

## Loudsoft Design Tutorial, Part 2

The April issue of Voice Coil featured Part 1 of Peter Larson's three-part CAD tutorial showing the complete design of a two-way loudspeaker system starting with the woofer design. This month's installment will show the development process for the 1" tweeter dome, again using the suite of loudspeaker design tools from Loudsoft (FINEMotor, FINECone, FINEBox, and FINEXover). Part 3 will appear in the June issue and finalize the design process showing the development of a complete network design using Loudsoft's FINE Xover program. – Vance Dickason

*By Peter Larsen*

This two-way system will require a good tweeter with a low resonance  $F_s$ , plus high sensitivity and power handling capacity to match the woofer. From experience you know that a 1"/25mm dome tweeter will be a good choice.

**FINEMotor Tweeter Simulation** - Initial FINEMotor tweeter simulations begin by specifying a common 25mm silk dome diaphragm in "Acoustic Components" (this menu is located in the upper right-hand part of the main screen, which you can see in **Fig.7**), where you enter the effective dome diameter of 2.95cm (this includes half surround), followed by Fixed Mass of 0.25g (dome + half surround + VC former (no VC winding yet)). When you enter these numbers, a [v] appears in the  $Q_{ms}$  field and means that  $Q_{ms}$  will be estimated (depending on VC material) and  $F_s = 1500$  Hz entered as a first "guess". The nominal 4 $\Omega$  voice coil is specified with  $R_e = 3.0\Omega$ , along with a true 1" (25.40mm) Voice Coil ID for a two-layer round copper wire coil (**Fig. 3**).

In the "Motor Parts" menu (also located on the right side of the main menu in **Fig.7**), select the default 72x32x15mm ferrite magnet and at the same time specify a thin 4mm Top Plate. Instead of setting the Top Plate ID to a fixed value, set a [v] for "Compensated Top Plate ID" and set the clearance (between VC and Top Plate) to 0.2mm (the [v] entry allows the program to vary the value according to other motor part choices).

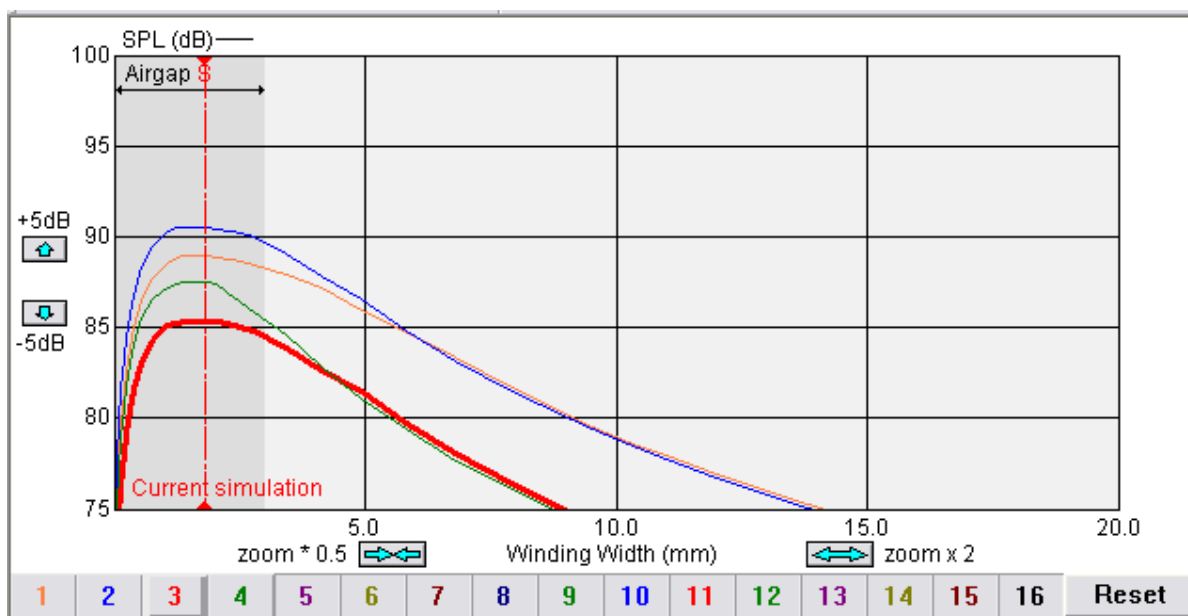
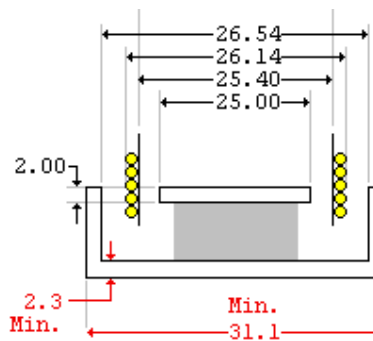


FIGURE 1: FINEMotor Main Design Graph with 4 active simulations, #3 red is current

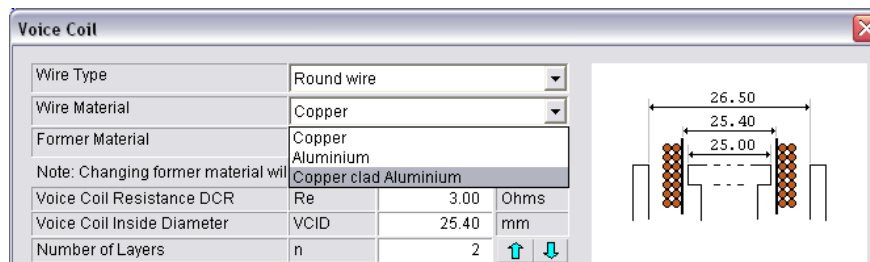
The FINEMotor graph in **Fig.1** shows the curve (brown #1) with possible tweeter designs, having a flat top around 2mm VC winding width. The corresponding SPL level is around 89 dB, which is acceptable. But reducing the Top Plate thickness to 3mm gives an SPL of 90.5 dB (blue curve #2), due to the flux being concentrated in a smaller air gap. This gives an average gap flux density of 1.6T (Tesla), indicating that the steel is partly in saturation (which normally starts above 1.5T).

After you press the Outside Shielded button in the Motor Parts menu, the program calculates a 60x32x10mm shielding magnet and 78mm OD shielding can. However at this point I decided that this magnet system is too large and too expensive. What you really need is a small efficient motor, which you can obtain by incorporating a neodymium magnet instead of the ferrite design. After you press the “Inside Motor” button (located in the lower right-hand section of the main menu in **Fig.7**), FINEMotor automatically changes to simulate an inside neo “slug” type motor, which by its nature is a self-shielded system (see motor details depicted in **Fig. 2**). By choosing a N30H Neodymium material (from Magnet Parts menu), you can specify the custom magnet size as 24x3mm from “Edit Magnet Dimensions”.



**FIGURE 2: FINEMotor Neodymium Motor**

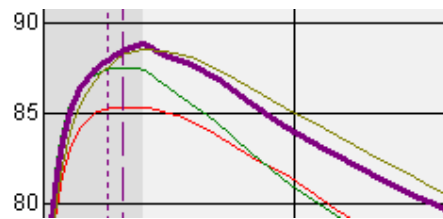
The result is shown as the red curve #3 in **Fig. 1**. Unfortunately the maximum sensitivity SPL has dropped down to around 85 dB, which is too low. You will therefore simulate an even thinner pole plate (top plate), by going to 2.0mm thickness. The sensitivity has now increased to approximately 87.5 dB (green curve #4). Further reduction of the pole plate thickness is probably going to saturate the steel; however, your other choice is to change from copper to much lighter aluminum wire, which also has lower conductivity, so you will need a thicker wire diameter and corresponding larger air gap.



**FIGURE 3: FINEMotor - CCAW Voice Coil selected**

Using the “Voice Coil” menu in **Fig. 3**, you can select between aluminum and CCAW (Copper Clad Aluminum Wire), which you can solder. The CCAW voice coil is simulated as the violet curve #5 in **Fig. 4** (same graph as **Fig1**, now displaying curves #4-6). At this point, the simulation has reached close to 89 dB sensitivity using the neodymium magnet, which is acceptable. The winding data for this voice coil can be read from the “Calculated

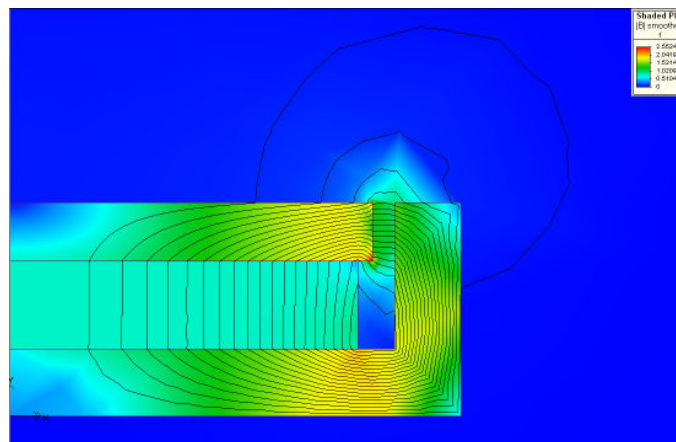
Winding” menu showing 20 windings of 0.13mm CCAW, with a 1.60mm winding width, a maximum OD=26.14mm and winding mass M<sub>vc</sub>=0.093g.



**FIGURE 4: FINEMotor Curves #4-6**

Because the pole plate is only 2mm thick, the position of the voice coil could be very critical. Because you know this from experience, it may be a good idea to make a Magnetic Finite Element (FEM) simulation of the neodymium motor to evaluate this issue.

**Fig. 5** shows an axis-symmetrical magnetic simulation (using the MagNet FEA software from Infolytica) made with the FINEMotor recommended minimum dimensions from **Fig. 2**.



**FIGURE 5: Magnetic FEA of Neo motor in MagNet**

The U-cup (yoke) has a maximum flux density of 1.98T in the steel, which is close to optimum thickness as predicted, and the pole plate is max. 1.86T, so a thinner pole plate is not advisable, because it will saturate around 2T. The black flux lines are concentrated in the air gap, with stray field emanating above and below the 2mm air gap. There are slightly more lines below the pole plate, because the outside steel is extending down. If you draw a line down through the air gap and record the flux density you get the air gap flux profile, which you export as a text file.

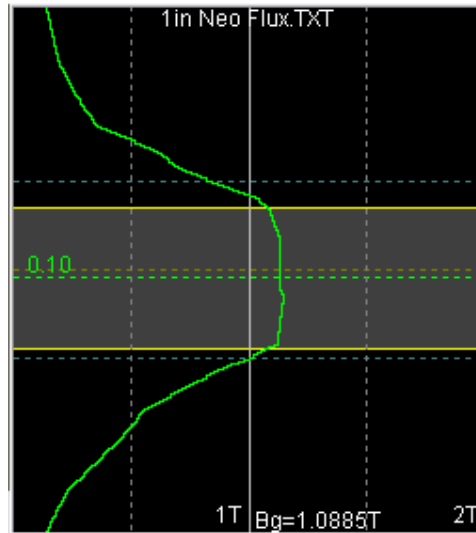
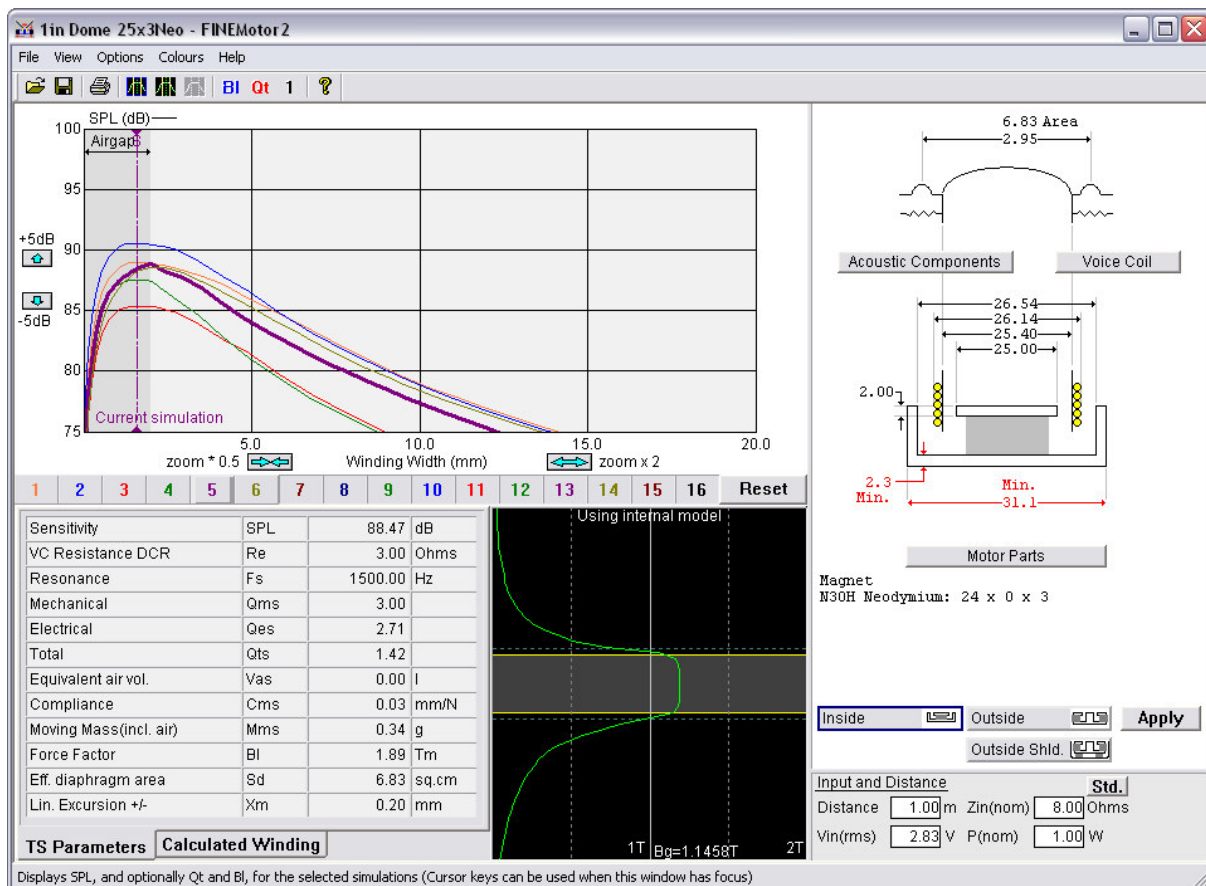


FIGURE 6: Flux profile imported into FINEMotor, VC offset 0.10mm down

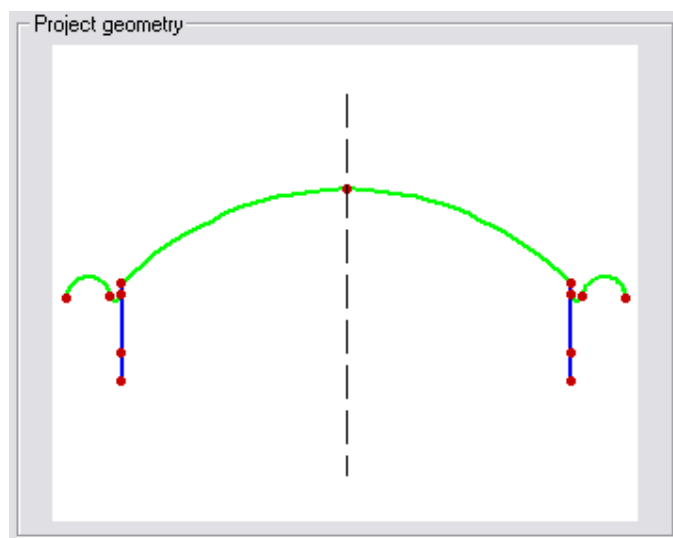
**Fig. 6** shows the flux profile imported as it looks when imported into FINEMotor, where the white horizontal dashed lines indicate the 2mm pole plate. Note that the profile is pretty symmetric, but having more flux below the pole plate (down). The voice coil winding extends between the yellow lines. In this flux window it is possible to simulate an offset voice coil by dragging it up and down with the left mouse button and simultaneously watching the change in sensitivity and all the T/S parameters changes due to the offset.

The resulting sensitivity SPL is reduced by 0.17 dB when offset 0.20 mm up, but only 0.02 dB when moved 0.20 mm down. Therefore, it is preferable to have the centre of the VC winding offset approximately 0.1mm down. This offset feature is actually very useful and can be employed to determine acceptable production tolerances of VC offset, sensitivity, and other T/S parameters. You can see the finished 1" Neo Motor design in **Fig. 7**.

The last curve in **Fig. 4** (green #6) is the result with the imported flux profile and is very accurate. Curves #5 and #6 are rather close, indicating that the FINEMotor simulations are quite accurate even without importing FEM flux profiles. You can import FINEMotor files into FINEBox to calculate the voice coil temperature and calculate maximum excursion  $X_{max}$  as approx.  $\pm 0.1$ mm for 1W input (more on this in Part 3). You can use this information later to evaluate the tweeter excursion with the crossover installed in the system.



**FIGURE 7: FINEMotor Optimized Neodymium Motor (No Flux import)**



**FIGURE 8: FINECone 25mm Dome Geometry**

**FINECone Tweeter Simulation** – You begin modeling the tweeter in FINECone by importing the geometry for the 25mm silk dome that was saved as a DXF AutoCad file into FINECone (**Fig. 8**). The electrical parameters shown in **Fig. 9** are defined by importing the FM3 file from FINEMotor and setting some initial values for Le1 (0.01mH), Le2 (0.01mH), and Rp (2Ω) in order to be able to simulate a typical tweeter impedance curve. Because this will only affect the SPL at high frequencies, the values are not critical.

The image shows a software interface with two main sections: Mechanical and Electrical. The Mechanical section contains three buttons: 'Geometrical properties...', 'Material properties...', and 'Lumped parameters...'. The Electrical section contains several input fields with units: Re: 3 Ohm, Le1: 0.01 mH, Le2: 0.01 mH, Rp: 2 Ohm, and Bl: 1.891384 Tm. There are also small red icons next to the Re and Bl fields.

**FIGURE 9: FINECone buttons and Electrical Input**

The image shows a dialog box titled 'FEM Material properties'. It has a 'Select component:' dropdown menu set to 'Dome'. Below it is a 'Select segment(s) in component:' field. A table lists the segments:

Number	Type	Start point	End point	Mass, g
1	Arc	(12.85, 3.97)	(0.00, 7.51)	0.078979

Below the table, there are fields for 'Properties for selected segment(s):' including 'Thickness (h): 0.140000 mm' and 'FEM mass: 0.078979 g'. The 'Material properties' section includes 'Description: Silk \*', 'Young's Modulus (E): 1500.000 MPa', 'Mass density (rho): 1000.000 kg/m³', 'Poisson's number (nu): 0.330000', and 'Damping (delta): 0.003000'. There are buttons for 'Set as project default', 'Apply', 'Material Data...', 'OK', and 'Cancel'.

**FIGURE 10: FINECone Dome Material setting**

Next, you can open the “Material properties” as seen in **Fig. 10**. After you enter the dome thickness as 0.14mm, “Silk Material” is selected from the Material Database. Note that the default damping number of 0.010 is modified to 0.003. This will allow you to observe any breakup in the initial simulations. Also, the surround material is defined exactly as the dome material, neglecting any influence of glue beads or other adhesive affectations in the first simulation.

Continuing the process, the voice coil former specification is set to 0.05mm Aluminum from, again from the database. Last, the voice coil winding is defined as copper (CU) wire and the thickness is set to 0.1mm to give a VC mass ( $M_{vc}$ ) of approximately 0.10g as calculated by FINEMotor. This accomplished, the first FINECone simulation is initialized and displayed in **Fig. 11**.

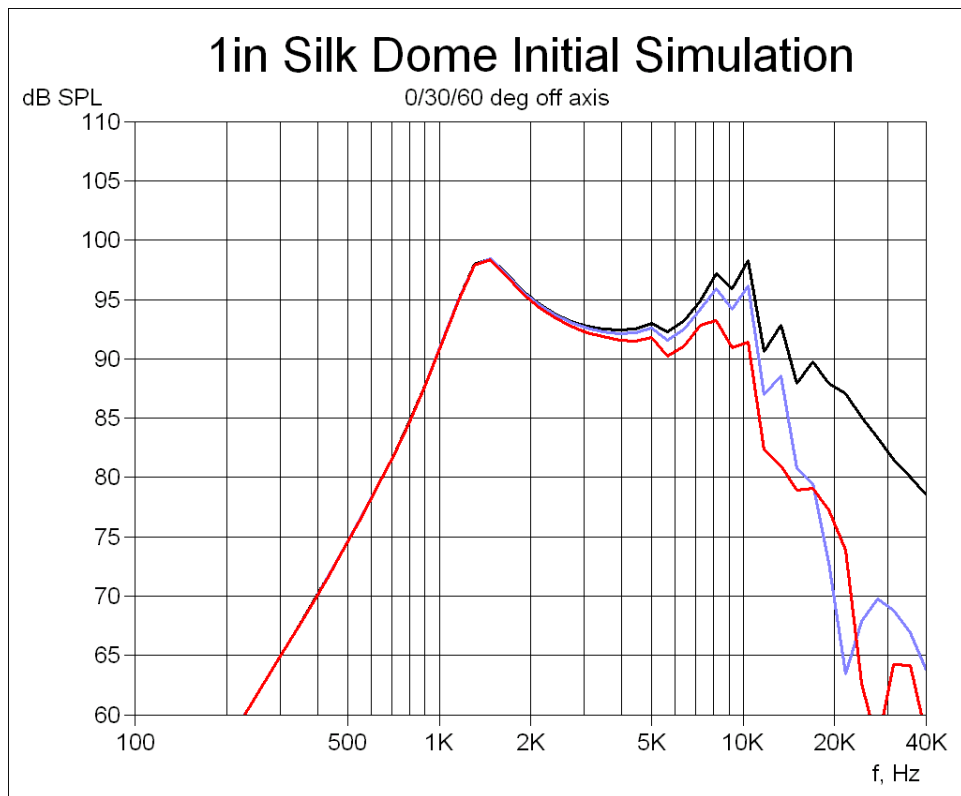


FIGURE 11: FINECone first Dome Simulation 0/30/60 deg

The first FINECone simulation response in **Fig. 11** is not bad, having response up to 20 kHz, but with a top 8-10 kHz and a 7 dB drop up to 20 kHz. In order to study the break-up modes responsible for this response, I set the 3D Animation Plot at 8160 Hz (**Fig. 12**). Here you clearly see the centre of the dome breaking up, which is caused by insufficient stiffness.

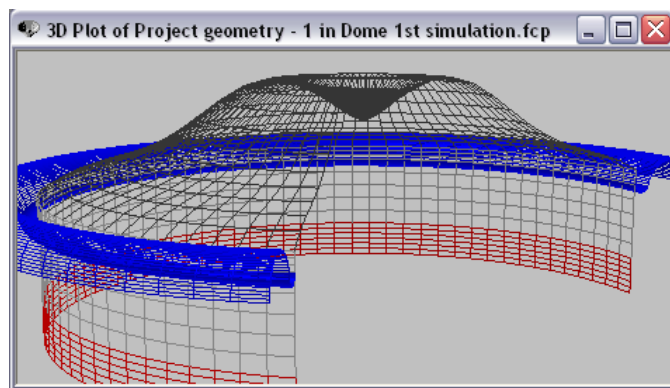


FIGURE 12: FINECone 3D Animation of mode at 8160 Hz

Given this situation, you now have two options: A) Modify the material including glue beads or B) changing the Geometry. In my experience as a driver designer, I always found the geometry to be the most important to get right before turning to adhesive changes or other “tweaks”. Given this experience factor, I went with option B and change the dome geometry. Referring to my AES Paper (AES Preprint #6095 by Peter Larson) titled “Geometrical Stiffness of Loudspeaker Cones”, you know that a high profile will provide more geometrical stiffness than a shallow profile, so draw the highest possible dome that can be made (**Fig. 13**).

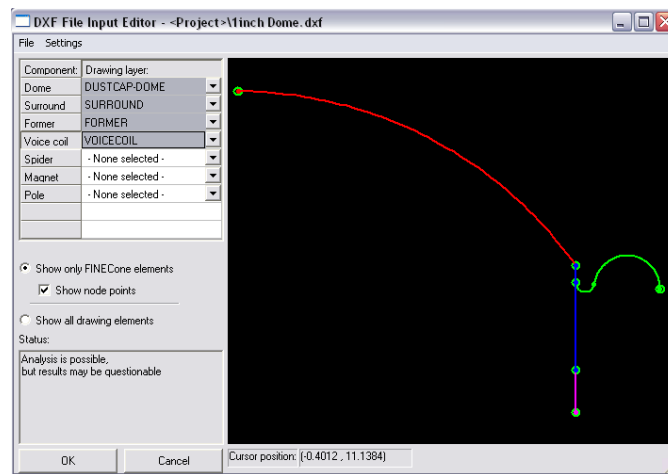


FIGURE 13: FINECone 1in High Dome Profile

The result of the high dome profile simulation is shown in **Fig. 14** (black curve). As a result of changing the profile, the first dome breakup mode has moved up above 10 kHz and not only improved the response but extended the response to above 20 kHz. However, another interesting option is to try a different voice coil former material. The results of simulating a Kapton voice coil former are given by the blue curve in **Fig. 14**. While the new former material offered a small increase in SPL, it did so at the expense of a larger peak and too early a high frequency rolloff.

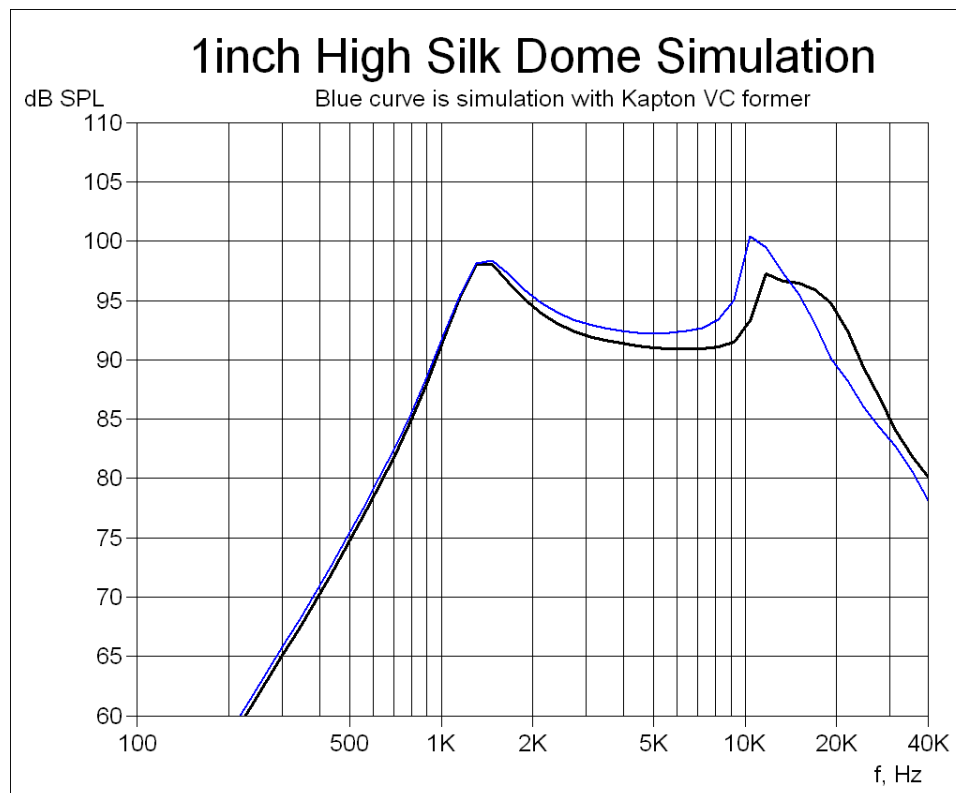
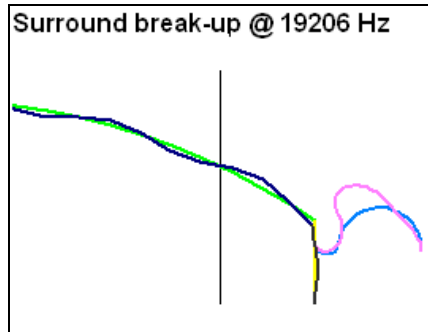


FIGURE 14: FINECone High Dome Simulation (+ Kapton Voice Coil Former)

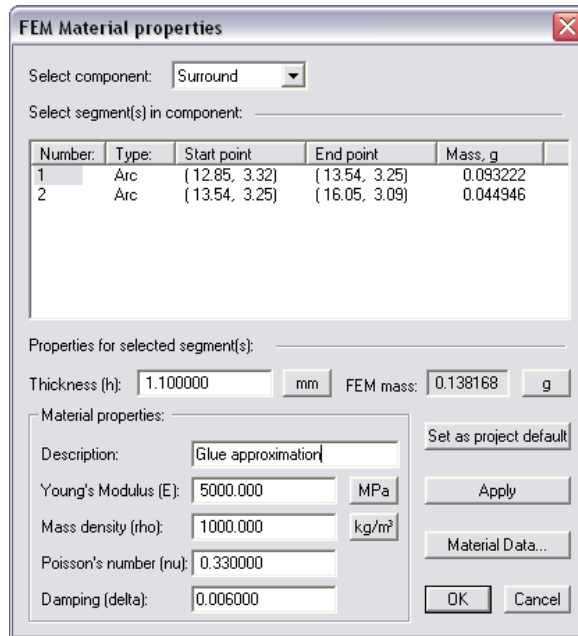
Focusing on the surround, I performed further analysis using the 2D Animation Plot at 19206 Hz. This reveals that the surround is moving excessively (**Fig. 15**). In order to improve the surround, it is possible to adjust the stiffness by adding glue to the smaller radius of the surround. **Fig. 16** shows the “FEM Material Properties” menu, where the



cyanoacrylate glue joint is simulated by increasing Young's Modulus and the thickness in this area.



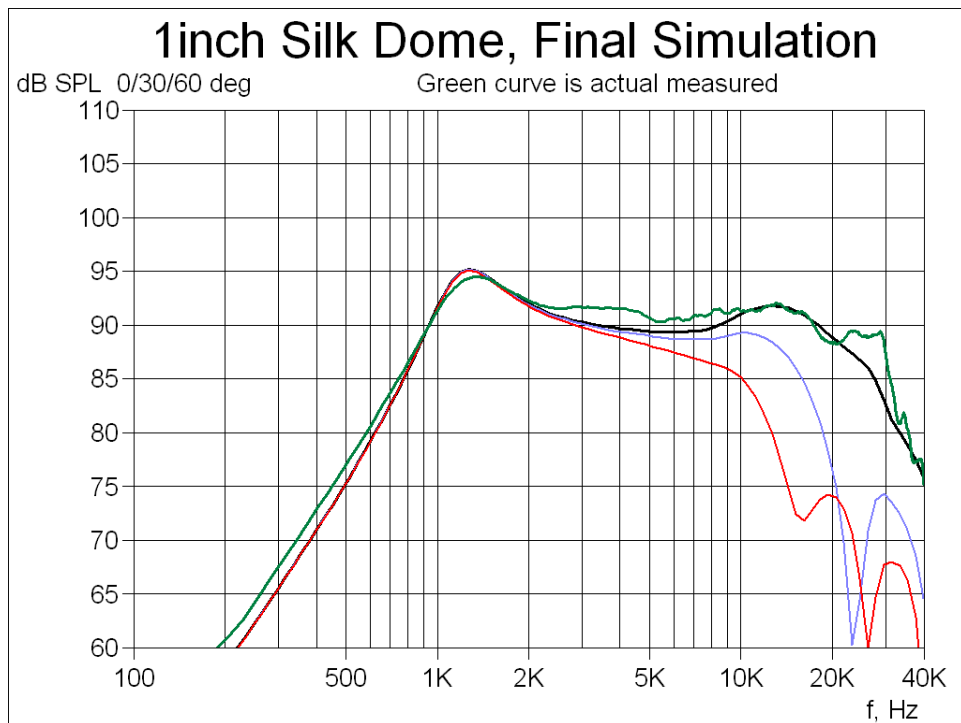
**FIGURE15: FINECone Surround 2D Animation**



**FIGURE16: FINECone VC Glue Simulation**

The final 1" Dome simulation with 30 and 60° off-axis responses is displayed in **Fig. 17**. The silk damping is now back to normal to match the material used in the actual prototype, which is measured and shown as the green curve in the same graph. The agreement between the simulated and measured responses is quite good up to 20 kHz.

Note that more detailed HF analysis over 20kHz requires a more refined model, and is beyond the scope of this short tutorial. The actual prototype has a small horn or wave-guide that is designed to increase SPL in the area between  $F_s$  and 10 kHz. While the detail of this procedure is not discussed, design of short tweeter horns and waveguides is a consulting service that can be provided by LOUDSOFT.



**FIGURE17: FINECone Final 1in Dome Simulation / Actual measured SPL (green)**

Part 3 will show the final system design and deal with the development of an appropriate crossover network to join the woofer and tweeter you have designed in Parts 1 and 2.

## Loudsoft Design Tutorial, Part 3

*By Peter Larson*

*The April and May issues of Voice Coil featured Parts 1 and 2 of Peter Larson's three-part CAD tutorial showing the complete design of a two-way loudspeaker system starting with the woofer design in Part 1 and the tweeter development in Part 2. This month's installment will show the development process for a crossover network that is appropriate for the previously designed woofer and tweeter utilizing Loudsoft's FINE Xover network design software. – Vance Dickason*

**2-Way FINE X-over Simulation** – The last step in the complete design process presented in this three-part two-way tutorial example will be to design a passive crossover circuit, necessary to equalize the frequency response of the loudspeaker system. This will be done not only for the on-axis response of the new speaker, but also for the off-axis response in order to get a more controlled power response, essential to produce a musically convincing product. Other important features for the network will be to provide controlled impedance at all frequencies for the connected amplifier and to protect the tweeter from the low frequencies and excessive excursion.

Up to this point, I have simulated and measured the driver frequency responses assuming a large (infinite) baffle. However, in order to design a network, it was necessary to physically build the 12 ltr bass reflex box described in Part 1 of this article and mount both of the drivers as indicated in **Fig. 1**. The next step is measuring the 0 and 15/30/45/60° off-axis frequency responses of each driver with the microphone preferably in the listening position. Note that you must measure the true (anechoic) response of the system without room interference. Since that requires quite a large room and/or special time windowing, I used MLSSA FFT analyzer to measure at a relatively short distance and normalized the curves to 1m.

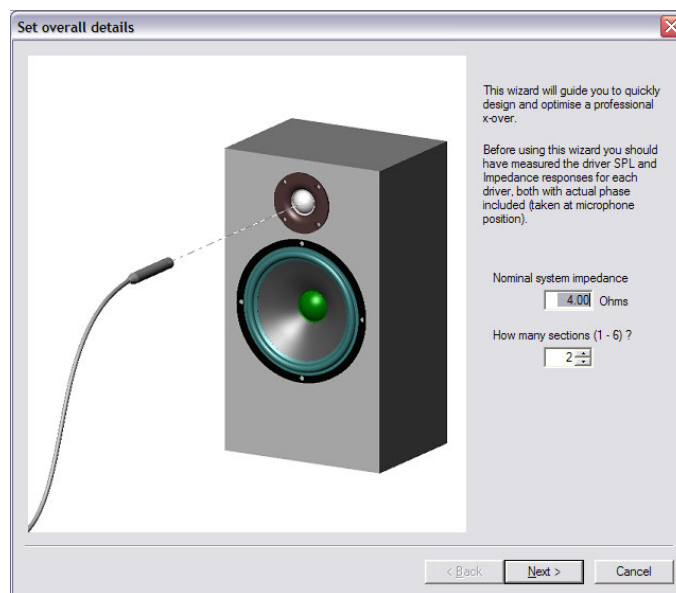
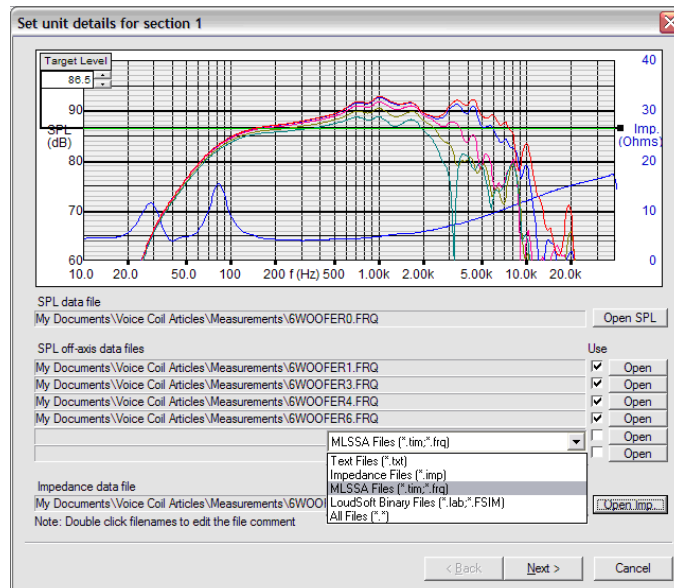
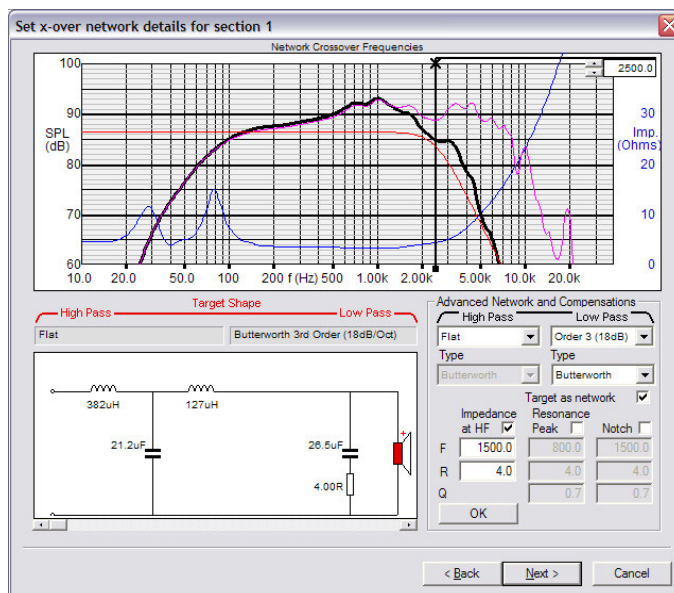


FIGURE 1: FINE X-over Wizard



**FIGURE 2: FINE X-over 0/15/30/45/60 Response Input**

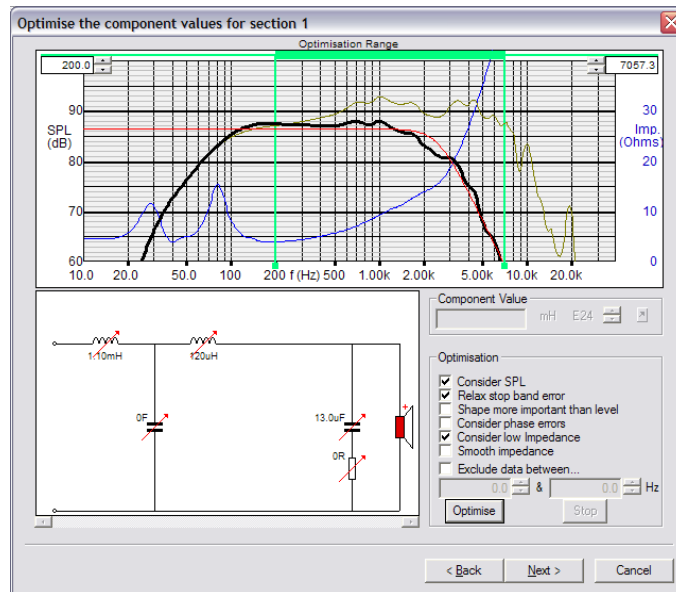
You can view the frequency response curves in the File import window, and the imported 0/15/30/45/60° on- and off-axis woofer frequency response measurements are depicted in **Fig. 2**. FINE X-over provides you with the option of choosing between various text file formats and LOUDSOFT FSIM format, which is the common exchange format between all the Loudsoft programs. In this example, I used the \*.FRQ file format to import MLSSA curves directly without conversion to text format.



**FIGURE 3: FINE X-over Woofer Section Setup**

The next step for the import Wizard is to develop the woofer low pass section 1 shown in, **Fig. 3**. Looking back at **Fig. 2**, I decided that the woofer had good dispersion up to above 2500 Hz, which I now set as the initial crossover frequency by dragging the vertical X-line to the 2.5kHz position. After previewing some simulated responses with a 2<sup>nd</sup>- and 3<sup>rd</sup>- order low-pass network topography, I decide to use a 3<sup>rd</sup>-order LP filter and include RC conjugate type impedance compensation filter (sometimes referred to as a Zobel network), which will help to bring the actual response much closer to the red -6dB 2.5kHz target response. The RC compensation is specified from 1500 Hz (see the lower right-hand side

of the low-pass menu shown in **Fig.3**), which automatically gave the RC network value of 26.5  $\mu$ F for a 4 $\Omega$  resistance value. It is also possible for the woofer impedance curve to be optimized separately.

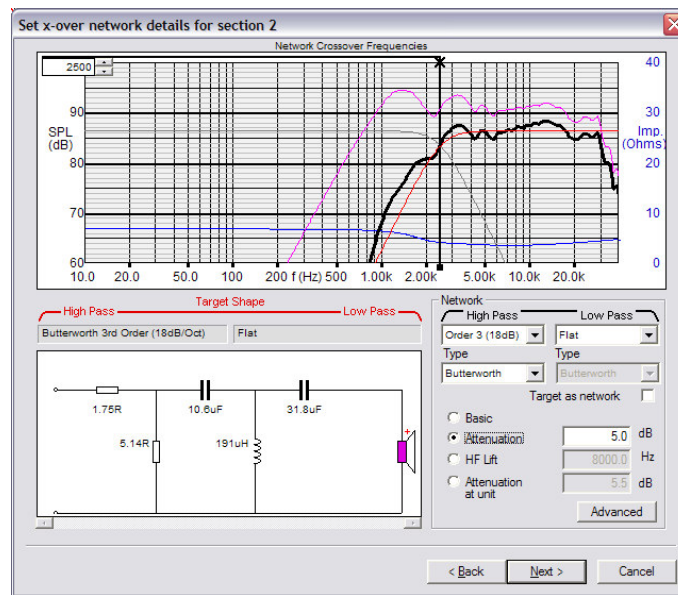


**FIGURE 4: FINE X-over Optimized Woofer Response**

In order to finish dialing in the woofer response for a closer fit to the red target response, depress the “Optimize” button. For this first attempt, all components including the RC impedance are marked for optimization (the red arrow through the component). When complete (**Fig. 4**), you get the closer match to the target response with the resulting new component values. Note that some values are not listed as “0”, but these will likely change as you continue with the optimizing process.

Next, the same process is completed for the tweeter section of the crossover. In this case, 3<sup>rd</sup>-order network topography is selected as well as specifying 5 dB attenuation using an L-type resistor circuit as seen in **Fig. 5**. Entering 5dB in the attenuation field at the lower right-hand side of the high-pass section 2 menu causes the software to automatically calculate the two resistor values, even though you may later omit the parallel resistor. It is also possible to select “Attenuation at unit” to have the attenuator resistors placed on the driver side of the circuit, but that is no help in this case. If the tweeter slope is not appropriate, it is also possible to select a different Target Shape (1/2/3/4 order), but that is not necessary for this example.

Once you have preliminary designs for the woofer section 1 and tweeter section 2 filter sections, it’s time to look at the total system response as illustrated in **Fig. 6**. The initial summation is given by the gray curve on the response graph. This response is not optimally flat, but by choosing “System Optimization” all the components having red arrows will be optimized against the green target (a flat system response), while keeping a minimum impedance at 3.2 $\Omega$ . The resulting on-axis response is the black curve, which is quite linear and above the selected minimum impedance at all frequencies.



**FIGURE 5: FINE X-over Tweeter Section Setup**

The two other red and olive-green curves are the calculated 30 and 45° off-axis responses using the same components (the 15 and 60° off-axis responses are also calculated, but not been selected for clarity). Note that the parallel resistor in the tweeter section has been removed (using a right click with the mouse) before final optimization. Ideally the off-axis responses should be smooth with a gentle downward slope, which is only partly the case here. Relocating the tweeter slightly or even changing the baffle shape may improve this situation. However, if the driver position cannot be changed, you still have another option, which I will discuss later.

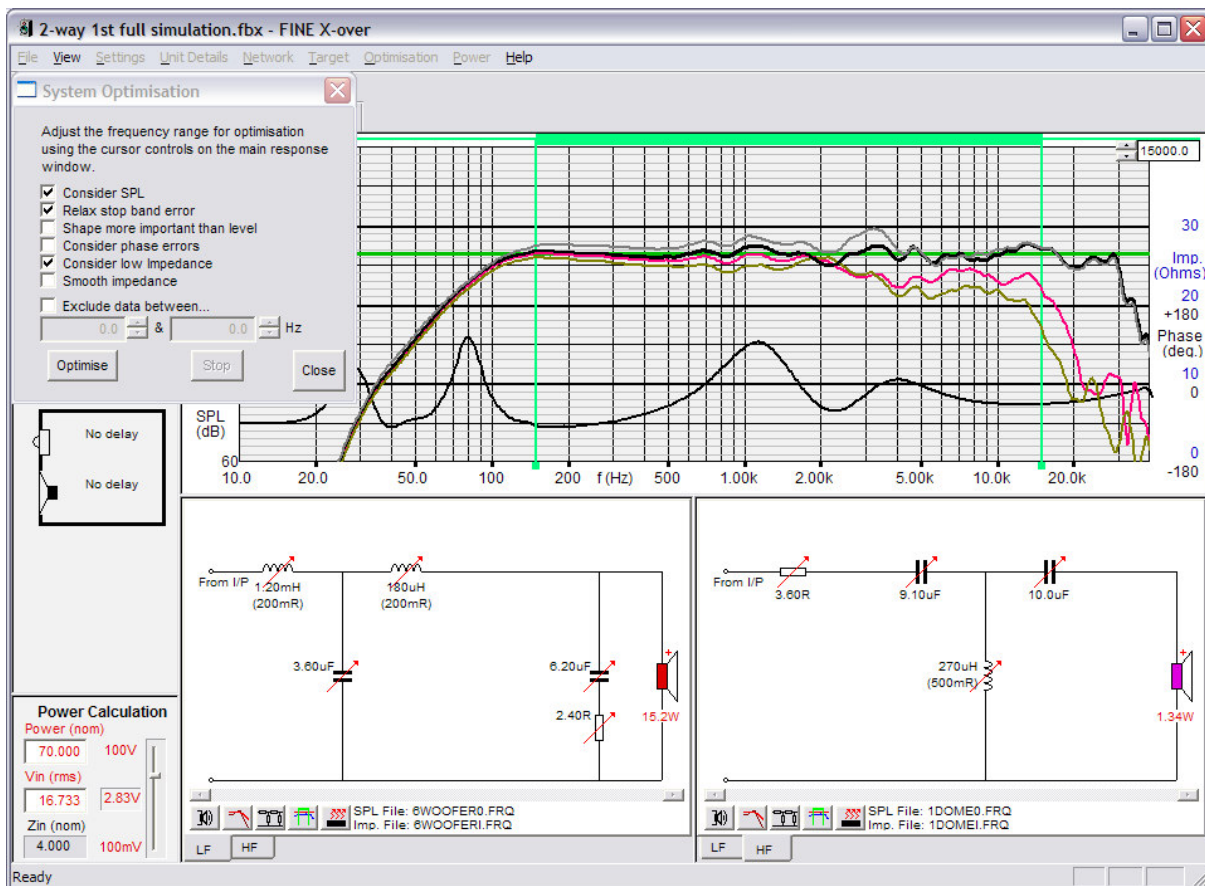


FIGURE 6: FINE X-over Optimized On-axis Response with 30 and 45 deg Off-axis Responses

Now that a satisfactory system response has been established, perform a Power Calculation by specifying a 70W music program material level (per IEC 268-1). The Power Calculation entry is made on the small section at the lower left-hand side of the System Optimization menu. The real power in the drivers is calculated and indicated by the red numbers: 15.2W for the woofer and 1.34W for the tweeter. These power-handling values can be considered safe, especially for the tweeter because power handling on tweeters, which can dissipate only a few watts of power, is generally critical. The power delivered to the other (resistive) crossover components is also calculated and shown in **Fig.7**.

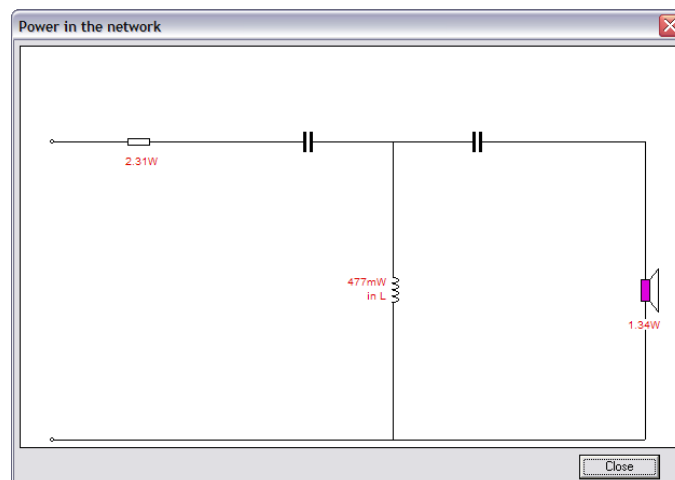
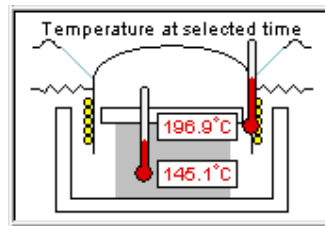


FIGURE 7: FINE X-over Power in Resistive Components

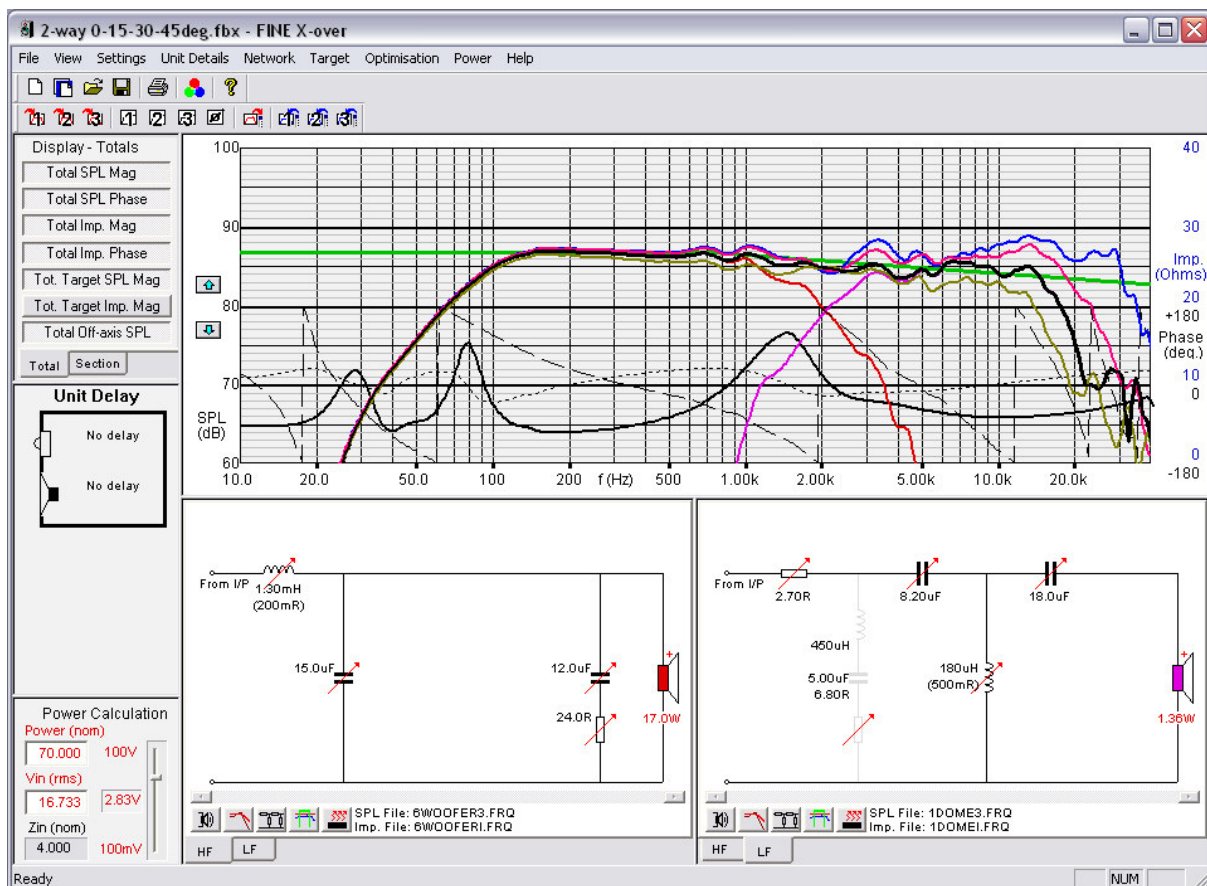


It is actually also possible to simulate the tweeter voice coil and magnet temperature in FINEBox, as seen in **Fig. 8**. Using the 1.34W power input, you get a voice coil temperature of only 37.4°C, which is not a problem. FINEBox also indicated that the expected Xmax is approximately +/- 0.10mm, which is also realistic.



**FIGURE 8: FINEBox Tweeter Temperature**

Interestingly, if this tweeter was used in a high power car system, you could seriously damage the tweeter under high load conditions with a responding high environment temperature. The example in **Fig. 7** was calculated using a 10W input and 70°C environment temperature, which gave a VC temperature of nearly 200°C and 145°C for the magnet. Such a high temperature would likely demagnetize the neodymium magnet, even if a high temperature neodymium grade were used.



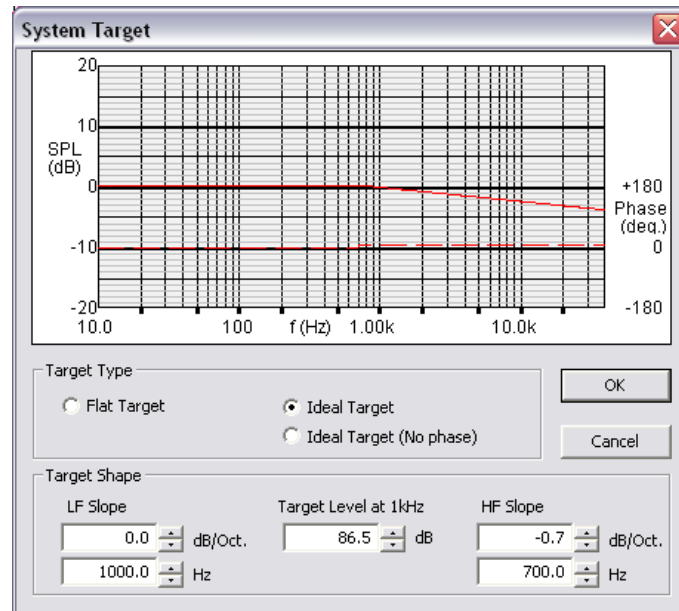
**FIGURE 9: FINE X-over Optimized 30 deg Off-axis Response. 0/15/45 deg Responses Included**

In the previous section I mentioned that the off-axis responses were not as smooth as it is desirable and that it might possibly be corrected by repositioning the tweeter or changing the baffle shape. Fortunately, there is also another method to handle this problem that is accomplished by interchanging the on-axis for one of the off-axis curves such as the 30°



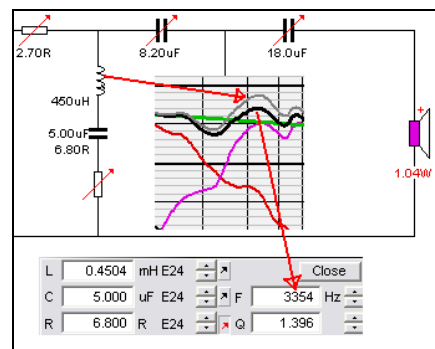
off-axis curve. This has been done and is depicted in **Fig.9**. The black curve is now the optimized 30° off-axis response, and the blue, red and green curves the 0, 15 and 45° responses, respectively.

In order to ensure a downward-sloping target curve, which is now being used to optimize the 30° off-axis response, the target curve production section was set to change to incorporate a -0.7dB low-pass slope from 700 Hz (**Fig. 10**). The optimized 30° response in **Fig. 9** (the black curve) is now significantly smoother than it was in **Fig.6**. The on-axis (blue) and 15 / 45° (red / olive green) responses are shown on the same graph. There is now a response peak at around 3 kHz in the blue on-axis response.



**FIGURE 10: FINE X-over Special System Target Setting**

While it is true that a smooth off-axis response is extremely important, it would be a good idea to do something about the 3 kHz peaking in the on-axis response. The solution was to incorporate a tuned anti-resonance LCR circuit as shown in **Fig. 11**. By using the mouse wheel to real-time continuously vary the component values, the frequency and Q was tuned so that the peak was effectively removed as indicated in the response graph. The two-way system and drivers are now fully optimized and ready for a listening test.



**FIGURE 11: FINE X-over Tuned Anti-resonance Circuit**

For more information on the complete loudspeaker development package available from Loudsoft used for this three-part CAD tutorial, visit the Loudsoft website at [www.loudsoft.com](http://www.loudsoft.com).