculation by using the button shown in **Fig. 14**. (Note that this will also remove the stiffening of the cone caused by the dust cap). The result is shown as the pink response curve in **Fig. 12**. The 3 kHz peak is now completely attenuated.



**FIGURE 14: FINECone component control**

The obvious conclusion from this data is that the dust cap needs to be improved. Because you have already tried using a rather stiff dust cap material, you must change the dust cap shape to obtain more geometrical stiffness (*for more on this subject, check AES 116 Paper titled "Geometrical Stiffness of Loudspeaker Cones"*). Reducing the dust cap diameter to fit the voice coil, while increasing the height, is an effective position. The modified DFX file imported into FINECone is illustrated in **Fig. 15**. The new dust cap shape works well and produces a response very close to the pink curve in **Fig. 12** even when you choose the same PP material as the cone.

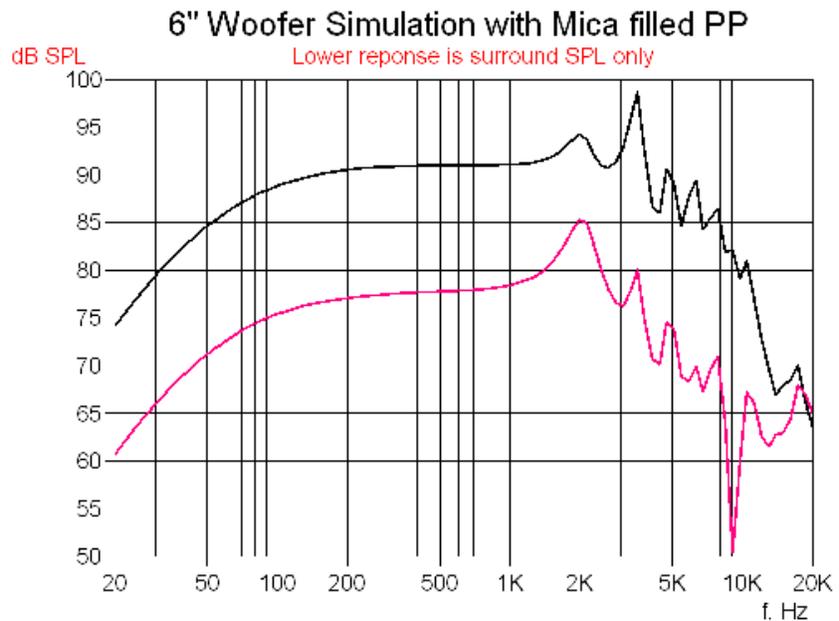


**FIGURE 15: FINECone Edge mode @ 1988Hz + Improved Dust Cap (Mesh visible)**

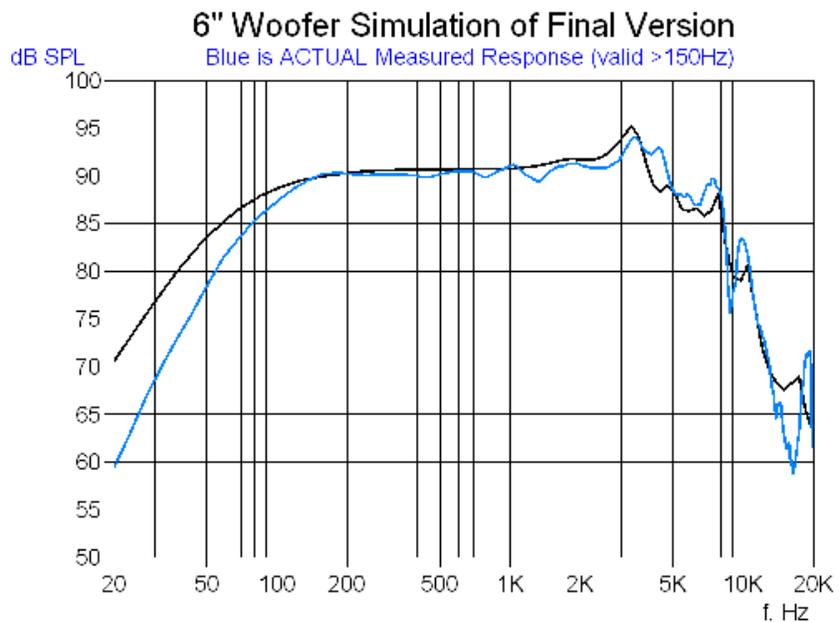
In order to extend the high frequency response of the 6.5" woofer, one solution is to incorporate a stiffer cone. This is accomplished using the same mica-filled poly cone material but increasing the Young's Modulus from 3000 to 9000 MPa in the "Material Parameters" menu (**Fig.11**). The improved simulated response is displayed by the black curve in **Fig. 16**. The overall frequency response is now extending to above 5 kHz, with two peaks at 2 and 3.5 kHz.

Before making any changes in the cone shape and material, it is necessary to first analyze these two break-up modes in "3D Animation". From **Fig. 15** you can conclude that the lower peak is due to a break-up mode @ 1988 Hz, caused by a bending cone and surround edge. That is confirmed by the 2kHz peak in the lower pink curve in **Fig. 16**,

which gives the surround SPL only. There are a number of methods you can use to correct this issue such as by changing cone material or cone shape.



**FIGURE 16: FINECone simulation of Mica-filled PP Cone**



**FIGURE 17: FINECone Simulated and Measured Final 6" Woofer**

After attempting multiple iterations of thicker and thinner cones and surrounds in the FINECone simulations, the final solution is to increase the surround thickness from 0.4 to 0.6mm. The Simulated response is shown as the black curve in **Fig. 17**. As you can see, the thicker surround change was very effective by removing the 2KHz peak, and even reducing to 3.5kHz peak. At this point, the first prototype woofer using all the detailed information from all the simulations was constructed and the frequency response measured using a MLSSA analyzer and the data file imported as the blue response curve in **Fig. 17**, which, as you can see, is very close to the final simulation. MLSSA was also used to produce a T/S parameter set as follows:

$F_s = 57.507\text{Hz}$   
 $R_e = 3.170\Omega$   
 $R_{es} = 16.570\Omega$   
 $Q_{ms} = 2.768$   
 $Q_{es} = 0.529$   
 $Q_{ts} = 0.444$   
 $L_1 = 0.266\text{mH}$   
 $L_2 = 0.355\text{mH}$   
 $R_2 = 2.794\Omega$   
 $V_{as} = 9.675\text{Ltr}$   
 $M_{ms} = 19.668\text{g}$   
 $C_{ms} = 389.445\text{uM/Newton}$   
 $BL = 6.523\text{TM}$

Sensitivity	SPL	89.13	dB
VC Resistance DCR	$R_e$	3.20	Ohms
Resonance	$F_s$	59.02	Hz
Mechanical	$Q_{ms}$	3.00	
Electrical	$Q_{es}$	0.54	
Total	$Q_{ts}$	0.46	
Equivalent air vol.	$V_{as}$	8.76	l
Compliance	$C_{ms}$	0.35	mm/N
Moving Mass(incl. air)	$M_{ms}$	20.54	g
Force Factor	$Bl$	6.72	Tm
Eff. diaphragm area	$S_d$	132.73	sq.cm
Lin. Excursion +/-	$X_m$	4.95	mm

**TS Parameters**    **Calculated Winding**

**FIGURE 18: 6" Woofer: FINEMotor Simulation and Measured TS Parameters CCAW**

The simulated and measured T/S parameters (**Fig. 18**) are close, and this much agreement is usually enough to proceed with the initial system design. The FINECone model was made in a few hours and may be further refined to simulate the top end response even better by simulating different glue joints and varying cone thickness. Next month, the final two-way design will be completed using FINE Xover. For more about Loudsoft design software, visit the Loudsoft website at [www.loudsoft.com](http://www.loudsoft.com).